



# Business Models for Industry 4.0

Developing a framework to determine and assess impacts  
on business models in the Dutch oil and gas industry

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Graduation Thesis  
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# BUSINESS MODELS FOR INDUSTRY 4.0

## DEVELOPING A FRAMEWORK TO DETERMINE AND ASSESS IMPACTS ON BUSINESS MODELS IN THE DUTCH OIL AND GAS INDUSTRY

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*“We must develop a comprehensive and globally shared view of how technology is affecting our lives and reshaping our economic, social, cultural, and human environments. There has never been a time of greater promise, or greater peril.”*

--- Klaus Schwab, The Fourth Industrial Revolution – What It Means and How to Respond

## PREFACE

This thesis is the result of eight months of research. I have conducted the research for the partial fulfilment of the requirements for graduation for the Master's degree of Systems Engineering, Policy Analysis and Management at Delft University of Technology. The research was facilitated by Accenture the Netherlands.

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## EXECUTIVE SUMMARY

In the energy industry, owners of assets like oil platforms, gas pipelines and refineries are currently faced with a highly dynamic market. Market developments such as internationalization and low oil prices, as well as environmental issues like climate change and fossil fuel depletion put pressure on the way incumbent firms in the oil and gas industries do their business. Recently however, there is a common belief of a new era of digitized production in the engineering and manufacturing industries. This era is referred to as The Fourth Industrial Revolution, also described as Industry 4.0. The essence of Industry 4.0 is the introduction of Cyber-Physical Systems (CPS) into industrial systems. CPS consist of objects, sensors and actuators that should be able to continuously communicate and exchange information through the Internet of Things (IoT) and so creating connected networks of machines, materials and products along the value chain. Also, Industry 4.0 enables the improvement or even re-engineering of the services and products offered by companies. The paradigm allows the ubiquitous and real-time accessibility of data, and more data will become available. This gives rise to opportunities to more efficient and intelligent analysis and (autonomous) control of industrial systems, and could even cause disruptive changes in the way these systems are designed and utilized. Specific cases of CPS, being combinations of these innovative technologies, are referred to as *Industry 4.0 components* in this study.

The adoption of Industry 4.0 components can allow firms in the manufacturing industry to cope with the dynamics in the market. However, these operational changes have consequences for the way companies offer value to clients, their competitive position in the market and thus their business model. The business models for Industry 4.0 are expected to have a focus on the creation of value from generated data, a more central role for end-users (customers) and networks that enable value creation. The reasoning is that data from value chains can improve automation and operational effectiveness, enabling optimized value creation structures and networks. Furthermore, platforms for CPS or IoT can enable the co-creation of value through networks because they allow for the sharing of data and services between stakeholders.

Available literature offers insights into the characteristics a business model that is effective in the creation and capturing of value taken the business logic of Industry 4.0 components. However, these empirical results are based upon discrete or batch-based production processes, where the production process can be changed disruptively through embedded technology into products (thus creating Smart Products). In the oil and gas industry, the petrochemical products cannot be embedded with technology. Furthermore, the essential difference between the conventional manufacturing industry and the oil and gas industry is that production is done discrete or batch-based, instead of continuous. The exploration of business model changes for Industry 4.0 for continuous industrial production systems is a new field of study. Therefore, available literature does not offer insights into the impacts of Industry 4.0 within this industry. For this reason, the Dutch oil and gas industry is studied, using the following research question: *“How can the impacts of the adoption of Industry 4.0 components on the value proposition, value creation and value capturing characteristics of the business models of owners of industrial production systems in the Dutch oil and gas industry be determined and assessed?”*

The *how* featured in this question indicates the need to create a tool or framework to explore impacts on the business model within this sector. For this purpose, a conceptual framework to identify and assess these impacts was created through literature review and refined with six experts during semi-structured interviews. Furthermore, the refined framework was demonstrated and its practical utility was evaluated by conducting case studies of business models in the upstream, midstream and downstream sectors. Additionally, for comparative purposes, a business model in the steel industry of the Netherlands was studied. The case studies are based on the triangulated results of

desk study, 25 questionnaire responses and four semi-structured interviews with SMEs from the oil, gas and steel industry in the field of Industry 4.0.

