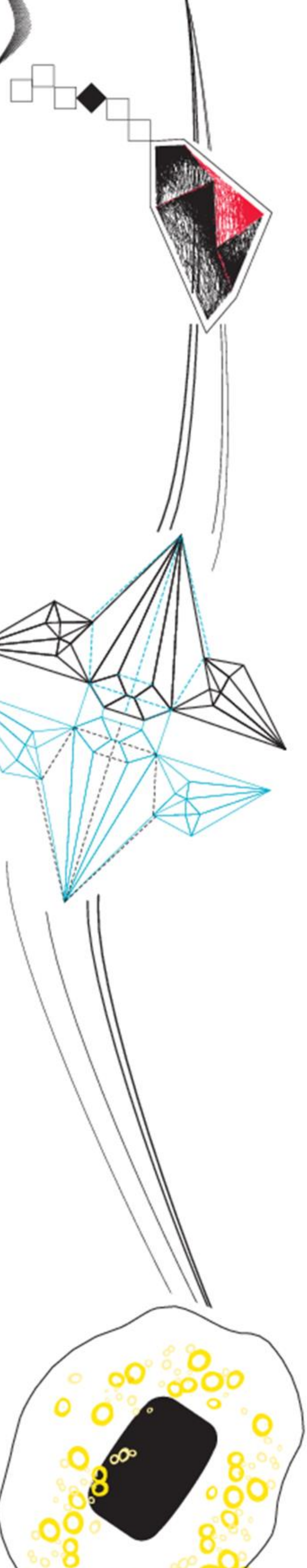

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DEVELOPMENT OF SMART INDUSTRY MATURITY MODEL

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FACULTY OF ENGINEERING TECHNOLOGY
DESIGN, PRODUCTION AND MANAGEMENT

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UNIVERSITY OF TWENTE.

Preface

"The best way to predict your future is to create it."
- Abraham Lincoln

When writing these words, I can't help thinking the first time I learned the term - **Smart Industry**. It was during one lecture of the course *Manufacturing Facility Design* that Assistant professor dr. ir. Juan M. Jauregui Becker played a video about Smart Industry. At that time, I decided to learn more about this approach and tried to combine the theory with practice. I believe in the smart future, i.e. the industries and cities will become smarter and smarter, which are conducive to both human beings and the nature. According to what Abraham Lincoln once said, the best way for me to predict the smart future is to create from now on. That's why I finally decided to take 'Development of Smart Industry Maturity Model' as the topic of my thesis.

And this thesis would certainly not have been possible to achieve the goal without the great supports from teachers, supervisors, external experts and my beloved family members.

Firstly, I would like to express my heartfelt gratitude to my supervisor dr. ir. Juan M. Jauregui Becker. I admire your professional knowledge and your valuable suggestions for the thesis during these nine months. From you, I have not only learned about how to produce excellent academic output, but also how to be a down-to-earth and passionate person. Thank you very much for your great supports.

Secondly, I would like to express my sincere gratitude to Mr. Wilbert Pontenagel from Novel-T. I have learned a lot from your broad knowledge. Thanks to your recommendation, the evaluation of my thesis model has been successfully conducted. And thank you very much for your friendly attitude which has encouraged me a lot to bravely face the life.

Many thanks to dr. Marcus V. Pereira Pessoa, Mr. Jasper Kerkwijk, Ms. Biba Visnjicki, Mr. Marc Peters and Mr. Geert Haisma. Thank you all for giving the valuable inputs to my thesis.

Finally, I want to thank my family members, especially my mother, grandmother and grandfather, for always supporting me. Your unconditional love helps me in every day of my life no matter in China or in the Netherlands.

HAI ZHU
Hengelo, 2017

University of Twente

Abstract

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by Hai ZHU

The new industrial revolution is emerging, termed as **the Fourth Industrial Revolution**. Many countries and regions are making strategic approaches to ensure that their industries transit to the new production paradigm, such as Smart Industry in the Netherlands, Industry4.0 in Germany, China Manufacturing 2025 in China, and Smart Manufacturing Leadership Coalition in the US. In this changing business environment, companies in the Netherlands need to understand the possibilities of Smart Industry in order to determine the best possible strategy for implementing it. For this aim, there is a need for tools and models to guide them.

In this context, this thesis developed the **Smart Industry Maturity Model (SIMM)** as a tool to aid industry in identifying the status of their processes and technologies in relation to Industry4.0 and Smart Industry, and help them to develop a strategy to achieve a transformation. SIMM consists of four parts, i.e. '**SIMM elements and relevant technologies and methods (TMs)**', '**KPIs and Market Trends**', '**SIMM processes and relevant Value-add points (VAPs)**', and '**SIMM maturity levels and relevant questionnaire**'.

KPIs and Market Trends, and SIMM processes support companies to identify the VAPs where process redesign and innovation could be conducted by implementing SIMM elements and TMs. SIMM maturity levels and questionnaire determine the extent to which a company has implemented the business and production processes that are compatible with the Smart Industry paradigm. Moreover, KPIs can guide companies to determine which SIMM elements have the priority of being improved.

SIMM has been developed based on the exploration of different approaches (Industry4.0, Smart Industry), Porter's value chain model and Capability Maturity Model Integration. Then **SIMM** has been evaluated with field tests by interviewing three companies with different business fields. The results of evaluation are used to improve this tool.

It is concluded that **Smart Industry Maturity Model** could offer new perspectives of understanding for the business and production processes in companies, could help companies to identify the status quo of their processes and technologies, and could supply the guidance of developing a strategy for companies to conduct the process redesign and innovation, thereby achieving the transformation in terms of Smart Industry.

Contents

Chapter 1

INTRODUCTION

In this chapter, firstly, the status quo of industry is introduced with a vivid example. Secondly, the new industrial revolution is briefly introduced as well as the approaches that currently have been taken by different countries and regions. Thirdly, the problems that companies have encountered during the new revolution are discussed. After that, the objective of this thesis is defined, the research method is described. Finally, the outline of this thesis is presented.

1.1 Industrial status quo and new revolution

1.1.1 Industrial status quo

You may know the automotive company **General Motors Corporation (GM)** (hereinafter referred to as GM), which was an iconic American company founded in 1908. However, it was forced into bankruptcy in 2009[1]. There were many triggers that have incurred this bankruptcy. And one of them was that the company experienced the sales slump, especially the high-end Hummer which had larger power, but lower fuel economy.

FIGURE 1.1: GM has bankrupted in 2009

During 2007 and 2008, the oil price continued going up with the record peak of over 145 US dollars per barrel which reached in July, 2008[2]. It became one of the important reasons that customer demands had changed to the vehicles with higher fuel economy. That is to say, customers would prefer to buy a car which could consume lower amount of gasoline with a compromise of lower but enough power.

[1]General Motors Corporation filed for bankruptcy protection on June 1st, 2009.
[2]http://www.nytimes.com/2008/10/17/business/worldbusiness/17oil.html

However, it is under these circumstances that GM still decided to continue producing Hummer H3, which could consume 17 liters gasoline per 100 kilometers, while the vehicle *Reiz* produced by the company Toyota around the same years, could consume 12 liters gasoline per 100 kilometers, which is almost 30% energy saving. In addition, Hummer H3 would discharge more pollutants to the environment due to the higher consumption of gasoline, which was another reason that this vehicle model was unwelcome to the customers[3].

GM encountered the sharp decrease of market share, due to the slow response to the rapid changes of customer needs and the failure of catching up with the market trends, which would be the significant reasons that this famous company couldn't avoid fading in the history. And then consequently comes the conceivable question - How can companies lead or catch up with the market trends and improve their Key Performance Indicators (KPIs), thereby surviving in this dynamic world?

That is not an isolated case only for GM but a universal circumstance which has occurred in different industries across many countries and regions, e.g. the bankruptcy of V&D, which was a famous chain of department store in the Netherlands founded in 1887. This company also responded slowly to the market trend of supplying online service, which has already become the inevitable tactic for the other competitors in the same business field [Martin13].

Moreover, it has been observed by Erik Eliason, the co-founder & CEO of Storefront[4], that nowadays customers are more self-expressive, i.e. individuals want to express themselves through customized products such as the cars they drive, the clothing they wear and etc[5]. And it has also been observed by Njål Sivertstøl, a researcher at the Norwegian School of Economics, that more and more companies offer various online services, e.g. opening their own online communities where customers help each other[6].

1.1.2 New industrial revolution

It is perceived that there is a fusion of technologies that is blurring the boundary between the physical and digital worlds, which meanwhile is able to meet the increasing demands for customized products and services. Some researchers from institutes, managers from companies, have already been aware of this undergoing change, and they have named this change - **The Forth Industrial Revolution**, since there have been three industrial revolutions in the history.

The fourth industrial revolution is emerging, which is predicted a-priori, not observed ex-post[7]. This provides various opportunities for companies and research institutes to actively shape the future. Moreover, the economic impact of this industrial revolution is supposed to be tremendous, because it enables the sharply increased operational efficiency as well as the development of entirely new business models, services, and products. Facing the challenges and opportunities of the new revolution, many countries and regions are making strategic approaches to ensure that their industries transit to the new production paradigm, such as **Smart Industry** in the Netherlands, **Industry4.0** in Germany, **China Manufacturing 2025** in China, and **Smart Manufacturing Leadership Coalition** in the USA.

[3]Carty, S.S. and USA TODAY. *7 reasons GM is headed to bankruptcy*.
Source: http://abcnews.go.com/Business/

[4]Storefront is a sharing-economy company that provides short-term retail spaces for rent to companies through an online platform, used specifically as pop-up retail locations.

[5]Erik Eliason. *3 Reasons Why Mass Customization is the Future of Consumer Products*.(2012).

[6]Ingrid P. Nuse.*Customers and companies benefit from online support communities*.(2015).

[7]Hermann, M. (2015). Design Principles for Industrie 4.0 Scenarios: A Literature Review.

1.2 Supply and demand imbalance

As mentioned above, the Netherlands is preparing for the new industrial revolution. However, there is still imbalance between the demands of Dutch companies and the supports from the approach - Smart Industry.

1.2.1 Demand

Companies in the Netherlands want to survive and become more competitive given the rapid changes in the Fourth Industrial Revolution. They need to understand the approach of Smart Industry in order to determine the best possible strategy for implementing it. Meanwhile, they need tools and models which can guide them to implement this approach in their companies. For this purpose, there is a demand for tools and models to guide them.

1.2.2 Supply

There have been some supports from universities, research institutes, companies and the government. For example, the organization - **Smart Industry Partners** has offered a framework, including **seven Smart Industry elements (SI elements)**, to help companies to understand and to implement the Smart Industry approach[8].

However, the imbalance still exists between the demand and the supply, since there is a need for tools and models which could determine the extent to which a company has implemented the business and production processes that are compatible with the Smart Industry paradigm. Only after the benchmarks have been set up by some tools, then the company could use Smart Industry approach to redesign its processes, so that the transformation of this company would be ultimately achieved.

1.3 Objective

The objective of this study is to develop a tool to help companies clearly identify their performance levels of business and production processes from the perspective of Smart Industry, and then to guide them to choose feasible technologies and methods, so that companies could make their own strategies, thereby successfully achieving the transformation and maintaining their competitiveness during the Fourth Industrial Revolution. And this tool is termed **Smart Industry Maturity Model (SIMM)**.

1.4 Research method

Design Research Methodology (DRM) is applied to this study, which is developed to help the researchers to identify research areas and projects, and to select proper research methods to address the issues [Blessing09][Blessing04]. Figure 1.2[9] depicts the four steps of the DRM, i.e. Criteria, Descriptive Study 1, Prescriptive Study, and Descriptive Study 2. It is worth noticing that DRM is not a purely sequential process, that is to say, many iterations will take place, and some steps may have to run in parallel.

[8] http://www.smartindustrypartners.nl/smart-industry/

[9] Graphic source: Blessing, L. DRM: A Design Research Methodology. (2002).

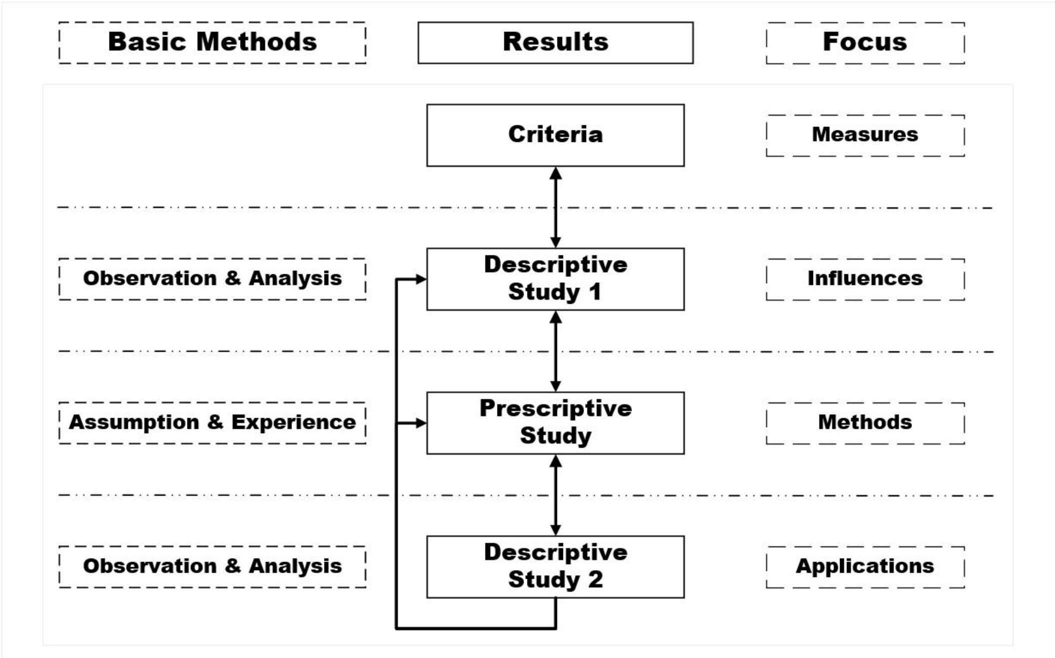


FIGURE 1.2: Framework of DRM

1.4.1 Criteria

The first step in the Design Research Methodology, is used to define the overall context, research questions and design objectives which has already been mentioned in previous sections. Also the success criteria are defined here, and they are:

- The study must be easy to understand for the readers, such as the language and the terminology.
- The study must have a clear structure, indicating how the SIMM has been developed and how the SIMM would benefit the audiences (e.g. users, target organizations and etc.) from the perspective of Smart Industry.
- The SIMM must be useful and reliable for the audiences.

1.4.2 Descriptive Study 1

This step is focusing on investigating existing literature to further understand the problems, then finding the factors that contribute to or prohibit success. These factors will be identified and be discovered how they influence the design of the SIMM. The result of this step would be a reference model or theory. For instance, references on Industry4.0 and Smart Industry would be studied in chapter 3, which would offer the knowledge foundation for developing the SIMM elements.

1.4.3 Prescriptive Study

This step is aiming at developing a new model or theory, based on the reference model or theory from the Descriptive Study stage 1, and describing the expected improved situation. This would result in a set of supports to achieve the goals and alleviate problems identified in the previous two stages. For instance, maturity models are studied in chapter 5, which would offer the foundation for developing the Smart Industry Maturity Model.

1.4.4 Descriptive Study 2

The fourth step is used to evaluate the new model or theory. Also the evaluation would show the usefulness, implications and side-effects. For example, the evaluation of SIMM will be carried out in chapter 7.

1.5 Outline of thesis

The outline of thesis is presented as follows (Figure 1.3).

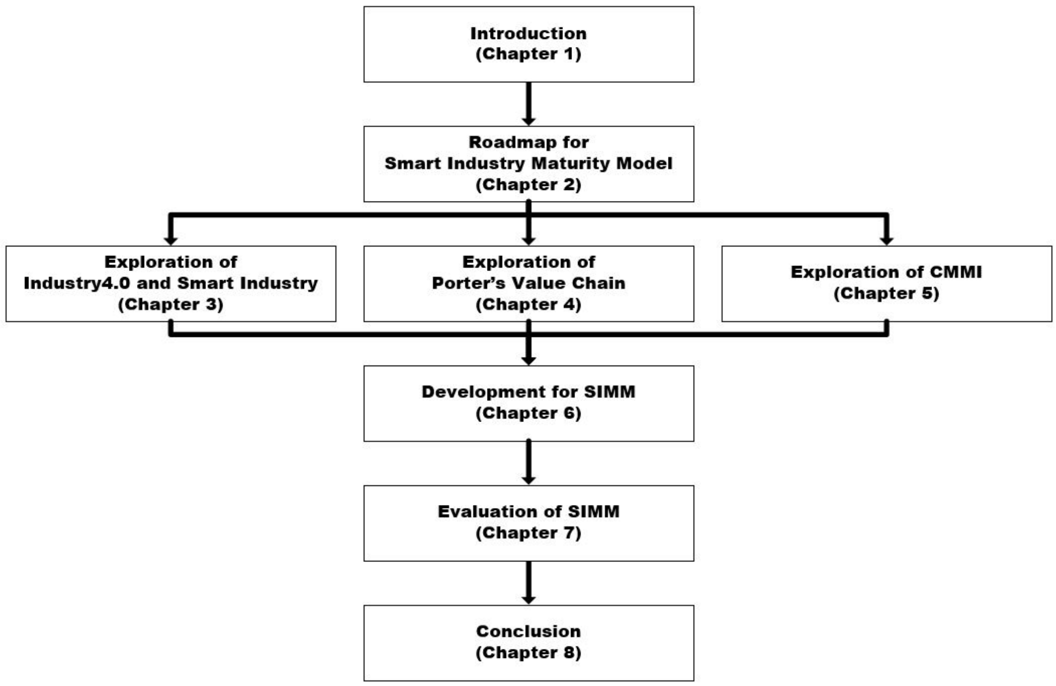


FIGURE 1.3: Outline of thesis

This thesis starts with the introduction section in chapter 1, which includes background information, problem identification, objective and research method.

Then a roadmap is designed for the development of SIMM in chapter 2.

After that, the exploration of two approaches, i.e. Industry4.0 and Smart Industry, is conducted in chapter 3, as well as the development of SIMM elements and their relevant technologies and methods (TMs).

Then the exploration of Smart Industry Canvas and Porter's value chain model is executed in chapter 4, as well as the development of KPIs, market trends, SIMM processes and their relevant Value-Added Points (VAPs).

In chapter 5, the exploration of Capability Maturity Model Integration (CMMI) is carried out, and the structure of SIMM and SIMM maturity levels are developed.

After all the explorations, the SIMM questionnaire is developed in chapter 6 and the evaluation of SIMM is carried out in chapter 7.

Finally, the conclusion is made in chapter 8.

Chapter 2

ROADMAP FOR SMART INDUSTRY MATURITY MODEL

As mentioned in chapter 1, companies need a tool to clearly identify their performance levels of business and production processes from the perspective of Smart Industry. For this aim, a new maturity tool will be designed for companies, which is termed as **Smart Industry Maturity Model (SIMM)**.

By using **SIMM**, companies should be able to:

- Determine the extent to which the organization has implemented the processes comparing to the best practices of Smart Industry;
- Identify areas where process redesign can be made;
- Determine what technologies and methods can be utilized;
- Inform external customers and suppliers of how well the organization's processes have performed comparing to the best practices of Smart Industry.

In order to successfully develop the tool, a roadmap for the development becomes necessary. And the roadmap would explain what procedures are needed, and why these procedures are chosen.

In this chapter, this roadmap will be designed and explained, including the aspects on how to develop, deploy, evaluate and improve the Smart Industry Maturity Model.

2.1 Main phases for a roadmap

According to the theory on *Introduction to Problem Solving* by Robert Harris, there are six phases that need to be carried out in order to develop a roadmap for problem solving. [Harris98]

- **Problem Exploration** – state the problem, clarify the problem, explain the problem and put the problem in context.
- **Goal Establishment** – consider ideal goals and establish practical goals.
- **Idea Generation** – generate ideas for possible solutions.
- **Idea Selection** – evaluate the possibilities and choose the solution(s).
- **Implementation** – try the solution and make adjustments.
- **Evaluation** – determine whether the solution worked.

Therefore, the Harris' theory is adapted for building a suitable roadmap for developing the tool - **SIMM**, which is elaborated as follows (Figure 2.1).

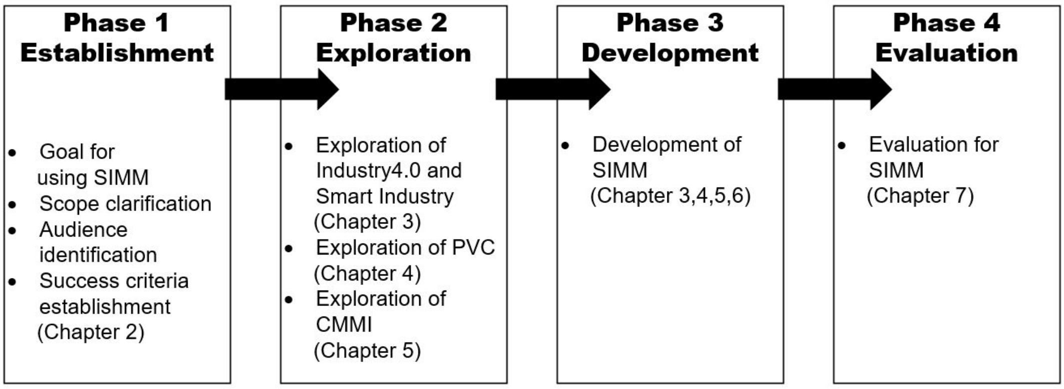


FIGURE 2.1: Roadmap for SIMM

2.2 Phase One – Establishment

2.2.1 Goal for using SIMM

As mentioned at the beginning of this chapter, **SIMM** is used to help companies to implement Smart Industry. By using this tool, companies would also gain insight of their business from a new perspective. Moreover, the tool sets a series of benchmarks to measure how well a organization's processes have performed in terms of Smart Industry. Then the redesign of processes in the companies, could be carried out based on the scanning results.

2.2.2 Scope clarification

Smart Industry Maturity Model is a domain-specific model, because most of the cases and references I have studied are within one field, i.e. the manufacturing industry, which includes manufacture and trade based on the fabrication, processing and preparation of products from raw materials and commodities. The other industries don't have the product design or fabrication processes, such as retail and energy industries. That is why they can't use the SIMM.

2.2.3 Audience identification

There are three types of stakeholders involved in the usage of SIMM.

- Users - They would use the SIMM to scan their companies in order to define the maturity level. They could be managers or engineers, who understand all the processes in the company, such as design and engineering, production, logistics, sales, services and etc.
- Target organizations - Users come from the target organizations. And the processes in these organizations need to be improved from the perspective of Smart Industry.
- Implementers - They are the managers or even top-ranking executives who are in charge of process redesign and innovation in the organizations. They can make the decision whether to start the implementation of Smart Industry based on the result of SIMM.

2.2.4 Success criteria establishment

Three success criteria are defined, so that SIMM can be evaluated in the **Phase 4**. And the results of evaluation can reflect whether SIMM could meet the success criteria.

The success criteria are designed as follows.

- SIMM should be easy to understand and to use by the audience.
  - The user understands the language and the terminology.
  - The user easily understands the questions.
  - The user easily chooses the answer which fits for the company.
- SIMM should be useful for the target organization.
  - The organization gains insights of their business and production processes from a new perspective.
  - The organization understands the Smart Industry approach.
  - The organization is able to use the results of SIMM to make decision whether to implement Smart Industry.
- SIMM should be reliable for the target organization.
  - Different staff in the organization gain the same maturity level with slightly different results in details, due to the different knowledge of the processes in the organization.
  - The user trusts the results of SIMM.

2.3 Phase Two - Exploration

Smart Industry Maturity Model has four main parts. It consists of '**SIMM elements and relevant technologies and methods (TMs)**', '**KPIs and market trends**', '**SIMM processes and relevant Value-add points (VAPs)**', and '**SIMM maturity levels and relevant questionnaire**'.

According to the four parts of SIMM, the following chapters are carried out in the **Phase 2**.

In chapter 3, the exploration of Industry4.0 and Smart Industry is conducted. And based on this exploration as well as the discussion of industrial status quo mentioned in chapter 1, KPIs and Market Trends are selected. After that, SIMM elements are and TMs are developed, which are used to support the implementation of Smart Industry in companies, thereby helping companies to improve their KPIs and to lead or catch up with market trends.

In chapter 4, the exploration of Porter's value chain model is carried out. Based on the exploration, SIMM processes are determined. And companies could find out the VAPs in these SIMM processes, where process redesign and innovation can be made by implementing SIMM elements and relevant TMs.

In chapter 5, the exploration of Capability Maturity Model Integration (CMMI) is executed. Then the structure of SIMM are designed. After that, SIMM maturity levels are defined, which are utilized to determine the extent to which a company has implemented the business and production processes that are compatible with the Smart Industry paradigm.

2.4 Phase Three - Development

The development of Smart Industry Maturity Model is explained in four chapters, i.e. from chapter 3 to chapter 6.

In order to make the thesis structure more concise and well-organized, the development of KPIs and Market Trends, SIMM elements and relevant TMs is conducted right after the exploration of Industry4.0 and Smart Industry in chapter 3. The same approach is also used in chapter 4 and chapter 5 for developing SIMM processes and relevant (VAPs), the structure of SIMM and SIMM maturity levels.

Then the development of SIMM questionnaire is carried out in chapter 6, which consists of the determination of the questions and answers in the questionnaire, and the assessment mechanism of SIMM. The questions and answers are developed based on the VAPs within SIMM processes and TMs within SIMM elements. Therefore, a generic question-making template is designed for every element and process in order to design questions (Appendix A).

2.5 Phase Four - Evaluation

This phase is used to evaluate the SIMM, and to receive the feedback from users. The feedback is used for improving the tool. It is worth pointing out that the evaluation is an iterative process. And when the evaluation results are acceptable, the SIMM can be regarded that it meets the success criteria.

SIMM would be evaluated for two aspects, i.e. the contents and the construct.

- Evaluation for SIMM contents is used to find out whether the model could properly represent the actual business practice, including the KPIs, market trends and business processes in a company, meanwhile whether it can fulfill its function for implementing Smart Industry.
- Evaluation for SIMM structure is used to figure out whether the mechanism of SIMM and the determination of maturity levels are properly designed and the results of SIMM are correct and accurate for companies.

Interviews with the evaluators in companies are necessary for the evaluation, because the questions and answers need to be slightly adjusted due to the different backgrounds of companies. And from the perspective of statistics, field tests are needed, and the more tests are carried out, the better evaluation would be.

Meanwhile, an online survey form for user experience is designed in order to assist the evaluation (Appendix B). In the survey, twelve questions are designed in order to cover all the success criteria. And the options of answers are designed with five levels, thereby evaluating whether the SIMM is successfully developed.

For instance, SIMM is said to successfully meet the criterion 'The organization could gain insights of their business and production processes from a new perspective.', if more than half of the evaluators have chosen the option which is higher than or equal to rank 3 in the question 'SIMM offers contributions to understanding the business and production processes from a new perspective.'

The roadmap for developing SIMM has been designed in this chapter. Then the exploration of references and the development of SIMM will start from the next chapter. And the next chapter is mainly about the exploration of two approaches for the Fourth Industrial Revolution, and the development of KPIs and Market Trends, and SIMM elements and TMs.

Chapter 3

EXPLORATION OF INDUSTRY4.0 AND SMART INDUSTRY

In this chapter, references on Industry4.0 and Smart Industry are studied, in order to further understand these two approaches. Then, Key Performance Indicators (KPIs) and Market Trends are selected for SIMM. After that, Smart Industry elements (SI elements) are briefly discussed as an external input from the organization - Smart Industry Partners. Finally, based on the previous three sections, the development of SIMM elements and relevant technologies and methods (TMs) is conducted.

