**MASTER THESIS**

# System dynamics tool to increase the awareness of Smart Industry adoption urgency.


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# Abstract

The fourth industrial revolution is here and can lead to significant benefits for many industries. However, due to several challenges, most organisations are still reservedly regarding the adoption of Smart Industry. One of the main reasons, especially among SMEs, is the lack of awareness of SI urgency. Therefore, this four-phased study created and tested a system dynamics based method to increase this awareness by stimulating double-loop learning. This method illustrates plausible scenarios in the form of causal loop diagrams and allows executives to review their theories by creating a model according to their expectations. Experimental sessions showed that this method can cause knowledge of executives regarding future scenarios for their organisation. Furthermore, it enables executives to estimate and measure the effects of SI and market disruption on essential factors of their organisations and therefore increase their awareness of SI adoption urgency. When specified to a specific industry, this method can help to fasten SI adoption by increasing awareness of its urgency among unaware executives. This research proves that system dynamics-based models can stimulate double-loop learning to achieve knowledge growth. Furthermore, it shows that scenarios, which are mainly used for strategic planning, can also be used to stimulate organisational learning.

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## Preface

In front of you lies my master thesis that I have written for the final phase of my Master of Business administration programme at the University of Twente. The research for this thesis was conducted in co-operation with Boost Smart Industries. In this section, I would like to express my gratitude to the people who supported me during my thesis and made it possible to finish my studies.

First of all, I would like to thank Robin Burghard from Boost Smart industries for giving me the opportunity to conduct my assignment and providing me with useful contacts. When needed, you provided me with useful feedback, and supported me in the preperation several phases of this research. Furthermore, I would like to thank Margriet Bouma from Koninklijke Metaalunie district Oost and Sjoerd Keijser from the FME for their input in several meetings to prepare research phases and for recruiting participants for this research.

Secondly, I would like to thank my supervisors Fons Wijnhoven and Raymond Looohuis for their support during the research design and research, their critical and useful feedback and quick responses when feedback was needed. Even in times of the pandemic, it was still possible to receive answers to urgent questions or to plan last-minute video calls.

Thirdly, I would like to thank my family and my friends for their mental support during my studies.

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# 1. Introduction

## 1.1 Problem Statement

The fourth industrial revolution, also known as Smart Industry (SI), has recently started and has already changed the industry on a significant level. With concepts for smart manufacturing such as the Internet of Things (IoT), cloud computing and 3D printing, it will not only change the industry on a substantial level but will also have a huge impact on society. Especially with increasing threats such as lack of labourers, decreasing market share and outsourcing to low-wage countries, the implementation of SI can be urgent for the manufacturing industry (Kuivanen, 2008). However, the adoption of SI does not go rapid due to several challenges and barriers (Zhou, Liu, & Zhou, 2016).

According to Gumbi and Twinomurinzi (2020), these challenges are even more significant among SMEs due to their high level of heterogeneity and the low amount of research on SI adoption among SMEs. One of the main barriers causing this slow adoption is the lack of awareness regarding SI and its urgency among CEOs (Raj, Dwivedi, Sharma, Lopes de Sousa Jabbour, & Rajak, 2020) (Stentoft, Jensen, Philipsen & Haug, 2019). Zinn and Vogel-Heuser (2019) found that lack of awareness is the most frequently addressed challenge for SI adoption among SMEs.

Several studies address this lack of SI awareness and the importance of it. A recent study regarding SI awareness among professionals stated that only 19.4% claim to have high awareness and 40% has average awareness (Manocha, Sahni & Satija, 2020). However, the majority of the respondents (53%) in this paper also stated that the implementation does increase an organisations overall competitiveness. Sari, Güles and Yiğitol (2020) stated that unawareness is especially present among micro-enterprises and SMEs and that the implementation rate of these organisations is relatively low.

According to Boost Smart Industries, this problem is also existent in the metal industry in the eastern region of the Netherlands. Boost is an organisation that helps the manufacturing industry with the adoption of SI in many ways such as education, financial support and research labs (Boost, 2020 June 8). Even though several methods were applied to promote SI such as webinars/seminars, workshops and vouchers for financial support, the adoption rate is still low, especially among SMEs.

Faran and Wijnhoven (2012) say “unawareness applies when the theory holder does not imagine the very possibility that the theory is false, due to omitted forces”(p. 496).

Meaning that individuals in organisations form theories on misinterpreted cause-effect relationships which could be caused by conservatism or biases. When managers do not have the ability to recognise the urgency of change, we speak of unawareness. To achieve awareness, a critical and reflective view regarding the possible false theory is needed to recognise the necessity to change.

Therefore, tools that increase this level of awareness regarding SI urgency could be of high importance. However, existing literature on methods to increase this awareness is limited. One method that has been created is an awareness game by Mortensen, Nygaard and Madsen (2019) which was proven to be a useful learning approach to increase awareness for SI. However, this method is mainly focused on the implementation and effects of SI and pays less attention to the urgency of SI implementation based on plausible future scenarios.

## 1.2 Research goal

Due to the above-stated problem, this research aimed to create and test a method that can increase awareness of SI adoption urgency among executives of SME metal organisations. To increase this awareness, this method is aimed at knowledge growth regarding SI urgency as defined in the scale of Bohn (1994). In this scale, knowledge is divided into eight stages ranging from complete ignorance to complete knowledge, which is elaborately explained in section 4.1. In order to grow on this scale, a certain form of double-loop learning is required. Double-loop learning is an educational concept that focuses on the deep beliefs of an individual by changing key assumptions of the individual's theory (Wijnhoven, 2001) (Cartwright, 2002). It is mainly focused on reflective learning and aims for continuous change by a high level of evaluating information into knowledge (Matthies & Coners, 2018). Therefore, stimulation of double-loop learning regarding SI adoption urgency is used in this research to increase the awareness of this topic.

The method consists of models with a system dynamics approach including plausible scenarios. Simulation tools with scenarios are known to have a positive effect on organisational learning (Kim, MacDonald & Anderson, 2013). The created method is specified on jobber organisations in the Dutch metal industry. A jobber organisation can be defined as a distributor that is usually specialised in producing one sort of product based on customer specifications. Firstly, the main systems and trends of these type of organisations were identified. Secondly, different scenarios regarding the future and its impact on the organisations were created and discussed by stakeholders of the metal industry such as executives, consultants and representatives from entrepreneur organisations. The acquired data is transformed into a method, which is aimed to allow SME executives in the metal industry to discover what impact plausible scenarios have on their organisation and how SI can be used to ensure these enterprises to stay profitable or even gain competitive advantage. Therefore, the main goal of this research is to test the effect of this method on the awareness of SI urgency to increase SI adoption among SMEs.

In order to create this method and test its effectiveness, the following research question was created:

**Research question**: *To what extent can a system dynamics-based tool with plausible scenarios contribute to awareness development regarding the urgency of Smart Industry adoption?*

## 1.3 Relevance and contribution

Since SI is a relatively new topic, there is still a high need for research and methods to increase the awareness of its urgency (Thoben, Wiesner, & Wuest, 2017). Therefore, this study contributes to the range of methods to increase this awareness and therefore fasten the adoption rate of SI.

*Theoretical contribution*

As mentioned in the problem statement, current literature lacks SI methods to increase the urgency among SME holders, even though several studies address a low awareness level, especially among SMEs (Manocha, Sahni & Satija, 2020) (Sari, Güles & Yiğitol, 2020). Currently, one method has been proven to raise awareness of SI and its implementation but pays less attention to its urgency due to external forces (Mortensen, Nygaard & Madsen, 2019). Therefore, this study contributes by creating a method that raises awareness of SI adoption urgency by increasing knowledge of both SI solution effects as the effect of market trends on the organisation. Secondly, it contributes to the range of studies that focuses on scenario-planning effects other than just strategic planning for which it is used and addressed as in most existing literature (Tiberius, 2019). Thirdly, this study explains how system dynamic based modelling can be used as a method to stimulate double-loop learning among executives.

*Practical contribution*

On a practical level, this research contributes by increasing the awareness of SI adoption urgency of SI for the SME metal industry. This is done by creating and applying a method where SME holders can experience and learn about the effect of SI adoption in different plausible scenarios. Consultancies such as Boost can benefit from this study by using the method in sessions which could lead to the increase of SME holders deciding to adopt SI. Secondly, when this method is proven to be effective, similar methods could be created for different industries as well. However, this requires new scenarios and simulation models specified to these industries. Therefore, this research could lead to an increase in SI adoption of not only the metal industry but other industries as well.

# 2. Literature review Smart Industry

## 2.1 Smart Industry

The first part of the literature creates an understanding of SI. Firstly, SI is introduced, followed by its nine pillars, its effect on performance objectives, the most frequent challenges and a suitable maturity scan that is used for this research.

The current industrial revolution that is described in this paper as SI, is also known as Industry 4.0 (German Terminology) or Smart Manufacturing (American Terminology). SI will be the fourth major revolution with its predecessors being; mechanisation (1784), mass production (1870) and automation (1969) (Speringer & Schnelzer, 2019). Every single one of these revolutions has had a major impact on the industry. Building on these previous revolutions, SI is expected to have a similar impact. It was first announced as the fourth industrial revolution in 2011 in Hannover for promotion reasons by German government institutions. German scientists introduced 'Industrie 4.0' as the new revolution that would change business models by both cyber-physical systems and the internet of things (Drath & Horch, 2014).

According to Monostori, Kádár, Bauernhansl and Kondoh (2016), the three principles of SI are intelligence, connectedness and responsiveness. Intelligence is defined as the ability to learn and improve from generated data autonomously. Connectedness includes the ability to be connected with all elements within the factory and the internet to co-operate and share knowledge. Responsiveness refers to the ability to adapt to changes, both internal as external (Monostori, Kádár, Bauernhansl & Kondoh, 2016). Several years after it was announced, the first organisations started with the adoption. Even though the industry is moving into this new revolution, researchers state it will still take a significant number of years for it to be fully realised due to its slow adoption and the challenges that come with it (Zhou, Liu, & Zhou, 2016).

## 2.2 Nine pillars of Industry 4.0

To distinct the technologies of SI, the nine pillars of Industry 4.0 is used in this study (Erboz, 2017). However, several researchers claim that these nine pillars are not evenly adoptable and relevant for the SME-manufacturing industry (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018) Therefore, existing literature has been consulted to research the relevance for SMEs of each of the nine pillars.

*Autonomous robots*

Robotic machines are already in use in the manufacturing industry for several years. However, due to the innovations of SI, robots are able to work significantly more autonomously, flexibly and cooperatively (Rüßmann, et al., 2015). Due to the use of sensors, control panels and interconnectivity between machines, robots are able to operate more flexibly and precisely than humans (Vaidya, Ambad, & Bhosle, 2018). However, the use of autonomous robots is the only one of the nine pillars that was not addressed in any of the selected papers on SI among SMEs. Moeuf, Pellerin, Lamouri, Tamayo-Giraldo and Barbaray (2018) also addressed the absence of existing cases of autonomous robots implemented in SMEs, which could be a result of high implementation costs.

*Big data*

Big data can be identified as large datasets that are coming from different technologies. Haseeb, Hussain, Ślusarczyk, & Jermsittiparsert (2018) say: "Big Data is a collection of data from traditional and digital sources inside and outside your company that represents a source for ongoing discovery and analysis" (p. 6). They also state that it can be categorised by volume, variety and velocity. Due to the size, it takes extensive measures to handle these large datasets (Haseeb, Hussain, Ślusarczyk, & Jermsittiparsert, 2019).

How to manage large datasets and how to gain an advantage of this data has been a challenge for every organisation that is implementing SI technologies (Oliff & Liu, 2017). Despite possible benefits of Big Data, the inability to process and handle it with current techniques and technologies makes it unable to fully achieve these benefits (Anagnostopoulos, Zeadally & Exposito, 2016).

*Simulation*

Simulation in the context of SI refers to the simulation of production processes, products, production systems, value chains and markets. By using this technique, processes can be simulated and their performances can be tested before implementation. This leads to cost reduction, shortening of production processes, increase in knowledge and the improvement of product quality. (Müller & Voigt, 2018). According to Rodič (2017), simulation modelling is a concept that dates from the 1940s with the introduction of the first computer and software for this technique. Since the third industrial revolution (digitization), it has evolved at a rapid pace and the innovations that come with SI result in many possibilities as well as challenges for simulation modelling. However, Rodič (2017) states that there are specific solutions to integrate these techniques without major financial investments, which is especially attractive for SMEs since the financial aspect is one of the major challenges for this industry.

*Cloud computing*

As mentioned before, the technologies that come with SI generate a significant amount of large datasets. Cloud computing is a technique that can be used to store, share and process these datasets. With the new SI technologies regarding cloud computing, SMEs can i.e., expand the maximum capacity and provide large facilities without IT infrastructure which reduces the costs significantly (Paul & Ghose, 2012) (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018).

Moeuf et al. (2018) identify five purposes where cloud computing is used by SME manufacturing companies: sharing documents, servitization, collaboration, distributed production and resource optimisation. Their research paper on the use of SI concepts in SMEs also showed that 65% of the researched cases had implemented cloud computing, which made it the most used pillar.

*Cybersecurity*

The fourth industrial revolution comes with several challenges and risks. One major risk is that of cybersecurity. The increasing amount of data and digital systems such as artificial intelligence also creates possibilities for cybercriminals (Birkel, Veile, Müller, Hartmann, & Voigt, 2019). Especially data breaches, system breaches and information theft are among the concerns of organisations. These concerns are not limited to an organisation's own data. Since SI enables several organisations in the supply chain to be connected, i.e. by the use of cloud computing, also connected organisations are at risk (Müller, Buliga & Voigt, 2018). Birkel, Veile, Müller, Hartmann and Voigt (2019) state that several solutions can be used to minimise these risks such as the use of white hat hackers, honeypots and security infrastructures and policies. However, the number of experts on these topics is limited.

*Internet of things*

The internet of things (IoT) is one of the main technologies for SI (Müller, 2019). IoT is a combination of RFID, cloud computing, middleware and other software applications that enables objects, products and humans to be interconnected (Müller, Buliga & Voigt, 2018). Especially with the rise of 5G, the use of IoT is expected to increase massively due to increased bandwidth which allows more data to be transferred (Li, Xu, & Zhao, 2018). With these technologies, organisations are provided with significantly more data and knowledge which leads to numerous advantages. The case studies that were analysed by Moeuf et al. showed that IoT is used by SMEs to i.e. measure and validate the system, ensuring the reliability of data, recover data from production machines and improving automation and flexibility within an organisation. The research on the effect of IoT on SMEs by Müller (2019) showed that it also has a positive effect on the implementation of other SI technologies. He states that the introduction of IoT might, therefore, be crucial for SMEs to increase the adoption of SI.