## ANSWERING THE RESEARCH QUESTION

The available literature did not provide a specific tool to determine impacts of Industry 4.0 on a business model. For this reason this research provides a framework designed for this purpose. The first step towards the development of such a framework is the identification of expectations regarding appropriate business models for Industry 4.0. Through a literature study, combined with expert interviews, an appropriate business model for Industry 4.0 should show the following ten characteristics:

1. A high level of differentiation and customization with respect to the product and service offering;
2. A comprehensive service offering, in addition to the offered products. The optimal balance between the complementary products and services needs to be found;
3. An automated process for data collection on asset, plant and enterprise level;
4. The use of gathered data for the assessment of equipment condition and health. Examples are condition-based maintenance and preventive maintenance of assets;
5. A well-defined innovation process for both product/service innovations (value propositions) as well as for innovations aimed at new ways of working (operational excellence);
6. A value network of partnerships between the company and its suppliers and customers wherein co-production and development can be done and alignment of workflows and responsibilities is done;
7. Horizontal integration of equipment, assets, plants and suppliers and customers through a digitalized supply chain;
8. Vertical integration through integration of sensors and actuators with control, production, MES and ERP systems;
9. Data-based revenue sources to gain value from the increased importance of information;
10. Smart and flexible contracts

Since the goal of this research is to design a framework that can be used to assess impacts of Industry 4.0 on business models, the above-mentioned characteristics were translated into a list of five appearances of these characteristic. Consequently, a model was created which takes the expectations of the appropriate business models as desired situation. After this, literature research and six interviews with experts in the field of Industry 4.0 and business models led to the creation of a five-point scaled description of appearances of each characteristic, ranging from less appropriate for Industry 4.0 to highly appropriate.

The framework was used to evaluate business models in the Dutch oil and gas industry, by conduction case studies in the upstream, midstream and downstream sectors. Impacts on business model characteristics have been observed in all three use cases in the oil and gas industry, as well as in a case study done for a manufacturing company. This indicates that the framework is suitable for the determining of impacts of adoption of Industry 4.0 components on business models of asset owners. However, the business models featured in the case study analyses show many similarities in the sense of production process, asset type and size, network and enterprise structure. Whether the framework is suitable for the evaluation of business models of asset owners that have different characteristics, is studied using tests for nomological validity. The practical utility of the framework was evaluated by examining the scope of the constructs and variables of the framework, as well as its explanatory potential.

## IMPLICATIONS AND RECOMMENDATIONS

Based on the study results, recommendations can be made for asset owners in the oil and gas industry:

- I. The establishment of networks with strategic partners (like technology and service providers), are becomes increasingly important. The safe and secure interconnection of value chains, enables closer and more intensive relationship to suppliers and customers. The creation of value networks with collaborative strategic partners is recommended.
- II. The investment required to upgrade assets to create Industry 4.0 components should not discourage companies. Industry 4.0 components promise several potential cost reductions. Also, new income sources can be found by the asset owners through the development of new product and service offerings.

Also, as a result of this study, multiple suggestions for further research can be made:

- I. Using the framework for the design of new business models, without having to take into account existing business models and structures.
- II. Further examine the interactions and interrelations between the different characteristics and levels within the framework.
- III. Apply the framework on different manufacturing cases, where discrete and batch production is done. The different nature of production is expected to require different business processes. The framework could be tested for appropriateness of evaluating these different business processes. Furthermore, the discrete and batch industries more often produce products that can be made 'smart' due to embedded technology. The creation of smart products shows a lot of potential to increase the interaction between the producer and end-user, and opens the door towards new analytics methods for product use, production optimization and product lifecycle analysis. This leads to the expectation that the value propositions and value capturing models within the discrete and batch industries will change. This hypothesis is yet to be verified by future research.

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# PART I – INTRODUCTION

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# 1 INTRODUCTION

In the energy industry, owners of assets like oil platforms, gas pipelines and refineries are currently facing a highly dynamic market. Market developments such as internationalisation and low oil prices, as well as environmental issues like climate change and fossil fuel depletion put pressure on the way incumbent firms in the oil and gas industries do their business.