3.1 Exploration of Industry4.0

The main purposes of this section are:

- To understand the approach Industry4.0, by investigating relevant papers and references;
- To supply the foundation which will be used in section 3.3 to select KPIs and Market Trends, together with the exploration of Smart Industry.
- To supply the foundation which will be used in section 3.5 to develop all SIMM elements and TMs, together with the exploration of Smart Industry.

It is necessary to firstly to explore Industry4.0, since the Dutch approach Smart Industry is inspired by the German approach Industry4.0[1].

3.1.1 Introduction of Industry4.0

The term **Industry4.0** was mentioned in 2011 at the Hannover Fair[2]. **Industry4.0 is the high-tech strategic approach of the German government for the Fourth Industrial Revolution, with the aim of maintaining the global competitiveness of German industry.** [Smit16]

Industry4.0 is currently a top priority for many research institutes and universities. However, a generally accepted definition of the term does not exist. Mario Hermann, from Technical University of Dortmund, have made the literature review with 51 publications, and provided a definition of Industry4.0. [Hermann15]

'Industry4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over

[1] https://www.mt.nl/dossiers/made-in-nl/smart-industry-in-7-vragen/87935

[2] http://www.vdi-nachrichten.com/Technik-Gesellschaft/Industrie-40-Mit-Internet-Dinge-Weg-4-industriellen-Revolution

the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross-organizational services are offered and utilized by participants of the value chain.'

Therefore, based on his research, **Industry4.0** consists of four pillars, i.e. Cyber-Physical Systems, Internet of Things, Internet of Service and Smart Factory (Figure 3.1). And they would be discussed in the section 3.1.2.

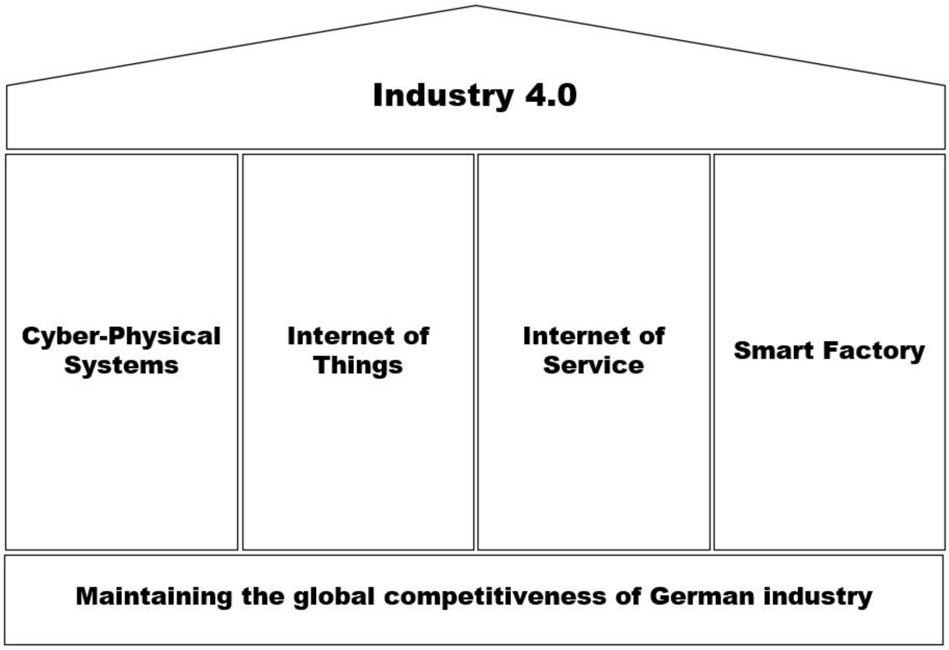


FIGURE 3.1: Four pillars of Industry4.0

3.1.2 Four pillars of Industry4.0

- **Cyber-Physical Systems (CPS)**

  CPS integrate the physical world and the virtual digital world, i.e. the physical processes and the computation. Equipment, embedded with sensors, microprocessors and software, is able to monitor and control the physical processes. And the equipment usually has feedback loops where physical processes can affect computations and vice versa.

  CPS consists of three layers (Figure 3.2), based on the research by Dr.-Ing. Rainer Drath who is the senior principal scientist and program manager in ABB Corporate Research, Germany. [Drath14]

  - **Smart physical objects** with embedded sensors and/or microprocessors has their own traceable identities in the network.
  - A **network infrastructure** enables the physical objects to exchange data in order to communicate with each other.
  - **Services** based on the analyzed data and algorithms, offers the possibility to optimize the collaboration among different physical objects as well as that between equipment and human.

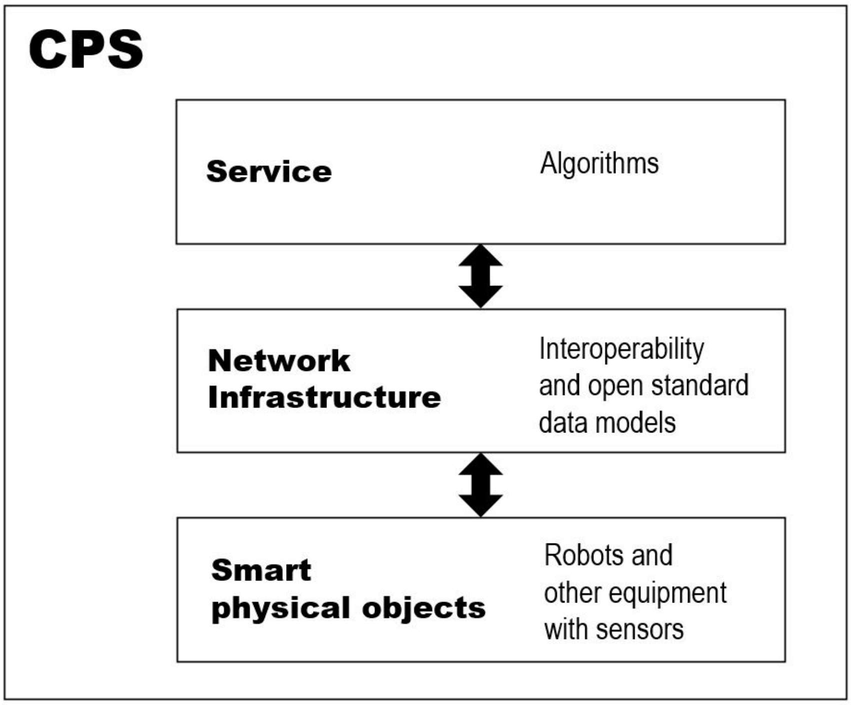


FIGURE 3.2: Three layers for Cyber Physical System

- **Internet-of-Things (IoT)**

  IoT was first used in 1999 by Kevin Ashton, former director of the Auto-ID Center of the Massachusetts Institute of Technology[3]. Nowadays, it is referred as the technology that integrates Information Communication Technology (ICT) into the Cyber-Physical Systems, which can be extended to various fields (Figure 3.3)[4].

  By the utilization of IoT, products, machines and processes are interconnected. They can communicate with each other, control the information over the Internet, and analyze the data to optimize or deliver better products or processes.

- **Internet of Service (IoS)**

  IoS provides values for both customers and companies by the utilization of the Internet of Things. IoT may be complicated to understand by customers, but IoS enables customers to easily use services that have been offered online by using the Internet of Things.

  Companies can offer not only special production types but also production technologies. And these production technologies would be offered over the IoS and could be used to manufacture products or compensate production capacities. For instance, one company have owned two 3D printers. They could sell the 3D printing service online, when one of these printers is idle.

  Moreover, customers can receive not only products but also professional technologies from companies. Meanwhile, companies would gather large amount

[3]http://www.symbolbv.nl/smart-industry/internet-of-things-digital-factory/

[4]Diagram derived from: Kagermann, H. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0, p19

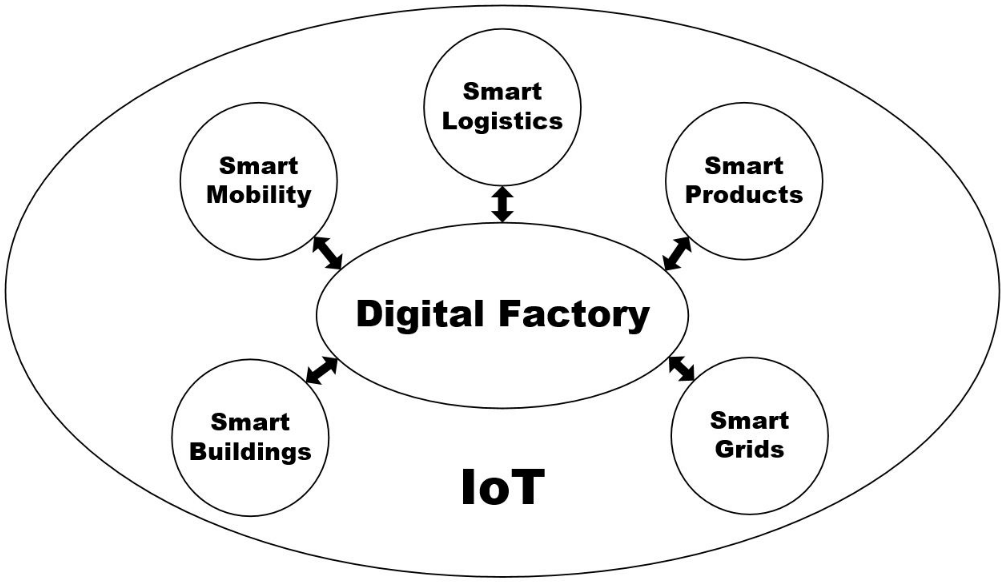


FIGURE 3.3: Interconnection based on Internet of Things

of valuable data when customers use their services. And these data could be used as the input for the process improvement or redesign.

- **Smart Factory**

  The Smart Factory is a context-aware factory that assists people and machines in achieving their tasks. **Context-aware** means the position and the status of one object (e.g. a product or a pile of raw material) can be perceived and transformed into data which are been collected and analyzed through IoT. For example, when a semi-product is ready for being transported to the next workstation, the system can inspect the position and status of this semi-product so that the system can automatically decide the proper handling tool to do the job.

3.1.3 Features of Industry4.0

Every approach has its own features distinctive from the other approaches, which indicates the different understanding and thinking of the fourth industrial revolution and shows the significant issues that one approach want to address. There are six features of Industry4.0, which are identified by the '**Policy Department A**: Economic and Scientific Policy' in the European Parliament. [Smit16]

These features are interoperability, modularity, virtualization, decentralization, real-time capability, and service orientation.

- **Interoperability**

  It is a characteristic of a product or system whose interfaces are completely understood by the other products, systems or human users, and the information or services can be exchanged directly and satisfactorily among these products or systems [Creps08].

  Interoperability is one of significant features of Industry4.0, because it increases the degree of operability. That is to say, not only same types of products and systems, but also different types of products and systems could communicate with each other. It enables the seamless connection and communication with other products, systems or users, which supplies the foundation of Internet of Things.

Comparing the structure of interoperability with that of compatibility and dominant system (Figure 3.4[5]), it is observed that interoperability could sharply increase the degree of operability, which is explained as follows.

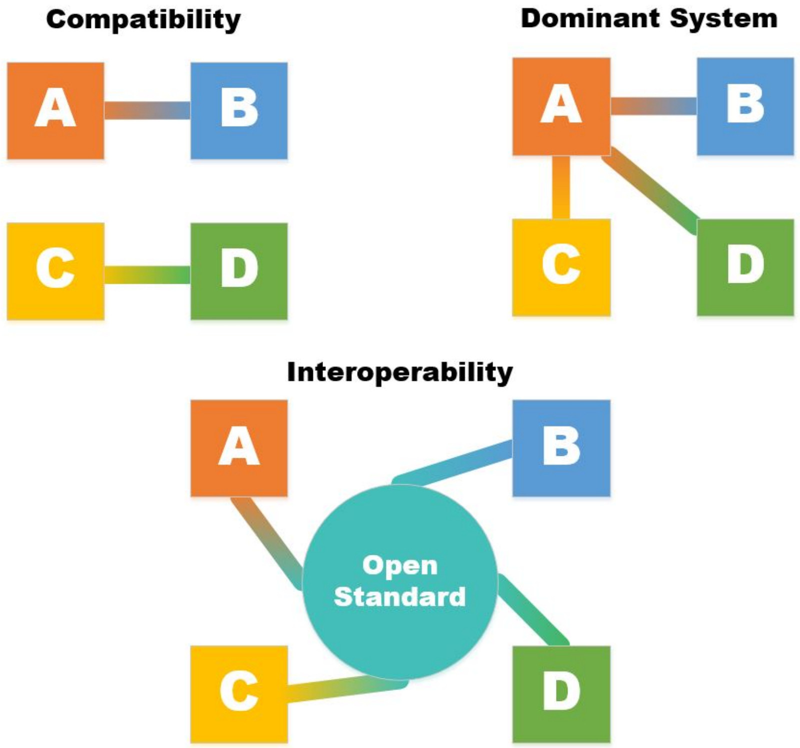


FIGURE 3.4: Interoperability increases the degree of Operability

a **Compatibility** - It enables two different types of systems to communicate with each other. But this two-way communication has its limits. Different systems, like A and C, can NOT communicate with each other.

b **Dominant system** - When there are more than two systems, if one becomes dominant in its field, then the other systems need to ensure themselves to be compatible with the dominant one. The advantage is that all systems can communicate with each other. But the disadvantage is that the dominant system have the possibility to control the other systems.

c **Interoperability** - Interoperability makes it possible that different systems can communicate with each other without depending on a particular system. It is based on the presence of an open standard.

- **Modularity**

  This feature of Industry4.0 offers the flexibility for systems. In case there are some changes of customers' requirements or seasonal fluctuations, modular

[5]Graphic source: http://interoperability-definition.info/en/

systems can be easily adjusted, for example, by plugging in new modules, replacing the existing modules, or decreasing the existing modules. Moreover, modularity can realize the reduction in cost comparing to the full customization, due to the advantages of standardization, assuming that high volume normally equals low manufacturing costs.

- **Virtualization**

  This feature transforms the physical world into the digital world. Sensors, embedded in the equipment, can offer huge amount of data which are collected and analyzed via the virtual simulation models. By doing so, Cyber-Physic Systems can connect to and monitor the entire processes in the physical plants.

- **Decentralization**

  In terms of industry, it is the philosophy of reconfiguring the functions and resources away from a central location, due to the growing demand for customized products. Unlike the conventional centralized control system in the plant, decentralized CPS embedded with microprocessors and sensors, can make decisions on their own based on the digital data through the IoT. Only in case of failures, tasks are delivered up to a higher level. It is worth noticing that it is necessary to keep track of the whole system at any time for quality assurance and traceability.

- **Real-Time Capability**

  As mentioned above, the monitoring and tracking of the entire system at any time is quite significant. And real-time capability can offer the permanent inspection, i.e. collecting and analyzing data of the status of the plant in real time, thereby ensuring the emergency response to the potential failures.

- **Service orientation**

  This feature depicts a company which can offer its services over the IoS, both internally and across company borders. For instance, based on a service oriented architecture in a plant, CPS offers functionalities as a module. Then the digital data of customer requirements would reconfigure all the modularized CPS to form a specific operational process. Finally, the tailored products are produced through this process.

3.2 Exploration of Smart Industry

The main purposes of this section are:

- To understand the approach Smart Industry, by investigating relevant papers and references;
- To supply the foundation which will be used in section 3.3 to select KPIs and Market Trends, together with the exploration of Industry4.0;
- To supply the foundation which will be used in section 3.5 to develop all SIMM elements and TMs, together with the exploration of Industry4.0.

3.2.1 Introduction of Smart Industry

Smart Industry (SI) is a broad concept, covering a number of technological developments, which will change the way companies function and help them to improve their productivity and to maintain the competitive position. Smart Industry is the high-tech Dutch approach for the Fourth Industrial Revolution, which was devised by TNO research institute and the FME organization [Huizinga16].

The purpose of implementing Smart Industry is to increase the competitiveness of Dutch industry, to promote the profit growth of Dutch companies, and to create new jobs in the Netherlands. This approach is enabled by a network-centric approach, making full use of the value of information driven by digitization and the latest available proven manufacturing techniques, which constitute the three pillars of Smart Industry (Figure 3.5). [Post16]

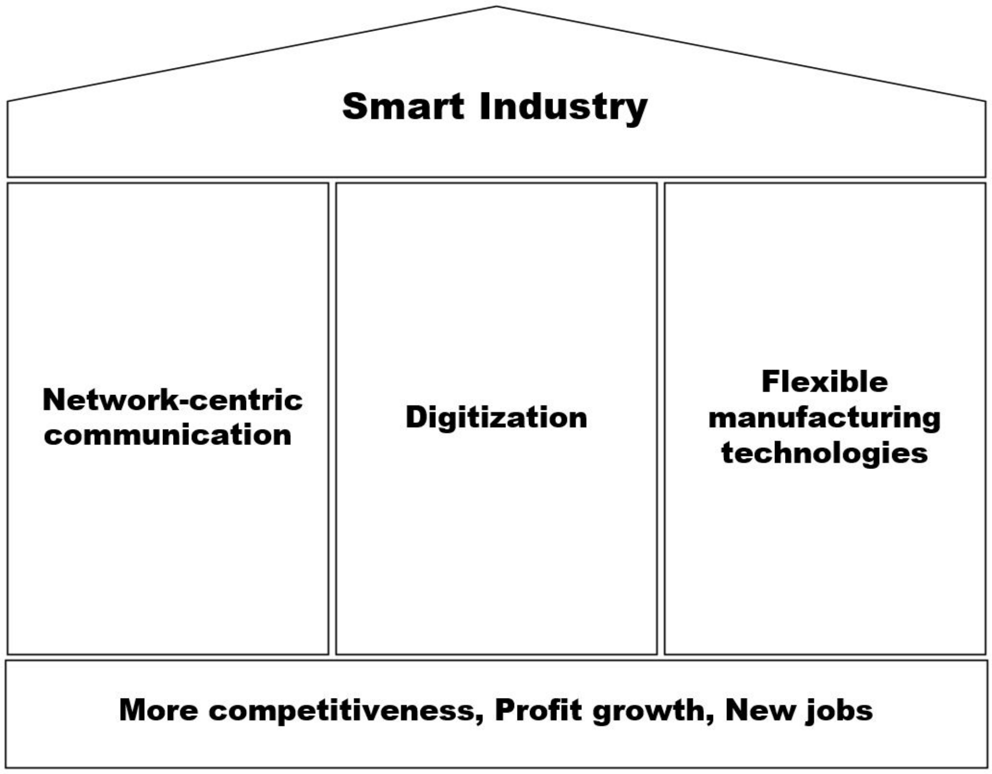


FIGURE 3.5: Three pillars and three motivations for Smart Industry

3.2.2 Three pillars of Smart Industry

There are three pillars of Smart Industry, i.e. Network-centric communication, Digitization and Flexible manufacturing technologies.

- **Network-centric communication**

  High quality network-centric communication would have profound influence on two fields.

  On one hand, network-centric communication would gather all the stakeholders in the entire value network, such as suppliers, clients, end-users, governments, and the company per se. It is more intelligent and efficient to add value in the network comparing to the linear chain.

On the other hand, in terms of production, network-centric communication would interconnect all the material flows, energy flows, and information flows along the production plant and the company. And this approach will reconfigure the conventional linear production processes and form a new flexible production network.

- **Digitization**

  It refers to the action or process of digitizing, i.e. transforming analogue information (e.g. images, video, and text) into digital data. It enables companies to redesign their capabilities and to keep in contact with the connected consumers in real time. By doing so, these companies are able to not only maintain the continuous customer intimacy, but also gain superior revenues.

  Moreover, when digitization of information and communication has established among all value chain partners and in the production process on all levels, the holistic industry, based on sensory systems, would be radically upgraded due to the new innovations in the production process, products and services.

- **Flexible manufacturing technologies**

  Carel van Sorgen, director of 247 TAILORSTEEL, once said that the time to market was often too long and the total cost of ownership was too high, with the conventional way of operating the companies. So, he thought the enabling technologies of Smart Industry were important for his company [Huizinga16].

  Additive manufacturing, full-process-chain simulation, modular design, ubiquitous sensors and new generation robots - these advanced technologies would work together to enable cost-effective flexible manufacturing. That means companies can Make To Order, so that customers can purchase the products which are tailored to their specific demands. It is worth pointing out that these advanced technologies are also significant in the approach - Industry4.0, which have already been discussed in section 3.1.

3.2.3 Features of Smart Industry

Similarly with Industry4.0, the Smart Industry approach also has its distinctive features and its own issues to deal with.

According to the research *A Vision For Dutch Industry Fit For The Future*, Smart Industry has the following features [Sol16]:

- High degree of flexibility in product needs (specifications, quality, design), volume (what is needed), timing (when it is needed), resource efficiency and cost (what is required);
- Ability to tune to customer needs;
- Ability to capitalize on the entire supply chain for value creation.

Another research *Smart Industry - Dutch Industry Fit For The Future*[6] [Huizinga16], provides more detailed features of Smart Industry, which have the consistency with the previous research.

[6]This research collects the contributions from more than 100 companies, knowledge institutions, government authorities and economic development organizations across the Netherlands.

According to this study, the three technological developments mentioned above (i.e. three pillars), are leading to six major changes within companies, which also constitutes the features of Smart Industry. The technological developments and the features have formed a **Smart Industry Wheel**, which can drive all the stakeholders to achieve the goals of Smart Industry (Figure 3.6[7]).

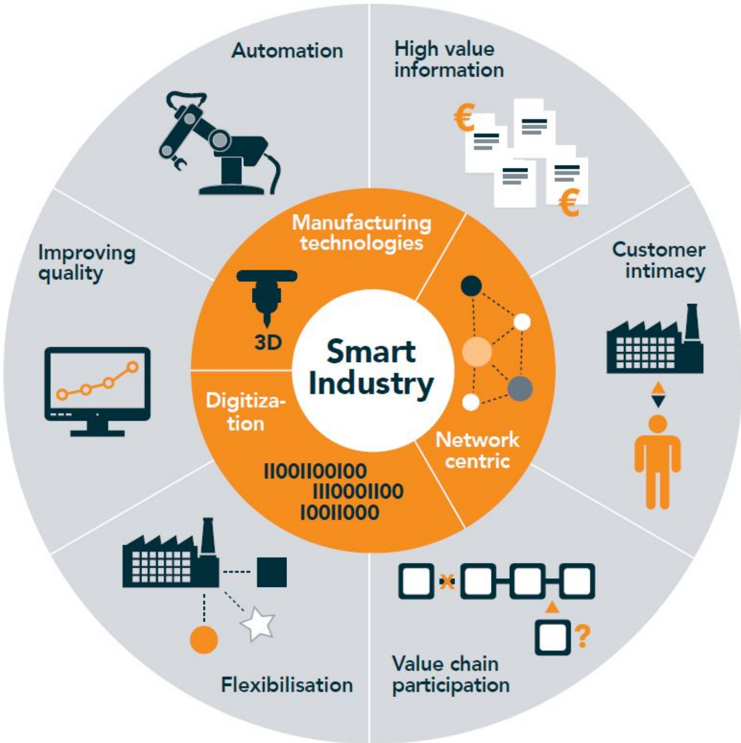


FIGURE 3.6: Smart Industry Wheel

- **Value chain participation**

  Network centric approach and digitalization are changing production chains and they would enable a closer collaboration among various stakeholders in the value chain. And one significant feature would be that new stakeholders may become part of the value chain.

  For example, unlike the conventional production process, customers would join in the design phase of their unique products in Smart Industry, so that the products can meet the customers' requirements and can be manufactured efficiently.

- **High-value information**

  The network-centric communication and the utilization of sensors will lead to an overwhelming amount of information for companies, therefore it is reasonable to focus on the use of the information as the new source of value creation. [Huizinga16]

  For instance, the high-value information may come from a production process, indicating which workstation becomes the bottleneck. Then production manager can use this information to optimize the production process.

[7]Graphic source: *Smart Industry Action Agenda Standardisation 2016*, p6

Another example, the high-value information may be the real-time feedback of customer usage from the sensors which have been embedded into the products. Then companies can monitor the quality of products and offer the maintenance before the failure occurs, in order to avoid the unexpected downtime.

- **Improving quality**

  As mentioned previously, the high-value information would be the data from the production process or the data of the customer using experience. By utilizing the high-value information, companies would improve the design, engineering, and production processes, which would result in better quality of products.

- **Automation**

  The further developed automation would create more value only if the collaboration happens among the different types of machines, equipment and systems, which would result in consistently high quality and lower costs at the factory floor. And Industrial Ethernet could provide the interoperability based on the open standards, which could support the automation to generate more value. As discussed in section 3.1.3, interoperability enables different systems to exchange information and to work with each other without any restrictions.

  For example, ten semi-finished products need fine grinding. Because they are tailored for different customers, the position and the angle to grind are different. This circumstance requires, for every semi-finished product, that an industrial robot should precisely turn the work piece to the right position, deliver it to the grinding machine and hold it while grinding. If the industrial robot could communicate with the grinding machine, then it could autonomously adjust the position for every semi-finished product, which could lead to an efficient production process. On the contrary, if the robot and the grinding machine could not communicate with each other, then operator has to set the parameters of robot for ten times in order to hold the work piece with a right position to the grinding machine, which could incur a relatively time-consuming process. And that is why, an industrial robot would offer more value if it can work together with other machines on a production line without human intervene [Nagtegaal16].

- **Flexibilization**

  With the development of manufacturing technologies and the implementation of digitization, factories become more and more flexible, which enables companies to offer the customized products by using the cost-effective production process.

  For instance, manufacturing robotics could be easily switched from one type of product to another with a little change of programming; 3D printing technology allows to produce products with almost any shape or geometry, which would facilitate cost-effective flexibility to an unprecedented level.

- **Customer intimacy**

  Since customers will be more demanding, companies should tailor the products to meet the individual requirements of customers. Also, customers would prefer to buy a unique product at a low price. Due to these demands, the previous five features of Smart Industry would help to add more value to products with a cost-effective way, so that companies can satisfy their customers and increase the customer intimacy.

3.3 Selection of KPIs and Market trends

As discussed in the bankruptcies of GM and V&D in chapter 1, these two companies failed to catch up the market trends, i.e. sustainability and E-commerce respectively. They lost their market share and revenue, and couldn't recover from the impact of the wrong decision (i.e. lacking of organizational resilience). Meanwhile, based on the observation of industrial status quo by Erik Eliason and Njål Sivertstøl in chapter 1, customers want to have their tailored products, and companies have started to offer additional online services (e.g. opening an online community) in order to supplement their products and services. Moreover, as mentioned in the references of Smart Industry, productivity, time to market and total cost are also the important aspects considered by companies.

Therefore, there are six **Key Performance Indicators (KPIs)** and four **Market Trends** selected for SIMM. These KPIs are Productivity, Time To Market, Market share, Resilience, Revenue and Cost. And the market trends are Sustainability, E-commerce, Individualization and Servitization.

3.3.1 Definitions of six KPIs

Key performance indicators (KPIs) are a set of measurable values that demonstrates how effectively one company is achieving its key strategic and operational goals over time. Also, these metrics can be used to compare a company's finances and performance against other companies within its industry.

Six KPIs are selected for SIMM, which are elaborated as follows.

- **Productivity**

  It is an economic measure of the cost efficiency of a company, in converting inputs into useful outputs. Inputs are total costs incurred or resources consumed include capital, material, energy and personnel, while output is measured in revenues and/or business inventories.