*Augmented reality*

Augmented reality is a technology that links virtual reality with reality. By sensors, a display and augmented reality software it can integrate virtual graphics into the user's view of real surroundings (Paelke, 2014). Mainly due to the increase in mobile devices, the use of augmented reality in software has significantly increased over the last couple of years. Besides commercial use of augmented reality, it also creates many possibilities for organisations. Especially for the manufacturing industry, it can lead to advantages such as identifying errors, reduction of prototypes and cost and time reduction (Horváth & Szabó, 2019). Moeuf et al. (2018) reviewed a case study where augmented reality was implemented in combination with IoT and cloud computing in an SME manufacturing company. The data that was generated and managed by IoT and Cloud computing, enabled information for disturbing events to be displayed through smart glasses which made the organisation significantly more reactive (Moeuf et al, 2018).

*Additive Manufacturing*

One aspect of SI that is not been used frequently in the consulted case studies is the use of additive manufacturing. A literature review that researched several papers on additive manufacturing use states that additive manufacturing or 3d-printing can be defined as a set of different technologies, which all work according to the same principle: based on a digital blueprint, materials are joined to form 3D objects (Ortt, 2016) (p. 890). It also states that it is currently being used in several industries. However, it is more used as an addition to traditional manufacturing than a substitute. Rodič (2017) states that organisations can use this type of manufacturing to make small amounts of products at the same costs of mass production. Which significantly improves the flexibility of manufacturing organisations.

*System integration*

System integration is the interconnection of all systems that are used by an organisation. The literature distinguished two types of system integration, vertical and horizontal. Vertical is the interconnection of all system within an organisation, whereas horizontal system integration connects the systems of all organisations in a certain supply chain (Haseeb, Hussain, Ślusarczyk, & Jermsittiparsert, 2019). Even though these technologies create significant potential advantages, it is also very complex to be implemented (Birkel, Veile, Müller, Hartmann, & Voigt, 2019). Birkel et al. (2019) state that this technology comes with challenges for SMEs because they lack the necessary technology available to collect the data necessary for horizontal and vertical integration. Moeuf et al. (2018) addressed two cases of SMEs that have implemented vertical integration, however, none of the cases in this paper showed horizontal integration among SMEs.

## 2.3 Performance objectives

To create insight into the effects of SI adoption, this research uses the big five operational management objectives by Neely (2007). Neely (2007) distinguishes five performance objectives for productivity and competitiveness:

1. Quality
2. Dependability
3. Speed
4. Flexibility
5. Cost

Neely (2007) states that these performance objectives are highly interconnected. This means that the improvement or decline of one performance objective can lead to another performance objective experiencing the same effect. The selected literature is analysed to identify to what extent these five performance objectives connect with the SI constructs. Each objective is briefly explained according to the theory of Neely (2007), followed by the findings regarding this objective. Also, the importance of the objectives for SMEs in the current industrial revolution is explained, together with the technologies for improving these objectives.

*Quality*

Quality management and improvement is a business objective that is integrated into almost every manufacturing organisation. Different measurement models and methodologies are created and used to control an organisations quality (Neely, 2007). The first of these methodologies of measuring quality was mainly focused on the output of the company. However, over the years more methods have been created on the operations and processes of the organisation. Therefore, this paper will focus on the effect of SI on quality improvement on both products as process quality.

One of the aspects of SI that affects quality control and improvement is the use of data (Oliff & Liu, 2017). With the solutions of SI, organisations can generate and process a significantly larger amount of data. This data can be used to detect bottlenecks in processes and improve product quality. Moeuf et al. (2018) also addressed the use of archived data to improve product quality. The same paper addressed that the use of RFID technology on parts can control the quality of production processes.

*Flexibility*

The definition and interpretation of flexibility as a performance objective causes a high level of debate (Neely, 2007). Slack (1987) stated that it includes the range and response of an organisation. Range asks the question to what extent the manufacturing organisation can adapt to change and response tells at what cost and how fast the organisation can change. Mainly because the current industry is fluctuating rapidly, flexibility is one of the most addressed performance objectives when it comes to SI. (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). Especially with mass customization and large fluctuations in customers' demands, organisations have to be able to produce these changing amount of individualised products (Goerzig & Bauernhansl, 2018). The large increase in generated data enables organisations to have more insight into their production processes. An example is to make use of advanced algorithms aimed at production planning that makes use of real time-data (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). This enables the production rate to be adjusted to the demand as much as possible.

*Cost reduction*

The third performance objective is the reduction of costs. Neely, Gregory and Platts (2005) state that, similar to flexibility, the measurement and definition of costs have been subject of debate by several researchers. According to Swain (2000), costs can be measured by the sum of all the activities that are necessary to produce and deliver the product of a certain organisation. Bain (1982), on the other hand, states that costs should be measured by the productivity of an organisation. Productivity can be defined as the ratio of output and input. A third measurement is the ROI of a company, which calculates the return on investment. Even though all these measurement methods are still widely used, each of them has its limitations.

In the reviewed literature, cost reduction is, together with flexibility, the most addressed performance objective. One example is the use of digital real-time production planning and process transparency, which can lead to the reduction of storage times and logistics cost (Müller & Voigt, 2018) (Birkel, Veile, Müller, Hartmann, & Voigt, 2019). Other technologies such as 3D printing and process simulation allow organisations to improve their processes with significantly reduced costs (Rodič, 2017). Due to the financial shortage compared to larger companies, the cost reduction or return on investment is of high importance for SMEs (Goerzig & Bauernhansl, 2018).

*Speed*

The performance objective 'speed' is also often referred to as 'time' (Neely, Gregory and Platts, 2005). This objective not only refers to the amount of time that is between the actual quoting of the product by the customer until the delivery of the product but also to the time of development of new products. Neely (2007) states that by shortening i.e. delivery time, production time or development time, organisations capable of responding to customer requests more quickly.

As mentioned in the explanation of cost reduction, one effect of SI technologies that is addressed by several papers is the shortening of delivery times by the use of process transparency and real-time production planning (Müller & Voigt, 2018) (Birkel, Veile, Müller, Hartmann, & Voigt, 2019). Another example is the use of IoT to detect possible bottlenecks in production processes that lead to time waste (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). With a better overview of the processes, improvements can be made more rapidly to shorten production time. Especially with the fluctuations in costumers demand, shorter production and delivery times might be a challenge for the manufacturing industry (Goerzig & Bauernhansl, 2018)

*Dependability*

Neely (2007) refers to dependability as the ability to meet promises made to customers and other organisations within the supply chain. This includes the ability to keep to the schedule plan, delivery performance and the price-performance. Same as speed, one main aim of dependability is to pursue the Just in Time approach (JiT) (Neely, 2007). JiT can best be defined as the ability to deliver what is demanded when the customer needs it so that it will not be produced too early or late which is assumed as waste.

In the reviewed papers, a few examples of technologies that improve the dependability have been addressed. Again, the use of real-time production planning helps to improve this objective since the goal of this technology is to only produce what is necessary to lower storage time (Müller & Voigt, 2018). The fact that these technologies are stated to improve several performance objectives highlights the interconnectivity of these objectives. Another example is that the use of autonomous robotics, which are known to work more precisely than humans, will ensure the quality and price performance of the products (Vaidya, Ambad, & Bhosle, 2018). However, as stated before, the use of autonomous robots has not been addressed in the papers focused on SMEs, mainly due to high implementation costs.

## 2.4 Challenges of Smart Industry

As stated in the problem statement, even though SI can result in significant advantages for organisations, its adoption comes with several barriers and challenges. These challenges result in SI not being (fully) adopted. Several studies in various countries and industries have been conducted to identify challenges that organisations face during all phases of the adoption process (Horváth & Szabó, 2019) (Orzes, Rauch, Bednar & Poklembam, 2019) (Raj, Dwivedi, Sharma, Lopes de Sousa Jabbour, & Rajak, 2020). These challenges differ significantly per industry, size and country of the organisation (Horváth & Szabó, 2019). Orzes, Rauch, Bednar and Poklembam (2019) conducted a literature review to identify the most adressed barriers in the existing literature. To create an understanding of these barriers, the four that are most frequently addressed are elaborated on:

*Lack of knowledge and standards regarding SI*

On both a managerial level as an organisational level, sufficient knowledge regarding SI and its urgency are necessary for SI adoption. Several studies show that organisations lack an understanding regarding SI, its adoption and its urgency which causes these organisations to be reservedly towards adoption (Raj, Dwivedi, Sharma, Lopes de Sousa Jabbour, & Rajak, 2020). A recent study focused on challenges for SMEs showed that lack of knowledge is most frequently addressed. It is shown that the existence of adoption guides, especially based on real cases, increases technology adoption due to better understanding and certainty of benefits (Zinn & Vogel-Heuser 2019). However, there is a significant lack of these standards for most industries.

*Financial barriers*

To adopt SI into an organisation, high amounts of investments are necessary for it to be fully operational. The investment expenses of an organisation are estimated to increase by 50% for approximately 5 years to integrate SI (Raj, Dwivedi, Sharma, Lopes de Sousa Jabbour, & Rajak, 2020). Since most organisations do not receive short-term returns after SI adoption, high investment costs form a significant barrier (Orzes, Rauch, Bednar & Poklembam, 2019). Even though SI can lead to significant financial benefits in the long term, uncertainty and lack of knowledge regarding the return on investment cause many organisations to be hesitant about the success of SI solutions. This barrier seems to be more present among SMEs compared to larger enterprises since SMEs usually possess less (Goerzig & Bauernhansl, 2018).

*Security risks*

As mentioned in the section regarding cyber-security, one of the main challenges is the number of risks that come with the new industrial revolution. Especially the increasing amount of data, decentralization and interconnectivity increase the possibility for data breaches. While some studies show that especially SMEs show concerns regarding data security (Sommer, 2015), others state that it is a concept that is rarely discussed in case studies regarding SI among SMEs (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). This could be explained by the fact that the first study focuses on SMEs that have not yet adopted SI, while the study by Moeuf et al. (2018) researched cases where SI was already adopted.

*Lack of technical resources*

To make the SI solutions operative, an organisation needs employees with high expertise regarding the technologies and solutions. Many SMEs state they do not have the required personnel and need to attract new personnel or train current employees (Horváth & Szabó, 2019). However, there is a lack of highly skilled personnel and educating employees requires high costs and acceptance of the employees. Secondly, implementing and synchronizing certain technologies with existing production systems comes with several risks and costs. Therefore, technical resources such as existing systems can result in significant challenges (Müller, Kiel & Voigt, 2017).

## 2.5 Smart Industry Maturity

To determine the degree to which an organisation has adopted SI and its readiness to increase this so-called degree of maturity, several studies have created maturity and readiness theories. These theories are mainly assessment tools to test different factors of an organisation regarding its maturity (Mittal, Khan, Romero & Wuest, 2018). For both the workshop as the testing sessions, one suitable maturity scan is needed to select the right participants. For the selection of this maturity scan, two requirements were set beforehand. Since this research focuses on SI adoption specifically for SMEs, the first requirement is that the maturity assessment can be applied to SMEs. The second requirement is that the assessment tool makes use of enough detailed dimensions. Due to the qualitative nature and sample size of this research, using a maturity scan that only divides three dimensions might not give a detailed enough view to compare the organisations.

Available maturity scans have been reviewed from an SME perspective by Mittal et al. (2018). This review highlights the strengths and gaps of 15 maturity theories. One gap in 9 of the theories is the lack of applicability for SMEs. However, the remaining theories either miss an assessment tool or are divided into too few dimensions. Therefore, the two most suitable scans are the maturity scan by Schumacher, Erol, and Sihn, (2016) and the Industrie 4.0 Readiness check by Lichtblau et al. (2015). Mittal et al. (2018) state that both scans contain items that do not meet the SME requirements mainly due to lack of financial resources which result in SMEs scoring relatively low. However, it can still be used for comparison between only SMEs or, when necessary, irrelevant items can be removed from the scans. The major difference between both scans is that Lichtblau et al. (2015) also provide an overall score, where Schumacher, Erol, and Sihn, (2016) only score the dimensions individually and use a method that does not allow to calculate an overall score. Therefore, this research uses the Industrie 4.0 Readiness check which is divided into organisational structure, smart factory, smart operation, smart products, data-driven security and employees. These dimensions are provided with maturity items which are used to score the dimensions from 0 (lowest) to 5 (highest) (Lichtblau et al. 2015).

# 3. Literature review simulation and scenarios

## 3.1 Scenario planning

Businesses and industries can face several harmful unexpected events. One method to predict and prepare for these plausible is scenario planning. Scenario planning has been used since the 1950s and increasingly applied by numerous organisations over the years to anticipate its environment in possible futures (Amer, Daim & Jetter, 2013). It is a tool where certain methodologies are used to create plausible scenarios so that suitable strategies can be created. These scenarios can be described as ‘‘a set of hypothetical events or values set in the future constructed to clarify a possible chain of causal events as well as their decision points” (p. 24) (Amer, Daim & Jetter, 2013). Scenario planning is a tool that stimulates double-loop learning due to its exploratory nature and causes significant changes in a company’s strategy (Worthington, Collins & Hitt, 2009). As stated before, double-loop organisational learning is necessary for innovation and therefore for SI implementation.

To create these scenarios, several qualitative methodologies have been created. The three most used qualitative methodologies for scenario planning are Intuitive Logics, Probabilistic Modified Trends (PMT) and the French Approach (Amer, Daim & Jetter, 2013). The Intuitive Logics method is the most used and creates 2-4 scenarios based on input from stakeholders (Wright, Bradfield & Cairns 2013). This method does not only try to create scenarios but also aims to create an understanding of situations and is therefore the best scenario planning methodology used for organisational learning. There are several versions of the intuitive logics method ranging from five to fifteen steps, with the most used version containing eight steps.

The PMT method uses interviews and computer analysis tools to create matrix-based scenarios. It combines traditional forecasting with cross impact analyses by identifying interrelationships between key factors. This method is usually executed by external teams that use simulation software to create 3-6 scenarios. The French method uses four essential concepts for scenarios: the base, the external context, the progression and the images. Firstly, the base is studied by an analysis and scan of the present situation. Secondly, the external context is created by studying the environment of the system. Thirdly, the progression is created by a historical simulation based on a combination of the base and the external context. Finally, an image is created for future events based on this simulation. This method is mainly used in public sectors (Amer, Daim & Jetter, 2013).

The PMT method and the French Method are both more outcome-focused and exist of one-time activities, which makes them less suitable for double-loop organisational learning. Furthermore, due to the organisational learning approach of this research and the absence/unavailability of data since SI is still a new concept, this research uses the Intuitive Logics method.

## 3.2 Simulation with a System Dynamics approach

Simulations are used by many organisations to address both operational as policy-related issues (Qudrat-Ullah, 2012). It allows organisations to run experiments and test different scenarios. Evaluation and decision making through simulation have gained popularity due to several benefits such as: presentation of real-life situations, learning process of modelling and interaction, creation of interactive models and simulation of potential future scenarios (Suryani, Hendrawan, Adipraja & Indraswari, 2020).