In the upstream oil and gas sector, production of crude oil and gas is highly capital intensive. The current prices and volatilities decrease margins on production and operations, increasing investment uncertainties. Nonetheless, the main reason for the low price level is the overproduction of oil and gas by countries like Iran (Smith, 2016). These global trends affect the Dutch oil and gas sector. In the midstream industry for instance, demand for storage is very high due to this overproduction. Currently, oil tankers are forced to anchor in the North Sea because the storage capacity of the terminals falls short (Financieel Dagblad, 2016). In the Dutch downstream sector, refineries have to comply with strict regulations (International Energy Agency, 2012). The owners of these refineries face heavy competition from other parts of the world, like Asia and the Middle East (International Energy Agency, 2012).

These developments however, are just an indication of the vast amount of complexities the firms in the Dutch oil and gas industry have to cope with. Traditionally, the oil and gas industry has been oligopolistic, where large globally operating firms dominate the market. The characteristics of the traditional business model of the large oil and gas companies are described by (Bereznoy, 2015):

- A global approach of value creation for customers of crude oil, gas and petroleum products;
- A large international network of oil and gas assets;
- A single chain of exploration, production, refining, transportation and marketing of hydrocarbons.

In particular for owners of assets in the capital-intensive oil and gas industry, the aforementioned complexities increase investment uncertainties. Also, the appropriateness of the traditional business models of asset owners in the industry are pressured by, among others, the dynamics stated above. To deal with these challenges, companies in the manufacturing industry need the capabilities to manage their complete value chain in a flexible and responsive way.

The adoption of technological innovations can allow firms to cope with dynamics in the market but also change the business logic of a firm. Therefore, the appropriateness of a business model should be continuously evaluated by any company in the manufacturing industry (Teece, 2010; Zott & Amit, 2010). The necessity to evaluate and innovate business models is induced by both market dynamics and technical innovations that make operational improvements possible.

Modern production technology is mostly driven by increasing efficiency of manufacturing processes. These efficiencies however, are mostly accomplished at the level of the individual firm and not over the whole value chain. At the economic level of companies, advances are seen, e.g. in the form of Lean Management. At the manufacturing technology (or Operations Technology) level, innovations in fields like additive manufacturing, robotics are observed (Locke & Wellhausen, 2014). Also at this level, the computing systems that are used to manage (industrial) production processes are becoming more intelligent through integration with innovations from the Information Technology (IT) level. These IT innovations enable more communication between humans and machines. Essential innovations at the IT level are wireless communication, RFID and embedded systems (Monostori, 2014). These developments and advances in technology have all led to significant yet isolated improvements of process efficiency and the quality of products.

Academics and practitioners envision a changing manufacturing landscape, induced by the need for more agile value chains and more collaboration and cooperation along the lifecycle of products, from development and innovation to manufacturing, distribution and service (Gligor & Holcomb, 2012). The innovations at the aforementioned levels of industrial production systems enable synergetic and significant efficiency gains through digital integration of the various steps of the manufacturing process, leading to both horizontal integration (across and along all steps of the value chain) and vertical integration (throughout all layers of automation) (Lanza, Haefner, & Kraemer, 2015)

Multiple recent concepts relate to this vision of fully integrated factories, machinery and products. Examples are the Internet of Things, Cloud-Based Manufacturing, Smart Manufacturing and the Industrial Internet. These concepts can all be incorporated in a new socio-technical paradigm, which is also one of the most important drivers of the need to reevaluate the business model by manufacturing firms. The paradigm is often called "Industry 4.0". This is a paradigm enabled by multiple intelligent technological developments that shows the potential to radically and fundamentally change processes for production and value creation. The concept Industry 4.0 (or Industrie 4.0) refers to the fourth industrial revolution, the previous three being (Kagermann, Wahlster, Helbig, Hellinger, & Stumpf, 2013):

1. The steam engine enabling mechanical production;
2. Mass production enabled by electric energy;
3. Enhanced manufacturing automation enabled by the application of electronic systems and information technology.