  Productivity growth means more value is added in production and this implies more income is available to be distributed. All the participants along the value chain can benefit from the growth of productivity:

  a **Shareholders** can receive higher profits or dividend distributions;

  b **Workforce** can get more wages;

  c **Customers** can buy cheaper products;

  d **Government** can receive more taxes and etc.

  Because of the productivity growth, the company can not only meet the obligations to all the stakeholders, but also become more competitive in the market.

- **Time to market (TTM)**

  It is the length of time taken in product development process from product idea to the finished product available for sale. It is a critical component of time based competition, where products are outmoded quickly in some industries.

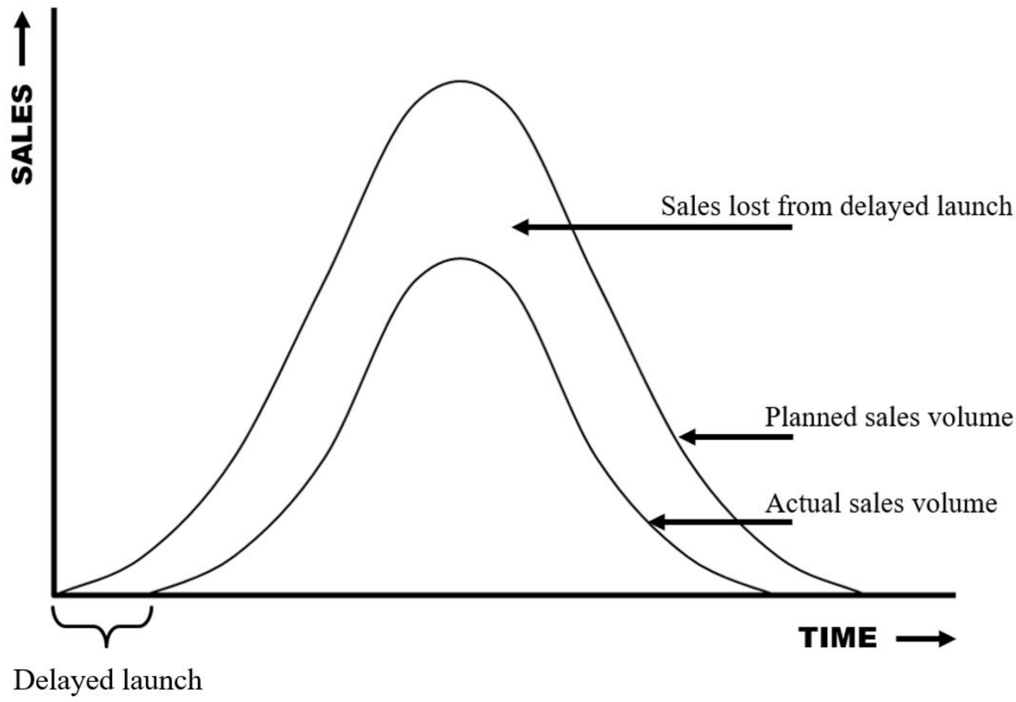


FIGURE 3.7: Influence of Time To Market on product sales

TTM can significantly influence the sales for the product (Figure 3.7)[8]. The blanket area between the two curves indicates that the total sales volume is reduced from the original planned volume, due to delayed product launch. On the contrary, assuming that the price of product in the actual sales is the same as that in the planned sales, then shorter time to market guarantees a relatively higher profit for the company. However, it is worth noticing that a company's TTM goals should be aligned with its business strategy rather than pursuing speed blindly.

- **Market share**

  It indicates that how much percentage of a market's total sales has been occupied by the company during a specified time period. That is to say, it is calculated by taking the company's sales over the period and dividing it by the total sales of the market over the same period. This KPI can offer a relative size of the company comparing to its market and its business competitors.

  Usually, it is easier to squeeze into a growing market and to increase the market share, where customers are just starting to know the market and want to try new products and services. On the contrary, a mature market is more difficult to get into, because the company has to spend extra resource to change the customers' regular buying behavior, in order to take them away from its competitors.

- **Resilience**

  British Standard, BS65000 (2014) defines **Organizational Resilience** as *the ability of an organization to anticipate, prepare for, and respond and adapt to incremental change and sudden disruptions in order to survive and prosper*. [Gui14]

[8]Graphic source: http://www.arenasolutions.com/resources/articles/time-to-market/

In such a turbulent business environment nowadays, companies need resilience. The higher level of resilience, the more efficient for a company to absorb the impact of the failure of one or more components in its products or a significant disturbance in its environment, and the more likely for a company to still continue to provide an acceptable level of service to the customers.

- **Revenue**

  It is the gross income of a company, including the amount of money that a company actually receives during a specific period, and the deductions for returned products. It is calculated by multiplying the price at which goods or services are sold by the number of units or amount sold. Therefore, it is an indication of the total cash flow generated by a company. It is worth pointing out that high revenue does NOT necessarily mean a high profit (or net income), since a company may have a high cost at the same time.

- **Cost**

  There are two branches of **cost** for a manufacturing company, i.e. the direct and indirect cost.

  A **direct cost** is completely attributed to the production of specific goods or services, such as the money spent on raw material, the salary paid for the workers. An **indirect cost**, such as depreciation or administrative expenses, are the cost belonging to the entire company, which is more difficult to assign to a specific product.

3.3.2 Definitions of four Market Trends

- **Sustainability**

  Sustainability, in terms of companies, is a strategy that creates long-term stakeholder value by considering how a business operates in the social, environmental, cultural, and economic environment. Sustainable companies have more opportunities to reap value in the form of reputation building, cost savings, and growth opportunities.

  Also, according to the book written by Bob Willard, there are seven sustainability strategies to increase revenue, improve productivity, reduce expenses, and decrease risks. The seven areas of focus are:

  a Increased Revenue & Market Share
  b Reduced Energy Expenses
  c Reduced Waste Expenses
  d Reduced Material & Water expenses
  e Increased Employee Productivity
  f Reduced Hiring & Attrition Expenses
  g Reduced Risks

  Cited as a real life example in the book, the Cambridge Ontario based metal fabricating company VeriForm achieved 58% reduction in electricity usage, 90% reduction in natural gas usage which led to 115 tonnes of reduction CO_2 emissions reduction, ultimately leading to an increase in profit by 76%. The company had invested $46,186 and yielded energy savings of $89,152 with an average payback period of 6.3 months [Willard12].

- **E-Commerce & Supply chain integration**

  E-commerce has been developed for quite a long time, since early 1970s when Michael Aldrich demonstrates the first online shopping system to realize the online transaction between businesses and consumers, or among different businesses [Tkacz09]. In the early stage, e-commerce was used to simplify the commercial trading activities, by EDI (Electronic Data Interchange) technology. Nowadays, the concept of E-commerce has changed a lot. It contains not only contains it ERP (Enterprise Resource Plan), Data mining, and Data warehouse, but also the logistics management and informatization along the entire industrial chain. That is to say, E-commerce and Supply chain integration can complement each other perfectly.

  For instance, Amazon.com Inc. is one of the big winners, due to E-commerce and Supply chain integration. The company is expected to account for more than half of all e-commerce growth in 2015, discovered by Macquarie Research[9].

- **Individualization**

  People naturally have the ability to see each person as one of a kind. They tend to remain unique and also to be curious about the unique qualities of other persons. Then customized products or services just perfectly satisfy the people's demands.

  With the newly developed technologies in recent years, individualized products or services would be purchased by more and more customers at affordable prices, which makes customization be a promising market trend.

- **Servitization & Pay per use**

  Servitization refers to industries offering additional services to supplement their traditional products and core services. These additional services including consultancy, all aim to improve the performance and profitability of a company. It appeared around the late 1980s. The most frequently source article is cited as Vandermerwe, S., & Rada, J (1988) *Servitization of Business: Adding Value by Adding Services*, European Management Journal, 6(4), 314–324.

  Pay per use is a hot topic recently in the business field. I consider it as a variation of the servitization, since it is a new way for companies to gain more profits by offering the extra services (e.g. maintenance and updating). The use of a product or service is metered, and customers are charged when they use the service.

  There is a vivid example from Rolls Royce, which demonstrates how the servitization works. Previously, Rolls Royce sold aero engines per se to customers. However, nowadays they sell the power of engine instead. That is to say, the customer can buy the power that aero engines generate. And Rolls Royce would take all the measures, including monitoring and maintenance, to ensure the continuous and stable power delivering of aero engines during the period that the customers are using them.

  Both the company and its customers can benefit from the servitization. For customers, they only pay for the value that they receive from the company. For the company, there are twofold benefits. Firstly, customers tend to pay more for the stability of products and services, especially the products that are

[9] http://www.marketwatch.com/story/amazon-will-account-for-more-than-half-of-2015-e-commerce-growth-says-macquarie-2015-12-22

the key components, such as engines in aeroplane, coal burners in coal chemical plants and etc. Secondly, R&D department in the company would receive data from customers which can be used into the continuous improvement of products and services.

3.4 Discussion of SI elements

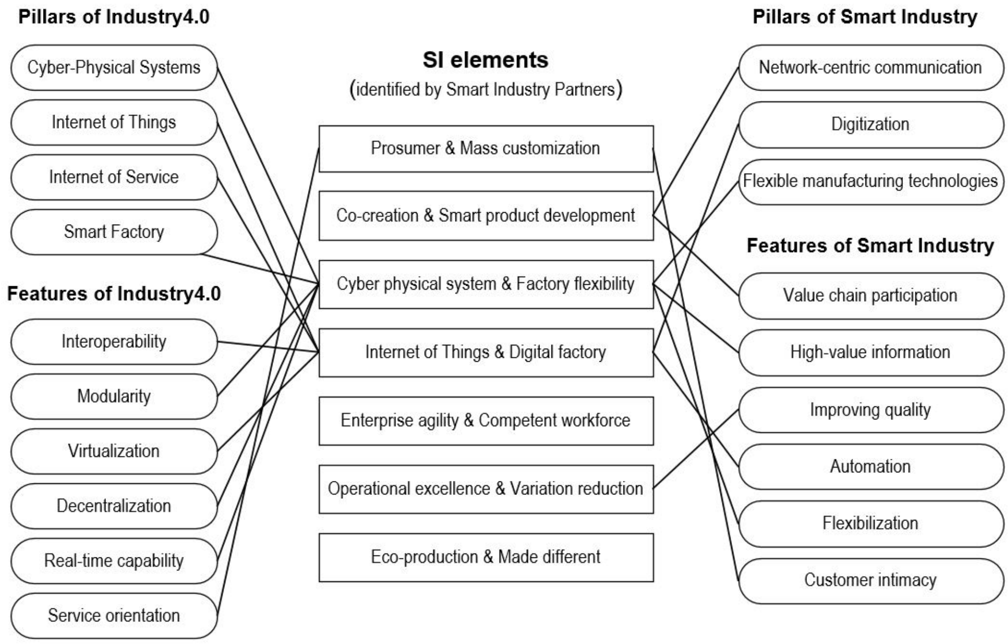


FIGURE 3.8: Comparison among SIC, Industry4.0 and Smart Industry

As mentioned in chapter 1, Smart Industry elements are provided by the organization - **Smart Industry Partners** in order to help companies to understand and to implement the Smart Industry approach. These SI elements comprises Prosumer & Mass customization, Co-creation & Smart product development, Cyber physical system & Factory flexibility, Internet of Things & Digital factory, Enterprise agility & Competent workforce, Operational excellence & Variation reduction and Eco-production & Made different.

These elements not only have fully covered all the pillars and features of the two approaches, i.e. Industry4.0 and Smart Industry, but also have proposed three extra aspects considering organization agility, competitive employees and eco-friendly production processes. The comparison is presented in Figure 3.8.

It would be better that the development of SIMM elements should have the consistency with SI elements. Otherwise, it is harmful for the implementation of Smart Industry, because the users or target organizations might get confused and feel difficult to understand the approach when they see different terminologies for the elements. Therefore, I would develop SIMM elements with new definitions based on what I have learned during the exploration of Industry4.0 and Smart Industry, but SIMM elements would have the same names as that of SI elements.

3.5 Development of SIMM elements and TMs

SIMM elements are utilized to help companies to make their own strategies based on the KPIs and market trends considered important to them. And the relevant technologies and methods (TMs) are used to add value into VAPs, thereby supporting the process redesign and innovation within SIMM processes. The main goal of this section is to develop the SIMM elements and relevant TMs, which belongs to **Phase 3** of the roadmap.

There are seven SIMM elements and twenty four relevant technologies and methods (TMs) for Smart Industry Maturity Model (Figure 3.9), which are elaborated as follows.

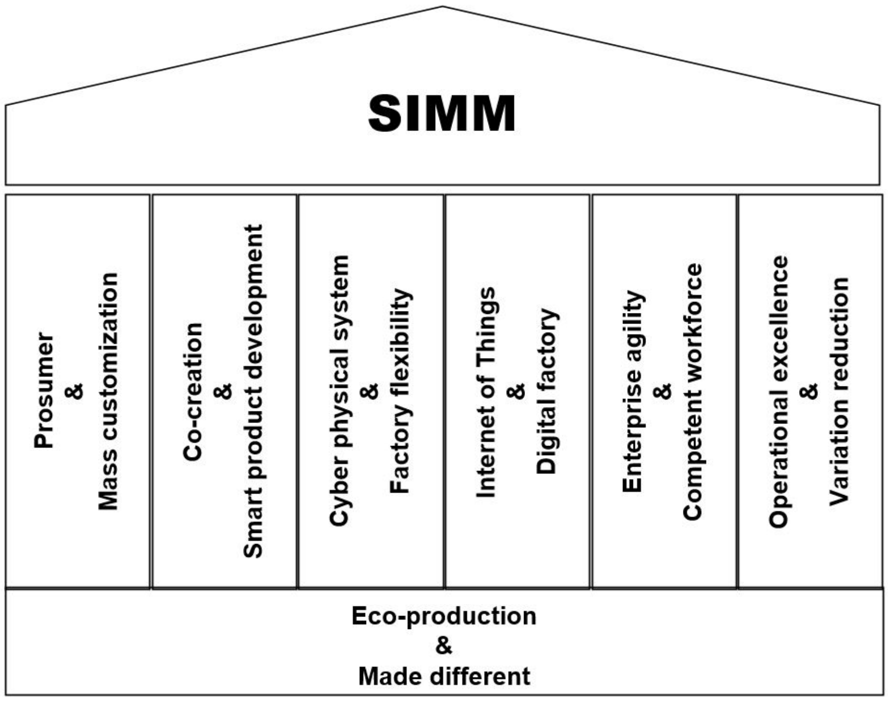


FIGURE 3.9: Seven SIMM elements

3.5.1 Prosumer & Mass customization

Prosumer is the appellation for a customer within Smart Industry. Prosumers want to purchase the tailored products and services for themselves at anywhere and anytime that they are convenient. And new technologies, such as Internet of Things and, enable them to directly influence the design, engineering, and production processes in a company.

In their spare time, prosumers would like to make reviews and comments for the products and services they have purchased and respond to reviews and comments from others. Moreover, prosumers are willing to learn, and share knowledge by using the social media. For instance, prosumers would record and upload the videos which can help the others with certain issues, e.g. how to use 3D printer to produce an action figure on your own. The contributions that prosumers would like to offer in their spare time, would have a significant influence on the buying behavior of the other prosumers, especially for the group of people who are shopping on line, no matter they are national or international customers.[Ingleton11]

The characteristics of prosumers have impelled companies to transform mass production into mass customization, so that companies can maintain high customer intimacy.

Mass production is the efficient process of manufacturing large quantities of standardized products, frequently utilizing assembly line technology. While **Mass Customization** is the integration of total customization and mass production. That is to say, customers can purchase customized products and services at a relatively low expense as much as that in mass production.

In order to achieve this goal, the modularization of design, engineering, and production processes has to be realized in the company. And products and services themselves also need to be set up modularly. Therefore, customers can receive their unique products and services based on an infinite number of possible configurations offered by the company. Take the IKEA kitchen for a successful example. Customers can select the favorite cabinets, counter tops and other modularized kitchen items, then configure them through the on-line service - *IKEA kitchen planner tool* and the tutorial videos. By doing so, customers would build their dreamy kitchens and IKEA wins the great satisfaction from them.

There are six TMs related to this SIMM elements, i.e. marketing analytics, additive manufacturing, social media, modular design & configurator, PLM (ERP/CRM/MES), supply chain data integration.

- **Marketing analytics** – Companies collect, manage and study the metrics data in order to determine the Return on Investment of marketing efforts, and then identify opportunities for improvement.

  Marketing metrics are the data points per se, such as Online Conversions metrics, and Web Traffic Sources. And analytics puts metrics data in the context of brand and market, indicating how marketing efforts are driving revenue in the company.

- **Additive Manufacturing (AM)** – It was a formalized name for Rapid Prototyping (RP) which depicts a process for rapidly making a prototype from which final product will be derived, and the prototype doesn't have a good quality. [Gibson09]

  Nowadays, AM encompasses many technologies including 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. It provides unsurpassed design freedom and opens up many favorable possibilities at system architecture level when combined with design optimization. The material nowadays contains plastic, metal, concrete, food material, and will include one day the human tissue.

- **Social media** – With the ever rising utilization of the Internet, social media are becoming the second communication channel between a company and its customers. Customers can get a lot of information, such as the reputation of company, the products and comments from other customers, which will influence the buying behavior of them.

- **Modular design/Configurator** – Modular design is a design method, splitting a design process into smaller sections (i.e. modules) which can be independently executed and then combined afterwards. Besides reduction in cost (due to less customization), modularity offers an easy extension of adding new design by merely plugging in a new module), thereby improving the performance of Time to Market.

Configurator, also known as choice board, or co-design platform, is used as a design tool that allows customers to co-design their own products. It enables mass customization, which depends on a deep and efficient integration of customers into value creation.

- **PLM (ERP/CRM/MES)** – Product Life Management (PLM) is a strategic business approach. By using the data from Enterprise Resource Planning (ERP) system, Customer Relationship Management (CRM) system, and Manufacturing Execution Systems (MES), PLM can support the collaborative creation, management, and information sharing across the extended enterprise, spanning from product concept to end of life. PLM forms the product information backbone for a company and its extended enterprise.

- **Supply chain data integration** – This technology enable companies to integrate their internal systems with external trading partners such as suppliers and 3PLs[10]. Only when all stakeholders along the value chain can work together based on the same data, then the supply chain can optimally fulfill its function by better, faster decision-making and execution from all the partners.

3.5.2 Co-creation & Smart product development

Co-creation enables all stakeholders to affect the product or process, e.g. by increasing and improving the collaboration with customers, suppliers and other relevant individuals or organizations, companies gain faster access to the knowledge of new and valuable technologies. Co-creation would also reduce the Product Life Cycles, because design, engineering and production processes can work in parallel instead of in a sequential way.[Sigogne16]

Co-creation supplies the knowledge resource for the smart product development.

Smart Product Development offers the solid foundation for Cyber Physical System and IoT, because big data can only be produced, collected, transformed, delivered, analyzed and finally utilized by smart products. For example, Siemens uses a new technology **Digital Twin** for smart product development. When engineers are working on the digital design of a new product, the development of the physical product is also executing at the same time.

There are three TMs related to this SIMM elements, i.e. collaboration R&D, digital twin, and concurrent engineering.

- **Collaboration R&D** – Collaborative Research and Development consists of the research methods, metrics and tasks, which can be used for developing a long-term partnership with an external organization. This collaboration could help companies to gain profits because the utilization of knowledge spillovers and the exploitation of synergies, such as solving complex challenges by sharing knowledge, skills, equipment and data source. [Allan99]

- **Digital Twin** – It is a virtual model used for fully describing a product or service. It can use data from sensors installed on physical objects to represent their real-time positions or working conditions. It is a bridge or medium to connect the physical and virtual worlds, which enable the companies to real-time monitor their products, to collect and analyze the data from products, and finally

[10] 3PLs means *Third-party logistics*.

to diagnose and solve problems even before they may occur, thereby reducing the downtime, and exploring the new opportunities for further improvement. [Grieves16]

Thomas Kaiser, SAP[11] Senior Vice President of IoT, once said: 'Digital twins are becoming a business imperative, covering the entire life-cycle of an asset or process and forming the foundation for connected products and services. Companies that fail to respond will be left behind.'[12]

- **Concurrent engineering** – It is an approach of designing and developing products, also known as simultaneous engineering. It emphasizes the parallelization of the tasks of product development. Than is to say, different stages, such as design engineering, manufacturing engineering, would run simultaneously rather than consecutively, which could removes the reworks that may happen in the design and engineering processes.

  By doing so, companies could improve the KPI – Time To Market, i.e. reducing the time required to bring a new product to market. Also it could contribute to other KPIs, i.e. improving the productivity and reducing the costs. It is worth pointing out that the initial implementation can be challenging for companies. However, concurrent engineering is a long term business strategy, with long term benefits to companies.

3.5.3 Cyber physical system & Factory flexibility

Cyber Physical System (CPS) makes it possible to integrate the physical world and the virtual digital world. This element also has been discussed in section 3.1.

The utilization of CoBots becomes sharply increasing, which relies on CPS. Human being is more flexible than any other robots. And CoBots capitalize on the advantages of both human and robot. CoBots are collaborations between robots and operators, where the physical task is executed by the robot and control task by the operator.

CPS is able to enhance the factory flexibility.

Factory Flexibility allows different products to be produced on the same production process with different operations, so that companies can meet the various requirements from customers. Firstly, the products have their own IDs so that they are traceable within their entire product life cycles, such as during the production process. Secondly, CoBots can efficiently accelerate the production process. Finally, the data generated by smart physical objects, can be automatically analyzed and be used to optimize the configuration of production modular cells.

There are three TMs related to this SIMM elements, i.e. CoBots, reconfigurable production cells, and track and trace.

- **CoBots** – Collaborative robot is a robot intended to physically interact with human beings in a shared workstation. It can offer an efficient collaboration between human operators and robots. That is to say, the physical task is performed by the robot, and the robot is controlled by the operator if necessary.

  The case I have learned is KUKA CoBots in Volkswagen. The CoBot is performing a highly-precise polishing work for car parts, which eliminates the

[11] SAP owns the 3rd place of The World's Biggest Public Companies in the field of software & programming.

[12] https://www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important/

production defects, while the operator are supplying semi-finished parts and collecting and testing the finished parts.

- **Reconfigurable production cells** – These cells use a modular structure for both hardware and software, such as for sensors, machines and conveyor belts, and for new controller algorithms and etc. They are designed for rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of its modular structure. The purpose of reconfigurable production cells are used to satisfy the change in market where customers want smaller batches of tailored products with shorter deliver times. [Mehrabi00]

- **Track and trace** – It would offer accurate digital information to help companies to monitor and manage the entire product life cycle. Automatic identification technologies such as barcode and RFID have been used for track and trace. Barcode is a passive tag, widely used in many fields. RFID has two types – passive and active tags. Unlike a barcode, the RFID doesn't need to be within the line of sight of the reader, so it can be embedded in the tracked object, which is more flexible under some circumstances.

  For instance, by using this method, companies can identify the all the information of raw materials, such as place of production, quality, and amounts in stock, so that inventories of raw materials could be controlled by the ERP system. Another example is that companies could clearly know where the customers are and which products have been delivered to them correspondingly. Therefore, when there is a maintenance require from one customer, all necessary information like mending tools, materials and human labor, would be automatically optimized based on the information of the customer and the product. By doing so, companies would supply accurate services in time with the lowest cost.

3.5.4 Internet of Things & Digital factory

Internet of Things (IoT) refers to the interconnection among smart physical devices, products and processes by integrating Information Communication Technology (ICT) into the Cyber Physical Systems. These smart devices with embedded systems can interact with human and other smart objects, so that they can autonomously make decisions to optimize or deliver better products or services. This element also has been discussed in section 3.1.

In order to use the technology IoT, factory must experience the digitization.

In a **Digital Factory**, all the smart apparatus and machines are connected with Enterprise Resource Planning system. Tremendous amount of digitized data, such as information about production performance, inbound/outbound logistics, market and sales, are generated and exchanged anywhere through the information network. Then data analytics becomes more important, and based on which smart devices can utilize the result and make autonomous decisions, such as mounting different tools according to different production requirements.

There are three TMs related to this SIMM elements, i.e. Internet of Service, big data analytics, and real time optimization.

- **Internet of Service** – IoS provides values for both customers and companies by the utilization of the Internet of Things (IoT). As mentioned in the **section 2.2.3**, services can be offered online by using the IoT. Customers can receive not only products but also professional technologies from companies. Meanwhile, companies would gather large amount of valuable data when customers use their services. And these data could be used as the input for the continuous improvement.

- **Big data analytics** – Analytics has been used to uncover the insights and trends. And the big data analytics has more advantages, such as high speed, more agility and efficiency and deeper insights of what customers really want, which are significant to the businesses today.

  Previously, decisions were made slower with more uncertainty, because companies could not quickly receive exhaustive information from the complex and changing conditions. They often had to simplify the conditions which incurred the distortion of the facts, therefore the decisions would not accurately solve the problems. However, nowadays, the big data analytics takes huge amount of data into account, to help companies understand the complex, dynamic and interrelated circumstances along the entire value chain, and to help them make immediate and feasible decisions.[Minelli13]

- **Real time optimization (RTO)** – Due to ability of the big data analytics, huge amount of production information have been transformed into real-time valuable data, including the customer orders, inventories, production status, logistics and so on. Then the digital factory uses RTO software (with optimization algorithms) to select the best procedure from a set of available alternatives. By doing so, all resources within the factory would be reconfigured quickly based on the best procedure in order to gain the best output.

3.5.5 Enterprise agility & Competent workforce

Enterprise Agility is the ability of an organization to adapt to this changing environment. It offers two ways to help companies become agile. One is, from top sector, using leadership and organization culture to raise the awareness of the potential opportunities and risks in the turbulent business environment. The other way is, from individuals in every department, enhancing the flexibility through the entire organization so that companies can quickly and appropriately respond to the internal and external changes. [pwc15]

Enterprise agility relies on the competent workforce.

Competent workforce are the mainstay for any company. In Smart Industry, they have several professional skills and are flexible to more than one type of tasks, instead of only working on the same job from joining in the company to the retirement. They are able to learn fast, aware of continuous improvement. Meanwhile companies offer various channels to encourage people to gain extra new knowledge for the dynamic future. Having such flexible and competent workforce can ensure the competitiveness of companies in the fierce business competition.

There are three TMs related to this SIMM elements, i.e. Flexible processes, digital obeya, and blended learning.

- **Flexible processes** – Flexible processes provides companies the ability of adapting to both external and internal conditions with minimum time and efforts. With regard to manufacturing companies, flexible processes enable Make To Order with small batches at a lower cost and shorter throughput time, thereby enhancing the competitiveness of companies.

Best practices for flexible processes could be implementing reconfigurable production cells, automated guided vehicles (AGVs) and robotics, enhancing the multidisciplinary working ability of labors, capitalizing on ERP/CRM/MES software and so on. [Sushil14]

- **Digital obeya** – Employees engagement should always be aligned with the goals of a company, so that employees will understand how their efforts fit into the company's progress and success. The digital obeya can be understood as a digital tool for the alignment purpose. In this digital obeya, employees can receive all the necessary information by IoT, in order to speed up communication and decision-making processes (Figure 3.10).