For the creation of the simulation model, a system dynamics approach is used. System dynamics is considered an effective method to stimulate double-loop learning by allowing managers not only to find out what is changing but why also changes are occurring (Kim, MacDonald & Anderson, 2013). This makes it possible to analyse the impact of internal and external factors on objectives defined in this system (Tan, Jiao, Shuai & Shen, 2018). This technique is used for evaluation in decision-making processes, by creating a better understanding of a system. There are two model types used in system dynamics: Causal Loop Diagrams (CLD) and Stock and Flow Diagrams.

Causal loop diagrams are the foundation of systems thinking (Hirsch, Levine, & Miller, 2007. Loops are drawn between variables in the model that have a causal relationship. The effects of these relationships are either positive (+) or negative (-) and the direction is indicated with an arrow. Two types of loops can be identified in CLDs: balancing loops and reinforcing loops. When change in a certain direction occurs in a balancing loop, this change is countered by change in the opposite direction, which keeps the system at its status quo (Hirsch, Levine, & Miller, 2007). Reinforcing loops, on the other hand, either result in growth or decrease when change in a certain relationship occurs. Causal loop diagrams are often argued to be advantageous in the practice of SD due to their lack of quantitative representation. However, other researchers state that it can be developed with fewer resources and creates insights into systems in a manner that is understandable for those who have less experience in SD (Dangerfield, 2014).

A stock and flow diagram is a more calculative model that depends on high amounts of data. The stocks are variables such as: produced goods, number of employees and cumulative sales. These stocks are influenced by flows of information which are represented by an arrow. Stocks are increased by ingoing flows and drained by outgoing flows. Also, more explanatory variables (auxiliaries) and parameters can be added to the model which increases its level of sophistication (Dangerfield, 2014). Due to the use of equations and computer simulation, stock and flow diagrams can give more quantitative insight into the system and additionally point out certain time delays in stock change. Therefore, several researchers state that stock and flow diagrams are an essential part of system dynamics (Hirsch, Levine, & Miller, 2007).

# 4. Awareness

As explained in the problem statement, unawareness occurs when an individual lacks the ability to recognise the necessity to change the theories he or she holds. To recognise and realise necessary innovation, a critical and reflective view on the existing theories is needed become more aware (Faran & Wijnhoven, 2012). This critical and reflective style of learning to realise innovation can be defined as double-loop learning. This research uses double loop-learning to increase the knowledge stage of the individual to become more aware of SI adoption urgency. Therefore, this section firstly explains the knowledge growth scale by Bohn, followed by an elaboration of single and double-loop learning.

## 4.1 Knowledge scale by Bohn

As stated before, the knowledge growth due to double-loop learning can be measured with the Knowledge scale of Bohn (1994). This knowledge scale is created to measure technical knowledge regarding processes in an organisation. Bohn defines technical knowledge as understanding the effects of input effects on the output. Bohn divides knowledge into eight stages varying from complete ignorance to complete knowledge (figure 1). In the methodology section of this research, it is explained how this scale is adapted to measure SI adoption urgency.

Stage one ‘complete ignorance’ means that an individual is not aware of the existence of a certain phenomenon, or its relevance to certain processes in the individual’s organisation. Stage two ‘awareness’ means an individual is aware of the phenomenon and its relevance but is still unaware of how to use relevant variables. This stage is often achieved due to serendipity or knowledge brought in from outside of the organisation. However, even though the individual is aware of certain effect, it is still not able to measure them.

Individuals on stage 3 ‘measure’ are able to measure the effect of certain variables with specific instrumentation. The variables can still not be controlled but Bohn (1994) states that the existing process can be changed to respond to these effects. On stage four ‘control’, an individual can control variables causing an effect in a process. However, this control is only over a few levels without the desired precision. In stage five ‘process capability’, a more precise level of control is reached. This level can be reached by gaining knowledge regarding the correct level of an input variable. When all important variables in a process reach this level, the desired output can be consistently be created.

In stage six ‘process characterization’, the individual can finetune the process to reduce costs and improve quality of the effects. This can be achieved by running experiments and testing different levels of effects on the process. The seventh stage ‘know how’ requires the individual to know how the process works and how certain variables interact with other variables. This can be achieved by simulating the processes and experimenting to gain other outcomes that have not been achieved before. In this stage, the precise interaction effects and connection between variables is known to reach the desired output. When stage eight is reached, ‘complete knowledge’ regarding the process are achieved in order to determine the result. The environment and the process are known to a level that all problems can be reacted to in advance. However, Bohn (1994) that this level can almost never be practically reached.

| Stage | Name | Comment | Typical Form of Knowledge |
|---|---|---|---|
| 1 | Complete ignorance | | Nowhere |
| 2 | Awareness | Pure art | Tacit |
| 3 | Measure | Pretechnological | Written |
| 4 | Control of the mean | Scientific method feasible | Written and embodied in hardware |
| 5 | Process capability | Local recipe | Hardware and operating manual |
| 6 | Process characterization | Tradeoffs to reduce costs | Empirical equations (numerical) |
| 7 | Know why | Science | Scientific formulas and algorithms |
| 8 | Complete knowledge | Nirvana | |

Figure 1: Stages of knowledge (Bohn, 1994)

## 4.2 Organisational learning styles

In the increasingly complex environments that many organisations operate in, expanding knowledge through organisational learning can be essential. However, several studies showed that it is mainly the capability of learning and not the knowledge itself that determines effectiveness (Wijnhoven, 2001). Two styles of organisational learning can be distinguished, single-loop learning (SLL) which is used for error fixing, and double-loop learning (DLL) which is necessary for innovation (Matthies & Coners, 2018). Single-loop learning focuses on responding to problems based on existing theories. When an individual makes decisions based on alternatives within his own mental theories, we speak of single-loop learning. Moreover, it requires learning to detect and correct problems by reusing existing knowledge. However, in order to counteract unknown problems, a more innovative and creative learning style is required.

DLL is an organisational learning style to counteract unknown problems, which requires innovation and creativity. It mainly focuses on reflective learning and aims for continuous change by a high level of evaluating information into knowledge (Matthies & Coners, 2018). Especially when environments are highly complex and dynamic, a high level of DLL may be required due to the high number of variation in factors that are continuously changing. DLL learning often also requires existing knowledge to be unlearnt in order to innovate, which conflicts with SLL since it relies on retaining and reusing existing knowledge (Wijnhoven, 2001). Therefore, formal rules but also enough flexibility needs to exist within an organisation to combine the two learning styles.

# 5. Methodology

As stated in the research goal, the aim of this study is to create and test a method aimed to increase the awareness of SI adoption urgency. This method consists of system dynamics-based models that represent Dutch metal jobber organisations and illustrate different plausible scenarios for the future. Therefore, this research consists of four phases as shown in table 1, together with their results and how these results are used in the following phases. Firstly, an understanding of essential processes and systems of Dutch metal organisations and trends in this industry is created by conducting a case study and consulting additional literature on systems of manufacturing organisations. The findings of this phase were discussed with stakeholders to determine the driving factors for the scenario planning workshop in the second phase. In these meetings, the set-up for the workshop is also determined. Followingly, this workshop is held with professionals to create plausible scenarios regarding the future of the metal industry and the effects of SI adoption. In the third phase, the findings of the first two phases were used to create system dynamics models that illustrates the scenarios created in phase two. These models were discussed with stakeholders and, followingly, the method wherefore these models are used was created. In this last phase, the effect of the created system dynamics tool on the awareness of SI urgency of SME holders was tested in experimental sessions.

| Phase | Method | Results |
|---|---|---|
| **1: Exploratory case study** | Interview and visit at a jobber organisation to gain insights into the systems, trends and SI solutions. | Insight into suitable SI solutions and market disruptive trends for this industry. This is used to determine the driving factors for the scenarios in phase 2.<br>Insight into essential organisational factors influenced by SI solutions and market disruptive trends. These are used for the creation of the system dynamics model in phase 3. |
| **2: Scenario Planning workshop** | Scenario planning workshop with 6 stakeholders of the Dutch metal industry. | Four plausible scenarios for the Dutch metal industry. These are implemented in the system dynamics models for the method which are created in phase 3. |
| **3: Model and Method Creation** | Creation of system dynamics models based on the findings of the first two phases and creation of the tool in co-operation with stakeholders. | System dynamics-based tool to increase the awareness of SI adoption urgency, this method is tested in phase 4. |
| **4: Experimental Sessions** | Online testing sessions with 6 executives or employees responsible for innovation and one consultant for the metal industry to test the effect of the method created in phase 3. | Results on the effect of the created method on the awareness of SI adoption urgency. |

Table 1: Research design

## 5.1 Exploratory case study

In order to create the desired method, firstly, scenarios and a system dynamics-based model needed to be created. However, before the scenarios could be formed, more insight in the market disruptive trends and possible SI solutions for this specific industry was needed. Furthermore, the essential aspects that are influenced by these factors needed to be identified as well in order to create the models. Therefore, an exploratory case study was conducted which exists of a semi-structured interview (appendix 1) and a tour through the organisation and is aimed at four main topics: production processes, supply chain, employees, and innovation. This study focused to create an understanding of these topics, how these are affected by SI and how these can be represented in a system dynamics model. Also, this case study identified market trends that affect the organisation and how the CEO expects these market trends to develop. In this first phase, also additional literature on system dynamics models for manufacturing organisations was conducted to create a concept version of the model that is used for the method.

## 5.2 Scenario planning workshop

In the second phase, a scenario planning workshop is conducted. A workshop is "an arrangement whereby a group of people learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-specific issue" (Ørngreen & Levinsen, 2017) (p. 71). The set-up for this workshop and the driving factors for the scenarios were determined in meetings with stakeholders from Boost and the FME. In these two meetings, the findings of phase one were discussed in order to create a framework for the workshop, which is further elaborated in chapter 7. This workshop included five participants existing of two executives from organisations with a high maturity level, one participant from Boost, one participant from the Koninklijke Metaalunie, and one participant from the FME. The Koninklijke Metaalunie (Metaalunie, 2020 June 20) is a Dutch organisation that serves and helps SME companies in the metal industry with many services such as business support, organising meetings, and insurances. The FME is a Dutch employers' organisation that serves and helps companies in the technological sector (FME, 2021).

The executives are included due to their specific experience in the effect that SI adoption and the market can have on their organisation. Participants from Boost, Koninklijke Metaalunie and FME are included for their broader level of experience in SI implementation and the industry. Including participants from different points of view on the industry resulted in more complete scenarios. This workshop was facilitated by paying attention to the group process and drawing the information from the group (Richardson & Anderson, 1995). The participants provided information and experiences necessary for the creation of the scenarios.

In this 3-4 long hour workshop, four scenarios for the next 5 years were developed by identifying both external factors that can impact SME metal organisations as internal factors such as the effects of SI adoption. The participants were provided with information regarding scenario planning and system dynamics beforehand together with a schedule for the workshop. The participants were also instructed that all results and recordings would be anonymised. Before the workshop started, a short introduction was given. The eight basic steps of Intuitive Logics served as a guideline for the workshop structure (Wright, Bradfield & Cairns 2013) (Derbyshire, & Giovannetti, 2017):

1. Defining the issue
2. Identifying driving forces
3. Clustering the forces
4. Defining clusters
5. Impact matrix
6. **Framing extreme outcomes into scenarios**
7. **Scoping scenarios**
8. **Developing scenarios**

In preliminary sessions with stakeholders from Boost and the FME, the driving factors for the scenarios were already determined so that only step 6 to 8 of the IL method are performed in the workshop (Wright, Bradfield & Cairns, 2013). This ensured that the scenarios are as specific and deeply executed as possible within the available time. The scenario planning workshop was conducted in Miro, which is an online platform that allows groups to work together to co-create models and whiteboards (Miro, 2020). This platform also allows video calling, presentations and screen-sharing which made it suitable for this workshop.

## 5.3 Creating the simulation method

In the third phase, a method with system dynamics models representing the four scenarios is created based on the results of the first two phases. This method aims to increase participants awareness regarding SI adoption urgency by increasing their knowledge according to the knowledge scale of Bohn. More specifically, the method aims to increase knowledge regarding SI effects and market disruption effects in plausible future scenarios.

For the simulation tool, firstly a Stock and Flow diagram was created. The model was created with Insight Maker which is a free online modelling and simulation tool. After the concept was created, it was discussed modified in co-operation with stakeholders from FME and the Koninklijke Metaalunie in online sessions . These sessions resulted that the model needed simplification and was, therefore, abridged and converted into a Causal Loop diagram.

The four scenarios were implemented into the Causal Loop diagram, to visualise what impact the different scenarios can have on the organisations. This visualises the possible urgency of SI adoption in different scenarios for the organisations to stay profitable. The method was tested with stakeholders from Boost, FME and the Koninklijke Metaalunie and prepared for its usage in the last phase. Also, before the intervention sessions with executives, the method was first tested with students to assure that the model is understandable and can be used for participants who are unfamiliar and inexperienced with Insight Maker and system dynamics-based tools in general. According to the received feedback, adjustments were made to the simulation tool.

## 5.4 Simulation method sessions

**Participants and data collection**

After the simulation method was created, it was tested in individual sessions to test its effect. The selection criteria for the sample group were 1) CEO or employee responsible for innovation, 2) from an SME jobber organisation in the Dutch metal industry, 3) with an Industrie 4.0 Maturity of 0 or 1, as defined in section 2.5. The interventions were conducted with seven participants: 5 CEOs from organisations in the metal industry, one employee responsible for innovation and an advisor of PKM. PKM Advies Metaal is a consultancy that advices, trains and coaches organisations in the metal industry to improve their business operations (PKM Advies Metaal, 2021). All the participants were recruited by the Koninklijke Metaal Unie and PKM (Metaalunie, 2020) (PKM Advies Metaal, 2021). 8-10 participants was set as the desirable number of participants. Therefore, 28 organisations have been approached to participate from which 8 prospective participants from 7 organisations responded with their will to participate. However, since one of the prospective participants cancelled, the experimental sessions were conducted with 7 participants from 6 organisations. The participants were instructed that all results of the sessions will be anonymised and recorded when approved by the participant.

The interventions were analysed through observation, a pre and post-test and an afterwards evaluation. The observation was mainly focused on the findings and conclusions drawn by the participants while creating their individual model in the form of a scenario. At the end of the intervention, the observed conclusions were summarised by the moderator to confirm if these were interpreted correctly. This increases the confirmability of the results. Followingly, the pre and post-test was used to determine if the conclusions drawn have resulted in a change of SI importance perception of market disruption barrier perception. When the conclusions drawn during the intervention did not cause a change in the pre and post-test, it is possible that the participant was already aware of these conclusions. The pre and post-test contained questions that measure the participants view regarding the following topics, which were determined with stakeholders from Boost and the Metaalunie:

- Smart Industry technologies importance
- Trends that cause market disruption and their effects
- Development of these trends in the following 5 years
- Importance of Smart Industry technologies in five years considering these trends
- Willingness to innovate

These topics include the same SI solutions and market trends as were included in the scenarios. The first four topics were chosen to measure the change in perception of effects of both SI solutions as market disruptive trends, now and in 5 years. The last topic was chosen to measure if an increase in knowledge also resulted in a change of willingness to innovate in SI.