The term was introduced at the Hannover Fair in 2011 (Kagermann et al., 2013) and it was launched as a German government initiative in April 2013 (MacDougall, 2014). The essence of Industry 4.0 is the introduction of Cyber-Physical Systems (CPS) into industrial production environments (Heng, 2014; Kagermann et al., 2013; Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Pisching, Junqueira, Filho, & Miyagi, 2015).

CPS consist of objects, sensors and actuators that should be able to continuously communicate and exchange information through the Internet of Things (IoT) and so creating connected networks of physical elements like machines, materials and products along the value chain, within virtual environments (Porter & Heppelmann, 2014; Rudtsch, Gausemeier, Gesing, Mittag, & Peter, 2014). As a consequence of these Cyber-Physical Spaces, Industry 4.0 enables the improvement or even re-engineering of the services and products offered by companies. The paradigm allows the ubiquitous and real-time accessibility of data, and more data will become available. This gives rise to opportunities for more efficient and intelligent analysis and (autonomous) control of industrial systems, and could even cause disruptive changes in the way these systems are designed and utilized. Specific cases of CPS, are referred to as *Industry 4.0 components* in this study.

These operational changes will lead to more complex manufacturing processes, which have consequences for the way companies offer value to clients, their competitive position in the market and thus their business models. Firms in the manufacturing industry The existing literature on Industry 4.0 is mostly technology-oriented, while there is a lack of insight into strategic and operational effects of Industry 4.0 components within manufacturing firms. Because of the novelty of the paradigm and lack of proven use cases of Industry 4.0 component adoption, it is unclear what the operational and monetary benefits of adoption of Industry 4.0 elements are and to what extent this will impact the way firms in the oil and gas industry do their business. Experiences have shown that companies have difficulties in grasping the overarching idea of Industry 4.0 and its related concepts and technologies

(Erol, Schumacher, & Sihh, 2016). They have problems relating principles of the paradigm in their operations and strategy. Also, firms are not able to determine to what extent their business strategy and operations align with the Industry 4.0 paradigm and can therefore not effectively determine strategies, plans and projects to transform their business. The tool to gain insight into the impact Industry 4.0 has on business models is not available at this moment. This is the knowledge gap that is addressed in this research.

## 1.1 RESEARCH PROBLEM

Research regarding the impact of adoption of Industry 4.0 components on business models is scarce. This research problem is shaped by developments in the academic field of business models. The specific domain of this research is Industry 4.0, which is a concept not clearly defined in literature. In order to sketch the solution space for this study, the relevant proceedings and issues in both the academic field and the research domain are described consequently. Hereafter, the knowledge gap, research goals, questions, scope and methods are described.

### 1.1.1 CONTEXT AND PROBLEM STATEMENT

The adoption of the technologies enabling Industry 4.0 and related business models within manufacturing environments can be a highly complex and pervasive change process. This process requires the coordinated development of many individual and organizational skills and competencies (Menon, Kärkkäinen, & Lasrado, 2016). Also, an important challenge is that the business model often evolves from business unit level to inter-organizational and even ecosystem-level, with associated increased complexities. Due to the extent and complexity of the Industry 4.0 concept, the understanding of impacts of adoption of Industry 4.0 components on *business models* is lagging among manufacturing firms.

A business model is understood to be the logic for creating value (Linder & Cantrell, 2000), and the logic that connects technical potential with the realization of economic value (Chesbrough & Rosenbloom, 2002). Furthermore, a business model is seen as a tool to position the value proposition of a firm in the value chain (Sabatier, Mangematin, & Rousselle, 2010). Following this logic, the business model as unit of analysis can be used to define how firms should structure their resources, capabilities and processes to create and capture value from the possibilities offered by this fourth industrial revolution.