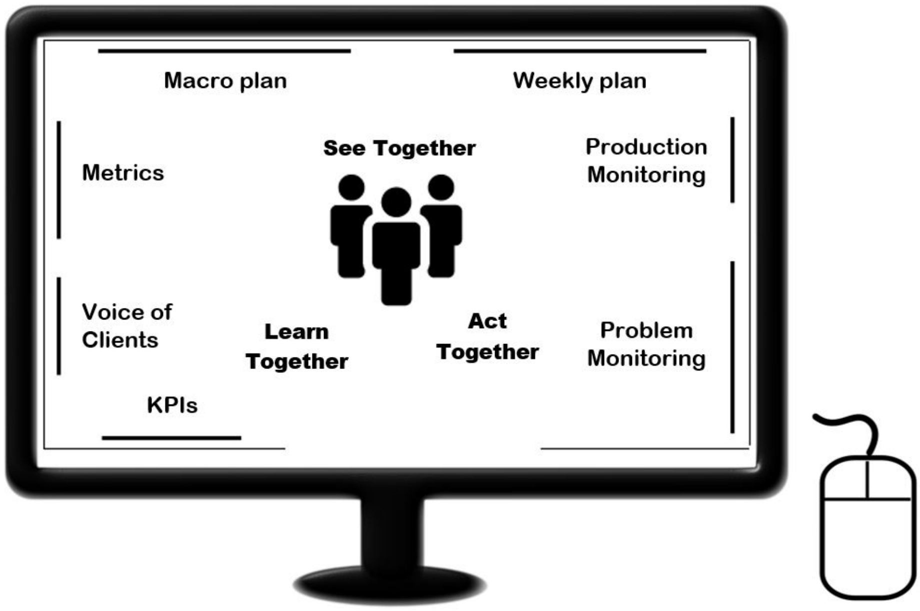


FIGURE 3.10: Digital obeya

- **Blended learning** – It is an education program that combines different training media, for instance, combining the online digital media with the traditional classroom methods [Bersin04]. Blended learning offers people the flexibility of learning. It allows people from different levels can make their own study plans based on their daily schedules, learning habits, and the status of how much knowledge they have mastered.

3.5.6 Operational excellence & Variation reduction

Operational Excellence focuses on an optimal production process based on customer requirements, without error, delay, or waste. Organized environment is needed to supply a safe and efficient workplace. Machines are reliable without unplanned downtime. Processes, such as design, engineering, production and logistics, are devised based on the principle **First Time Right**. The organization constantly work on improving its processes to become more efficient and effective. And all employees are involved in the continuous improvement process.

Operational excellence guarantees the variation reduction.

Variation Reduction enables the high quality of final product, and minimizes the waste during the entire process, because customers only pay for the things that add value to them. Statistical techniques and data analysis are used in design, engineering and production processes, so that companies can analyze and improve the performance of these processes and make sure new products can be produced efficiently without error and waste.

There are three TMs related to this SIMM elements, i.e. lean six sigma, reliability engineering, and design for excellence.

- **Lean six sigma (LSS)** – It is a methodology that combines two significant and complementary methods for improvement, i.e. Lean Manufacturing and Six Sigma. LSS would focus on systematically removing waste and reducing variation, by using many approaches like Total Productive Maintenance (TPM) and Total Quality Management (TQM). It is worth pointing out that LSS enables a top-down change in the company, so the success only would happen with the premise of the full support from company executives. [Voehl14]

- **Reliability Engineering** - Reliability engineering for complex machines and production systems considers four aspects, i.e. reliability, availability, maintainability, and safety (RAMS). It is used to develop methods and tools to assess RAMS figures of components, equipment and systems. Also it could be used to support development and production engineers in building in these characteristics into complex machines and systems. [Birolini17]

- **Design for excellence** – DfX is a systematic way to integrate a set of knowledge that focuses on successful product development. It is used in the continuous improvement process to reduce the time and cost for product design, engineering and manufacturing cycles. Meanwhile it can increase the product quality, reliability, thereby enhancing the customer satisfaction. [Lotz15]

  In practice, the term DfX could be regarded as Design for 'X' where the variable X is changeable depending on the particular design objectives, such as Design for Assembly (DfA), Design for Manufacturability (DfM) and etc.

3.5.7 Eco-production & Made different

Eco-production focuses on the entire process of production which has no environmental contamination, no depletion of natural resources, and no bad influence on sustainability. Also, the product and services offered by companies should have no damage to the environment during the production process, the period of usage, and the end of product life cycles. In practice, companies would use energy efficiently, find out alternative renewable energy resources, reduce the consumption of raw materials, and optimize the processes of design, engineering, production, recycling and logistics.

Eco-production and made different can complement each other perfectly.

Made Different asks companies to take sustainability into account for the entire process, especially in the design phase. Companies need to establish long-term strategy and medium-term tactics to ensure a steady pace for the utilization of new energy, new materials and new technologies which are eco-friendly. By doing so, companies will gain at least twofold benefits. That is, on one hand, they will be more independent in terms of the increasing limitation of energy resources. And on the other hand, they will receive higher reputation from customers, which resulting in higher level of customer intimacy.

There are three TMs related to this SIMM elements, i.e. design for disassembly, remanufacturing and alternative energy.

These TMs are all related to the **Product Life Cycle (PLC)**, so a brief elaboration is introduced here. A **PLC** could be divided into four stages, i.e. **material stage**, **manufacturing process**, **usage** and **end of life (EOL)**. At the beginning, raw materials are produced, where, obviously but needed to be pointed out, energy has been consumed. Then they are conveyed to the plants. After arriving to the plants, raw materials are used in the manufacturing process. After products have been finished, they are distributed to customers and serve them during the usage period. Finally, the products enter to their EOL stage and have been disposed.

Disposing all EOL products would be wasteful in terms of economic aspects and also be harmful to the environment, especially those with hazard substances. And it is worth noticing that energy consuming happens in every stages of PLC. Therefore, the waste discussed here contains not only the materials but also the energy.

- **Design for disassembly** – It is the method used in the design phase of the manufacturing process, which factors in the End of Life (EOL) stage of the PLC. Due to this design method, when the products finally come to the end of their services, they can be quickly, easily and cost-effectively disassembled into components and other remaining. Then they could be reused in other stages of the PLC for new products. [Vongbunyong15]

  There are many tactics for Design for disassembly, like minimizing the number of parts, minimizing the number and variety of fasteners and etc.

- **Remanufacturing** – It enables the remanufactured products to be produced with new parts and reused/repaired parts from the disassembled EOL products, thereby recovering various forms of waste, e.g. energy, materials, components and even the entire product per se.

  It allows the remanufactured products to perform in like new conditions, which could match the same customer satisfaction as the entirely new products could have done. Moreover, remanufacturing would close the material loops in terms of economy, which contributes to the implementation of the circular economy. [Golinska17]

- **Alternative energy** – Energy sources can be sorted into two categories, i.e. renewable energy sources (RES) and non-renewable energy sources. Non-renewable sources comprise coals, crude oil, natural gas and etc. RES would be the alternatives of the fossil fuel, which consist of solar energy, wind energy, tide energy, geothermal energy, biomass energy and etc.

  Using alternative energy would at least have triple benefits. Firstly, for the economy, it provides a new source of energy supply, which allows the continuous economic development for all countries and regions. Some of them would no longer fully rely on the non-renewable energy, otherwise they have to spend a huge amount of money in importing the energy source. Secondly, for the environment, it would mitigate the Greenhouse effect, which is considered as the main factor for the global warming. Thirdly, for the development of human society, it allows the human offsprings to have enough fossil energy sources as the backup, in case the RES would not be sufficient under some unexpected circumstances. [Michaelides12]

In this chapter, the exploration of Industry4.0 and Smart Industry has been carried out. After that the selection of KPIs and Market Trends, and the development of SIMM elements *and TMs have been conducted. In the next chapter, Porter's value chain will be explored, and the development of SIMM processes and VAPs will also be executed.*

Chapter 4

EXPLORATION OF PORTER'S VALUE CHAIN

In this chapter, the concept of value chain is firstly discussed, and the exploration of Porter's Value Chain is conducted. Then, the development of SIMM processes and relevant Value-added points (VAPs) is carried out right after the exploration.

4.1 Exploration of Porter's value chain

Before the exploration of Porter's value chain model, it is important to firstly understand the concept of the value chain. The term **Value Chain** was firstly introduced by Michael Porter in his book *Competitive Advantage: Creating and Sustaining superior Performance* in 1985. [Satpathy15]

'A value chain is a chain of activities performed by a firm or an organization, operating in a specific industry, so as to deliver a valuable product or service for the customers and links them to the competitive position of the organization. And how value chain activities are carried out determines costs and affects profits in a company.'

The SIMM processes and VAPs are used to identify the ways in which companies could create values for their customers, and then helps companies to think through how they could maximize these values. And the value chain analysis (i.e. Porter's value chain model) could supply the similar function for companies (find out more discussion in section 4.1.1). It is possible to adapt it in order to develop the SIMM processes. That is why the exploration of Porter's value chain will be conducted next.

The main purposes of this section are:

- To understand Porter's value chain, by studying relevant references;
- To supply the foundation which will be used in section 4.2 to develop all SIMM processes and VAPs.

4.1.1 Exploration of Porter's value chain model

Porter's value chain model describes the activities within and around an organization(Figure 4.1[1]). By using the model, companies could analyze all activities in order to enhance the efficiency of the entire value chain, thereby receiving maximum value for the least possible total cost. Porter's value chain model has nine activities in total, which fall into two categories, namely primary activities and support activities.

[1]Graphic source: https://www.toolshero.com/management/value-chain-analysis-porter/

FIGURE 4.1: Porter's value chain

There are five primary activities, which have an immediate effect on the production or delivery of a product or service.

- **Inbound logistics** - raw materials (or other goods) receiving, storing, inventory control and other value-adding activities.
- **Production** - fabrication, assembly, testing, packaging, equipment maintenance and other value-adding activities which contributes to transforming raw materials into finished products.
- **Outbound logistics** - warehousing, transportation, distribution and other value-adding activities which helps to deliver the products to customers.
- **Marketing & sales** - advertising, promotion, pricing, selling and other value-adding activities which could attract people to purchase the products.
- **Service** - installation, maintenance, customer support, training and other value-adding activities which could maintain and increase the value of products.

There are four support activities, which assist the primary activities.

- **Procurement** - all activities related to purchasing raw materials, equipment, factory facilities and etc.
- **Research & Development** - innovation, design and other activities that helps to develop technologies and products.
- **Personnel management** - recruiting, training, compensation of employees and managers and etc.
- **Organizational structure** - administrative management, strategy management, quality management, finance, accounting and etc.

Besides these nice activities, there exists the profit margin. It indicates that companies are able to deliver a product for which customers are willing to pay more than the total costs of all activities in the value chain.

4.1.2 Analysis of Porter's value chain

The first advantage of Porter's value chain model is that it concerns all the activities which could add value to the customers. Therefore, companies could use the model to better understand and optimize the activities to meet the customers' demands in a cost-effective way, which enables companies to have competitiveness and high profit levels. Secondly, it is flexible to almost all types of business, like manufacturing, software, retails and service, regardless of big or small size. Therefore it is easily to be adapted for different companies or business models[2].

However, it has two disadvantages. Firstly, to make a full value chain analysis for companies could take a lot of work, especially when companies have all nine activities. Secondly, it doesn't take organizational culture into account.

The organizational culture could influence the way employees interact with each other, and it could create a healthy competition environment at the workplace. In the long term, it could also create the brand image, adding value to both the company and the customers. Therefore, I would take the organizational culture into account when developing the business and production processes in the SIMM.

4.2 Development of SIMM processes and VAPs

Companies want to gain more profits by offering more added value to customers. That requires companies to improve their KPIs and to lead or catch up with the market trends. Smart Industry approach could offer the help by using its SI elements and their relevant technologies and methods. Then the next important thing is to find out the places where the help from Smart Industry could be utilized in order to guide companies to achieve their goals. Therefore, eight SIMM business processes and VAPs are developed for this purpose.

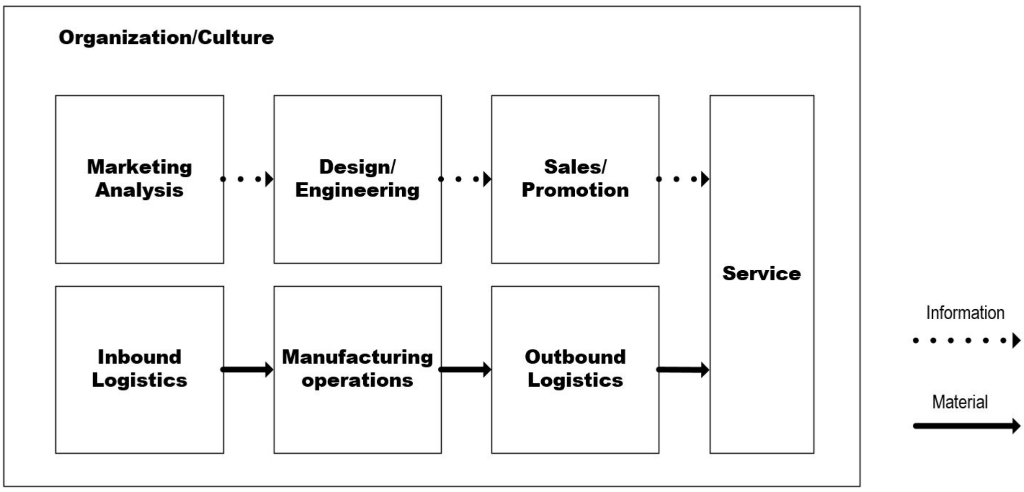


FIGURE 4.2: Structure for SIMM processes

Porter's value chain model is adapted to develop seven main processes and one support process in Smart Industry Maturity Model (Figure 4.2), all of which enable the information flow and the material flow to travel through the entire company.

[2]Paul Simister. *Advantages & Disadvantages of Value Chain Analysis*. (2011).

Within these processes, business and production activities are selected as Value-adding points (VAPs) which are used as the starting points for the process redesign and innovation. Both SIMM processes and VAPs are also used in the SIMM question-making template for generating questions in the SIMM questionnaire in chapter 6.

These eight SIMM processes are formed into five groups based on their interconnections, i.e. Market analysis & Sales/Promotion, Design/Engineering & Manufacturing operations, Inbound logistics & Outbound logistics, Service, and Organization/Culture.

4.2.1 Market analysis & Sales/Promotion

Marketing analytics is the practice of managing and studying metrics data in order to determine the performance of marketing efforts, tracking the data over time, and finally identifying opportunities for improvement. Market analytics consist of at least five dimensions, i.e. market trends, market size (current and future), market growth rate, market profitability and distribution channels. [Rackley15]

Sales and promotion always interact with each other. The data of sales can help to make promotion strategy. Meanwhile promotion can address at least five sales issues, i.e. increasing sale volume, increasing repeat purchase, creating interest and awareness, deflecting attention from price, retaining brand perception. [Mullin08]

Market analytics needs the data from sales and promotion, and in return it offers the scientific proofs for the decision making of sales and promotion. That's why these two processes are formed into one group. Within these two processes, four activities are developed as Value-adding points (VAPs), i.e. market trends, market size, company website and social media.

- **Market trends** – As mentioned previously, better perceiving the market trends would benefit the KPIs in a company.

- **Market size** – It is equally important to measure the market size from both the current market volume and the future market potential. The market volume indicates the totality of all realized sales volume of a special market. On the other hand, the market potential reveals the upper limit of the total demand and takes potential clients into consideration.

- **Company website** – Nowadays, company website is no longer just a beautiful window of the company. It almost involves all the business functions, except for physical production processes. Customers can communicate with the company at many levels, such as learning the knowledge of the product, understanding the brand culture, choosing or even configuring their products, interacting with the design and production progress, designating the delivering, and looking for after-sales services.

- **Social media** – With the ever rising utilization of social media, such as YouTube, Facebook, and Wechat, they are becoming the second communication channel between a company and its customers. Especially, prosumers of a company, they actively respond reviews and comments for the products and services they have purchased, which would significantly influence on the buying behavior of the other customers, especially for the group of people who are shopping on line, no matter they are national or international customers.

4.2.2 Design/Engineering & Manufacturing operations

As mentioned in section 3.5.2 about co-creation, Smart Industry approach enables **design, engineering and productions** to be executed in parallel. They are intertwined with each other, that's why these two processes are formed in one group. It is worth noticing that not all of companies have these processes. Some of them may only have R&D department, and some may only have assembly process. Within these two processes, four activities are developed as Value-adding points (VAPs), i.e. conceptual design, engineering and prototyping, production plan, and fabrication.

- **Conceptual design** – Technical drawings and models that reflect the requirements of customers would be finished in this activity. At the same time, based on the business strategy of the company, designers would also take several extra elements into account, such as design for dissemble, design for six sigma, and sustainability. [Keinonen06]

- **Engineering and Prototyping** – The detailed feasible solutions and specifications are further developed in this activity, such as the form, dimensions, tolerance, and materials. And prototyping is used as an evaluation tool, which can quickly validate a concept. By doing so, companies can iterate the design and engineering processes in order to supply the products which can fulfill the requirements of customers. [Liou07]

- **Production plan** – Production plan comprises the plan for tools and fixtures, production layouts, working schedule, quality controls and the information flow to control the manufacturing operation. [Liou07]

- **Fabrication** - It is a value added process which transforms raw materials into functional products. For instance, it is the building of metal structures by cutting, bending, and assembling processes. In Smart Industry, fabrication processes are modularized and flexible fabrication cells are needed. These cells can be reconfigured in order to fulfill the tailored requirements for a product. Also they enable the production flexibility in case of unpredictable market changes, so that companies would avoid the inevitable losses that often have occurred in the companies with low degree of flexibility. It is worth noticing that de-manufacturing should be considered as one important function for the fabrication process, since it is more sustainable to disassemble and recycle of obsolete products, thereby saving materials and energy. [Argoneto08]

4.2.3 Inbound logistics & Outbound logistics

Logistics is a scientific management of the flow of items between the original point and the destination point according to the demands from customers and companies. The logistics for the physical items also involves the integration of information flow, material handling, inventory, warehouse, transportation and so on. Within these two processes, two activities are developed as Value-adding points (VAPs), i.e. supply chain configuration and inventory control.

- **Supply chain configuration** – In Smart Industry, supply chain should be configurable and be integrated with both inbound and outbound logistics decisions, due to the complex environment where key factors (e.g. demands, materials inventory, production capacity and etc.) in the decision-making process may rapidly change. By configuring the supply chain, companies would minimize the negative influence incurred in the uncertainties. [Chandra07]

- **Inventory control** – By control the inventory, companies would improve their total investment in inventories, such as raw materials, WIP (work-in-progress), and finished products, so that they would have more cash available for other purposes. [Axsater15]

4.2.4 Service

Service perfectly complements the real products for the customers. In Smart Industry, it consists of installation, upgrading, maintenance, recycling and other customer supports (online and offline). Within this processes, four activities are developed as Value-adding points (VAPs), i.e. installation, upgrading and maintenance, recycling and online support.

- **Installation** – Customized products can be made by two ways. One is that the tailored requirements are considered at the conceptual design, and the subsequent processes until the unique finished products are received by the customer. The other way is that the components of products are modularized, and can be produced with mass production. The products would be customized when the technicians install the products in the customers' places.

- **Upgrading and maintenance** – Upgrading and maintenance are offered by companies, in order to extend the service life of the products, as well as to maintain a high level of product performance, or to improve the characteristics. It is worth noticing that upgrading and maintenance may be the activities that belong to the service process in one company, and at the same time be the activities that pertain to manufacturing operation process in the other company.

- **Recycling** – To reduce the financial and environmental cost of products, recycling can be a feasible method to execute. It includes materials recycling and energy recycling. If a product is designed for de-manufacturing, then it can be disassembled and its components can be reused for the new products, thereby saving the materials for new components as well as the energy for making new components. [Morgan06]

- **On-line support** – It is much more convenient for customers to receive supports by a click at anywhere and anytime, comparing to paying a visit to the physical stores or even the company during a fixed opening time. Thus good on-line supports, such as dealing with customer complaints, answering common or specific questions, and making an on-site recycling service, can enhance the customer satisfaction, which companies are always pursuing.

4.2.5 Organization/Culture

As a support process, organization structure and culture don't directly contribute to the KPIs, but it doesn't mean that organization and culture are less important than the other seven processes. On the contrary, they are the foundation for the others, since behind the seven processes are human beings who are born to connect to and are always influenced by organization and culture. They can provide profound impact on everyone in the companies, yet when they change, individuals have to adapt the change and it sometimes isn't that easy. Figure 4.3 demonstrates seven phases of individual responses over time when encountering organization and culture changes, which is adapted from *Kübler Ross Change Curve*[3].

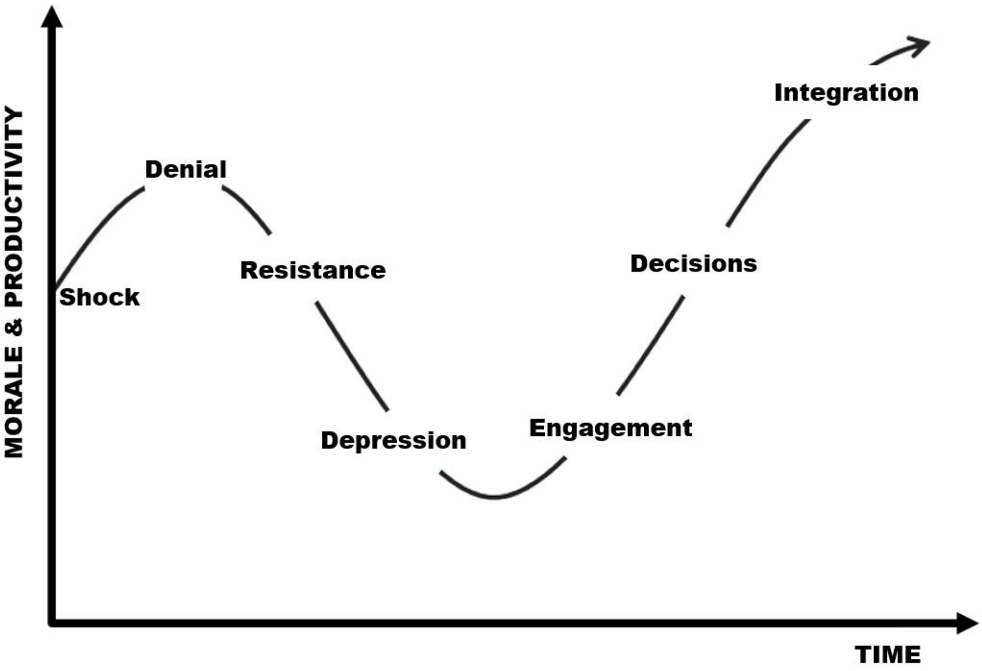


FIGURE 4.3: Productivity Curve for Individual Response to Changes

a **Shock** – Employees have unexpectedly been pushed out of their comfortable zones. They have to work in a different way from what they normally do.

b **Denial** – Employees may not want to believe that the organization culture has been changing. They put on a temporary defense mechanism and they need time to digest the disturbing reality.

c **Resistance** – When the reality becomes clear, employees may begin to feel fear from what lies ahead, and this feeling may turn into anger and resistance.

d **Depression** – When employees finally realize that they must adapt to new cultures, they may try to learn only what they think is important so that they can fit in the new environment. However, they have failed to adapt to the new circumstances, which makes them depressed, because they adapt based on their preference not on scientific basis.

e **Engagement** – Employees start to change their attitude and become more active to embrace the changes. Then they feel more comfortable to learn new things. This phase is the turning point for the morale and productivity.

f **Decisions** – After a period of learning new things, they see the results are better than what they expected and then decide to continue developing themselves. Morale and productivity keep on rising in this phase.

[3]Anastasia. *Understanding Kübler Ross Change Curve*. (2015).
https://www.cleverism.com/understanding-kubler-ross-change-curve/

g **Integration** – Employees successfully adapt to the new organization structure and culture. They are happy about the changes, and would like to share their experience with the other colleagues who may still struggle with the new changes.

Within these two processes, three activities are developed as Value-adding points (VAPs), i.e. digital obeya, online learning and workshop.

- **Obeya** – It consists of visual charts and diagrams to deliver the information such as planning schedule, milestones, metrics and problems. Obeya can be interpreted as a war room in a company to facilitate communication and decision-making across the departments.
- **Online learning** – With the development of the Internet, knowledge is available not only in the school but also on the websites and social media. On-line learning is cheaper and more flexible way to receive knowledge. Companies would support employees to study on-line in order to further polish their skills or extend their knowledge field so that they can be more flexible when facing the changes in the companies.
- **Workshop** – Companies would arrange workshops for employees, i.e. learning by doing. It is a vivid way for them to perceive how changes would affect everyone in the company. Thus, they would be inclined to accept the changes.

Porter's value chain model has been explored, and the SIMM processes and VAPs have been developed in this chapter. Then in the next chapter, the exploration of CMMI will be conducted, as well as the design of SIMM structure and the development of SIMM maturity levels.

Chapter 5

EXPLORATION OF CMMI

In this chapter, the exploration of **Capability Maturity Model Integration (CMMI)** is carried out, because it is a successful, widely adopted and recognized model. Then the development of SIMM structure and SIMM maturity levels is conducted after the exploration.

Before starting the exploration, the reason of choosing CMMI as the prototype of SIMM is discussed as follows.

Based on the research *The maturity of maturity model research: A systematic mapping study* by Roy Wendler from Technology University of Dresden in Germany, CMMI is the only maturity model that is dominant in the academic community, although the number of researcher's own ('own/other') model is larger due to the limitation of research articles and the exclusion of success stories or non-academic application reports (Figure 5.1[1]).

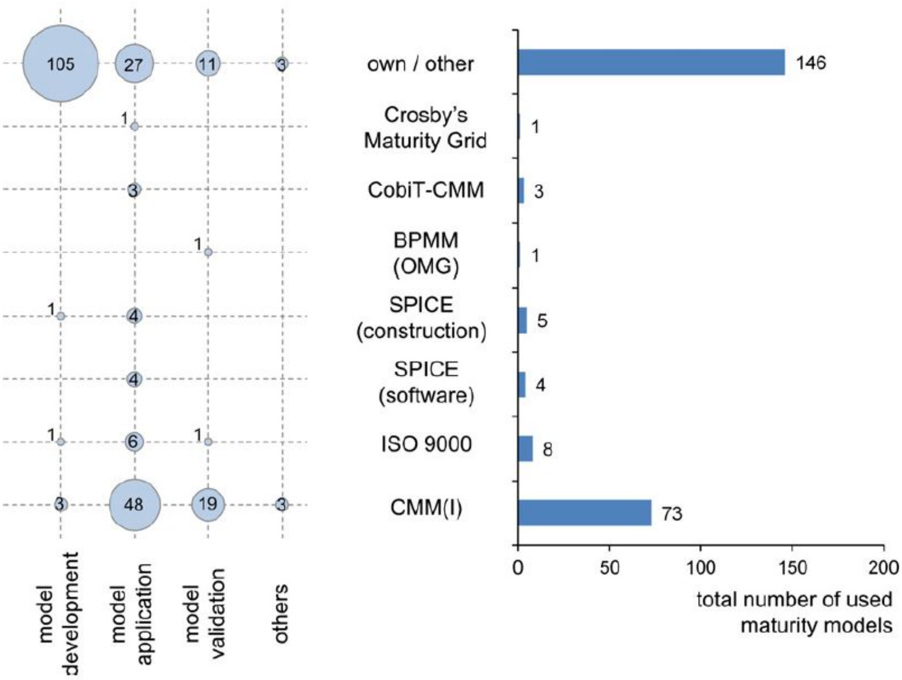


FIGURE 5.1: Number of used/developed maturity models per topic area.

In the research, it was concluded that CMMI 'has a great influence on other newly developed maturity models. Some articles adapted the structure and/or transferred

[1]Wendler, R. *The maturity of maturity model research: A systematic mapping study*.(2012).

the content of CMMI to other research domains.' and 'others were inspired by CMMI for the first versions of their maturity models and changed it more and more during their research' [Wendler12]. So, the exploration of CMMI is firstly conducted in order to find out whether it is useful for developing the structure of SIMM and the SIMM maturity levels.