The questions on the tests are scored with a 5 point Likert scale ranging from totally not agree to totally agree. This pre-test was sent approximately a week prior to the intervention and the post-test was sent after the intervention again after the sessions. The pre-test came with information regarding the research and the sessions, and a SI maturity scan. This scan determined the SI maturity level of the participant's organisations to only participants from organisations with a maturity level of 0 or 1 were included. The post-test also included questions to measure whether the method has had an effect on their perception and knowledge. (Sari, Güles & Yiğitol 2020) (Safar, Sopko, Dancakova, & Woschank, 2020).

Lastly, the afterwards evaluation was used to receive feedback regarding the method and its shortcomings and advantages.

**Test sessions set-up**

The experimental sessions consist of two parts. The first part included a short presentation regarding the research and a demonstration of the model and the scenarios. This demonstration was shown in the form of videos where the created model was shown and the scenarios were explained by demonstrating their implementations in the model. The most important events of each scenario were shortly explained with voice-overs and the part of the model illustrating this event was highlighted.

Thereafter, the participants chose the scenario they found most suitable for their organisation. This model was then used to create a personalised scenario for the participants. The participants were asked questions regarding certain variables and how this affected the organisations. This was implemented into the model by i.e. adding or certain variables and effects and modifying the effect sizes drawn in the scenario. After all factors of the model were discussed, a personalised model representing their organisation in 5 years was created.

**Knowledge growth measurement**

As explained in the research goal and the literature review, the knowledge growth of the participants will be measured using the scale of Bohn (1994). However, in order to use it for the experimental sessions it is specified for this research to determine on which stage the participants are regarding SI adoption urgency:

*Stage one:* The individual is not aware of market disruptive trends and SI solutions, or their relevance to the organisation.

*Stage two:* The individual is aware of market disruptive trends and SI solutions, and their relevance to the organisations but is not able to measure the effects of these variables on the organisation.

*Stage three:* The individual is able to measure or estimate the effects of both variables on the essential factors of their organisation.

*Stage four:* The individual is aware of how to implement SI solutions and control its effects on essential factors in order to respond to market disruption.

*Stage five:* The individual is aware of the precise effects that are needed to respond to market disruption and how these are created with SI solutions.

*Stage six:* The individual is capable of finetuning the effects of SI solutions such as cost reduction or quality improvement.
*Stage seven:* The individual knows the interaction effects of SI solutions and how to control these effects to get the desired output.
*Stage eight:* The individual has achieved knowledge regarding SI solutions and market disruptive trends to a level that all problems can be responded to in advance

## 6. Case study

The organisation that was researched in the case study is specialised in producing industrial metal parts and exists for 40 years. As explained in the methodology section, this case study was mainly aimed at four main topics: production process, supply chain, employees and innovation. The results of this case study are used to determine the driving variables for the scenarios and to identify the essential variables and factors for the system dynamics model.

***Production process***

The production process is almost completely dependent on incoming orders. Only for a few larger customers stocks are built up in advance. All orders all customized and vary from one product to a few hundred of the same product. Therefore, the CEO stated that a high level of flexibility is important to meet this diversity in orders. All incoming orders are processed and checked by office employees. Thereafter, the materials are ordered from the suppliers and the order will be scheduled to be sent to the suitable machines. These machines are operated and supplied by the employees who are responsible for several machines per person which are operated digitally. Some of the machines are supplied by robotic arms for larger batches of the same products. These are also operative outside of working hours since no human activity is required. A few activities are still done with more traditional machinery and a higher level of human interaction since digital machines are not possible.

***Supply chain***

The organisation has a small number of well-trusted suppliers for the raw materials. These materials are all pre-cut by the supplier and can be ordered on a short-term period. These materials are ordered in an ERP system, but the organisation is currently testing a completely digital system that will order materials automatically. However, this is still in a trial period and not working optimally.

The customers are mainly gained through the traditional way of visiting these organisations. However, the CEO stated that the industry is slowly becoming more digital-based meaning that more new customers can be reached by online marketing. Therefore, the budget for online marketing will probably increase in the following years. The customers mainly operating in the car manufacturing industry, ship manufacturing industry, food industry and packaging industry. These customers place their orders accompanied by the 3D design of the product. These orders are being checked and when necessary modified by the employees. The organisation also offers assistance for this development process.

***Employees***

The organisation has 23 employees. The CEO stated that it is not hard to find new employees, however, the education of these employees is mostly not sufficient. This problem is due to the fact that many programs are being merged by the educational institutions resulting in a lack of expertise of applicants. The CEO also stated to have been working on solutions to better prepare students for the industry. The employees are currently mainly selected on essential character traits and have to be trained internally. He stated that also a certain level of digital knowledge and skill is important for the employees since the organisation is adopting more Smart Industry solutions. The organisation focuses to train the employees on a broad level, so they can be operating in many positions. Lastly, the organisation offers growth opportunities such as office-based tasks for the operating employees.

***Innovation***

As stated earlier, the organisation has already implemented robots and is working with digital systems on the machines. The current innovations are mainly to improve the organisation's flexibility, productivity and to lower the costs. The two main reasons to improve the organisation's flexibility are the increasing fluctuation in demand and increasing demand for customization. This is mainly achieved by the structure of the work floor and machine positioning that allows the organisation to produce large batches as well as small batches/singles. Also, the broad training of the employees makes it possible to position them flexibly and have more manpower on certain stations when needed.

The productivity increase and cost decrease are due to the upcoming competition from low-wage countries. To stay profitable, the organisation needs to compete by producing the same quality with lower costs and therefore lower prices. This is mainly achieved by a higher level of automation in the production process, such as robotisation, as well as system automation, which the organisation plans to increase in the coming years. The organisation also plans to adopt automated guided vehicles (AVG) to improve the productivity by further automating the production process.

The results of this case study will be used for the following phases of this study. Firstly, for the determination of the driving factors of the scenarios created in phase 2, the SI solutions and market disruptive trends identified in this case study are discussed in meetings with stakeholders. The conclusions of these meetings are elaborated on in the next chapter. Secondly, the organisational factors influenced by SI solutions and market disruptive trends resulting from this case study are included in the system dynamics model created in phase 3 after being discussed with stakeholders. These factors are: productivity, flexibility, costs, personnel and market share.

# 7. Scenarios for jobber organisations of the Dutch metal industry

The scenarios were formed according to two driving factors and their two extreme outcomes: ‘Smart Industry maturity’ and ‘market disruption’. In order to assure that the scenarios are specific, secondary data and meetings with stakeholders from Boost, the FME and the Metaalunie were conducted to identify the most important aspects of both driving factors in the metal industry. According to the stakeholders, the solutions that are currently most suitable and implemented by organisations with a high SI maturity level in the metal industry are: 3D-printing, system integration and autonomous robots. The scenarios, therefore, have a main focus on these solutions but do not completely exclude other possible effective solutions. During the scenario planning workshop, big data analytics was also addressed to be a possible essential SI solution for the future but might be perceived as too complicated due to the high number of challenges and the inability of current technologies to process these datasets (Anagnostopoulos, Zeadally & Exposito, 2016). Therefore, this does not have the main focus but is included as a possible solution in the scenarios and the model that is created for the method. For market disruption, the following trends were included: shortage of trained suitable personnel, the competition of low-income countries and the increasing demand for customized products.

Since both driving factors for the scenarios were already selected, only step 6 to 8 of the IL method were performed in the workshop (Wright, Bradfield & Cairns, 2013). This ensured that the scenarios would be as specific and deeply executed as possible within the available time (3,5 hours). After a short presentation regarding the research, scenario planning and the driving factors, the participants started with step 6. In this step, the two extreme outcomes of both driving factors were defined. Each participant was asked to assign two to three effects that an extreme can have on an organisation in the metal industry, for two of the extremes. They were given ten minutes, followed by a group discussion on all four extremes.

To define the four scenarios in step 7, the same procedure was followed. The division of the four scenarios was given on a matrix with market disruption on the y-axis and SI maturity on the x-axis (figure 2). Each participant was asked to assign two to three changes that a scenario would bring for an organisation in this scenario in the next 5 years. After each participant filled in these changes for two scenarios that were assigned to them, a group discussion followed. Also, in this group session, the end plot of each scenario was given.

For the last step, the participants were divided into duos to fully elaborate three of the scenarios, one scenario per duo. However, since the workshop was conducted with 5 participants instead of 6, one of the participants was asked to switch after half-time. The participants were given 30 minutes for this step. Scenario 3, was elaborated in co-operation with Boost Smart Industries based on the input given by the participants in both steps 6 and 7.

In the following sections, firstly, the results of step 6 are shown. Thereafter, the four scenarios for jobbers in the metal industry are explained including the events that will occur in the next 5 years for organisations in these scenarios. These scenarios are implied in the stock and flow diagrams by implying the variables that have an effect on the organisation. Where possible, percentages are given to indicate at what rate certain flows will be affected.

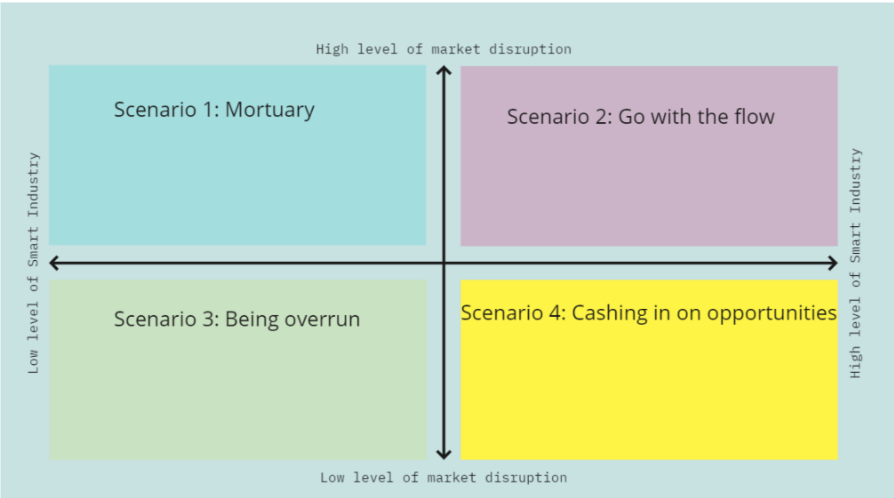



Figure 2: Scenario Matrex

## 7.1 Extreme outcomes driving factors

**Low Smart Industry maturity**

The first effect of low SI maturity is a low level of flexibility. Traditional production processes are designed to produce only a limited number of different products or variations of these products. Also, this extreme consists of a high level of human labour dependency which makes the organisation less flexible to respond to demand fluctuation compared to organisations that use robots. The second effect is a low level of productivity, again due to the use of human labour, whereas robots could be producing 24/7 autonomously. The third effect is that these organisations are found less attractive for employees. The participants stated that organisations with low SI maturity usually offer less growth and educational opportunities. They also expect these organisations to have a significantly lower chance of surviving the next 5 years, which makes them unattractive as an employer. This is a significant effect for these organisations since they are more dependent on staff compared to organisations with a high SI maturity level. The last effect is that it excludes a close connection through integrated systems with other organisations within the supply chain which might lead to a decrease in suppliers and customers.

**High Smart Industry maturity**

The first effect of high SI maturity is that it leads to a high level of flexibility. Due to the use of 3D printers and system integration, organisations can produce a large variety of product and allow customers to co-develop these products. With the use of robots that could operate autonomously when necessary, organisations are more reactive to fluctuations. These fluctuations can be identified since the organisation is able to process more data and its systems are integrated over the supply chain. The second effect is a high level of productivity since the organisation is less dependent on human labour due to the use of robots and systems that operate more autonomously. The third effect is a higher level of operational excellence. Since the production system is more automized and therefore the chance of errors caused by human interaction is limited. Also, a more automized production system decreases labour costs which results in lower retail price. The fourth effect is the high connectivity with suppliers and customers which leads to a faster production process, faster market response and a stronger connection. Lastly, a high SI maturity creates more growth and educational opportunities for employees and create a more secure workspace, according to the participants.

**Low level of market disruption**

For the low level of market disruption, we assume that current trends will not evolve or change rapidly in the following five years. Therefore, the main effects of these trends are that organisations experience a high shortage of suitable and educated personnel. According to a study conducted in 2019, 25% of the organisations in the Dutch metal industry experiences this as the largest barrier (Van der Aalst, Ijzerman & Maaskant, 2019). The participants stated that this is mainly a result of insufficient education. This shortage leads to lower productivity for organisations and results in higher labour costs due to an increase in wages. The second effect is the demand for customized products (PWC, 2020). This results in the need for flexible production processes for organisations to respond to this demand. However, the participants stated that “industrial organisations”, which order larger amounts of the same products still are the most important customers. The third trend is the competition from low-income countries, which are able to produce a large number of products for lower retail prices (CBS, 2017).

**High level of market disruption**

The participants stated that in the case of high-level market disruption, the first important effect regards the change of education. They assume that in this case, organisations and educational institutions will work together closely to improve the educational system. This will lead to available labourers being more function-specific educated and will also be more trained to operate in organisations with a high SI maturity. Due to a significant increase in wages in low-income countries, the participants expect that this competition will decrease over the next 5 years and result in more demand for the Dutch metal industry. Thirdly, the participants expect that in this extreme, the demand for customization will increase rapidly and that customized products will become the new standard. Therefore, a high number of customers demanding small customized orders will appear and become the most important customers. The fourth effect is that organisations within supply chains will be closely connected and will form clusters. One participant stated that “organisations will become part of its customers’ production processes, instead of just being a supplier”. This means that customers will have more influence in the organisations’ production process and that organisations within the supply chain will work co-operatively. The last change also concerns co-operation. More similar organisations will make cooperative investments, for example, to purchase certain machines or 3D printers that can be operated by these organisations. This can also be done in the form of so-called field labs.

## 7.2 Scenarios

**Scenario 1 Mortuary**

The first scenario consists of an organisation with **low SI maturity** within a **highly disrupted market**. Due to the low flexibility of the organisation in this scenario, it will not be able to meet the increasing demand for customized products. Therefore, it will mainly stay focused on customers ordering a larger number of the same products. According to the participants, however, the orders from this type of customers will rapidly decrease for these types of organisations.

Firstly, since these organisations will be unable to be interconnected in its supply chain and therefore unable to form clusters, this will result in a bottleneck for other organisations in the supply chain. Therefore, customers will move to other suppliers who are able to do this. Secondly, the production costs of these organisations will be higher due to higher labour costs and lower productivity. This productivity is expected to decrease even more due to lack of employees, also caused by personnel leaving for organisations with a high SI maturity that offer more growth and education opportunities and job security. Lastly, participants also expect that these organisations will attract very few new employees, even when more suitable labourers will become available due to the improved educational system. The participants expect these labourers to prefer working for organisations with a high SI maturity level due to better opportunities and their education being more focused on these types of organisations.