The field of business model research is characterized by a vague understanding and missing theoretical foundation of the concept itself (Spieth, Schneckenberg, & Ricart, 2014; Zott, Amit, & Massa, 2011). Because of this unstructured nature of the concept, any research into the business model concept requires a definition and elaboration of the understanding of the concept chosen for the specific research. Despite the various focuses on business models, it is regarded to provide managers with a holistic perspective on all of the firms' activities (Spieth et al., 2014). This holistic perspective can be used to develop a business logic around product and service innovations, enabling firms to gain from their potential both monetary and in terms of operational efficiencies (Chesbrough & Rosenbloom, 2002).

The business logic of Industry 4.0 for manufacturers revolves around new value propositions for highly customized and differentiated products, appropriately synchronized product-service combinations and value-adding services (Burmeister, Luettgens, & Piller, 2015; Rudtsch et al., 2014). Also, a digitalized and flexible supply chain together with high equipment efficiencies enable not only cost savings, but also strategic benefits such as short time-to-market, on-demand manufacturing and the improved ability to produce more complex products (Kagermann et al., 2013). This type of change can be technology-driven, whilst the required organizational structure and strategic blueprint lag behind. Taking the business model as unit of analysis, this intra- and inter-organizational change process can be

evaluated, enabling firms to synchronize their efforts of technology adoption and organizational change.

External factors like market changes, increased competition and socio-technological developments like Industry 4.0 are seen as the dominant triggers of Business Model Innovation (BMI) (Linder & Cantrell, 2000). BMI is seen here as a process that results in a qualitatively new business model that differs distinctively from the previous (Bucherer & Uckelmann, 2011). A clear change in elements like the value proposition has to take place, which can be both radical and incremental. The need for new business models for Industry 4.0 by firms in the oil and gas industry is created by:

- The possibilities for new ways of doing business, allowing for dealing with dynamics in the energy market;
- The need for appropriate business models alongside adoption of technological innovations.

Examples of innovative business models that require no new resources or technologies are the development of service orientation for manufacturers and increased customer centricity (Teece, 2010). Opportunities for BMI are commonly triggered by competitive forces, regulatory changes (Zott & Amit, 2010) but recently advances in IT are increasingly inducing the innovation of business models (Burmeister et al., 2015). The adoption of Industry 4.0 components are expected to provide firms in the oil and gas industry with possibilities for BMI. Hence, Industry 4.0 is here seen as an enabler for BMI that allows the firms to deal with the volatilities in the market.

During the process of developing business models for Industry 4.0, an assessment of the opportunities and impacts of adoption of Industry 4.0 components needs to be done. Since there is little empirical evidence on this process, research is necessary to uncover the interrelations between the adoption of Industry 4.0 components and the characteristics of business models in the oil and gas industry. Therefore, this research is aimed at the development of a framework for the assessment of impact of adoption of Industry 4.0 components on business models in the oil and gas industry. The problem statement thus reads:

*Developing appropriate business models for the Fourth Industrial Revolution for firms active in the oil and gas industry, requires a more thorough understanding of 1) opportunities and risks offered by Industry 4.0 components and 2) what business model characteristics are appropriate for gaining potential economic and operational benefits.*

#### 1.1.2 KNOWLEDGE GAP

Different scholars have addressed the business model in various sectors and industries. The business model as a tool has been under development, as many frameworks and ontologies exist. However, no consensus has been reached on its dimensions and nature. Furthermore, business models for Industry 4.0 is a topic that has not been the subject of many studies. Also, analytical frameworks or tools for the development of business models for Industry 4.0 in specific industries have not yet been designed. This research addresses the issue of linking the business model and Industry 4.0 concepts, and applying it to the oil and gas industry.

##### 1.1.2.1 Business models

Business models are frequently characterized by distinguishing various core elements or components (Zott et al., 2011):

- The Value Proposition
- Activities of Value Creation
- Models for Value Capturing



Business models are complex, as they are boundary-spanning entities that link dimensions of corporate strategy, technological capabilities and innovation processes of a company (Spieth et al., 2014). Exactly because of these characteristics, the business model itself has emerged as a promising unit of analysis for innovation (Spieth et al., 2014). However, the multi-disciplinary nature and lack of consensus on the elements or representation of a business model makes it an interesting but slippery unit of study (Morris, Schindehutte, & Allen, 2005; Spieth et al., 2014). This should be kept in mind during a study which has a focus on the business model, and creates the necessity to define coherent dimensions and units of analysis.