5.1 Exploration of Capability Maturity Model Integration

5.1.1 Introduction

Capability Maturity Model Integration (CMMI) is a process level improvement training and appraisal program, released in 2002[2], which is the successor of the **Capability Maturity Model (CMM)** developed from 1987. Not like its predecessor that only has been used in the software development, CMMI has been generalized in order to apply to different domains in the industry.

CMMI helps to integrate traditionally separate organizational functions, to set the goals and priorities of process improvement, and to provide guidance for quality processes. It also has been used as a framework to provide a point of reference for assessing current processes of organizations.

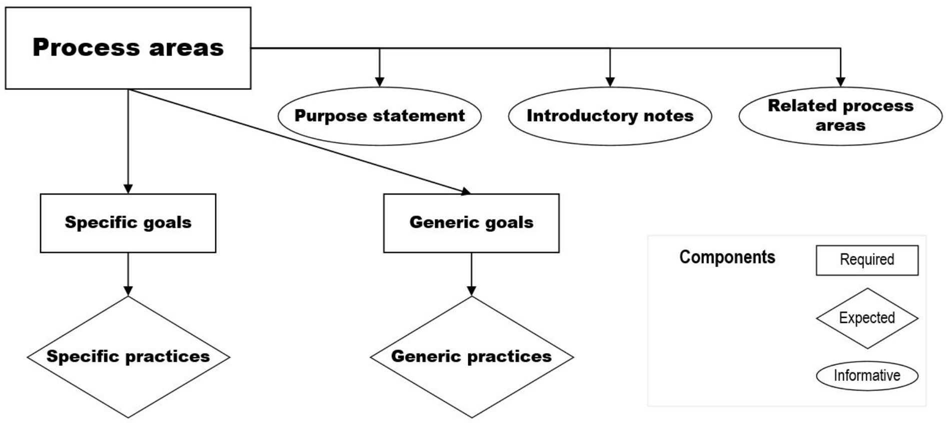


FIGURE 5.2: Components in CMMI model

CMMI model has three categories of components. Figure 5.2[3] indicates the relations among them. And they are:

- **Required components** - they are essential for achieving the process improvement in a given process area.
- **Expected components** - they describe the activities which are significant in achieving a required CMMI component. They are used to guide those who implement improvements or perform appraisals for the organization.
- **Informative components** - they help model users to understand the required and expected components of CMMI.

[2]CMMI version 1.1 was released in 2002, and the latest version - version 1.3 was released in 2010.
[3]Diagram is derived from CMMI® for Acquisition, Version 1.3, p12

5.1.2 Process areas

A **Process Area** is a cluster of related practices in an area. When it has been implemented collectively, then it would satisfy a set of goals which are considered important for making significant improvement in that area.

There are 22 process areas in CMMI. We just point out their names in alphabetical order by acronym, since it is not highly relevant to the main goal of my thesis, yet it guarantees the integrity of knowledge structure of CMMI model:

- Agreement Management **(AM)**
- Acquisition Requirements Development **(ARD)**
- Acquisition Technical Management **(ATM)**
- Acquisition Validation **(AVAL)**
- Acquisition Verification **(AVER)**
- Causal Analysis and Resolution **(CAR)**
- Configuration Management **(CM)**
- Decision Analysis and Resolution **(DAR)**
- Integrated Project Management **(IPM)**
- Measurement and Analysis **(MA)**
- Organizational Process Definition **(OPD)**
- Organizational Process Focus **(OPF)**
- Organizational Performance Management **(OPM)**
- Organizational Process Performance **(OPP)**
- Organizational Training **(OT)**
- Project Monitoring and Control **(PMC)**
- Project Planning **(PP)**
- Process and Product Quality Assurance **(PPQA)**
- Quantitative Project Management **(QPM)**
- Requirements Management **(REQM)**
- Risk Management **(RSKM)**
- Solicitation and Supplier Agreement Development **(SSAD)**

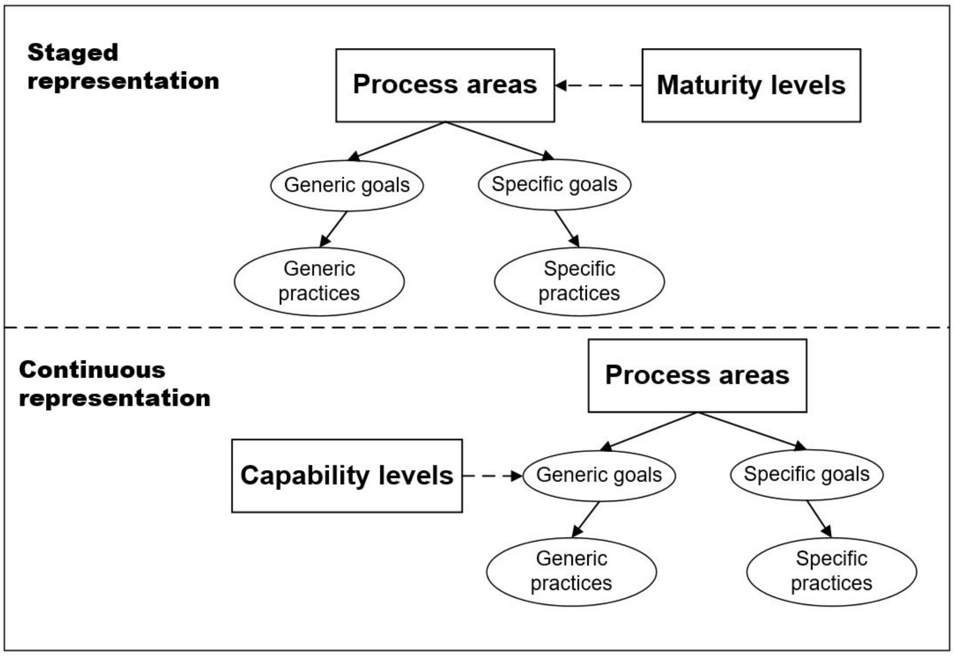


FIGURE 5.3: Structure of staged and continuous representations

5.1.3 Representation

Different representations help an organization to pursue different improvement goals. There are two representations in CMMI.

a **Staged representation**

It offers a path which enables an organization to improve a set of related processes by addressing successive sets of process areas incrementally. And it uses maturity levels to characterize the overall state of the organization's processes relative to the model as a whole [CMMI10]. Figure 5.3 illustrates the structure of staged representation[4].

b **Continuous representation**

It supplies a way to enable an organization to incrementally improve processes corresponding to an individual process area (or group of process areas) selected by the organization. And it uses capability levels to characterize the state of the organization's processes relative to an individual process area [CMMI10]. Figure 5.3 shows the structure of continuous representation.

5.1.4 Maturity levels

And mentioned above, maturity levels are used to characterize the overall state of the organization's processes, which meets the requirement of SIMM. Thus, maturity levels in CMMI are further studied.

Maturity levels are defined evolutionary plateaus for organizational process improvement. One maturity level comprises related specific and generic practices for a predefined set of process areas which improve the organization's overall performance. The maturity levels are measured by the achievement of the generic and

[4]Derived from CMMI® for Acquisition, Version 1.3, p24

specific goals associated with each predefined set of process areas. Each maturity level can guide the organization to improve its processes in order to move to the next higher maturity level. There are five maturity levels in CMMI (Figure 5.4).

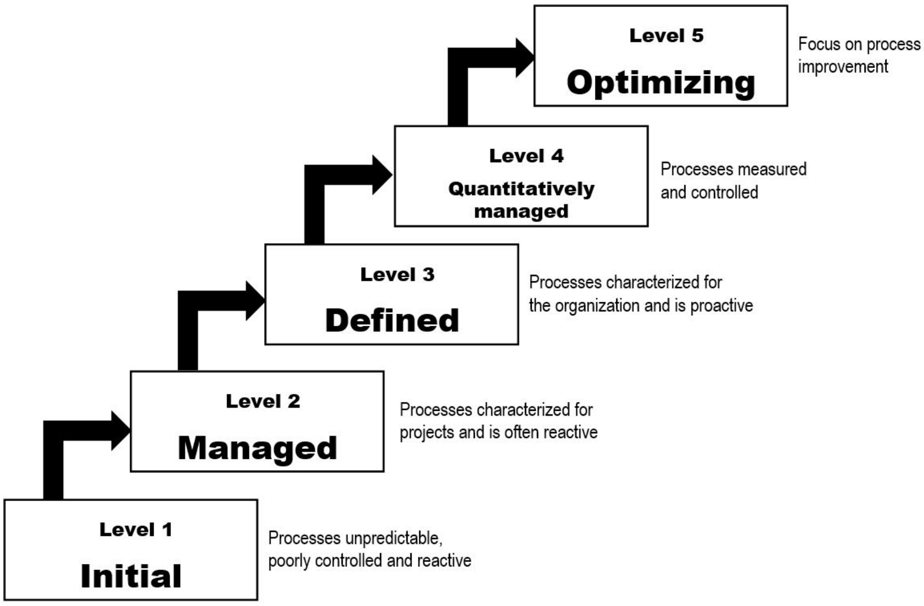


FIGURE 5.4: Maturity levels in CMMI

Level 1 - Initial
The characteristics of an organization in level 1 are:

- Having a tendency to over commit,
- Exceeding its budget or schedule,
- Abandoning processes during the time of crisis,
- Not being able to repeat their past successes.

Processes are chaotic and ad hoc, which indicates an unstable environment in the organization. In other words, the success of this organization depends NOT on the utilization of proven processes, but just on the competence of the people in the organization.

Level 2 - Managed
If the organization has achieved at level 2, then processes are managed, i.e. planned, performed, measured, and controlled; and work products[5] and services are delivered to meet with their specified requirements, standards, and objectives. It is worth noticing that each specific process may have its unique standards, process descriptions, and procedures, which is different from that in maturity level 3.

Level 3 - Defined
Unlike in maturity level 2, processes that are performed across the organization in level 3, have their consistency except for the differences allowed by the tailored guidelines. Processes are described in more details, such as more rigorous scope of

[5]Work product means 'Deliverable or outcome (such as a training course or a building) that must be produced to complete a project and achieve its objectives.'

standards, process descriptions, procedures, tools, and methods. Meanwhile, processes are managed more proactively by using the understanding of the interrelationships of the process activities and detailed measures of the process, its work products, and its services.

Level 4 - Quantitatively Managed

The organization have established quantitative goals for quality and process performance, and use them as the criteria in managing processes. These goals are designed based on the demands of customers, the organization per se, and the process executors. Quality and process performance are controlled, analyzed and managed throughout the entire life of processes. For instance, special causes of process variation would be identified, then the sources of special causes are corrected in order to prevent future occurrences.

There is a critical distinction between level 3 and level 4, which is the predictability of process performance. At maturity level 4, the performance of processes is controlled by using statistical and other quantitative techniques, and would be quantitatively predictable.

Level 5 - Optimizing

The organization in maturity level 5, would focus on the continuous improvement of process performance. Therefore, quantitative process-improvement objectives are set up and used as criteria in managing process improvement.

Optimizing processes depends on the participation of an empowered workforce aligned with the business values and objectives of the organization. The organization's ability of rapidly responding to changes and opportunities, is enhanced by the organization agility.

There is a critical distinction between level 4 and level 5, which is the type of process variation addressed. In maturity level 5, processes are concerned with addressing common causes of process variation and even changing the process in order to improve process performance, while maintaining statistical predictability, and finally the organization can achieve the established quantitative process-improvement objectives.

5.1.5 Analysis of CMMI

Firstly, CMMI has a clear structure for process appraisal and improvement. Secondly, it has been generalized in order to apply to different domains in the industry, which means it is adaptable for the manufacturing industry. Thirdly, the utilization of maturity levels fits one of the functions of SIMM, i.e. identifying the overall status of processes in companies. Therefore, CMMI could be selected as the prototype of the maturity model for SIMM.

However, the weak point is that *'CMMI is too detailed, requiring large expenditures for its full implementation'*[6]. Also, when CMMI is too detailed, companies would incline to strictly following a set of rules in the model, rather than using it in a flexible way. Therefore, when adapting the CMMI, one should add variables in the model, which are based on the various circumstances of different companies, thereby helping companies to use the model flexibly.

[6]Mutafelija, B. and Stromberg, H. (2003). *Systematic Process Improvement Using ISO 9001:2000 and CMMI*, p134

5.2 Development of SIMIM structure

In this section, the structure of SIMM is designed based on the exploration of CMMI as well as the development of KPIs and Markets Trends, SIMM elements and TMs, and SIMM processes and VAPs, which belongs to **Phase 3** in the roadmap.

The structure is used to clearly show the interrelations among the four significant parts of SIMM (Figrue 5.5).

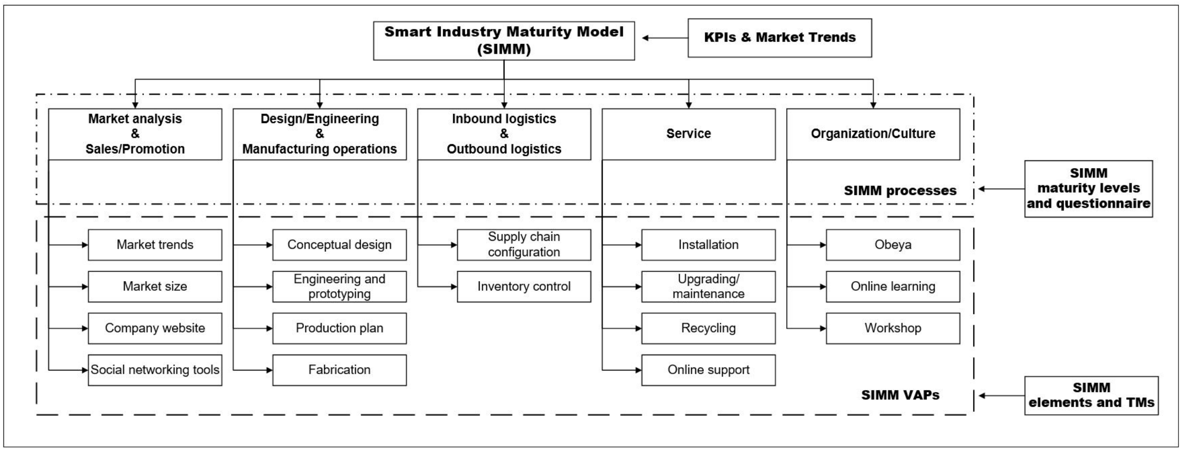


FIGURE 5.5: Structure of SIMM

The first part of SIMM is **KPIs and Markets Trends**. They are one of the input for SIMM from companies, of which CEOs or other senior officers have a clear goal. This part determines the first step to go during the implementation of Smart Industry, i.e. which SIMM elements and TMs they need to use firstly.

The second part is **SIMM elements and TMs**. They are utilized to support the implementation of Smart Industry approach, thereby helping companies to improve their KPIs and to lead or catch up with market trends.

The third part is **SIMM processes and VAPs**. They are used to identify the places where process redesign and innovation can be made by implementing SIMM elements and TMs.

The forth part is **SIMM maturity levels and relevant questionnaire**. The utilization of them would lead to the determination of the extent to which a company has implemented the business and production processes that are compatible with the Smart Industry paradigm.

5.3 Development of SIMM maturity levels

CMMI has been selected as the basis for the Smart Industry Maturity Model. In CMMI, there are five maturity levels, i.e. Initial, Managed, Defined, Quantitatively managed, and Optimizing. Therefore, these levels of CMMI are adapted and used to develop five SIMM maturity levels (Figure 5.6). And they are Initial, Aware, Visible, Improvable, and Optimized.

- **Initial** – Companies are not aware of the trend of Smart Industry. They don't implement Smart Industry theory system in their business processes.

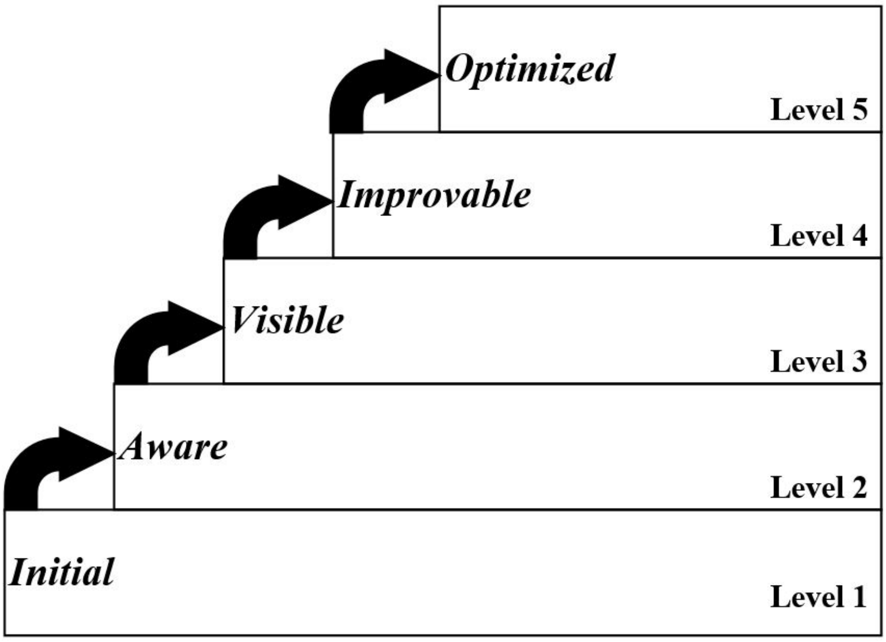


FIGURE 5.6: Five maturity levels for SIMM

- **Aware** – Companies have perceived the new trend of Smart Industry. They even have benefited a bit from it. However, there is lack of tools or models to guide them for the implementation of Smart Industry.
- **Visible** – Companies have partially implemented the Smart Industry approach into their processes. They understand the interrelations among KPIs, SIMM processes and VAPs, and SIMM elements and TMs. Also, they have gained profits from it.
- **Improvable** – Companies fully understand the interrelations among KPIs, SIMM processes and VAPs, and SIMM elements and TMs. They can predict the performance of their business processes, and based on which they can quickly make decisions in order to improve the performance.
- **Optimized** – Companies have fully implemented and mastered the Smart Industry approach. They are the frontrunner in their business field. They can perceive and grasp market trends in time. Meanwhile they have remarkable KPIs and receive high reputation.

The description of these five maturity levels are elaborated as follows.

- **Initial** - People in the organization might NOT be familiar with the name Smart Industry, yet they do have perceived the undergoing drastic changes happening to the entire industry, which actually is the prelude of Smart Industry. They have heard about the emerging technologies, such as Internet of Things, Cyber-Physical Systems and etc. Meanwhile, they have witnessed some successful cases occurring in the other organizations by utilizing these new technologies.

  Therefore, they are inclining towards the implementation of these new powerful technologies. And they would more willingly introduce Smart Industry to their organization, as long as they realize the fact that only this approach can deploy these powerful technologies, and maximize the synergistic effect of them, and finally bring huge profits for the organization.

- **Aware** - When having achieved maturity level 2, the digitization of everything has started in the organization, which offers a foundation for Internet of Things.

  Asset visibility has begun to take shape. With necessary technologies, like Radio-frequency identification (RFID), Real-time locating systems (RTLS), physical assets have been transformed from physical into real-time digital information, such as their accurate locations, inventory levels, and conditions. By doing so, the organization would deploy the right assets to the right places where they are needed. The non-value-added activities would reduce nearly into zero, and the cycle time would be shorter, which contributes to one of the business KPIs, i.e. the short-time-to-market goal.

  Process visibility has also emerged. They can trace one product's location and its status of completion. Process visibility refers to the ability to see and understand all aspects of a process at any point in time.

- **Visible** - In this level, the visibility of asset and process has successfully achieved. Organization has agility to respond to the changes in the market. Staff in the organization have continuous training opportunities in order to be adapt the new business model and process.

  Concurrent-engineering has been implemented into the organization. And relevant enabling technologies like additive manufacturing, have been used through the entire design and production processes. Robots have been introduced into the production line. Without people interference, they can cooperate with the other intelligent apparatus according to the orders coming from the data cloud.

- **Improvable** - Organization focuses on customer using experience. Technologies, like Digital twins, have been utilized, so that the product data, after the product has been sold to the customers, can still be collected by sensors, and delivered back to the organization. Then they can improve the quality and usage experience based on these data.

  The organization begin to participate as a part of a continuously-evolving, complex community which consists of people, devices, information and services interconnected by a communications network. It helps to optimize resource management and provide superior information on events and conditions, which could empower decision makers.

- **Optimized** - The organization has become network-centric entity, which involves all the stakeholders along the value chain of the organization.

  IoT and CPS have been successfully implemented into the process. In the Digital Factory, an information network has been built in the factory in which apparatus, machines and ERP systems are connected to each other. Huge amount of information has been generated in terms of operational performance, logistics, supply chain, product and marketing. Then, more attention and efforts are therefore shifting to big data analytics, including algorithms that enable machines to take autonomous decisions, such as starting production and delivery of raw materials. The data is always accessible anywhere in the cloud and is ready to be used to optimize the autonomous production process.

The factory has high flexibility. All the products within the production uniquely identified traceable, so it is very clear to any working cell what should happen to the product. This allows that different products on the same production may undergo several tailored operations.

Prosumers might print their own products at home. The transportation of goods would be reduced to its minimization. The emission of CO_2, would sharply decline. The organization has achieved the goal of becoming an eco-friendly entity.

In this chapter, the design of SIMM structure and the development of SIMM maturity levels have been conducted after the exploration of CMMI. In the next chapter, the development of SIMM questionnaire will be carried out.

Chapter 6

DEVELOPMENT OF SIMM QUESTIONNAIRE

SIMM questionnaire is developed for:

- Collecting the input from companies in order to scan the SIMM processes in companies;
- Determining the SIMM maturity levels;
- Supplying the analysis of the assessment results;
- Providing suggestions for the implementation of Smart Industry by utilizing SIMM elements and TMs.

This chapter addresses three main issues, i.e. firstly how to build the inventory of questions and answers of SIMM questionnaire, secondly how to make the assessment mechanism for the questionnaire, and finally how to establish the SIMM questionnaire.

6.1 Inventory of questions and answers

As discussed above, the SIMM questionnaire is highly related to SIMM processes, SIMM elements and etc. So, the questions and answers should be developed based on the VAPs within SIMM processes and TMs within SIMM elements.

However, some elements supply a great contribution to the processes and their VAPs, while the other elements might have no direct influence on the certain processes. Therefore, it is necessary to figure out the interrelations among SIMM elements and TMs, and SIMM processes and VAPs. For this aim, question-making templates are designed for every element and process in order to build the inventory of questions (see Appendix A).

All seven templates share the same structure but with different contents. To be specific, every template has all eight SIMM processes, but with different dominant SIMM element, i.e. Prosumer & Mass customization, Co-creation & Smart product development, Cyber physical system & Factory flexibility, Internet of Things & Digital factory, Enterprise agility & Competent workforce, Operational excellence & Variation reduction and Eco-production & Made different.

Taking the element 'Eco-production & Made difference' for example (Figure 6.1), there are five questions in this template, which clearly implies that this element has impact on all the SIMM processes except for Marketing analysis and Sales/promotion[1].

[1] Questions related to both inbound and outbound logistics only appears in the inbound logistics.

Further more, the question 'To which degree can your products be recycled (with material level and energy level)?' is designed for the VAPs 'Recycling' in the process 'Service' and the TMs 'Design for disassembly' within the element 'Eco-production & Made difference'.

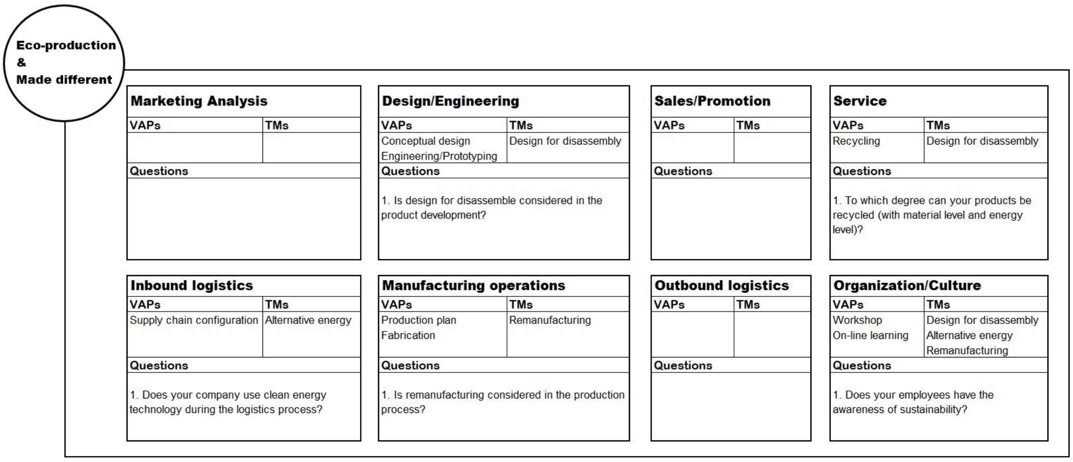


FIGURE 6.1: Template based on Eco-production & Made difference

For each question, five options (or answers) are designed based on the description of all the four parts of SIMM, i.e. KPIs and Markets Trends, SIMM elements and TMs, and SIMM processes and VAPs, and SIMM maturity levels. The circumstance at the lowest level of compatibility with the Smart Industry paradigm, the circumstance at the medium level and the circumstance at the highest level are described under each question as option 1, option 3, and option 5 respectively. And option 2 implies the circumstance between option 1 and 3. Similarly, option 4 implies the circumstance between option 3 and option 5.

To which degree can your products be recycled (with material level and energy level)?	
1	Our products are non-recyclable products.
2	\
3	All of the products can be recycled at the material level.
4	\
5	Recycling of products is the one of the significant factors we are taking into account for the entire process (e.g. design, procurement, production, logistics, sales and so on). Therefore, the products can be recycled both at the material level and energy level.

FIGURE 6.2: Example for a SIMM question and answers

For example in the Figure 6.2), the statement 'Our products are non-recyclable products' is the lowest level circumstance in terms of Smart Industry, the answer 'All of the products can be recycled at the material level' is the medium circumstance, and the statement 'Recycling of products is the one of the significant factors we are taking into account for the entire process (e.g. design, procurement, production, logistics, sales and so on). Therefore, the products can be recycled both at the material level and energy level.' can be the best circumstance with the compatibility of Smart Industry.

6.2 Development of SIMM appraisal mechanism

6.2.1 Score for each question

For each question, five options (or answers) are arranged in ascending order of the scores for SIMM maturity levels. There are five answers in each question, designated with scores from 1 to 5, according to the ascending order of the answers. That is to say, option 1 is assigned with score 1, and option 5 with score 5.

6.2.2 Calculation for SIMM maturity levels

The algorithm of determining the score of maturity level is presented as below.

$$F(x) = \frac{\sum_{i=1}^{N} x_i}{N} \qquad , \qquad N = 1, 2, 3, ...$$

where

F(x) the final score of maturity level
x_i the score of the chosen option for question **i**
i the i_{th} question for the certain SIMM process
N the number of questions involved for the certain SIMM process

The final score consists of one integer and two decimal places. And the score can determine the maturity level based on the table below.