This increase in production costs will result in higher retail prices which will further decrease the number of orders and therefore, the organisation's profit. Due to the higher retail prices and lower productivity, these organisations will also be unable to supply the demand that will become available for Dutch organisations due to an increase in wages in low-income countries. This ongoing decrease in profit leads to the decrease of budget for several factors such as educational purposes and R&D. This firstly results in more personnel leaving due to even less growth and education opportunities which again decreases productivity. Due to the decrease of budget for R&D, these organisations will be totally unable to innovate after a few years. Eventually, this company will stop making profit and eventually become irrelevant which will result in bankruptcy within 5 years.

However, the participants stated that the only opportunity for organisations in this scenario is to fully focus on the development of niche products. This consists of a high level of craftsmanship, which cannot be replaced by and does not require current SI technologies. However, this will probably still result in significantly smaller organisations due to the very limited amount of these types of products. Therefore, only a few organisations will be able to make this switch.

**Scenario 2 Go with the flow**

The second scenario consists of an organisation with **high SI maturity** in a **highly disrupted market**. A number of events will take place in this scenario. The first one is the change in customers. Due to the rapid increase in demand for customized products, most main revenues will be existent from these type of customers. The increase in wages of organisations in low-income countries will cause customers of these organisations to shift to customized products since the difference in retail price will be less significant. Due to the flexibility and shorter production time of these organisations, their market share will increase.

The second event is the increase of interconnectivity with the supply chain and other related organisations, also called cluster forming. Organisations in this scenario will create platforms to be more interconnected and cooperative. The connection with the supply chain will lead to shorter production times and more customization options. It is also expected that these organisations will be more involved with each other's production process which result in more trusted and stronger relationships. According to the participants, this will change the organisation from delivering products to delivering services, also known as servitization. Organisations will also co-operate with other related organisations for innovative purposes by creating co-operative platforms. This could lead to events such as organisations sharing data to improve production processes or co-operatively investing in innovations that can be used by organisations on this platform. One of the main reasons this will occur is to maintain the added value within the Dutch industry.

The last change contains the change in education. Organisations will work closely together with educational institutions to improve the education for this sector, which will lead to more suitable and educated personnel. These employees will also need to be constantly trained once employed by the organisation to adapt to market changes and new technologies.

Since organisations with a high SI maturity level have a high level of productivity, flexibility and more educated personnel will be available, these organisations will be able to meet the increasing demand for relatively low retail prices. Therefore, their market share is expected to increase approximately 5% per year which will lead to an increase in both revenues and profit. This will lead to more budget for R&D, co-operative platforms and educating personnel, which will result in the organisations being able to innovate and be more adaptive to market disruption. Therefore, these organisations are expected to experience growth in the following 5 years with a percentage of 10 to 15% per year.

**Scenario 3 Being overrun**

The third scenario contains an organisation with **low SI maturity** in a market with a **low level of disruption**. In this scenario, the largest challenges are the lack of suitable and educated labourers and competition from low-income countries and organisations with a high SI maturity. Even though the main orders will still consist of larger batches of the same product, it will still be hard for these organisations to compete due to low productivity.

Since these organisations are highly dependent on personnel which is scarce in this scenario, their productivity will decrease even more, causing an increase in production costs and retail prices. This low level of productivity, longer production times and higher retail prices will result in a slow decrease in market share of approximately 5% per year for these organisations.

It is also expected that the competition from organisations with high SI maturity will increase in this scenario. These organisations are expected to increase their added value by operational excellence and servitization. This operational excellence and servitization for these competing organisations will be increased more when these organisations form clusters that are interconnected through integrated systems and platforms. Since organisations in this scenario do not have the ability to follow these trends, they will lose the connection with developments in and around the Netherlands.

Due to the decrease in market share and productivity, revenues and net profit will also decrease resulting in a decrease of the available budget for R&D, educational purposes and other investments. The participants state that this will result in the same downward spiral as organisations in scenario 1. However, due to the low level of market disruption and the existence of demand for larger orders, this process will probably take longer and the organisation will be declining at a slower pace. Therefore, these organisations are expected to decrease by 10% in size per year in the next five years. For this scenario, the participants also stated that the only option to stay profitable is to focus fully on niche products, as in scenario 1.

**Scenario 4 Cashing in on opportunities**

The last scenario is an organisation with **high SI maturity** in a market with a **low level of disruption**. A number of events will take place in this scenario. According to the participants, organisations in this scenario are able to gain a competitive advantage mainly through “operational excellence” and “servitization”. With these two factors, these organisations are expected to increase market share in both customers that order larger batches and customers that demand smaller orders of customized products.

Operational excellence will be achieved by a couple of factors. Firstly, these organisations will have to invest more in the education of employees internally, since the educational system in this scenario is not sufficient. This will be improved co-operatively by organisations in the metal industry. This will lead to higher productivity and the employees to be flexibly educated causing the organisation to be more adaptable to market changes. This internal education is highly important due to the scarcity of suitable personnel and lack of sufficient education. Secondly, due to the high amount of available data, this organisation is able to respond quickly to market changes and improve production processes. The improvement of these production processes will lead to less waste and higher quality of products. Therefore, this organisation will be able to be more productive and flexible against lower production costs and lower retail prices.

This servitization will be achieved by the organisation’s flexibility and its interconnectivity with organisations within the supply chain and other related organisations earlier referred to as cluster forming or co-operative platforms. As explained in the previous scenario, this will lead to several advantages such as data sharing and cooperative innovations. It will also allow the organisations to be more involved in each other’s business processes and customers to co-create a high variety of products.

Due to the above-stated factors, this organisation is expected to increase its market share by 10% per year which will result in more revenues. Together with low production costs, this will lead to an increase in profit and more budget for factors such as R&D and educational purposes. The participants expect this organisation to grow in the next 5 years with a percentage of over 15% per year.

# 8. Simulation method development

Based on the results of the first two phases of this study, the simulation method was developed. The aim of this method is to increase the knowledge of possible SI urgency among CEOs of SME organisations in the metal industry. In this method, the plausible future scenarios are demonstrated by the use of system dynamic models and it allows the participants to create a personal scenario in the form of a model.

In this section, firstly the concept of the model in the form of a Stock and Flow diagram is explained. The importance of each aspect is shortly explained together with the most important effects on other aspects. Secondly, the conversion of this model into the final model is explained together with its functioning. Finally, the method wherefore the model is created is explained.

## 8.1 Concept Stock and Flow diagram

The main purpose of the model is to visualise the essential stocks together with their incoming and outgoing flows, affected by market trends and internal factors. These internal factors are affected by SI solutions. Therefore, this model exists of stocks and flows, internal factors and two variable factors: Smart Industry solutions and market disruption trends (figure 3). The model includes four stocks: net income, costs, employees and market share. For the creation of the model, only the essential stocks and factors have been selected to illustrate the scenarios that were developed in the previous phase of this research. According to the results of the previous phases, the four most essential aspects of metal organisations affected by both external as internal factors; net income, costs, market share and employees. Therefore, these aspects have been chosen as the main stocks of this model:

- Employees; the availability and the skills/education of employees are important factors and can have a large impact on the performances of an organisation (Kibira, Jain & McLean, 2009).
- Market share; this is an essential factor that highly influences the profit/loss and therefore the durability of an organisation. This is affected by the increase and decrease of customers (Kibira, Jain & McLean, 2009).
- Net income and costs; Net income is increased by the revenue rate. The expense rate of the organisation decreases the net income stock and increases the costs stock (Nalchigar, Yu & Easterbrook, 2014).

For the internal factors that influence stocks, flows and other variables, the following selection mainly based on the results of the case study and the scenario planning workshop are:

- Flexibility; the flexibility of the organisation is essential to respond to demand fluctuations, customization and other market disrupting trends. In this model, the flexibility is mainly influenced by system integration over the supply chain, product diversity and level of data automation.
- Internal training for employees; this is essential to assure the skills and education for the employees are on the required level. Especially when the available labourers do not meet the required level, internal training is of high importance.
- Productivity; the productivity in this model can be defined as the number of products produced per employee. Therefore, it is influenced by the level of automation and the employees. The productivity of an organisation can highly affect to cost per product and therefore the value for money.
- Quality; the quality of the products is an essential factor that can be influenced by SI solutions such as automation and solutions that enable a high level of product diversity. Automation can assure that the quality of the production is more consistent. Moreover, solutions such as 3D printing can produce a larger variety of products while maintaining high quality. The quality of the products determines the value for money.
- R&D; The level of R&D is essential for innovation and therefore influences the several factors of SI. The participants of the scenario planning workshop stated that it is an important factor that receives too little attention in many organisations.
- Value for money; the value for money of the product has a high influence on the market share of an organisation since it affects whether a customer will place an order.

In the model we distinguish two types of variable factors: Smart Industry related factors and market disruption related factors. For these variable factors, we mainly include the SI solutions and market disruption trends that were established during the scenario workshop: Level of SI:

- Level of automation. the level of automation within an organisation can be increased by technologies such as (autonomous) robots, machine learning and data automation. This has an effect on the productivity, flexibility and quality of the production process.
- Level of product diversity; the level of product diversity can be increased by 3D printing and automatic systems and mainly affects the flexibility of the organisation.
- Level of system integration; the integration of systems results in a closer connection with other organisations in the supply chain.

Level of market disruption:

- Availability of labourers; the availability of well-educated and skilled labourers determines whether suitable employees can be recruited by an organisation. According to the participants of the previous phases, this availability is highly dependent on the educational institutions.
- Demand development; the development of demand determines whether the majority of orders exists out of larger batches of the same product or if it will consist out of small batches of customized products.
- Competition from low-income countries; the level of competition of low-income countries has an effect on the market share by influencing whether new customers will be gained as well as whether existing customers will leave for cheaper alternatives.

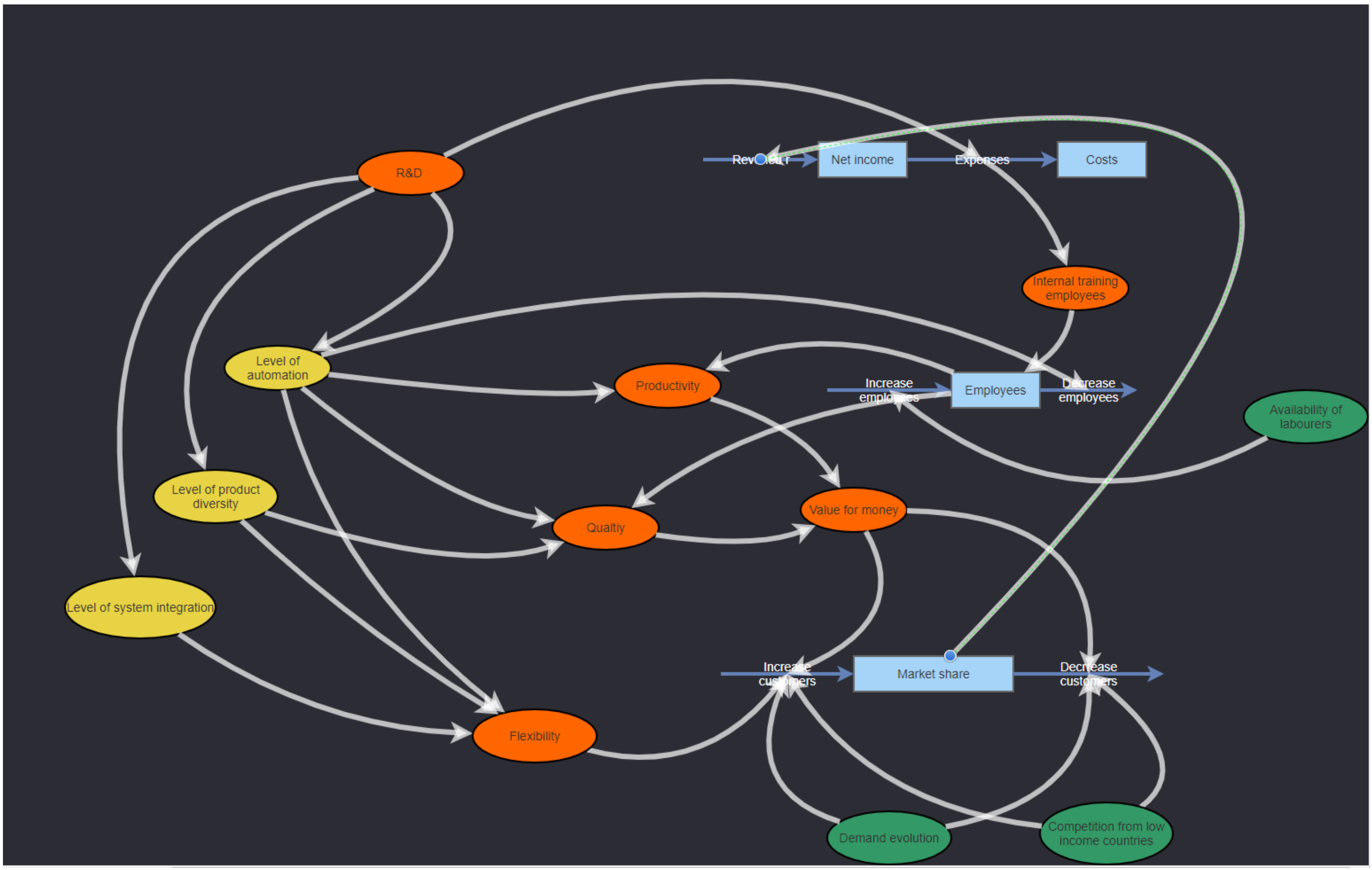



Figure 3: Stock and Flow diagram Dutch Metal Organisations, https://insightmaker.com/insight/225598/Basis-stock-and-flow

## 8.2 Causal loop diagram

After the Stock and Flow diagram was created, it has been discussed with stakeholders from Boost, de Metaalunie and the FME to assure its usability for the test sessions with CEOs from the metal industry. The main finding from these discussions was that the model, most of all, needed simplification. This is necessary since the testing sessions are conducted within approximately an hour with participants that are not familiar with system dynamic models. In these sessions, the model needed to be understood by the participants and they needed to be able to adjust the model. The stakeholders stated that dividing both the level of SI and the level of market disruption into three separate variables each would be too complicated and results in too many variations of the model. Secondly, explaining and using a stock and flow diagram would take more time than an hour considering too many different aspects of the model needs to be explained. Lastly, they stated that the number of factors in the model needs to be reduced significantly.