The need to change or innovate business models for Industry 4.0 comes from two different lines of reasoning:

- The adoption of technological innovations into business processes should be accompanied by the design of an appropriate business model for the creation and capturing of value from the innovation (e.g. (Chesbrough & Rosenbloom, 2002; Pateli & Giaglis, 2005).
- Value can be obtained by the innovation of the business model, through reconfiguration of extant resources and capabilities (Zott & Amit, 2010).

The innovation of business models is characterized by challenges like overcoming inertia in the organization, path-dependency and rigid corporate structures (Chesbrough, 2010). New value propositions can be highly disruptive as they also impact value creation and capturing activities, structures, resources and processes. When the chances and risks of changes like BMI are not clear to managers, they often react risk and change adverse (Rudtsch et al., 2014). Therefore, the assessment of the actual change from as-is business models and possible to-be scenarios in terms of operational and economic benefits can help to improve overall adoption of Industry 4.0 components.

Due to the novelty of the Industry 4.0 concept many companies lack a comprehensive understanding about the solutions it can offer. Therefore, experimentation and trial and error with novel technologies and related business models are required to learn how to proceed the innovation process. However, the success of these experiments is uncertain and many of them fail because they have not been designed to maximize learning effects among workers. A framework wherein a systemic approach for the evaluation and innovation of the business model for the changing business logic of Industry 4.0 can help overcome this bottleneck in the adoption of Industry 4.0 components for asset owners in the manufacturing industry. Such a framework needs to capture the business logic of Industry 4.0 and translate this into business model theory. The available knowledge on this convergence of concepts is described in the next section.

#### 1.1.2.2 Business models and Industry 4.0

Essentially, Industry 4.0 is a label for the proceeding digitized connection of industrial manufacturing leading to completely digitized, connected, intelligent and autonomous production systems (Hermann, Pentek, & Otto, 2016; Kagermann et al., 2013). Consequently, Industry 4.0 does not result in only production-technical challenges, but also in many organizational challenges, consequences and opportunities (Schuh, Potente, Wesch-Potente, Weber, & Prote, 2014). Taking this into account, industrial firms are advised to evaluate and innovate their business models to remain competitive (Kagermann et al., 2013; Loebbecke & Picot, 2015). Since Industry 4.0 represents a fairly young research domain, which has been mainly studied from a technological perspective, research in the management domain is lagging behind (Brettel, Friederichsen, & Keller, 2014).

In available literature, examples of business models for Industry 4.0 are discussed. The business models for Industry 4.0 are expected to have a focus on the creation of value from generated data, a more central role for end-users (customers) and networks that enable value creation (Kagermann et al., 2013;

Porter & Heppelmann, 2014). The reasoning is that data from value chains can improve automation and operational effectiveness, enabling optimized value creation structures and networks (Burmeister et al., 2015; Kagermann et al., 2013). Furthermore, platforms for CPS or IoT can enable the co-creation of value through networks because they allow for the sharing of data and services between stakeholders (Kagermann et al., 2013). Burmeister et al. (2015) conducted a study on the BMI process for Industry 4.0. Their study was focused on various German manufacturing companies and resulted in an overview of business model characteristics and best practices of BMI for Industry 4.0. Their results showed that certain business model characteristics are perceived to be successful for Industry 4.0. An evaluation of these results can provide this study with a collection of business model characteristics that are desirable in the context of Industry 4.0. A desirable business model characteristic in this case, means a feature of a business model that allows for the effective and efficient value creation and capturing in the light of Industry 4.0 business logic.

The studies mentioned in the previous paragraph all have a predictive nature in the sense that they all describe what a business model *should* look like. However, how firms should develop their business model to resemble the predicted and desired business models is currently unclear. In order to make sense of the *process* of changing existing business practices into business models that are desirable for Industry 4.0, the framework in this study will describe a path for building desirable business model characteristics. In other words, the framework enables firms to evaluate their current business model and gain a better understanding of how to change it towards desired business models for Industry 4.0.