Maturity score F(x)	SIMM maturity level
0.00 ≤ x < 1.50	Level 1 - **Initial**
1.50 ≤ x < 2.50	Level 2 - **Aware**
2.50 ≤ x < 3.50	Level 3 - **Visible**
3.50 ≤ x < 4.50	Level 4 - **Improvable**
4.50 ≤ x ≤ 5.00	Level 5 - **Optimized**

TABLE 6.1: Determination of SIMM maturity levels

6.2.3 Improving order of SIMM elements

After developing the KPIs and SIMM elements, the interrelations between them are becoming clear. Some elements supply a great contribution to the specific KPI, while the other elements might have no direct influence on the same KPI. Therefore, the improving order of SIMM elements is supplied by SIMM in order to give advice for companies that which SIMM elements would have the priority to be improved, due to the limitation of the resources (e.g. labor, capital and etc.).

Then, the contribution of each element to a certain KPI is necessary to be measured. Weight is used to measure these contributions (Figure 6.3). The higher value of the weight, the more contribution of that element gives to the specific KPI. If the weights are equal, then those elements would offer the same amount of contributions and they are as equally important as each other.

For instance, for KPI - 'Time To Market', the elements 'Co-creation & Smart product development', 'Cyber physical system & Factory flexibility' and 'Operational excellence & Variation reduction' are assigned with weight '0.20', which indicates big contributions to this KPI. In contrast, the element 'Eco-production & Made different' is assigned with weight '0.05', which might imply little contribution to reduce the time to market.

		KPIs					
		Productivity	Time to Market	Market share	Resilience	Revenue	Cost
SIMM elements	Prosumer & Mass customization	0.05	0.05	0.20	0.15	0.20	0.05
	Co-creation & Smart product development	0.15	0.20	0.20	0.05	0.15	0.15
	Cyber physical system & Factory flexibility	0.20	0.20	0.15	0.15	0.20	0.20
	Internet of Things & Digital factory	0.20	0.15	0.15	0.20	0.20	0.20
	Enterprise agility & Competent workforce	0.15	0.15	0.05	0.20	0.05	0.15
	Operational excellence & Variation reduction	0.20	0.20	0.20	0.20	0.15	0.20
	Eco-production & Made different	0.05	0.05	0.05	0.05	0.05	0.05

FIGURE 6.3: Weights assigned to each SIMM element

6.3 Establishment of SIMM questionnaire

SIMM questionnaire consists of five parts. And users have access to the first four parts.

- **Welcome Page** - It presents the structure and the contributions of SIMM.
- **Appraisal Form** - It consists of thirty seven questions, which are sorted into eight SIMM processes.
- **Result Zone** - It comprises five bar charts, and two tables for SIMM maturity levels, SIMM processes and SIMM elements.
- **Result Analysis** - It elaborates the analysis of the maturity results.
- **Appraisal mechanism** - It is designed for determining SIMM maturity levels.

6.3.1 Welcome page

This page presents the structure and the contributions of SIMM (Figure 6.4).

The contribution of SIMM are

- Offering new perspectives of understanding for the main processes in the company;
- Determining the extent to which the company has implemented the business and production processes that are compatible with the Smart Industry paradigm;
- Supplying the guidance of developing a strategy for the company to conduct the process redesign and innovation, thereby achieving the company transformation.

Moreover, this page also supplies the diagram of SIMM structure and the button to start the questionnaire.

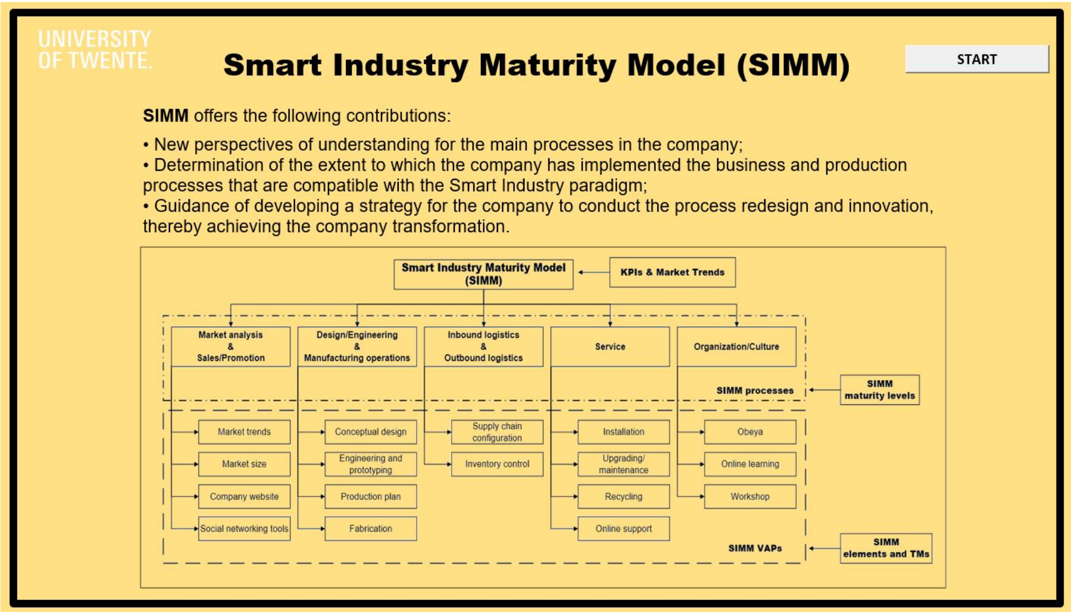


FIGURE 6.4: Welcome page of SIMM questionnaire

6.3.2 Appraisal form

This form comprises thirty seven questions, which are sorted into eight SIMM processes.

For instance, 'Is modular design implemented in the process of product development?' is the first question that belongs to the process 'Design/Engineering' (Figure 6.5). And there are five options (or answers) to this question. The user should choose the option that is closest to the current situation in the company. The options are:

- Option 1 - The process is running based on conventional design methods.
- Option 2 - Default (i.e. the circumstance between option 1 and 3).
- Option 3 - Modular design approach is implemented in the process.
- Option 4 - Default (i.e. the circumstance between option 3 and 5).
- Option 5 - Designers use modular design approach and involve customers to co-design by using configurators.

Next to the question, the term 'PM' implies this question is related to the element 'Prosumer & Mass customization'. And the button 'More info' is linked to the description of this element so that the user can learn more details about the element.

In the description (Figure 6.6), the introduction of 'Prosumer & Mass customization' is elaborated. The relevant TMs are also listed here, i.e. Marketing analytics, Additive manufacturing, Social media, Modular design & configurator, PLM (ERP & CRM & MES), and Supply chain data integration.

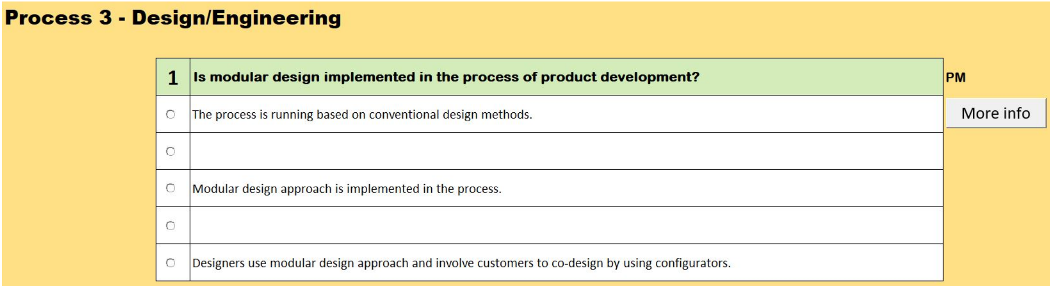


FIGURE 6.5: Description of SIMM element

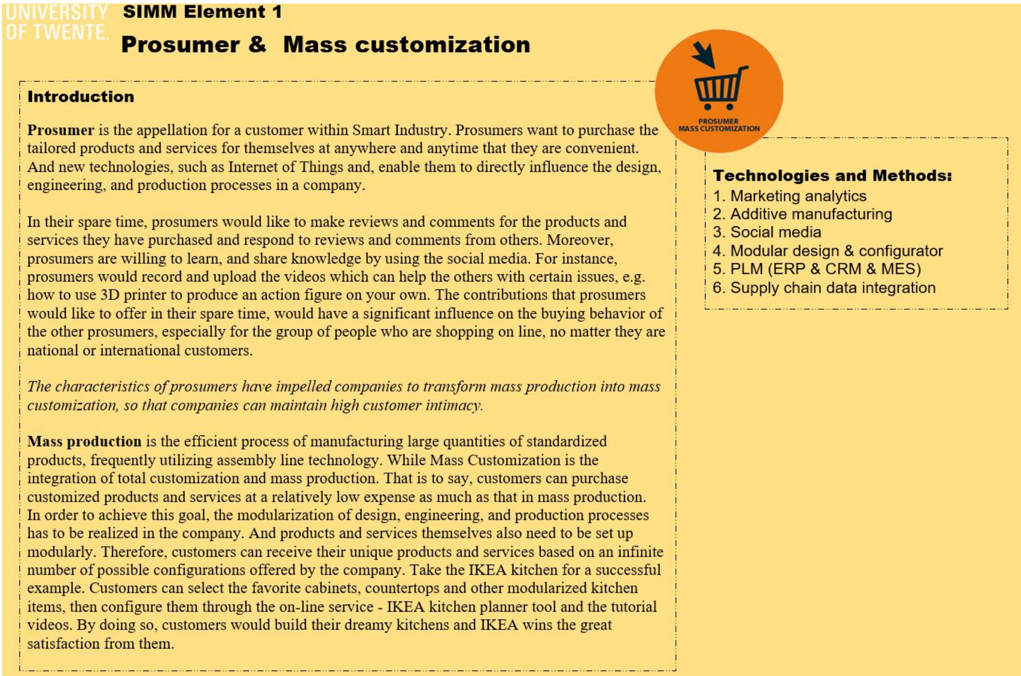


FIGURE 6.6: Description of SIMM element

6.3.3 Result zone

The result zone consists of three parts.

First part of the result zone is bar charts which demonstrate the maturity levels for each group of SIMM processes (Figure 6.7).

Second part of the zone is a table as well as the diagram for the eight SIMM processes (Figure 6.8). The table records the digit form of maturity levels for each group of SIMM processes. And the buttons 'More info' in the table can lead the user to the result analysis for each group of SIMM processes.

Third part of the zone is another table as well as the diagram for the seven SIMM elements (Figure 6.9). The table records the KPI and Market Trends most valued by the company, and it also suggests the improving order of SIMM elements based in the choice of KPI.

As mentioned previously, this improving order helps a company to think about which element should be invested firstly due to the limitation of resources. Also, it is worth pointing out that the elements ranking the first, second and third places, are as equally significant as each other, since they have the same contribution weight which has been discussed in the section 6.2.3. The table also includes seven 'More info' buttons, which can lead the user to the description of seven SIMM elements respectively.

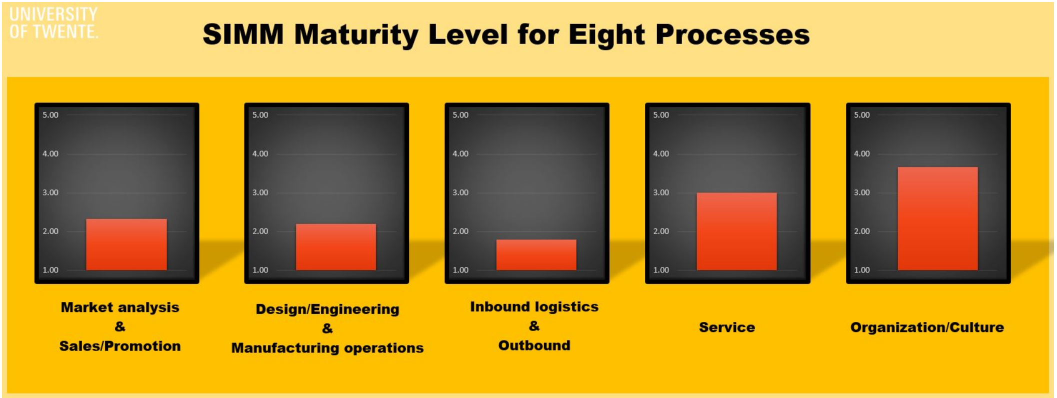


FIGURE 6.7: Bar charts for maturity levels

SIMM Processes	Maturity Score	Information
Market analysis & Sales/Promotion	2.33	More info
Design/Engineering & Manufacturing operations	2.20	More info
Inbound logistics & Outbound logistics	1.80	More info
Service	3.00	More info
Organization/Culture	3.67	More info

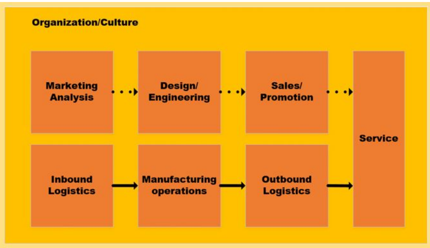


FIGURE 6.8: Result table for SIMM processes

KPI	Time to Market	
Market Trends	Individualization	
SIMM Element	Improving order	Information
Prosumer & Mass customization	6	More info
Co-creation & Smart product development	1	More info
Cyber physical system & Factory flexibility	3	More info
Internet of Things & Digital factory	4	More info
Enterprise agility & Competent workforce	5	More info
Operational excellence & Variation reduction	2	More info
Eco-production & Made different	7	More info

FIGURE 6.9: Result table for SIMM elements

6.3.4 Result analysis

Result analysis is made for five groups covering all eight SIMM processes, as discussed in section 4.2.

Take the process 'Design/Engineering & Manufacturing operations' for example (Figure 6.10). Firstly, the result is showed for the user, and 'AWARE' indicates the second level of SIMM maturity level. Secondly, the rose diagram presents the score of each question that belongs to this process. Then the suggestion is provided

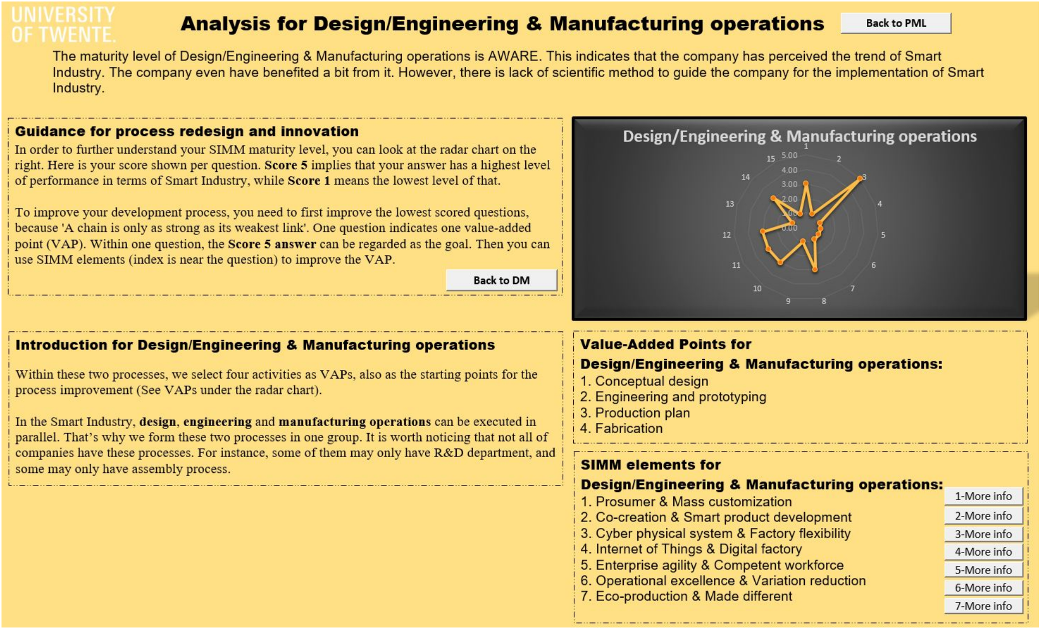


FIGURE 6.10: Result analysis of SIMM

to guide the company to identify where the process redesign and innovation could happen by implementation of Smart Industry. This page also supplies the introduction of the specific processes and relevant VAPs as well as the SIMM elements which have influence on this process.

In this chapter, the SIMM questionnaire and the mechanism of SIMM have been developed based on the study of previous chapters. And it ends the phase 2 'Exploration' and phase 3 'Development' in the roadmap. The next chapter will start the phase 4 of the roadmap, i.e. the evaluation of SIMM.

Chapter 7

EVALUATION FOR SIMM

7.1 Design of evaluation tests

As discussed in section 2.5, the purpose of tests is to evaluate both the contents and structure of SIMM. For this aim, two procedures are designed, i.e. filling the SIMM questionnaire and filling the online user experience survey. The survey is presented in the Appendix B.

- Filling the questionnaire enables the evaluators to fully understand SIMM. And they can receive the results of SIMM maturity levels which are used to compare with the current circumstance in their companies, so that they could determine whether the results are correct and accurate, and whether SIMM has fulfill its function to assist companies to implement Smart Industry approach.
- Filling the user experience survey allows the evaluators to offer the overall using experience so that it could determine whether SIMM has been successfully developed based the success criteria in section 2.2.4.

Also, as mentioned in section 2.5, interviews with the evaluators in companies are necessary for the evaluation, because the questions and answers need to be slightly adjusted due to the different backgrounds of companies, which could bring better using experience to the evaluators. The interview contains five procedures, i.e. filling the SIMM questionnaire, explaining the results of maturity levels, discussing the possibilities about implementing Smart Industry approach, identifying the advantages and disadvantages of SIMM, and finally filling the user experience survey. The entire evaluation process is flexible, which would last one hour or one and half hours depending on how further the interview and discussion would go. And the evaluators could be managers or engineers, who understand all the processes in the company, such as design and engineering, production, logistics, sales, services and etc.

Moreover, as mentioned in section 2.5, from the perspective of statistics, the more tests are carried out, the better evaluation would be. However, the number of evaluators involved is small, so the results of evaluation test would focus on improving SIMM rather than validating the tool.

7.2 Evaluation result and analysis

The overview of the evaluation is firstly discussed based on the results of user experience survey. It would determine whether the development of SIMM meets the success criteria. And it would also provide the advantages and disadvantages of SIMM. Then the results of maturity levels for three companies are presented, and the analysis of the results are conducted at the same time.

7.2.1 Overview of evaluation

According to the survey, the first impression to Smart Industry was very positive, which shows the great interest from the evaluators. They would like to learn more about this approach by using Smart Industry Maturity Model.

The overall appraisal of SIMM was positive. Evaluators identified several advantages of SIMM, and they saw the potential of further development for this tool so that SIMM could better help the implementation of Smart Industry. Also, they offered several suggestions for improving this tool (Appendix C).

Advantages of SIMM:

- It has fulfilled its functions, i.e. offering new perspectives of understanding for the main processes in the company, determining the extent to which the company has implemented the business and production processes that are compatible with the Smart Industry paradigm, and supplying the guidance of developing a strategy for the company to conduct the process redesign and innovation, thereby achieving the company transformation.
- The explanation of results is easy to understand. And the results per se are correct to reflect the status quo in the companies, and the description of SIMM maturity levels has a high degree of accuracy.
- The amount of SIMM questions and answers is appropriate. They are easy to understand and have covered the business and production processes in company with a high degree.
- Most questions and answers are described from the company's point of view, which is appealing to the evaluators and helps them to better understand the context.

Disadvantages of SIMM and suggestions:

- Some academic terminologies in the questions are obscure to evaluators. So, it would be better to either explain the concept under the question or to rephrase the question without the academic term.
- Some questions are too specific, not fully covering the processes. So, it would be better to expend the arrange of question.
- Some questions are too general. So it would be better to narrow down the scope of question.
- It would be better to deliver the results in the form of report.

7.2.2 Results of maturity levels

In this section, the results of maturity levels for companies are presented and discussed based on different diagrams, since using diagram could enables a clear demonstration of the results and an easy comparison across companies and SIMM processes. The participating companies are remained anonymous, so capital letter would replace the names of the organizations.

There are three companies involved in the evaluation of SIMM. Company A is a large company with a hundred years of history, providing products and services for health care. Company B is also a large company with more than a hundred years of history, providing products and services for electric power. Company C is a small innovative company with less than five years of history, providing products and services for sustainable energy.

There are three diagrams to be discussed next, i.e. the bar chart showing SIMM maturity levels for three companies based on each SIMM process group, the 100% stacked column diagram presenting the average questions scores for three companies on each SIMM process group, and

- **Diagram 1 - SIMM maturity levels for three companies**

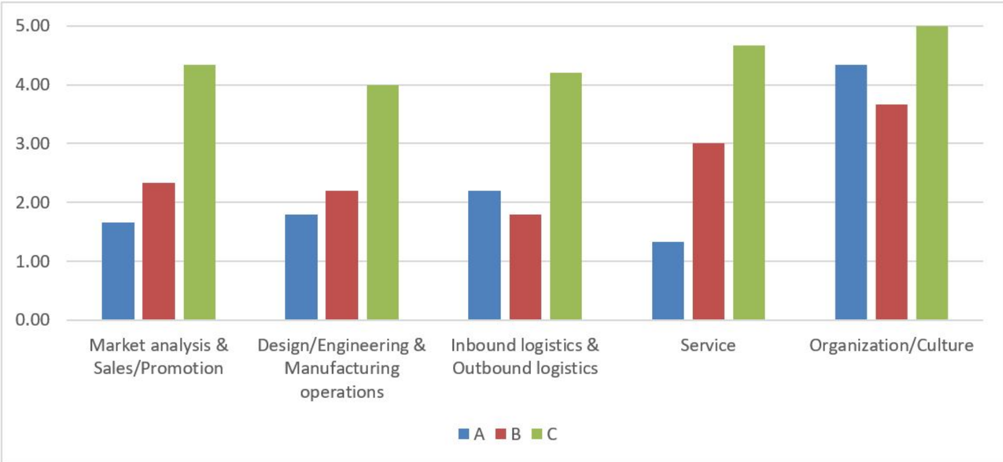


FIGURE 7.1: SIMM maturity levels for three companies

According to Figure 7.1, Company A and B are more conventional than Company C, because the maturity levels of Company C are all higher than that of Company A and B for every SIMM process groups. That is to say, the business and production processes in Company C are more compatible with the Smart Industry paradigm, and Company A and B should start to think about how they could redesign the processes so that the process innovation would enhance their competitiveness.

Also, every company has a relatively high maturity level of 'Organization/Culture'. That means people in these companies are ready to embrace radical changes in the industry, which has offered a good foundation for implementing Smart Industry approach.

Moreover, Company B and C have a relatively even maturity levels for every SIMM process group. In contrast, Company A has a rugged maturity levels, i.e. the highest score is over 4 in Organization/Culture while the lowest score is only 1.7 in Service. It indicates that service is the 'bottleneck' process, and Company A should firstly redesign the process of service, thereby enhancing the overall efficiency of the entire value chain.

- **Diagram 2 - Average maturity level for each SIMM process group**

Figure 7.2 indicates the average maturity level of three companies for each SIMM process group. There are five series in the diagram, i.e. Score1, Score2, Score3, Score4, Score5. And one series represents the average score of the same

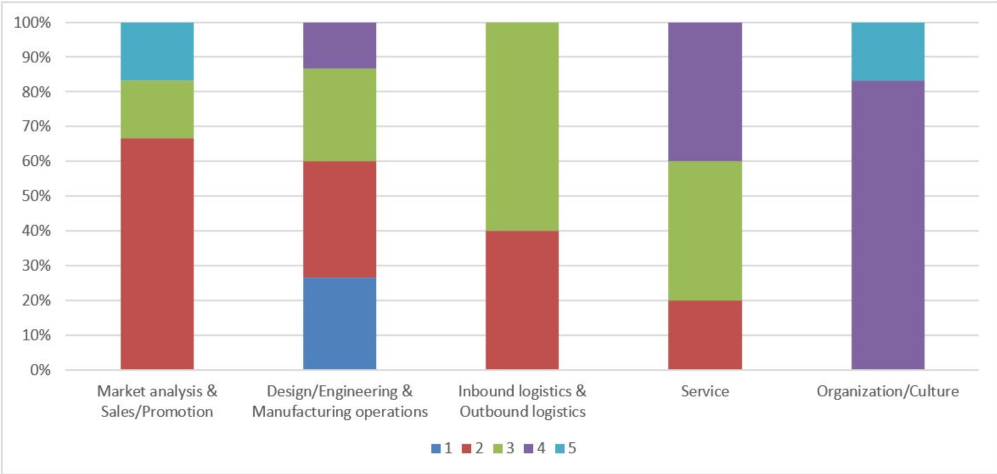


FIGURE 7.2: Average maturity level for each SIMM process group

question for three companies. And the diagram shows how many questions of a certain average score have occupied within the same SIMM process group.

For instance, there are five questions in the SIMM process 'Organization/Culture'. One question is 'Are your employees able to work in a multidisciplinary team when the project is complex and needs multidisciplinary knowledge?' All three companies have chosen the fifth option 'Employees can collaborate in a multidisciplinary team, which is guided and supported by the specific mechanism in the company.', then they all get score 5. So, the average score of this question is score 5 which belongs to the series Score5. The average scores of the other four questions are 4, 4, 4, 4, and 4, which all belongs to the series Score4. Therefore, in the process 'Organization/Culture', Score5 question has occupied around 16% of the total questions, and Score4 questions have taken the rest.

And this result indicates two facts. Firstly, comparing to the other SIMM processes, the 'Organization/Culture' has relative higher average maturity levels across three companies. It might imply that many Dutch companies have already built a good foundation for implementing Smart Industry, which leads to the same conclusion drawn in the analysis of diagram 1. Secondly, the series Score4 occupies the majority. It means there is still room for process innovation in terms of Smart Industry, so that all stakeholders could benefit from it.

- **Diagram 3 - SIMM elements improving order for three companies**

  Figure 7.3 is built on the reverse data of SIMM elements improving orders which are received from SIMM questionnaire. That is to say, the more important one element needs improving, the higher score would be assigned to this element.

  For example, Company B has chosen the KPI 'Time to Market'. Based on this choice, the element 'Co-creation & Smart product development', 'Operational excellence & Variation reduction' and 'Cyber physical system & Factory flexibility' are ranked at 1st, 2nd, and 3rd place in the list of improving order. Then the data would be transformed reversely in the Figure 7.3. The diagram shows that the three elements are assigned to the score 7, 6, 5 respectively.

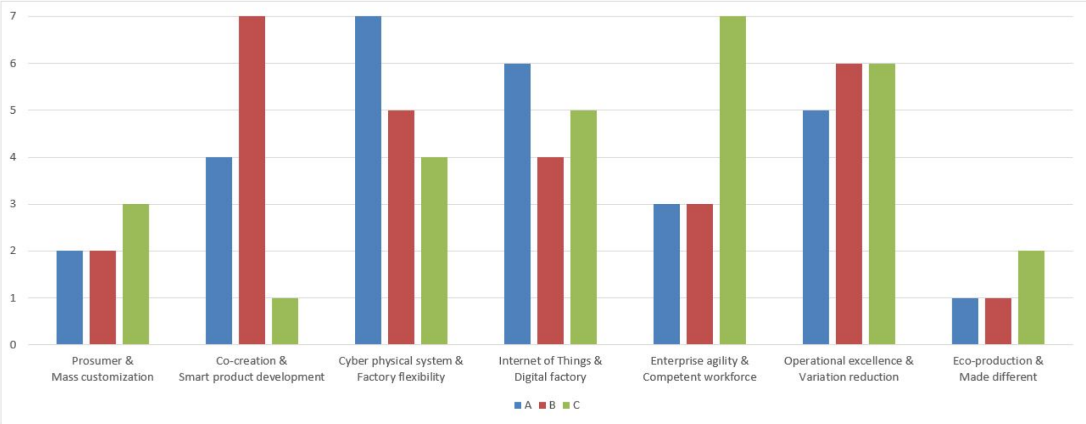


FIGURE 7.3: SIMM elements improving order for three companies

As discussed in section 6.2.3 and section 6.3.3, due to the equal importance of several elements for a certain KPI and the mechanism of assigning the weight to each element, those elements that have been assigned to score 7, 6, 5, are equally significant to the chosen KPI. Using the example above, Company B would have more choices among the elements 'Co-creation & Smart product development', 'Operational excellence & Variation reduction' and 'Cyber physical system & Factory flexibility'. Company B could choose one of them, and use it to help the process redesign and innovation in the company in order to reduce the time to market, thereby improving the KPI 'Time To Market' and receiving profits from it.