Therefore, the model has been converted into a more simplified Causal Loop Diagram (figure 4). The first adjustment is that all stocks have been changed into variables. These variables are connected by links in a certain direction representing a causal effect. This link can either be red (negative) or green (positive) and can range from -4 to 4. This range has been chosen so that the width of the links shows the size of the effect. With this range, the size of the effect is still optimally visible. However, other implications of the model could use different ranges. Secondly, all SI variables and all market disruption variables have been combined into two variables: level of smart industry and level of market disruption. These two variables can either be high or low, similar to the scenarios. Furthermore, a number of factors have been combined or deleted. For remaining factors are shortly explained how they are build up:

- Productivity; similar to the Stock and Flow diagram.
- Costs/value for money; This factor includes the cost price of a product and how this translates to the value for money of the product. This also includes the quality of the products and their sales price, resulting in an effect on the market share. Furthermore, the costs have a direct effect on the profit/loss of the organisation.
- Flexibility; similar to the Stock and Flow diagram.
- Market share; converted from a stock to a variable.
- Profit/loss; this variable is the combination is of the net profit and costs stock, representing the profit or loss of this organisation. The link from this factor to the employees represents the budget available for internal training of the employees. The link to the level of Smart Industry represents the budget for R&D and innovation, affecting the level of SI.
- Employees; converted from a stock to a variable.

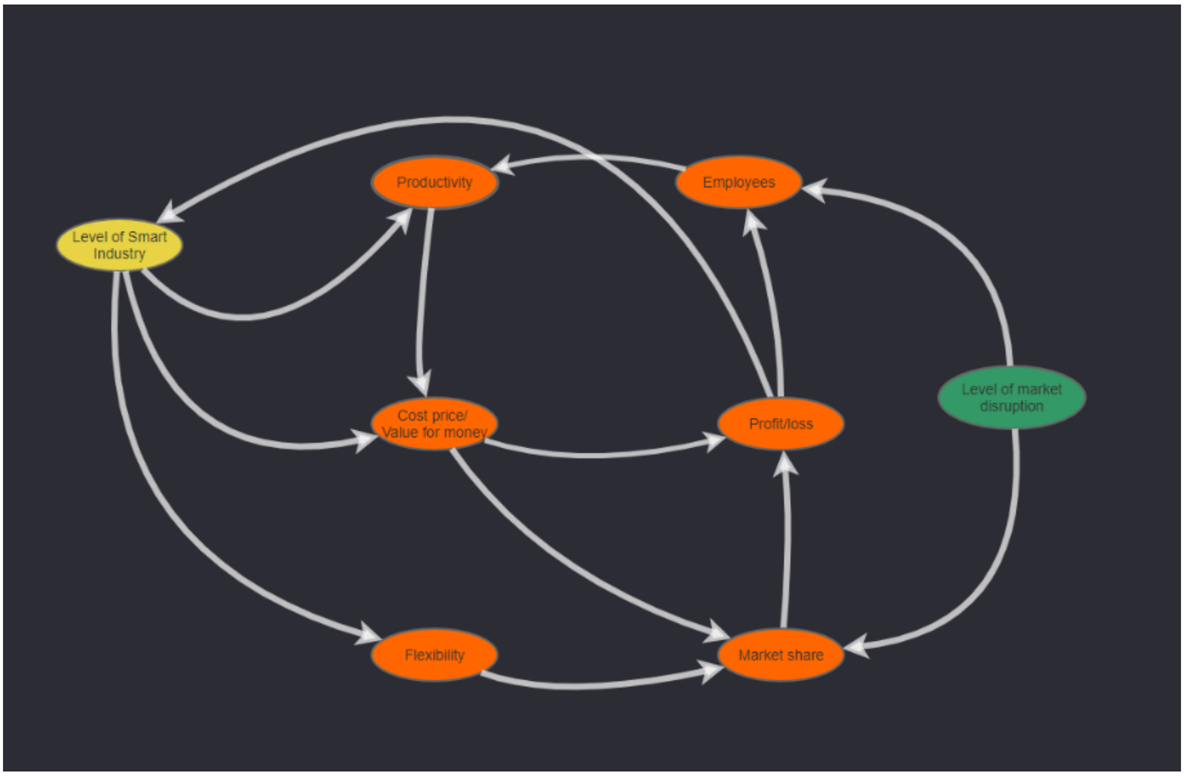
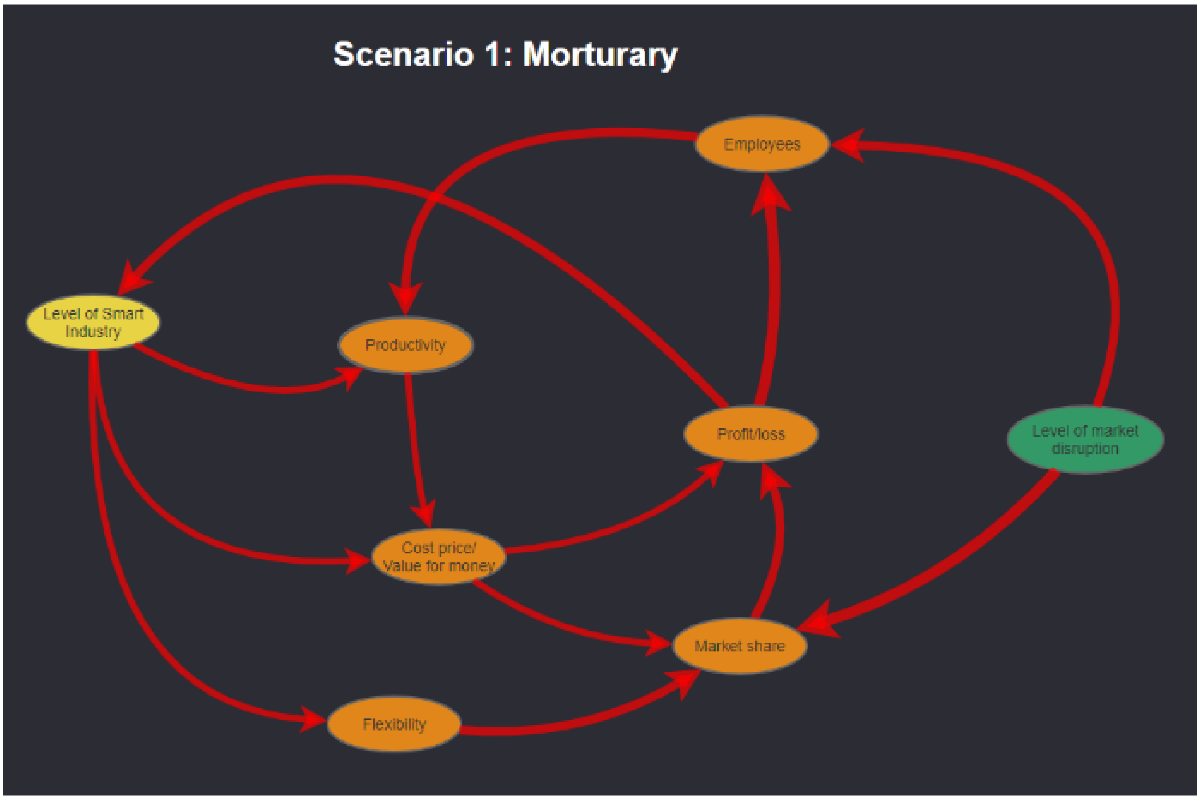



Figure 4. Causal Loop Diagram Dutch Metal Organisations, https://insightmaker.com/insight/220311/Standaard-Model

Followingly, the scenarios that were created in phase two of this researched were implemented into the model to create four different models (figure 5 till 8). The purpose of these models is to illustrate the different effects variables and factors have in different scenarios.



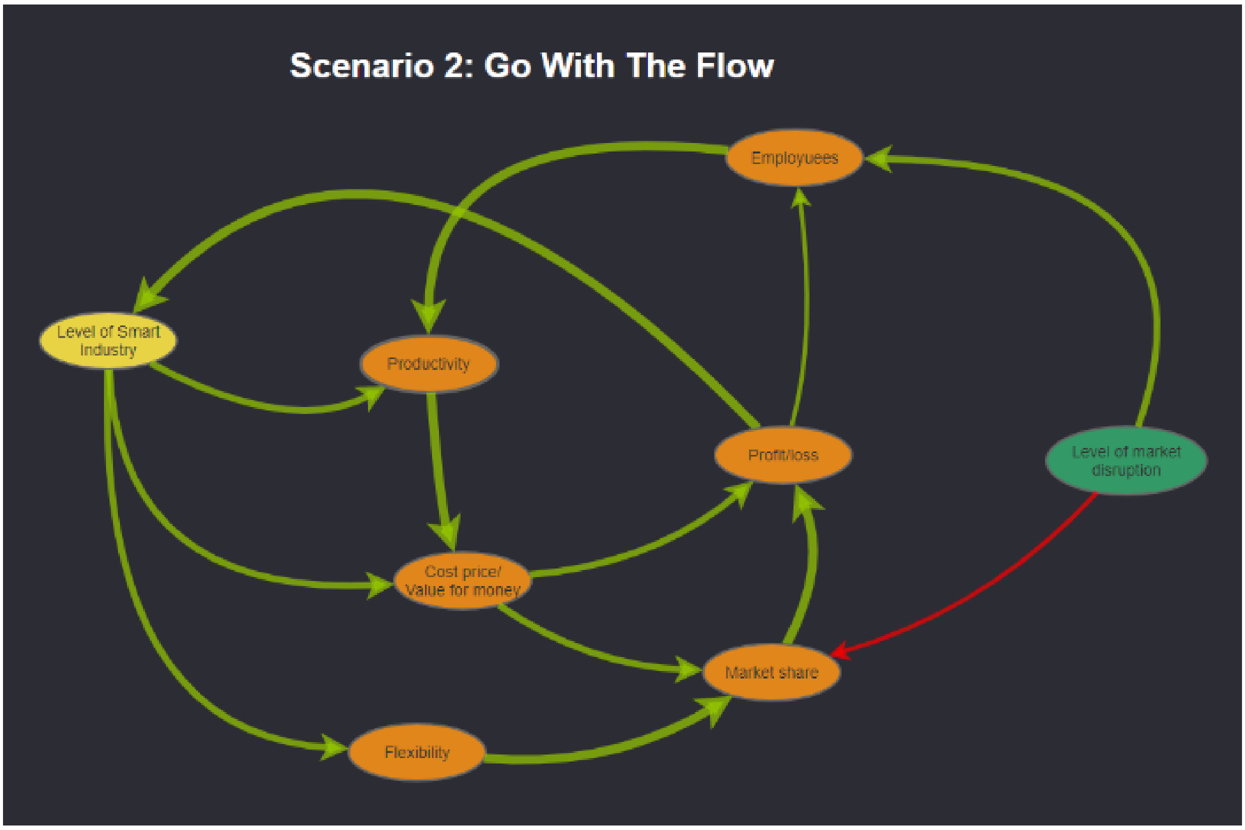



Figure 5. Causal Loop Diagram Scenario 1, https://insightmaker.com/insight/221753/Werkmodel-scenario-1

Figure 6. Causal Loop Diagram Scenario 2, https://insightmaker.com/insight/221761/Werkmodel-scenario-2

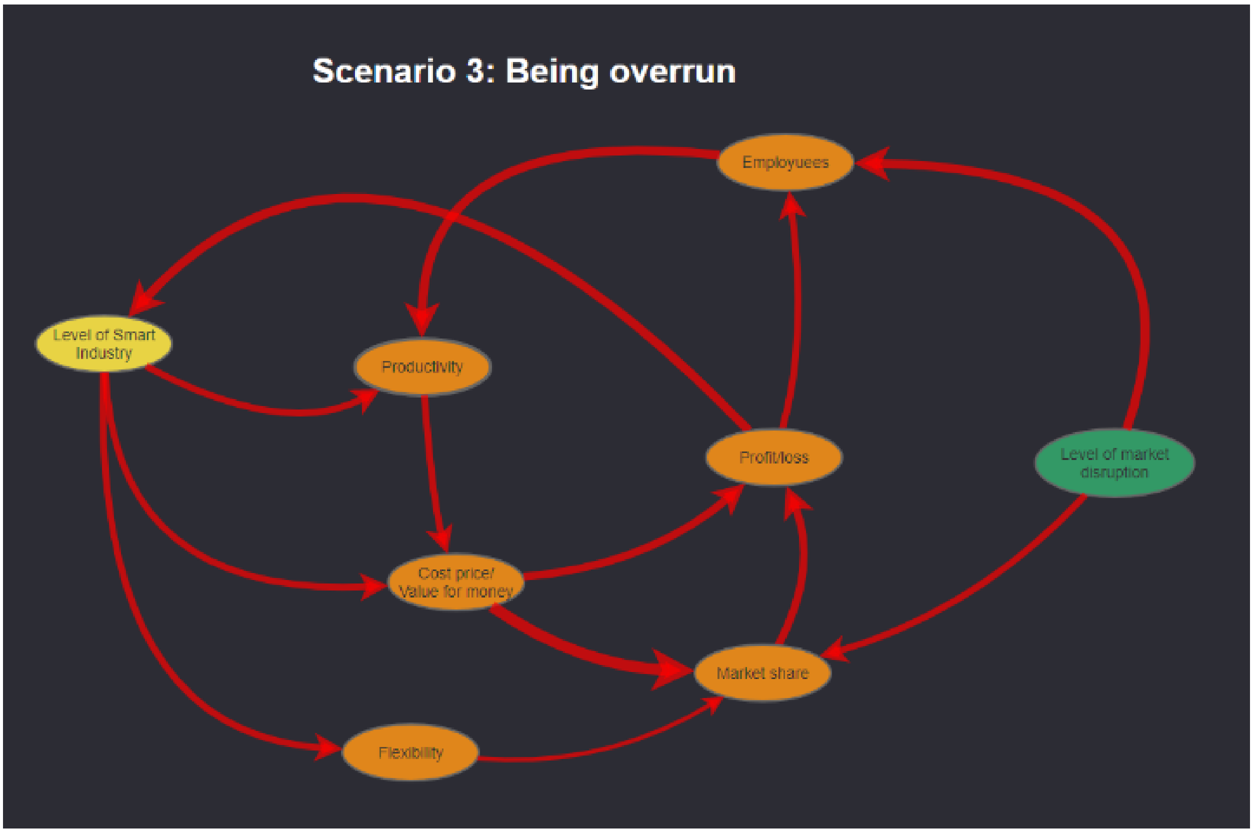


Figure 7. Causal Loop Diagram Scenario 3, https://insightmaker.com/insight/221763/Werkmodel-scenario-3