A small number of studies was aimed at studying changes in business models caused by Industry 4.0. (Arnold, Kiel, & Voigt, 2016)<sup>1</sup> conducted a comparative study on the impacts of the Industrial Internet of Things (IIoT) on the business models of established manufacturing companies in Germany. They conducted a qualitative study wherein several business model elements were discussed during interviews with representatives from the German manufacturing industry. As a result, they were able to identify the business model elements that are most likely to change due to the IIoT, based on the percentage of industry professionals mentioning changes in the elements. The findings by Arnold et al. (2016) contribute to the research domain in a different way than this study since the framework and this thesis allows practitioners to understand how the challenges and opportunities associated with Industry 4.0 influence their business model, but also provides them with steps to change it. The current study is in line with Bückner, Hermann, Pentek, & Otto (2016), who made an effort to develop a methodology for business transformation for Industry 4.0. However, Bückner et al. (2016) use the design principles for CPS as described by Hermann et al. (2016) together with desired organizational capabilities to provide a metamodel for the transformation of organizations towards Industry 4.0. Their contributions differ from the one chosen in this study because the framework takes as unit of analysis the business model using the capability based view and the resource-based view as opposed to the activity based view of with organizational processes as unit of analysis.

Although publications on business models in the research domain of Industry 4.0 in the oil and gas industry are scarce, there are available studies that can be used as grounding for the scope and goals of this study. An example is Gassmann, Frankenberger, & Csik, (2013), who suggest that innovative business models can be created by combining existing business models characteristics by looking at business model patterns. Westerlund et al. (2014), also support the use of patterns in BMI, but also suggest the shift of the level of analysis from the company level to a (networked) ecosystem. This should allow for a greater variety of value creation opportunities that can be taken into account. In line with

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<sup>1</sup> Note: The findings from Arnold, Kiel & Voigt (2016) were published in June 2016 and thus not available during the course of this study.

these studies, the choice is made to make use of business model as unit of analysis and look for patterns and the business ecosystem.

The fact that previous studies all have used the manufacturing industry as a domain, illustrates the need for diversification of industries in the research field. The essential difference between the conventional manufacturing industry and the oil and gas industry is that production is done discrete or batch-based, instead of continuous. The exploration of business model changes for Industry 4.0 for continuous industrial production systems is a new field of study.

#### 1.1.2.3 Lack of an Integrated Framework

As described in section 1.1.2.2, management research in the domain of Industry 4.0 is in its infancy. Using the (ecosystem) business model as unit of analysis and building a framework that consists of the desirable business model characteristics for Industry 4.0 and a five-step scale consisting of appearances of these business model characteristics allows firms to evaluate their business model, and identify and assess the impacts of Industry 4.0. This framework integrates conceptualizations of business model characteristics with operational appearances of these characteristics ranging from less desirable according to Industry 4.0 business logic to most desirable for Industry 4.0 business logic. The appearances of these business model characteristics are based upon various academic publications from computer science, engineering, operations research and information systems domains.

The majority of publications on Industry 4.0 have a focus on technology. However, some research on has been published on the characteristics of business models that are considered to be appropriate for Industry 4.0 components (e.g. Burmeister et al., 2015; Westerlund et al., 2014). These results can provide firms in the oil and gas industry with ideas on the possible business model configurations for Industry 4.0. However, available scientific literature does not provide the firms with a tool or framework that allows them to assess the impacts that adoption of Industry 4.0 components has on their existing business model. Doing this assessment is crucial for successful BMI processes (Pateli & Giaglis, 2005). This knowledge gap thus inhibits successful business model innovation in the oil and gas industry at the moment.

## 1.2 RESEARCH GOAL

Based on the above, the goal of this research is to develop a framework that can be used by firms in the oil and gas industry to assess the impacts of adoption of Industry 4.0 components on their business models. The owners of these assets are seen as the problem owner for the research. In order to create such a framework, the link between business model elements and technological characteristics of Industry 4.0 is established in a “if this, then that” overview. This research does not address the process of BMI for Industry 4.0 in the oil and gas industry but is intended to *evaluate* business models and to *identify* impacts on these business models.