It is observed that different companies have their own improving order lists of SIMM elements. For instance, the 'young' company - Company C, it is important to be resilient in order to survive in the radical changing environment, so it is reasonable that Company C should consider improving 'Enterprise agility & Competent workforce' as the priority, in order to successfully achieve the company transformation by implementing Smart Industry approach.

In this chapter, the evaluation of SIMM has been conducted. That is to say, the phase 4 has been finished and the roadmap has reached its end. In the next chapter, the conclusion will be presented in order to close the entire thesis.

Chapter 8

CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

The purpose of this thesis was to develop a tool which will help companies to identify their performance levels of business and production processes from the perspective of Smart Industry, and then to guide them to choose feasible technologies and methods. By doing so, companies could make their own strategies for implementing Smart Industry approach, thereby successfully achieving the transformation and maintaining their competitiveness during the Fourth Industrial Revolution. And this tool has been termed **Smart Industry Maturity Model (SIMM)**, which is comprised of four parts, i.e. '**SIMM elements and relevant technologies and methods (TMs)**', '**KPIs and Market Trends**', '**SIMM processes and relevant Value-add points (VAPs)**', and '**SIMM maturity levels and relevant questionnaire**'.

For this aim, Design Research Methodology (DRM) had been applied to this thesis, which is used to identify research scope, and to select proper research methods. Based on the utilization of DRM, a roadmap has been designed for the development of Smart Industry Maturity Model. It consists of four phases, i.e. **Phase One – Establishment**, **Phase Two - Exploration**, **Phase Three - Development**, and **Phase Four - Evaluation**. Phase One is used to set up and clarify basic issues. Phase Two and Phase Three are used to explore the references and to develop the four parts of SIMM. Phase Four has carried out the evaluation of SIMM in order to determine whether the development of SIMM meets the success criteria.

Phase One has been used to clarify the goal of using SIMM, to define the scope, to identify audience and to establish success criteria. In Phase Two, references of two approaches (i.e. Industry4.0 and Smart Industry), Porter's value chain model, and Capability Maturity Model Integration, have been explored. The exploration has supplied the foundation for developing the structure and the content of SIMM. In Phase Three, based on the exploration and the external input of Smart Industry elements from the organization *Smart Industry Partners*, the structure and the four parts of SIMM have been developed. The evaluation has been conducted in Phase Four. The response of all evaluators is positive and they see the potential in the tool. The results of evaluation have demonstrated the success of the development of SIMM, which has also helped to further improve the quality of SIMM.

The goal of this thesis has been achieved by developing Smart Industry Maturity Model. It is a tool to gauge the growth and increasing impact of Smart Industry approach in the Fourth Industrial Revolution from both business and technology perspectives. SIMM determines the extent to which companies have implemented the business and production processes that are compatible with the Smart Industry paradigm. Meanwhile, it provides new perspectives of understanding the business and production processes within companies. Finally, Smart Industry Maturity Model helps companies to develop their own strategies for conducting the process redesign and innovation, thereby achieving the transformation and maintaining their competitiveness during the Fourth Industrial Revolution.

8.2 Recommendations

For the aim of further development, it is recommended to firstly validate the content of SIMM. The validation should involve more organizations, since from the perspective of statistics, the more tests are carried out, the better results would be. Also, discussions with experts and organizations in the Smart Industry academic communities would support the validation of the tool. Once being validated, the tool can be used to effectively guide companies to implement Smart Industry approach.

Secondly, the tool should be not only utilized for the manufacturing industry, but also for more types of industries, such as agriculture, architecture, education, energy, food and etc. And the tool should be redesigned more flexible in order to fit different types of industries.

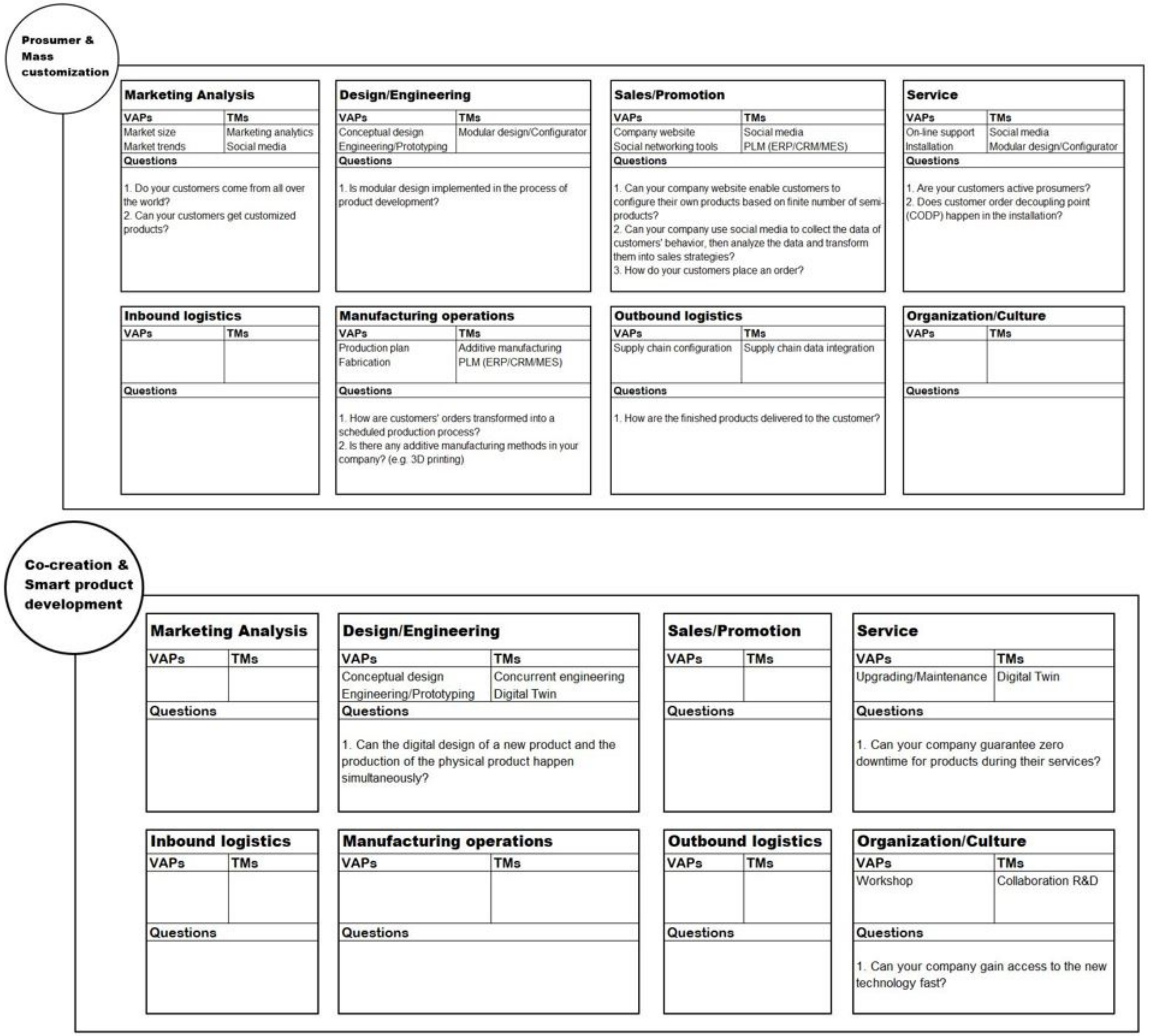
Thirdly, SIMM has demonstrated the interrelations between KPIs and the improving order of SIMM elements. However, is there any connection between Market Trends and the improving order of elements? SIMM has identified seventeen Value-added points. Are there more VAPs existing within the processes? SIMM has also identified twenty four technologies and methods for supporting the implementation of Smart Industry. Are there more technologies and methods available for the implementation?

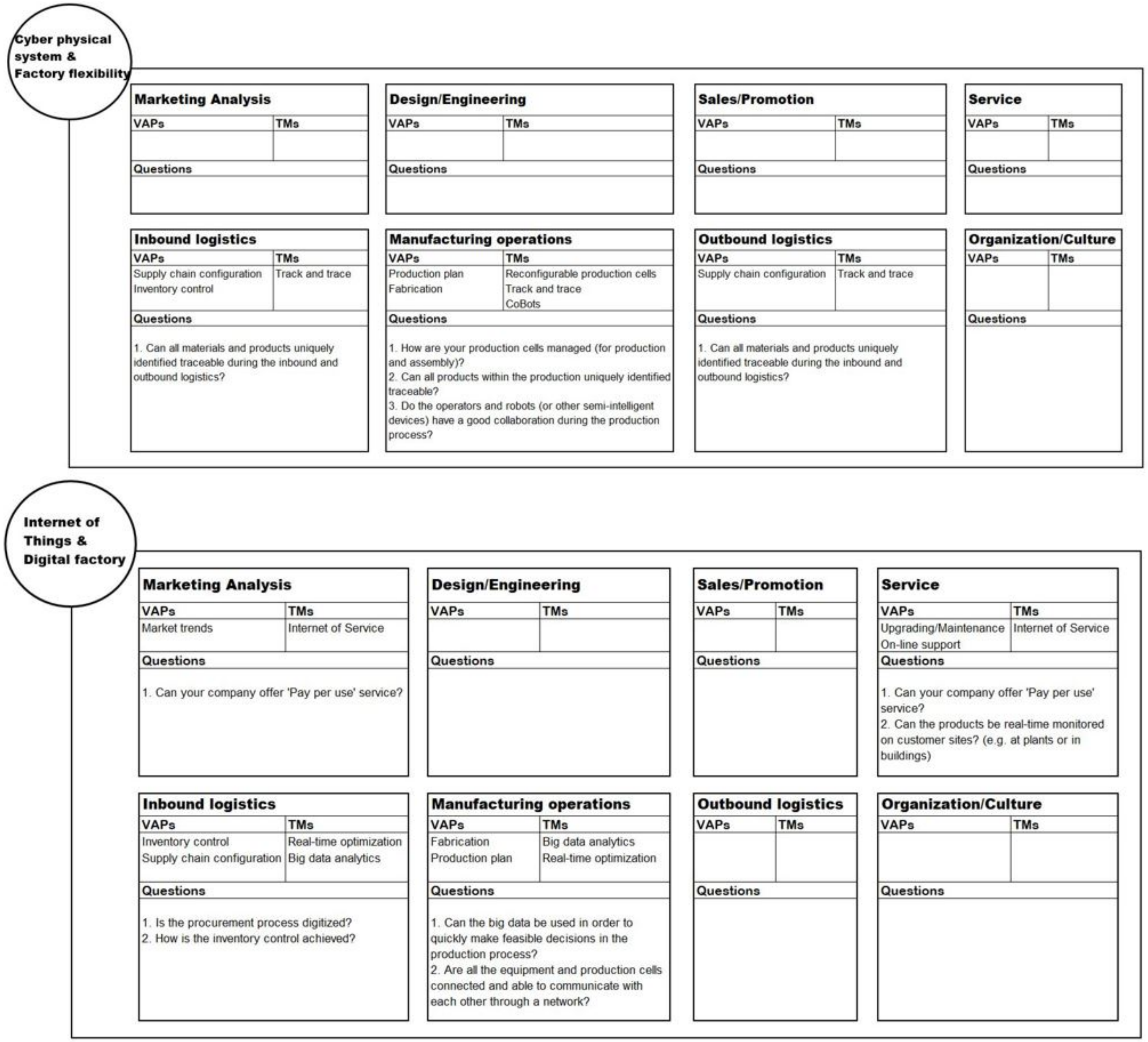
These research questions and recommendations demonstrate that there is plenty of research needed to perform, in order to develop a successful tool for the implementation of Smart Industry. However, the first steps have been taken in this thesis.

Appendix A

TEMPLATES FOR DEVELOPING SIMM QUESTIONNAIRE

There are seven question-making templates in total for developing SIMM questionnaire, based on seven SIMM elements and TMs as well eight SIMM processes and VAPs.


Prosumer & Mass customization
Marketing Analysis
VAPs
TMs
Market size
Market trends
Marketing analytics
Social media
Questions
1. Do your customers come from all over the world?
2. Can your customers get customized products?
Design/Engineering
VAPs
TMs
Conceptual design
Engineering/Prototyping
Modular design/Configurator
Questions
1. Is modular design implemented in the process of product development?
Sales/Promotion
VAPs
TMs
Company website
Social networking tools
Social media
PLM (ERP/CRM/MES)
Questions
1. Can your company website enable customers to configure their own products based on finite number of semi-products?
2. Can your company use social media to collect the data of customers' behavior, then analyze the data and transform them into sales strategies?
3. How do your customers place an order?
Service
VAPs
TMs
On-line support
Installation
Social media
Modular design/Configurator
Questions
1. Are your customers active prosumers?
2. Does customer order decoupling point (CODP) happen in the installation?
Inbound logistics
VAPs
TMs
Questions
Manufacturing operations
VAPs
TMs
Production plan
Fabrication
Additive manufacturing
PLM (ERP/CRM/MES)
Questions
1. How are customers' orders transformed into a scheduled production process?
2. Is there any additive manufacturing methods in your company? (e.g. 3D printing)
Outbound logistics
VAPs
TMs
Supply chain configuration
Supply chain data integration
Questions
1. How are the finished products delivered to the customer?
Organization/Culture
VAPs
TMs
Questions
Co-creation & Smart product development
Marketing Analysis
VAPs
TMs
Questions
Design/Engineering
VAPs
TMs
Conceptual design
Engineering/Prototyping
Concurrent engineering
Digital Twin
Questions
1. Can the digital design of a new product and the production of the physical product happen simultaneously?
Sales/Promotion
VAPs
TMs
Questions
Service
VAPs
TMs
Upgrading/Maintenance
Digital Twin
Questions
1. Can your company guarantee zero downtime for products during their services?
Inbound logistics
VAPs
TMs
Questions
Manufacturing operations
VAPs
TMs
Questions
Outbound logistics
VAPs
TMs
Questions
Organization/Culture
VAPs
TMs
Workshop
Collaboration R&D
Questions
1. Can your company gain access to the new technology fast?


Cyber physical system & Factory flexibility
Marketing Analysis
VAPs
TMs
Questions
Design/Engineering
VAPs
TMs
Questions
Sales/Promotion
VAPs
TMs
Questions
Service
VAPs
TMs
Questions
Inbound logistics
VAPs
Supply chain configuration
Inventory control
TMs
Track and trace
Questions
1. Can all materials and products uniquely identified traceable during the inbound and outbound logistics?
Manufacturing operations
VAPs
Production plan
Fabrication
TMs
Reconfigurable production cells
Track and trace
CoBots
Questions
1. How are your production cells managed (for production and assembly)?
2. Can all products within the production uniquely identified traceable?
3. Do the operators and robots (or other semi-intelligent devices) have a good collaboration during the production process?
Outbound logistics
VAPs
Supply chain configuration
TMs
Track and trace
Questions
1. Can all materials and products uniquely identified traceable during the inbound and outbound logistics?
Organization/Culture
VAPs
TMs
Questions
Internet of Things & Digital factory
Marketing Analysis
VAPs
Market trends
TMs
Internet of Service
Questions
1. Can your company offer 'Pay per use' service?
Design/Engineering
VAPs
TMs
Questions
Sales/Promotion
VAPs
TMs
Questions
Service
VAPs
Upgrading/Maintenance
On-line support
TMs
Internet of Service
Questions
1. Can your company offer 'Pay per use' service?
2. Can the products be real-time monitored on customer sites? (e.g. at plants or in buildings)
Inbound logistics
VAPs
Inventory control
Supply chain configuration
TMs
Real-time optimization
Big data analytics
Questions
1. Is the procurement process digitized?
2. How is the inventory control achieved?
Manufacturing operations
VAPs
Fabrication
Production plan
TMs
Big data analytics
Real-time optimization
Questions
1. Can the big data be used in order to quickly make feasible decisions in the production process?
2. Are all the equipment and production cells connected and able to communicate with each other through a network?
Outbound logistics
VAPs
TMs
Questions
Organization/Culture
VAPs
TMs
Questions

Enterprise agility & Competent workforce

Marketing Analysis

VAPs	TMs

Questions

Design/Engineering

VAPs	TMs

Questions

Sales/Promotion

VAPs	TMs

Questions

Service

VAPs	TMs

Questions

Inbound logistics

VAPs	TMs

Questions

Manufacturing operations

VAPs	TMs
Fabrication Production plan	Flexible processes

Questions

1. How easily can the employees change their tasks when fabrication cells are reconfigured?

Outbound logistics

VAPs	TMs

Questions

Organization/Culture

VAPs	TMs
Obeya On-line learning Workshop	Digital obeya Blended learning

Questions

1. Are your employees able to work in a multidisciplinary team when the project is complex and needs multidisciplinary knowledge?
2. Can your employees continuously develop themselves in your company in order to meet the future growth from the company?
3. Does your company have collaboration on Smart Industry together with external partners so that companies can become more competitive in the turbulent business environment?

Operational excellence & Variation reduction

Marketing Analysis

VAPs	TMs

Questions

Design/Engineering

VAPs	TMs
Conceptual design Engineering/Prototyping	Reliability Engineering

Questions

1. Is the reliability of products considered as a factor in the design and engineering processes?

Sales/Promotion

VAPs	TMs

Questions

Service

VAPs	TMs
Upgrading/Maintenance	Reliability Engineering Design for excellence

Questions

1. Can your company guarantee zero downtime for products during their services?

Inbound logistics

VAPs	TMs

Questions

Manufacturing operations

VAPs	TMs
Production plan Fabrication	Lean six sigma Design for excellence

Questions

1. Does your company have an optimal production process, in a cost effective manner and without variation?
2. Can the production process be stable, reliable and predictable?

Outbound logistics

VAPs	TMs

Questions

Organization/Culture

VAPs	TMs
Workshop Obeya	Lean six sigma

Questions

1. Does your employees have the awareness of continuous improvement?

Eco-production & Made different

Marketing Analysis

VAPs	TMs

Questions

Design/Engineering

VAPs	TMs
Conceptual design Engineering/Prototyping	Design for disassembly

Questions

1. Is design for disassemble considered in the product development?

Sales/Promotion

VAPs	TMs

Questions

Service

VAPs	TMs
Recycling	Design for disassembly

Questions

1. To which degree can your products be recycled (with material level and energy level)?

Inbound logistics

VAPs	TMs
Supply chain configuration	Alternative energy

Questions

1. Does your company use clean energy technology during the logistics process?

Manufacturing operations

VAPs	TMs
Production plan Fabrication	Remanufacturing

Questions

1. Is remanufacturing considered in the production process?

Outbound logistics

VAPs	TMs

Questions

Organization/Culture

VAPs	TMs
Workshop On-line learning	Design for disassembly Alternative energy Remanufacturing

Questions

1. Does your employees have the awareness of sustainability?

Appendix B

USER EXPERIENCE SURVEY

This appendix consists of two parts, i.e. the content of online survey and the result of it.

B.1 Content of survey

These are twelve questions for the online survey in order to collect information about the users experience with SIMM. Also, the results of the survey would be used to determine whether the development of SIMM meets the success criteria in chapter 2.

1 **My first reaction to the approach of Smart Industry is . . . .**

Very negative ○ ○ ○ ○ ○ Very positive

2 **SIMM offers contributions to understanding the business and production processes from a new perspective.**

Very much disagree ○ ○ ○ ○ ○ Very much agree

3 **SIMM offers contributions to the redesign and innovation within the business and production processes and the transformation of the company.**

Very much disagree ○ ○ ○ ○ ○ Very much agree

4 **Language and terminology in the questions are . . . to understand.**

Very difficult ○ ○ ○ ○ ○ Very easy

5 **Language and terminology in the answers are . . . to understand.**

Very difficult ○ ○ ○ ○ ○ Very easy

6 **Answers to the question are . . . to choose.**

Very difficult ○ ○ ○ ○ ○ Very easy

7 **The results of analysis are . . . to understand.**

Very difficult ○ ○ ○ ○ ○ Very easy

8 **The amount of questions is . . . .**

Too little ○ ○ ○ ○ ○ Too much

9 **The questions have fully covered the business and production processes in the company.**

Very much disagree ○ ○ ○ ○ ○ Very much agree

10 **SIMM processes and VAPs have fully covered the business and production processes in the company.**

Very much disagree ◯ ◯ ◯ ◯ ◯ Very much agree

11 **SIMM elements and their TMs are sufficiently to support the redesign within the business and production processes.**

Very much disagree ◯ ◯ ◯ ◯ ◯ Very much agree

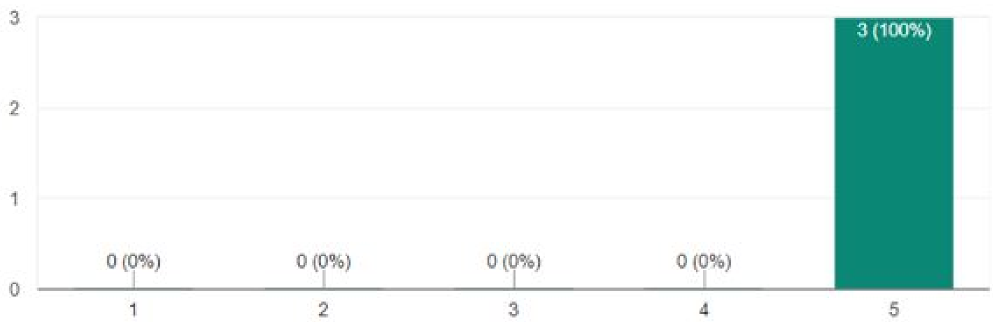
12 **The descriptions of maturity levels are . . . .**

very inaccurate ◯ ◯ ◯ ◯ ◯ Very accurate

B.2 Result of survey

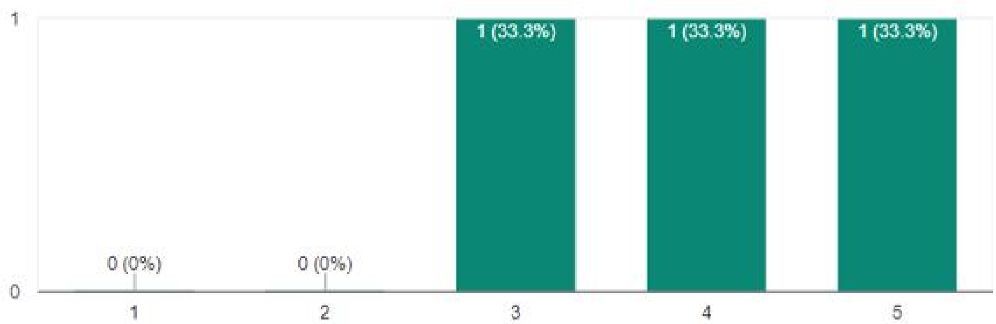
My first reaction to the approach of Smart Industry is

3 responses



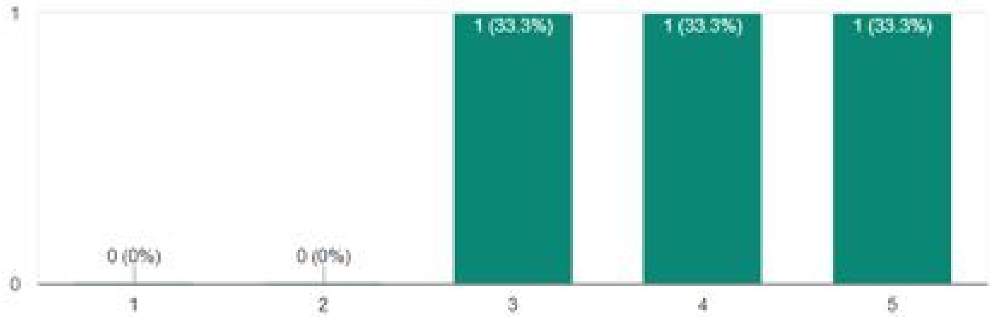
SIMM offers contributions to understanding the business and production processes from a new perspective.

3 responses



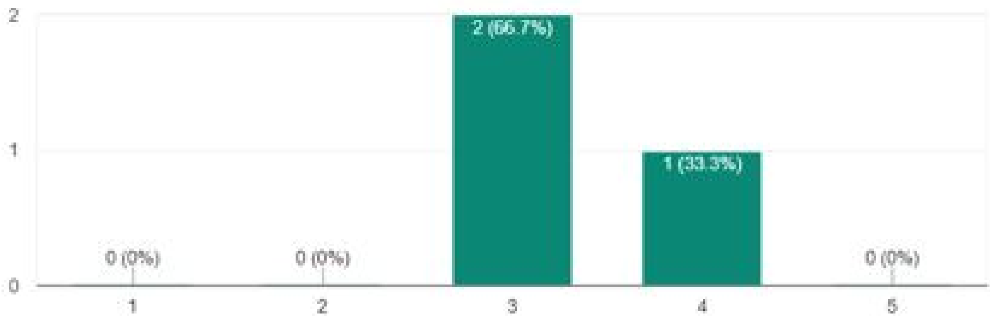
SIMM offers contributions to the redesign and innovation within the business and production processes and the transformation of the company.

3 responses



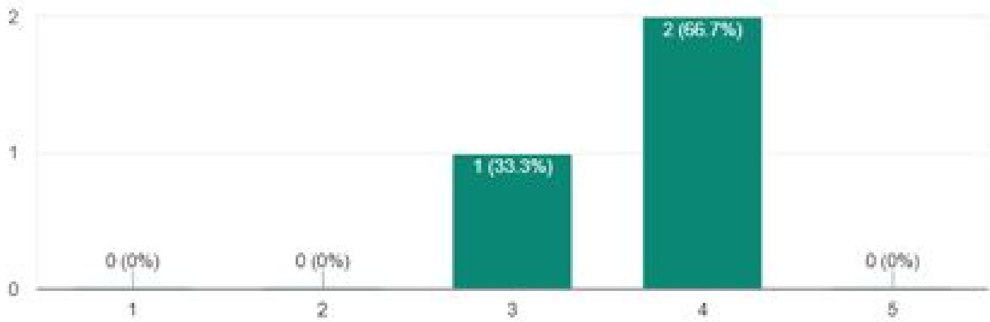
Language and terminology in the questions are ______ to understand.

3 responses



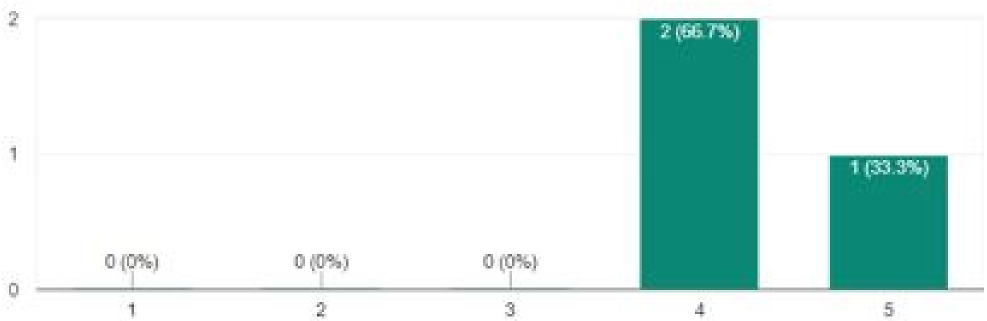
Language and terminology in the answers are ______ to understand.