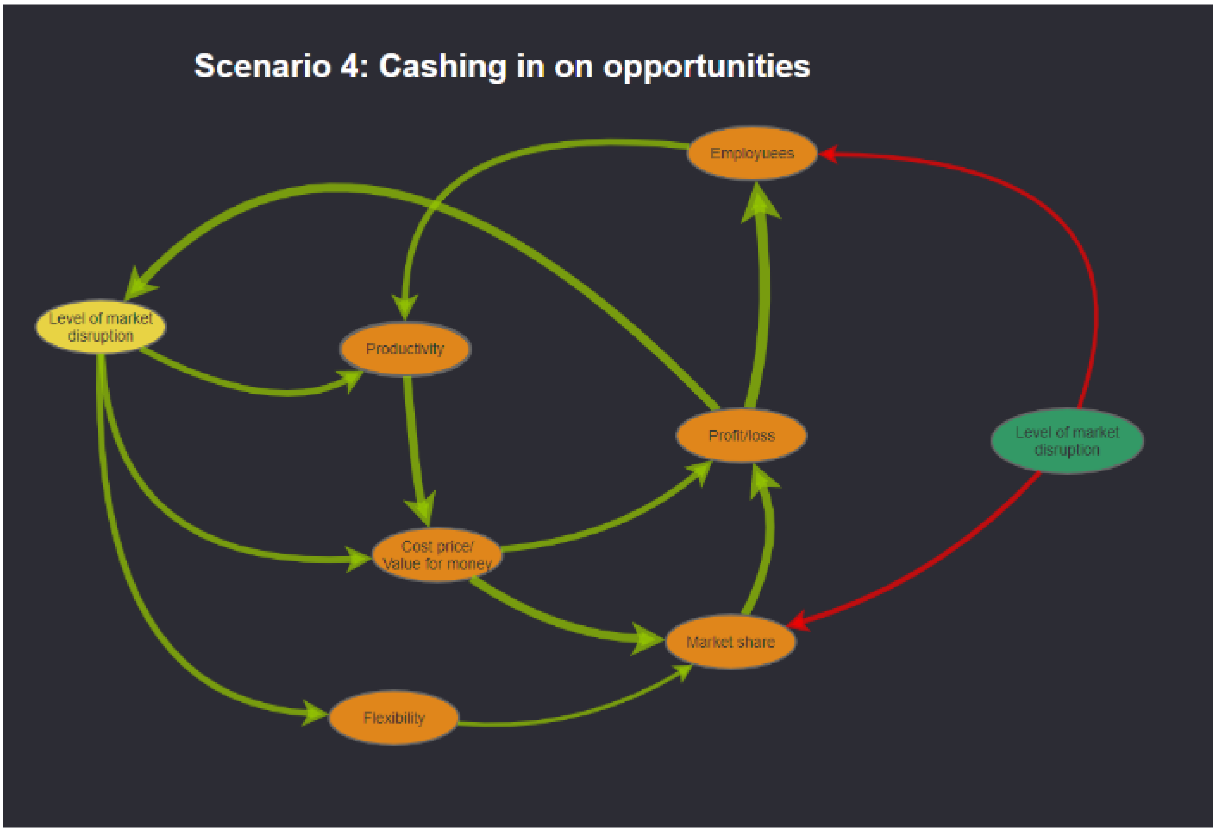



Figure 8. Causal Loop Diagram Scenario 4, https://insightmaker.com/insight/221768/Werkmodel-scenario-4

## 8.3 Method

After the Causal Loop Diagram was developed and approved by the stakeholders, the method was developed. This method is divided into three parts: a short presentation, demonstration of the videos, developing the model.

**Presentation**

The method starts with a short presentation regarding the agenda of the session, the research and an explanation of both variable factors. For both variables is explained what is understood by both a high as a low level of both variables, as defined in the scenario planning workshop. The same SI solutions and market trends are included as in the scenario planning workshop. However, the participants are informed that these aspects only form a framework and that other market trends and SI solutions that are relevant for their organisation need to be taken into consideration as well.

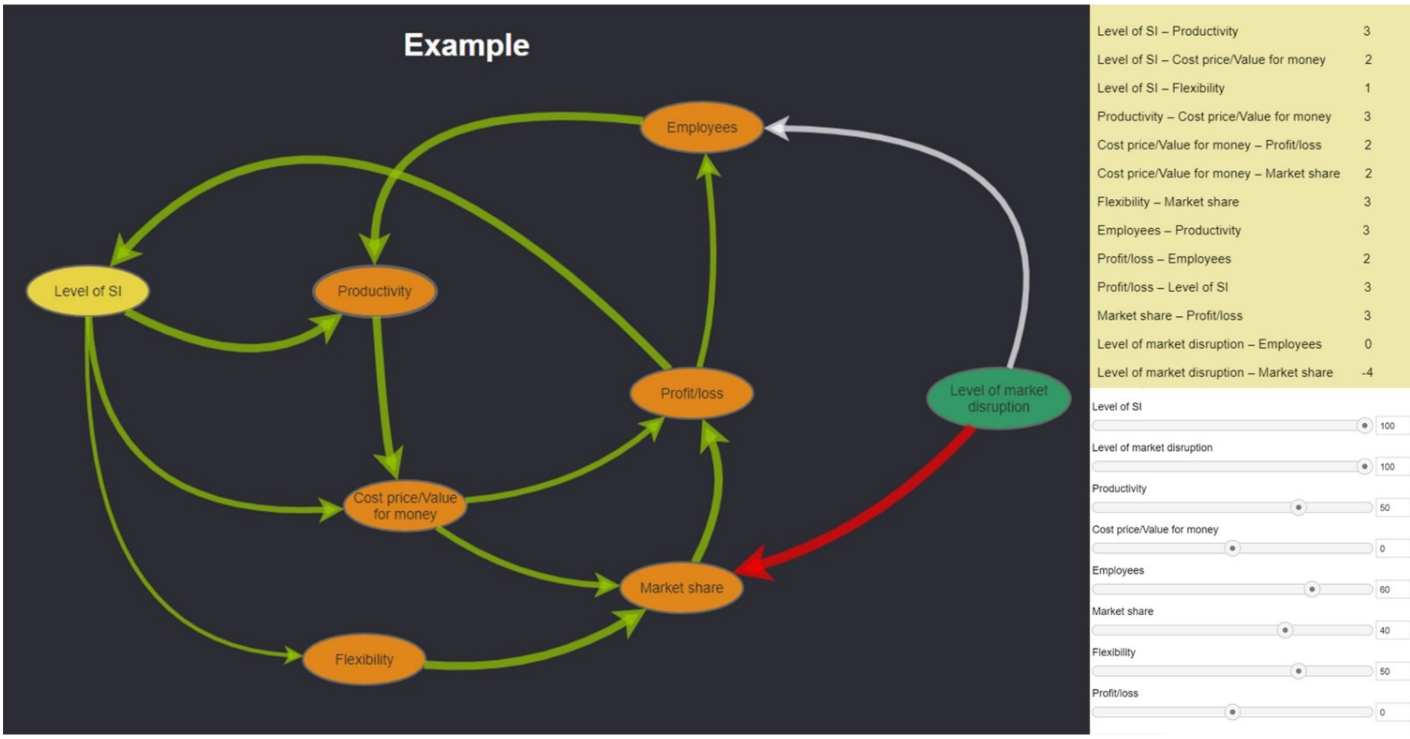
**Instructional videos**

After this short presentation, two videos are shown to the participants. Both videos contain screen recording from the models in Insight Maker, supported with voiceovers by the researcher. The first video explains how causal loop diagrams work and which components are existent in the model used for the session. Thereafter, the basic form of the model is explained. Each factor is clarified together which each link and, therefore, the effects on other factors. After the first video, the participants are asked whether the functioning of the model is clear. The second video shows all four scenarios with support of the specific model for that scenario. Before the video is shown, the participants are told to choose the scenario they expect to be closest to their organisation afterwards. Each scenario is shortly explained and a textual summary is given that points out the three most important events occurring in the specific scenario. These three events are highlighted step by step in the model so that causal effects are clarified to the participants.

**Model building**

In the second part of the method, the participants create their own personal model and scenario. This part is the essential phase of the method, since it is aimed to stimulate double-loop learning to achieve knowledge growth. Double-loop learning is stimulated by enabling the participants to apply the information regarding future scenarios to their own ideas and situation. As stated before, the participants choose the model of the scenario that they expect to be the closest to their organisation's situation in 5 years. This model is used as the starting point and shared with the participant. As stated in the section regarding the creation of the models, each effect has a score between -4 and 4 and each factor has a score from -100 to 100. This personal model is created through three steps. The purpose of this part is to stimulate thinking about the levels of both variable factors for their organisation in 5 years, and how this will affect their organisation by creating their own scenario.

Firstly, it is explained to the participants which SI solutions and market trends have been taken into consideration for the chosen scenario and how this leads to the effects the two variables have on other factors. Thereafter, the participants are asked how they expect their level of SI to be, this includes technologies or solutions that already have been implemented but also plans for innovation for the next 5 years. After this is discussed by the participant, the effects of Smart Industry on flexibility, productivity and costs are adjusted accordingly. Also, they are asked if any other effects need to be drawn. Secondly, the participants are asked about their vision regarding the disruption of the market within five years, relevant for their organisation. The three market trends that were addressed in the presentation are discussed and the participant is asked which other market trends they expect to have a significant effect on their organisation. Again, after this is discussed the relevant effects on the organisation are adjusted and possible new effects are added according to the participant. The last part concerns the core of the model. The participants are asked to score each factor from -100 to 100 also taking the effects of both variable factors into consideration. Also, they determine the strength of each effect from between -4 and 4. This starts from productivity, followed by its effects on other factors. This is done till all six factors and their effects are assessed by the participant. An example of one of these models is shown in figure 9. Thereafter, the participants are asked if they want to add any effect or factor to the model that they find significant for their organisation in 5 years. Finally, a short conclusion of the findings of this model is discussed by addressing the most significant market threats, the factors they affect and how the organisation can possibly




respond to these events.

Figure 9. Example personalised model, https://insightmaker.com/insight/230088/Example-personalised-model

## 9. Results Testing Sessions Method

After the method is created, an intervention study is conducted to test its effect. In experimental sessions, the effect of the method on awareness development regarding SI urgency is measured by observations and a pre and post-test. A week before the intervention, the pre-test was sent to the participants to set the baseline measurement on five topics, as explained in the methodology section. The post-test was sent after the intervention and included the same topics to measure change caused by the intervention.

The results of the intervention are divided into two sections: measurement of knowledge growth and feedback regarding of the method. The first section consists of two types of analyses to measure knowledge growth of the sample group regarding both future market disruption trends as the importance of SI adoption, due to the intervention (Bohn, 1994). This is firstly based on observation and conclusions that are drawn by the participants during the intervention. This observation is mainly focused to identify the stage of knowledge the participant reaches according to the specified knowledge scale in section 5.4. Knowledge regarding SI solutions effects and the effects of market disruptive trends are identified. When both variables reach the same level, we can conclude that the knowledge regarding adoption urgency is on this level.

Followingly, it is measured if these findings resulted in a change of technology importance perception, barrier perception or willingness to innovate in the pre and post-test to conclude if the intervention caused this knowledge growth. When there is no significant change in the pre and post-test, it is possible that the participant was already on this stage or that other factors have caused this. Secondly, the participants were asked if their knowledge had increased on SI solutions urgency, market disruptive trends and possible future scenarios. This was measured with a 5-point Likert scale ranging from totally not agree to totally agree. These results are also used to confirm if the method has caused knowledge growth. For this analysis, the session with the advisor from PKM was not included. The results of the pre and post-test, change in answers between the surveys and whether this change was observed during the sessions can be found in Appendix 2.

The second section consists of the results of all feedback regarding the method received from the participants, divided into shortcomings and advantages. The feedback is presented in a table 3 and the three most stated shortcomings and advantages are shortly explained. For this analysis, all participants were included.

## 9.1 Knowledge growth analysis

As explained in the methodology section, all participants were provided with information and a presentation the two driving variables: regarding SI solutions and market disruptive trends. After this presentation, all participants stated to be aware of the existence of these variables. Therefore, it can be stated that all participants were at least on stage two of the knowledge scale (Bohn, 1994). Each experimental session is shortly elaborated on in order to determine knowledge growth. Followingly, knowledge growth per participant due to the method is shown in table 2.

*Session 1*

The participant of the first session expected the organisation to be in a situation close to scenario 2 'Go with the flow' in five years. Therefore, this model was chosen to be modified into a personal model. During the first experimental session, the participant concluded that mainly labourer shortage is a barrier for the organisation and will still be in five years, which is also noticeable in the post-test. Furthermore, he concluded that especially system integration is of high importance in order to retain a high level of flexibility and productivity, especially with the expected barriers. It can be concluded that the conclusions regarding market disruptive trends were a result of the intervention since there is a change in barrier perception in the pre and post-test. The conclusions regarding SI importance were already visible on the pre-test. The participant showed to be able to measure the effects of both variable factors on the essential factors of the organisation. Furthermore, the participant stated to have gained knowledge on only market disruption events and plausible future scenarios. Therefore, it can be concluded that the intervention caused knowledge growth of participant 1 from stage 2 to stage 3 (measure) regarding market disruption trends. The knowledge growth regarding SI effects cannot be determined, possibly because the participant was already on stage 3. However, since the participant was assumably not on this stage regarding market disruptive trends, we can assume that the participant has grown from stage 2 to 3 regarding SI adoption urgency.

*Session 2*

The participant of session 2 stated that the model and the presented scenarios do not apply to this participant's organisation. This is mainly because the production processes of this organisation rely on a high level of human interaction and knowledge that is not possible to be automized according to the participant. However, the participant did state to already have implemented system integration to a certain level. For the model building, the model of scenario 2 'Go with the flow' was chosen to be modified. Even though small adjustments were made to the model, the participant still stated that the method was not representative for the organisation. Therefore, the participant stated to not have gained knowledge regarding SI technology, market disruption or possible future scenarios. Also, no significant changes between the pre and post-test were detected that could lead to an increase in knowledge. Therefore, it can be concluded that the knowledge of participant 2 is unchanged. It cannot be determined on which stage the participant currently is since it was stated that the intervention was not relevant to the participant's organisation.

*Session 3*

The third experimental session was conducted with two participants of the same organisation, the CEO and an employee responsible for innovation. Both participants of experimental session 3 expected the organisation to be in a situation close to scenario 2 'Go with the flow' in five years. Therefore, this model is chosen to be modified into a personal model. During the intervention, the effects of several Smart Industry technologies were discussed and acknowledged to be of high importance, mainly to increase the organisation's flexibility. The participants expected labourer shortage and customization to be a large barrier in the future which makes the adoption of Smart Industry technologies necessary. Both participants showed to be able to measure the effects of both variables on the organisations. Especially for the CEO, these conclusions also mainly resulted in a change of barrier perception. The willingness to innovate that was already high, did not change. This could be due to the fact that the participants were already aware (stage 2). Both participants stated to have gained knowledge on all three aspects. However, both participants mentioned they are still not aware of how to specifically adopt these solutions meaning they cannot control the variables yet. Since the effects of both SI and market disruption on the organisational factors were identified and measured, both participants of the third testing session have increased on the knowledge scale from stage 2 to 3 on both variables, and therefore also on SI adoption urgency.

*Session 4*

The participant of the fourth experimental session expected the organisation to be in a situation close to scenario 3 'Being overrun' in five years when no changes will be made. Therefore, this model was chosen to be modified into a personal model. During the intervention, the SI solutions that were already implemented, such as robotisation, were discussed and concluded to have resulted in a high productivity level. However, it was concluded that the SI maturity level needs to be increased mainly to increase the organisation's flexibility, by technologies such as system integration. This is due to the increasing demand for customized product and the indirect effect of low-income country competition. The participant stated that the customers can be affected by low-income country competition, meaning his market share could be affected when the customers can no longer compete. Therefore, the participant stated that the market share needs to be increased, mainly by increasing the organisation's flexibility. These effects were implemented into the model by the participant, who showed to be able to measure these effects. These conclusions are also visible in the participant's increased willingness to innovate with autonomous robotisation and system integration on the pre and post-test. Furthermore, the participant stated to have gained knowledge on all three aspects. Therefore, the participant of the fourth testing session has increased on the scale to stage from stage 2 to stage 3 on both variables, and therefore also on SI adoption urgency.

*Session 5*

The participant of the last experimental session expected the organisation to be in a situation close to scenario 4 'Cashing in on opportunities' in five years. Therefore, this model was chosen to be modified into a personal model. Firstly, the participant stated the organisation already has a strategy regarding Smart Industry that is in operation for a few years. During the session, no new conclusions could be observed. According to the participant, he already had a sufficient level of awareness and the method did not give him new insights. There were also no significant changes that can be detected between the pre and post-test. However, the participant did state that the method was a confirmation of what he was already aware of. Therefore, the participant of the last testing session does not grow on the knowledge scale of Bohn, mainly since he was already on stage 4 (control).

| | *Knowledge stage SI adoption urgency before intervention* | *Knowledge stage SI adoption urgency after intervention* |
|---|---|---|
| *Session 1* | 2 | 3 |
| *Session 2* | Unknown | unknown |
| *Session 3 participant 1* | 2 | 3 |
| *Session 3 participant 2* | 2 | 3 |
| *Session 4* | 2 | 3 |
| *Session 5* | 4 | 4 |

Table 2. Knowledge stage before and after

## 9.2 Shortcomings and advantages

All feedback received during the session and the afterwards evaluation has been identified (Table 3). The most frequently addressed shortcoming is that the method does enable to measure the urgency of SI adoption but does not provide a clear plan for implementation of Smart Industry. Three participants stated that the method does increase the willingness to innovate but gives no clarification on how to take action, which might result in no action being taken. Secondly, two participants stated that it can be confusing that the factors and the effects are measured with different scales. Also, one participant stated that when rating the individual factors, more effects must be taken into consideration that are not included in the model. Lastly, two participants addressed that the method is not usable for all organisations in the metal industry. They stated that it is only relevant for jobber organisations.

The most frequently addressed advantage of the model is that it stimulates thinking about matters that receive too little attention. Five participants stated to be aware of the existence of the discussed possibility of barriers and Smart Industry importance. However, due to ‘day to day business’, it is not the priority it should be. Secondly, three participants stated that the tool provides a clear representation of causal effects. It was stated that the effects in the model are ‘obvious’ but are easier understood when presented as in the method. Lastly, three participants stated that the model shows which factors need to be improved by Smart Industry in order to respond to external threats and barriers.

| *Shortcomings* | *Advantages* |
|---|---|
| It does not provide a clear plan for implementation. (3 participants) | It stimulates thinking about important long-term matters that get too little attention due to everyday business. (5 participants) |
| Measuring individual factors and effects with different scales is be perceived as confusing and complicated. (2 participants) | It is a clear and insightful tool that presents important matters in a logical way. (3 participants) |
| The model and the scenarios are not usable for all metal organisations. (2 participants) | It gives insight into which 'buttons to push' to react to certain effects (3 participants) |
| The scenarios are based on extremes on both variables. (1 participant) | It is a conversation starter between CEOs and employees regarding the future. (2 participants) |
| The method has no added value when awareness is already on a sufficient level. (1 participant) | It is an eyeopener and presents new information regarding SI importance. (2 participants) |
| The method provides a large amount of information to process in a short time. Therefore, information beforehand is necessary. (1 participant) | It gives more insight into future plausible scenarios. (1 participant) |
| | It is an independent source of information. (1 participant) |

Table 3. Shortcomings vs. Advantages

# 10. Discussion and conclusion

## 10.1 Conclusion

This study researched the effect of a system dynamics-based method on the awareness development of SI adoption urgency of CEOs in the Dutch metal Industry to answer the following research question: *To what extent can a system dynamics-based tool with plausible scenarios contribute to awareness development regarding the urgency of Smart Industry adoption?*

This section draws conclusions based on the findings of this research. Firstly, conclusions regarding the findings of the creation of the method are drawn, followed by conclusions regarding the effect of the method.

This research created a method that illustrates future plausible scenarios in the form of system dynamics-based models for executives and allows these executives to create a personalised model based on their expectation. This research showed that in order to create a method that increases SI adoption urgency for a specific industry, both specified scenarios as a system dynamics-based model need to be created. These scenarios need to illustrate plausible futures based on both SI adoption as market disruptive trends. The scenarios that were created by professionals of the Dutch metal industry showed the urgency of SI adoption in markets with high and low level of market disruption. These results confirmed the urgency of SI adoption of this industry due to current market trends and threats. However, in order to create specific and well-founded scenarios, certain preliminary steps were taken based on a small case study and interviews with stakeholders to limit the variables to a certain amount of market trends and technologies. Therefore it needs to be addressed that this could lead to the fact that certain technologies and trends that are relevant for some jobber organisations are not considered in the scenarios.

By using these scenarios in the method, executives are exposed to new theories other than their own which is necessary for double-loop learning. Followingly, the system dynamics-based model in which the scenarios are implemented and which is used to build a personalised model needs to be created by identifying key variables and factors for the specific industry. Discussions with stakeholders showed that these models need to be accessible and, therefore, contain a maximum of two variables and six factors affected by these variables.

In the intervention sessions, the method proved to have a positive effect on knowledge growth by enabling executives to measure and estimate the effects of SI adoption and market disruptive trends, meaning they reached stage 3 of Bohns knowledge scale. However, for executives who are already on this stage or higher, the model had no effect on knowledge growth. The method also had no effect on one participant whose organisation could not be identified as a jobber organisation, which confirms the need for specification of this method. Furthermore, the participants stated that the method does increase awareness regarding the urgency of SI adoption, but gives no clarification regarding actual adoption and implementation which is needed to reach stage 4. The participants also say that the method stimulates thinking long-term due to the presented scenarios and helps to become aware of necessary change and innovation by testing the effects of both variables on their organisation.

This means that it could be concluded that the method which stimulates double-loop learning, is only effective for knowledge growth till stage 3 is reached. However, when this method is used by organisations such as consultancies who can additionally provide implementation plans and other support, it is possible that further stages of knowledge can be reached. Even though knowledge growth was identified, it needs to be addressed that the effect of other possible variables is not measured in this research. Variables such as age or education level of the participants could have an effect on knowledge growth due to double-loop learning. This means that the method can show different or no effects when tested with individuals from different age groups, regions or educational levels.

To summarise this section and answer the research question, a system dynamics-based method with implemented scenarios showed to be able to grow the knowledge of SI adoption urgency among executives from SME organisations to level 3 (measure). However, a certain method does need the required specification for both the model as the scenarios that are implemented, in order to be applicable to a specific industry. This specification needs to be created in cooperation with stakeholders and experts from that industry. Furthermore, such a method needs to be accessible, clearly presented and guided by a moderator. However, it will most probably still not increase the adoption rate directly due to the lack of an implementation plan but can be used to increase the awareness of SI adoption urgency.

## 10.2 Recommendations for future research

In the final section, the limitations of this research will be discussed and recommendations for future research will be given. Despite the useful findings resulting from the research phases, this study also contains some limitations. Firstly, the created and tested method was specified on jobber organisations of the Dutch metal industry. This leads to limitations regarding the external validity since it is not clear if the results are generalisable for other types of organisations and other industries as well. Therefore, future research could test this method specified to different industries. Secondly, due to the qualitative nature of the experimental sessions, they were conducted with a relatively small sample size which limits the internal validity of the results. Future research could test this method with a larger number to gather more data. Also, the method could be tested in different settings such as more participants at once, which could stimulate discussions between the participants and therefore result in more new insights. This effect was already visible in the testing session conducted with two participants from the same organisation. Lastly, the effect of other variables is not measured in this research. Future research can test the effect of variables such as age, educational level and region of residence on the effect of the method on knowledge growth.

## 10.3 Practical and theoretical implications

**Practical implications**

This research provides an effective method that can be used to increase awareness regarding SI adoption urgency. This method can be used by consultancies such as Boost Smart Industries to fasten the necessary adoption of SI among SMEs. However, as explained in the conclusion, the method does increase awareness but will most probably not result in a higher adoption rate directly since it does not provide clarification regarding implementation. Therefore, it should be used by organisations that can provide certain plans and support for this implementation. Furthermore, the steps taken in this research to create the method have proven to be effective. Therefore, this method can be re-created to be used in other industries as well in order to fasten SI adoption. However, for this method to be effective, it needs to be specified to certain industry by creating system dynamics-based models and scenarios specifically created for this industry.

**Theoretical implications**

The results of this research show that system dynamics-based models can stimulate double-loop learning in order to achieve knowledge growth. When enabling individuals to create models specified to their organisation, it stimulates to rethink their existing theories by measuring and estimating effects from driving variables on their organisation. This research also proves that scenario planning can be used for more purposes than just strategic planning, as which it is described in most existing literature. The scenarios created in this research proved to stimulate organisational learning.

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# Appendices

## Appendix 1. Semi-structured Interview set-up

**Information organisation**

1. Can you please give a short introduction regarding your company? How large is the company and how long does it exist?

**Production**

2. Can you please give a description of the (primary) production processes?
3. What kind of machines are used for these processes and to what extent are these processes automized?
4. Which measures have been taken to counteract crashes and defects?
5. Is the production purely dependant on incoming orders or do you also build up stock?

**Supply chain**

*Suppliers*

6. How does the selection of suppliers work and what is included in the contracts?
7. What is the delivery time of the materials, is this flexible?

*Customers*

8. What type of organisations are your customers and how are these customers gained and maintained?
9. How are orders created and treated?
10. How are demands such as customization, price and delivery time agreed upon?
11. Do you also deliver services such as maintenance or reparation for delivered products?

**Employees**

12. How are new employees gained and how is the availability of labourers currently?
13. Are there growth opportunities for the employees and is there attention for development, for example in the form of training or education?

**Innovation**

14. What innovations have been implemented recently (last 5 years and are there plans for further innovation implementation for the next 5 years?
15. Is there a specific R&D team? If yes, is this internally or in cooperation with other organisations?

## Appendix 2. Results surveys

| | Participant 1 | | | | Participant 2 | | | | Participant 3 | | | | Participant 4 | | | | Participant 5 | | | | Participant 6 | | | | Participant 7 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Dif | con | Pre | Post | Dif | Con | Pre | Post | Dif | Con | Pre | Post | Dif | Con | Pre | Post | Dif | Con | Pre | Post | Dif | Con | Pre | Post | Dif | Con |
| Automation/Robots Importance now | 4 | 4 | - | | 2 | 2 | - | | 4 | 4 | - | | 4 | 4 | - | | 5 | 4 | -1 | X | 5 | 4 | -1 | | 4 | 4 | - | |
| System integration importance now | 5 | 5 | - | | 5 | 4 | -1 | | 5 | 4 | -1 | X | 4 | 4 | - | | 5 | 4 | -1 | X | 4 | 3 | -1 | | 5 | 5 | - | |
| 3D printing importance now | 4 | 4 | - | | 4 | 2 | -2 | | 2 | 3 | +1 | X | 4 | 4 | - | | 2 | 1 | -1 | X | 2 | 2 | - | | 4 | 3 | -1 | X |
| Threat labourer shortage now | 4 | 4 | - | | 2 | 4 | +2 | | 4 | 4 | - | | 3 | 4 | +1 | X | 5 | 3 | -2 | X | 4 | 4 | - | | 5 | 5 | - | |
| Threat low-income country competition now | 4 | 1 | -3 | X | 2 | 2 | - | | 3 | 3 | - | | 4 | 4 | +1 | X | 3 | 1 | -1 | X | 4 | 4 | - | | 3 | 5 | +2 | X |
| Threat increasing demand customization now | 1 | 1 | - | | 1 | 2 | +1 | | 3 | 4 | +1 | X | 3 | 4 | +1 | X | 4 | 4 | - | | 3 | 4 | +1 | | 3 | 3 | - | |
| Threat labourer shortage in 5 years | 4 | 4 | - | | 4 | 4 | - | | 4 | 5 | +1 | X | 3 | 4 | +1 | X | 5 | 3 | -2 | X | 4 | 4 | - | | 5 | 5 | - | |
| Threat low-income country competition in 5 years | 4 | 1 | -3 | X | 2 | 2 | - | | 3 | 3 | - | | 4 | 3 | -1 | X | 3 | 1 | -2 | X | 3 | 3 | - | | 4 | 5 | +1 | X |
| Threat increasing demand customization in 5 years | 1 | 1 | - | | 1 | 2 | +1 | | 3 | 4 | +1 | X | 4 | 4 | - | | 5 | 5 | 1 | X | 3 | 3 | - | | 3 | 4 | +1 | X |
| Automation/Robots Importance in 5 years | 4 | 4 | - | | 4 | 3 | -3 | | 5 | 4 | -1 | X | 4 | 4 | - | | 5 | 5 | 1 | X | 5 | 4 | -1 | | 4 | 5 | +1 | |
| System integration importance in 5 years | 5 | 5 | - | | 5 | 5 | - | | 5 | 5 | - | | 4 | 4 | - | | 5 | 5 | 1 | X | 4 | 3 | -1 | | 5 | 5 | - | |
| 3D printing importance in 5 years | 4 | 4 | - | | 3 | 3 | - | | 4 | 4 | - | | 4 | 3 | -1 | X | 5 | 1 | -4 | X | 2 | 2 | - | | 4 | 4 | - | |
| Chance of adoption Automation/Robots | 2 | 1 | -2 | X | 3 | 2 | -1 | | 4 | 4 | - | | 4 | 3 | -1 | | 4 | 5 | +1 | X | 5 | 4 | -1 | | - | - | - | |
| Chance of adoption system integration | 5 | 5 | - | | 4 | 5 | +1 | | 5 | 5 | - | | 3 | 2 | -1 | | 3 | 4 | +1 | X | 4 | 3 | -1 | | - | - | - | |
| Chance of adoption 3D printing | 4 | 4 | - | | 2 | 2 | - | | 4 | 4 | - | | 4 | 2 | -1 | | 1 | 1 | - | | 1 | 2 | +1 | | - | - | - | |

Pre = Pre-survey scores
Post = Post-survey scores
Dif = Difference
Concluded = Concluded in testing session

Table 4 Results pre and post-test