3 responses



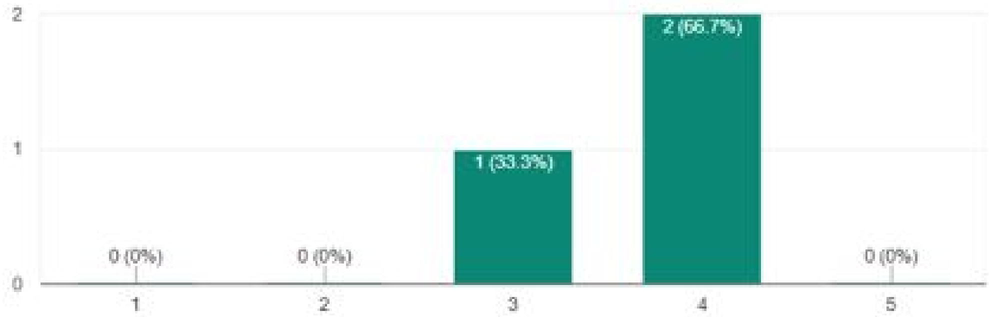
Answers to the question are ______ to choose.

3 responses



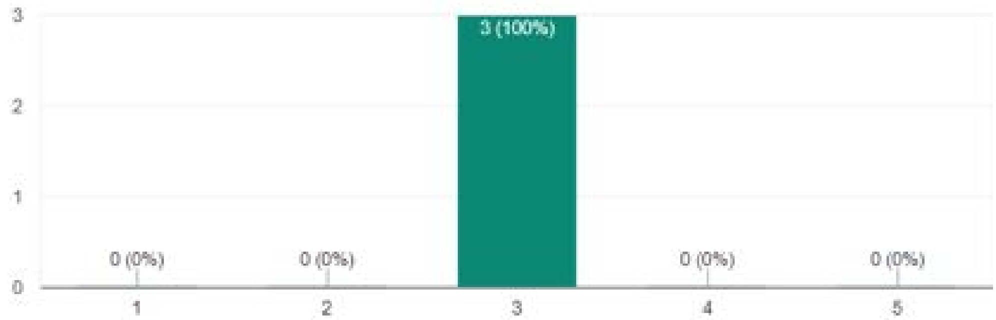
The results of analysis are ______ to understand.

3 responses



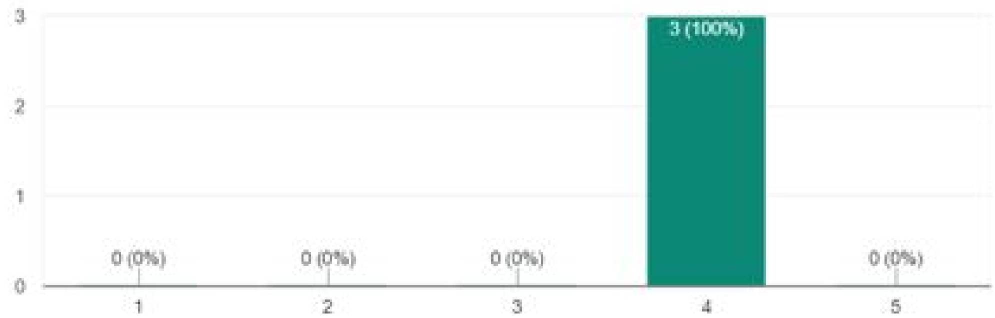
The amount of questions is

3 responses



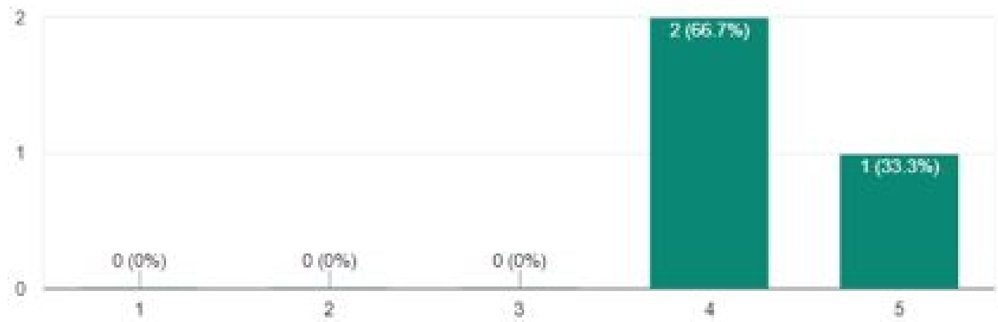
The questions have fully covered the business and production processes in the company.

3 responses



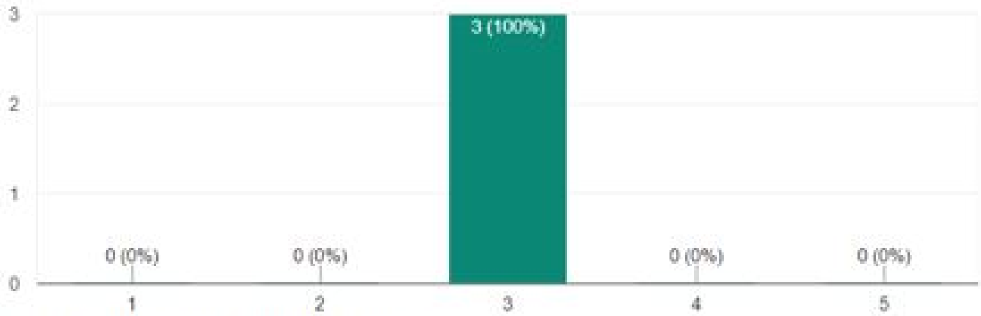
SIMM processes and VAPs have fully covered the business and production processes in the company.

3 responses



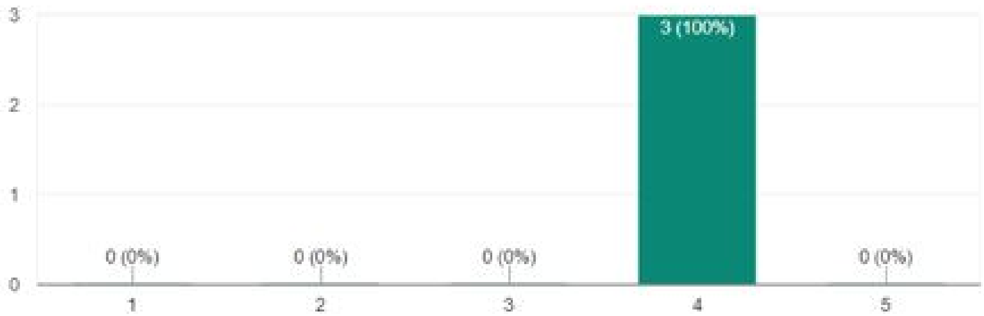
SIMM elements and their TMs are sufficiently to support the redesign within the business and production processes.

3 responses



The descriptions of maturity levels are

3 responses



Appendix C

IMPROVEMENTS OF SIMM

This appendix shows the questions and options in the SIMM questionnaire, and the improvement of SIMM that are suggested by the evaluators from three companies.

C.1 SIMM question

C.1.1 KPIs and Market trends

1	Which KPI does your company want to improve most?
◯	Productivity
◯	Time To Market
◯	Market Share
◯	Resilience
◯	Revenue
◯	Cost
◯	Other
2	**Which market trends does your company want to follow most?**
◯	Servitization & Pay per use
◯	E-Commerce & Supply chain integration
◯	Individualization
◯	Sustainability
◯	Other

C.1.2 Process 1 - Market analysis

1	Do your customers come from all over the world?
◯	Customers only come from local region.
◯	\
◯	The amount of international customers is as much as that of local customers.
◯	\
◯	No borders. Customers come from all over the world, and have positive influence on the buying behavior of other prosumers.

2	**Can your customers get customized products?**
◯	Production process is based on mass production, thus there is no customized products.
◯	\
◯	Half of the products are modularized so that customers can get unique products based on finite semi-product, which would cost more expensive than the products made by mass production.
◯	\
◯	Production process is based on mass customization. Customers can get unique products at low production cost.
3	**Can your company offer 'Pay per Use' service?**
◯	'Pay per use' is still an obscure concept.
◯	\
◯	Just recently, we have started to offer 'Pay per Use' service.
◯	\
◯	We have offered 'Pay per Use' service for a long time.

C.1.3 Process 2 - Sales/Promotion

4	**Can your company website enable customers to configure their own products based on finite number of semi-products?**
◯	Customers can only buy the assembled products on the website.
◯	\
◯	Half of the products are modularized so that customers can choose what they like on the website.
◯	\
◯	Product modularization is implemented. Customers can configure the unique products they want on the website.
5	**Can your company use social media to collect the data of customers' behavior, then analyze the data and transform them into sales strategies?**
◯	Social media doesn't launch for now.
◯	\
◯	Social media can not only offer the news from company, but also collect the data of customers' behavior.
◯	\
◯	Customers are very active on the social media. Company can collect, analyze and utilize the data from social media, and transform them to successful sales strategies.
6	**How do your customers place an order?**
◯	Via an catalog where customers can select among our products.
◯	\
◯	Via an ordering template where customers can specify its requirements.
◯	\
◯	Via an web application where customers can configure their own products.

C.1.4 Process 3 - Design/Engineering

1	**Is modular design implemented in the process of product development?**
◯	The process is running based on conventional design methods.
◯	\
◯	Modular design approach is implemented in the process.
◯	\
◯	Designers use modular design approach and involve customers to co-design by using configurators.
2	**Can the digital design of a new product and the production of the physical product happen simultaneously?**
◯	Always design first, then production. If the necessary requirements are not met, then the process can NOT move on.
◯	\
◯	The concurrent engineering is implemented in some of the product developments, and it reduces the time to market.
◯	\
◯	The design process of a new product is digitized, and it can carry on at the same time with the production of the physical product.(e.g. by using 3D printing technology)
3	**Is the reliability of products considered as a factor in the design and engineering processes?**
◯	Reliability of products is not considered in the whole process.
◯	\
◯	Reliability of products is considered only in the manufacturing process.
◯	\
◯	Reliability of products is an import factor, which is fully considered in the processes of design and engineering.
4	**Is design for disassembly considered in the product development?**
◯	Design for disassembly is not considered in the whole process.
◯	\
◯	For some of the products or parts, design for disassembly is considered in the product development.
◯	\
◯	Design for disassembly is the significant factor that we consider in the product development for all products.

C.1.5 Process 4 - Manufacturing operations

5	**How are customers' orders transformed into a scheduled production process?**
◯	Orders are manually planned into the production schedule.
◯	\
◯	ERP system automatically makes schedules for the machines and human recourses to manufacture the product.
◯	\
◯	Systems (ERP, MES and etc.) collaborate together, and autonomously make optimal decisions for the orders in terms of production process.
6	**Is there any additive manufacturing method in your company? (e.g. 3D printing)**
◯	Conventional manufacturing methods are used in the company.
◯	\
◯	We use additive manufacturing methods in the design and engineering processes (or in the fabrication process).
◯	\
◯	We use additive manufacturing methods in both the design and engineering processes and the fabrication processes.
7	**How are your production cells managed (for production and assembly)?**
◯	Workshops for fixed functions installed with several machines.
◯	\
◯	Manufacturing cells are easy to be set up for different product categories.
◯	\
◯	Flexible manufacturing cells are built in order to produce or assemble different products.
8	**Can all products within the production uniquely identified traceable?**
◯	Products within production can NOT be uniquely identified.
◯	\
◯	Not all the products within production can be uniquely identified.
◯	\
◯	Every product within the production can be uniquely identified traceable. (e.g. by RFID)
9	**Do the operators and robots (or other semi-intelligent devices) have a good collaboration during the production process?**
◯	No robots are used in the factory.
◯	\
◯	Several robots are used in the fabrication. But it seems not flexible or efficient than we have expected.
◯	\
◯	High efficient collaboration between robot and operator. (e.g. the physical task is performed by the robot, and operator gives instruction and help when necessary)

10	**Can the big data be used in order to quickly make feasible decisions in the production process?**
◯	Data are NOT digitized.
◯	\
◯	Data are digitized and collected. But we have not analyzed the data yet.
◯	\
◯	Big data analytics are very much significant for the production process. We can quickly make feasible decisions based on the analysis.
11	**Are all the equipment and production cells connected and able to communicate with each other through a network?**
◯	Equipment and cells are NOT connected through any network, thus they can NOT communicate with each other.
◯	\
◯	The equipment has embedded system, and has been connected in their own networks. Operators have to coordinate these networks in order to achieve an effective process.
◯	\
◯	All equipment and production cells are connected to each other in ONE network, and (wireless) communicate with each other. The process is optimized without the intervention of operators.
12	**How easily can the employees change their tasks when fabrication cells are reconfigured?**
◯	Every employees are recruited for certain required skills, so they can NOT change to other tasks.
◯	\
◯	Some of the employees are able to change their tasks.
◯	\
◯	All of the employees are able to learn fast and effectively, and we also encourage them to develop themselves. So they can successfully change to other tasks based on the company's need.
13	**Does your company have an optimal production process, in a cost effective manner and without variation?**
◯	Production process remains the same as it has been built originally many years ago.
◯	\
◯	Half of the production process has been upgraded in order to remain cost effective.
◯	\
◯	Production process has been continuously improved in order to gain an optimal process.
14	**Can the production process be stable, reliable and predictable?**
◯	Production process can NOT be predictable. It has downtime sometimes that we can not control.
◯	\
◯	The production process is under periodical monitoring.
◯	\
◯	The production process is under real-time monitoring. We have a stable, reliable and predictable process.

15	**Is remanufacturing considered in the production process?**
○	Remanufacturing is not considered in the whole process.
○	\
○	For some of the products or parts, remanufacturing is considered in the production process.
○	\
○	Remanufacturing is the significant factor that we consider in the production processes for all products.

C.1.6 Process 5/6 - Inbound & Outbound logistics

1	**How are the finished products delivered to the customer?**
○	Customers need to go to the company or the physical store to get products
○	\
○	All products can be delivered to customers.
○	\
○	No onsite delivering needed. With instruction offered by the company, customers can produce the parts and assemble them into a finished product with advanced technology at anywhere.
2	**Can all materials and products uniquely identified traceable during the inbound and outbound logistics?**
○	Materials and final products can NOT be uniquely identified.
○	\
○	Not all the materials and products within logistics can be uniquely identified.
○	\
○	Every materials and final products can be uniquely identified traceable. (e.g. by RFID)
3	**Is the procurement process digitized?**
○	Procurement is executed by staff, based on the periodic procurement plan.
○	\
○	Half of the process is digitized, which has saved time and labor cost.
○	\
○	Totally digitized. The procurement is automatically and optimally executed when there is a demand .
4	**How is the inventory control achieved?**
○	Inventory level is manually checked with a periodic time.
○	\
○	Inventory control system automatically recognizes that inventory needs to be replenished.
○	\
○	Zero inventory: we have collaboration with stakeholders along the upstream and downstream. As long as there is an order from customer, the production plan would autonomously order materials from suppliers. After finishing production, the product will immediately delivered either to the customer or to retailers.

5	**Does your company use clean energy technology during the logistics process?**
◯	We are not aware of the importance of using clean energy.
◯	\
◯	Half of the fleets run by clean energy.
◯	\
◯	Clean energy technology is the only energy source we have in the company. We can make full use of it.

C.1.7 Process 7 - Service

1	**Are your customers active prosumers?**
◯	Our customers are passive buyers. They have no more interaction with our company.
◯	\
◯	Our customers are active prosumers. They like to make comments about the products.
◯	\
◯	Our customers are very active prosumers who have sufficient knowledge about our products. They like to make comments and upload videos to help other customers.
2	**Can your products be customized only when they have been delivered to the customers?**
◯	The company does not offer customized product.
◯	\
◯	Products maintain standard during the production process. When they are delivered to customers, they can be customized on customer site. By doing so, our company can reduce the costs due to the product customization.
◯	\
◯	Products can be customized at any time, so that the company can offer customized products at the cost effective way.
3	**Can your company guarantee zero downtime or zero failure for products during their services on customer sites?**
◯	Products have downtime or failure during their service, and we can not control them.
◯	\
◯	Products are under periodical monitoring by our company. The downtime can be reduced.
◯	\
◯	Products are under real-time monitoring by our company during their service on clients sites. We guarantee the stable and reliable products and services.

4	**Can the products be real-time monitored on customer sites? (e.g. at plants or in buildings)**
◯	Products can not be monitored after being delivered to customers.
◯	\
◯	Products can be periodically monitored on customer sites.
◯	\
◯	Products are under real-time monitoring by our company during their service on clients sites.

5	**To which degree can your products be recycled (with material level and energy level)?**
◯	Our products can not be recycled.
◯	\
◯	All of the products can be recycled at the material level.
◯	\
◯	Recycling of products is the one of the significant factors we are taking into account for the entire process. Therefore, the products can be recycled both at the material level and energy level.

C.1.8 Process 8 - Organization/Culture

1	**Can your company gain access to the new technology fast?**
◯	Our company does not need to gain access to the new and valuable technology.
◯	\
◯	Our company would use new technologies only if they have been proved effective by other companies.
◯	\
◯	Our company always keep an eye on the latest valuable technology. Comparing to the competitors in the same business field, we gain the access most quickly.

2	**Are your employees able to work in a multidisciplinary team when the project is complex and needs multidisciplinary knowledge?**
◯	They are NOT able to collaborate with staff from the other disciplinary.
◯	\
◯	Employees are willing to collaborate with the others, but there is no mechanism in the company to support them.
◯	\
◯	Employees can collaborate in a multidisciplinary team, which is guided and supported by the specific mechanism in the company.

3	**Can your employees continuously develop themselves in your company in order to meet the future growth from the company? (e.g. IT skills)**
○	Employees only need to finish the jobs assigned to them. No further requirement or support from the company.
○	\
○	Employees want to develop themselves. But no support comes from the company.
○	\
○	Employees are encouraged to develop themselves, and can receive fully support from the company. We believe that developing employees is a conducive investment for both sides.
4	**Does your company have collaboration on Smart Industry together with external partners so that companies can become more competitive in the turbulent business environment?**
○	Smart Industry is still an obscure concept. We haven't found any partners to work together on it.
○	\
○	We understand the Smart Industry. We are waiting a chance to start to implement Smart Industry in our company.
○	\
○	We fully understand the meaning of Smart Industry, and we are aware about the golden opportunities and the challenges it would offer at the same time. We are one of the frontrunner companies to implement Smart Industry.
5	**Do your employees have the awareness of process redesign and innovation?**
○	We don't familiar with the process redesign and innovation.
○	\
○	Half of the employees understand and accept the process redesign and innovation.
○	\
○	Process redesign and innovation is one part of our company culture. Everyone has the awareness of it, and implement it into the practice.
6	**Do your employees have the awareness of sustainability?**
○	Sustainability is not known by the employees.
○	\
○	We are aware of sustainability and half of us can follow this philosophy.
○	\
○	Everyone knows about sustainability. It is one of the most criteria that need to be implemented in the company.

C.2 Improvement of SIMM

- **Process 1 - Question 2**

  'Normal products' is an informal and blurry term. According to the context, the products should be termed as 'the products made by mass production'.

- **Process 5/6 - Question 1**

  The option 5 should be rephrased as 'No onsite delivering needed. With instruction offered by the company, customers can produce the parts and assemble them into a finished product with advanced technology at anywhere.'

- **Process 5/6 - Question 5**

  It is a good question. But the scope is too narrow. Sustainable energy should be utilized not only for the logistics but also for the companies building, the plant and the production process.

- **Process 7 - Question 2**

  Customer Order Decoupling Point (CODP) is a obscure terminology. It is better to rephrase the question, such as 'Can your products be customized only when they have been delivered to the customers?'

- **Process 7 - Question 3**

  'Downtime' usually relates to the machine. It is better to add 'failure' into the question in order to describe the situation when a service doesn't function well.

- **Process 8 - Question 3**

  The question 'Can your employees continuously develop themselves in your company in order to meet the future growth from the company?' is too general. It is better to make an example for the question, such as IT skills.

- **User experience survey**

  The scales should be termed as 'very much agree' and 'very much disagree', instead of 'very agree' and 'very disagree'.

Bibliography

[1] Allan, G. (1999). *Collaborative R and D Manufacturing's New Tool*.

[2] Argoneto, P., Perrone, G. and etc. (2008). *Production Planning in Production Networks*. Springer. ISBN: 978-1-84800-058-2.

[3] Axsater, Sven. (2015). *Inventory Control*. Springer.

[4] Bersin, J. (2004). *The Blended Learning Book: Best Practices, Proven Methodologies, and Lessons Learned*. Pfeiffer.

[5] Birolini, A. (2017). *Reliability Engineering: Theory and Practice (Eighth Edition)*. Springer.

[6] Blessing, L., Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Springer.ISBN 978-1-84882-587-1.

[7] Blessing, L.,(2004). *DRM, a Design Research Methodology*. Technische Universität Berlin.

[8] Chandra, C. and Grabis, J. (2007). *Supply Chain Configuration: Concepts, Solutions, and Applications*. Springer.

[9] CMMI Product Team. (2010). *CMMI® for Acquisition, Version 1.3*. Carnegie Mellon University.

[10] Creps, R., Polzer, H. and etc. (2008). *Systems, Capabilities, Operations, Programs, and Enterprises (SCOPE) Model for Interoperability Assessment*. Network-Centric Operations Industry Consortium (NCOIC).

[11] Drath, R. and Horch, A. (2014). *Industrie 4.0: Hit or Hype*. IEEE industrial electronics magazine (June 2014).

[12] Gibson, I., Rosen, D., and Stucker B. (2009). *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*. Springer. ISBN: 978-1-4939-2113-3.

[13] Gochman, I., and Storfer, P. (2014). *Talent For Tomorrow: Four Secrets for HR Agility in an Uncertain World*. People & Strategy.

[14] Golinska-Dawson, P. and Frank Kubler, F. (2017). *Sustainability in Remanufacturing Operations*. Springer.

[15] Grieves, M. (2016). *Origins of the Digital Twin Concept*. Florida Institute of Technology.

[16] *Guidance on organizational resilience.* (2014). British Standards Institution. ISBN 9780580779497.

[17] Harris, Robert. (1998). *Introduction to Problem Solving*.

[18] Hauschild, S., Licht, T., and Stein, W. (2001). *Creating A Knowledge Culture*. McKinsey & Company.

[19] Hermann, M., Pentek, T., Otto, B. (2015) *Design Principles for Industrie 4.0 Scenarios: A Literature Review*.

[20] Huizinga, G., Bouws, T., van der Beek, H., van der Horst, T. and etc. (2016). *SMART INDUSTRY - Dutch Industry Fit for The Future*. Smart Industry, NL.

[21] Ince, Darrel. (2009). *A Dictionary of the Internet (2 ed.)*. Oxford University Press. eISBN: 9780199571444.

[22] Ingleton, R. (2011). *The digitisation of everything*. Ernst & Young LLP, UK.

[23] Kagermann, H., Wahlster, W., Helbig, J. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*. Industry-Science Research Alliance.

[24] Keinonen, T. and Roope Takala, R. (2006). *Product Concept Design: A Review of the Conceptual Design of Products in Industry*. Springer. ISBN: 978-1-84628-125-9.

[25] Lindemulder, M. (2015). *Development of a Continuous Improvement Maturity Model Assessment Instrument*. University of Twente.

[26] Liou, F.w. (2007). *Rapid Prototyping and Engineering Applications: A Toolbox for Prototype Development*. CRC Press.

[27] Lotz, C., Webb, W. and Collins, P. (2015). *DfX – Design for Excellence*. 29TH AEROSPACE TESTING SEMINAR. L.A., US.

[28] Martin, C. (2013). *Mobile Influence: The New Power of the Consumer*. Palgrave Macmillan, U.S.

[29] Mehrabi, M.G., Ulsoy, A.G., Koren, Y. (2000). *Reconfigurable manufacturing systems: Key to future manufacturing*. Journal of Intelligent Manufacturing, 11/4:403–419.

[30] Michaelides, E. (2012). *Alternative Energy Sources*. Springer.

[31] Minelli, M., Chambers, M. and Dhiraj, A. (2013). *Big Data, Big Analytics*. John Wiley & Sons, Inc.

[32] Morgan, Sally. (2006). *Waste, Recycling and Reuse*. White-Thomson Publishing Ltd.

[33] Mullin, R. and Cummins, J. (2008). *Sales Promotion: How to Create, Implement and Integrate Campaigns that really work*. Koganpage.

[34] Nagtegaal, B., Punter, M., Van der Pol, V., Meijers, K. and de Leeuw, R. (2016) *Smart Industry Action Agenda Standardisation 2016*. Smart Industry, NL.

[35] Neely, Andy. *The Servitization of Manufacturing: An Analysis of Global Trends*. University of Cambridge.

[36] Porter, Michael. (1985). *Competitive Advantage: Creating and Sustaining superior Performance*. The Free Press.

[37] Post, J., Meinders, T., and etc. (2016). *High Tech Systems & Materials - Roadmap Smart Industry*. TNO, NL.

[38] Probst, L., Frideres, L. and etc. (2015). *Service Innovation for Smart Industry: Cyber-physical systems in the value network*. Business Innovation Observatory, EU.

[39] *PWC - 2016 Global Industry 4.0 Survey: Industry4.0: Building the digital enterprise* PwC.

[40] *PWC - Building Enterprise Agility*. (2015). Technology Institute, PwC.

[41] Rackley, Jerry. (2015). *Marketing Analytics Roadmap: Methods, Metrics, and Tools*. Apress.

[42] Reinders, A., Diehl, C.J., Brezet, H. (2013). *The Power of Design*. JohnWiley & Sons Ltd. ISBN 978-1-118-30867-7.

[43] Rohs, Micheal. (2005). *Linking Physical and Virtual Worlds with Visual Markers and Handheld Devices*. Darmstadt University of Technology.

[44] Satpathy, A., Agrawal, A., and Mohapatra, S. (2015). *Innovation Strategy for Enterprises in Emerging Economies*. Emerald Group Publishing limited.

[45] Seufert, Eric Benjamin. (2014). *Freemium Economics: Leveraging Analytics and User Segmentation to Drive Revenue*. Elsevier Inc.

[46] Sigogne, A., Mornas, O., Tonnellier, E., and Garnier, J. (2016). *Co-Engineering: A Key-Lever of Efficiency for Complex and Adaptive Systems, Throughout Their Life Cycle*. Springer.

[47] *The Smart Industry action program of the Netherlands*.(2016). Smart Industry, NL.

[48] Smit, J., Kreutzer, S., Moeller, C., Carlberg, M. (2016). *Industry4.0*. Policy Department A: Economic and Scientific Policy. European Parliament.

[49] Sol, Egbert-Jan. (2016). *A vision for Dutch Industry fit for the future*. Smart Industry, NL.

[50] Sushil and Stohr, E.A. (2014). *The Flexible Enterprise*. Springer.

[51] Theisens., H.C. (2015). *Climbing the Mountain. mindset, skill set and tool set for lean six sigma green & black belts*. LSSA BV.

[52] Tkacz, E., and Kapczynski, A. (2009). *Internet Technical Development and Application*. Springer. ISBN 978-3-642-05018-3.

[53] Voehl, F. and Harrington, H.J. (2014). *The Lean Six Sigma Black Belt Handbook*. CRC Press.

[54] Vongbunyong, S. and Chen, W.H. (2015). *Disassembly Automation*. Springer.

[55] Wendler, R. (2012). *The maturity of maturity model research: A systematic mapping study*. Information and Software Technology 54 (2012) 1317–1339.

[56] Willard, B. (2012). *The New Sustainability Advantage*. New Society Publishers.

[57] Wittig, Cynthia. (2012). *Employees' Reactions to Organizational Change*. OD PRACTITIONER Vol.44.