## 1.3 Research questions

*“How can the impacts of the adoption of Industry 4.0 components on the value proposition, value creation and value capturing characteristics of the business models of owners of industrial production systems in the Dutch oil and gas industry be determined and assessed?”*

The answering of the following sub-questions is necessary to give a substantiated answer to this main research question:

1. What are frameworks and methods that could aid in determining the impacts of Industry 4.0 on business model characteristics in the oil and gas industry?

2. How is value created and captured in the upstream, midstream and downstream sectors of the oil and gas industry?
  - 2.1. What are the current market conditions in the upstream, midstream and downstream sectors?
  - 2.2. What are current business models in the upstream, midstream and downstream sectors?
3. What are business model characteristics that are appropriate for Industry 4.0 and how can impacts on these characteristics be determined?
4. What are operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry (e.g. labor intensive, unhealthy, unsafe or ineffective operations)?
5. How can operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry be assessed?

These sub-questions are answered in sequential order to gain the required insights to the research problem. Sub-question 1 is used to guide a review of the theoretical concepts of business model concept and Industry 4.0 and the available methods to evaluate impacts on business models. Sub-question 2 aims at the exploration of the research domain, being the oil and gas industry, and more specifically the institutional characteristics that determine the (economic) success of business models in the industry. Sub-question 3 is used to guide the building and refining process of the theoretical framework in this study. Sub-question 4 guides the empirical research in the Dutch oil and gas industry. This step is aimed at the determining and assessing of impacts adoption of Industry 4.0 components on various business models in the industry.

## 1.4 RELEVANCE

Due to an increasingly digitizing world, firms have more opportunities to innovate the way they do their business. The use of innovations like those associated with the Industry 4.0 paradigm can result in cost-reductions, waste reduction, higher profits, and the development of new products and services. In the case of the oil and gas sector, energy-efficiency can be improved, leading to a more sustainable energy system. Other societal benefits of this study could be the knowledge spill-overs concerning successful business model innovation for Industry 4.0. These spill-overs can benefit society since a more customer-centric business approach is associated with these innovations. However, these benefits can only be reaped when the firms in the Dutch oil and gas industry overcome the problems of determining and assessing their state of development with regard to the Industry 4.0 paradigm. The framework should allow a structured analysis of technological competencies, business strategies and operations in the light of Industry 4.0.

The current state of research is extended in two ways. Firstly, by providing a better understanding of Industry 4.0 driven business model changes, in particular within manufacturing businesses with a continuous production process. The structured observation of business model dynamics induced by the Industry 4.0 paradigm in the oil and gas and steel industry gives insight into the state-of-development of business models for Industry 4.0 in this section of the manufacturing industry. The crux of the scientific relevance of the article however, is the way how these insights have been gathered. The framework is a conceptual model of Industry 4.0 business models intended to structure the identification and assessment of impacts of Industry 4.0 on existing business models. This framework is a collection of business model characteristics and related 'appearances' consisting of technical capabilities and operational processes. The framework allows us to collect data on the current and desired state of business models of asset owners across various industries. Using the framework, cross-industry comparisons can be made in order to identify effective combinations of technologies, strategies and operational processes for Industry 4.0.

## 1.5 SCOPE OF THE RESEARCH

The focus of this research is on the oil and gas industry, using the different steps of the value chain to distinguish businesses and business models. For the upstream, midstream and downstream sectors,

the business model of a firm is studied and evaluated to determine impacts of Industry 4.0. Furthermore, the methods developed to determine these impacts are applied to the business model of an industrial production system in the manufacturing industry, for comparison goals.

To limit the case study, the choice has been made to limit the geographical scope of the study to the Netherlands. This choice was made due to the impacts of the different regulatory regimes on strategic choices and thus business models, thus decreasing complexity of the results.

In general, the firms that are active in the oil and gas industry can be classified into three categories:

- The owners and operators of industrial assets;
- The providers of services to asset owners;
- The developers of technological (engineering) systems and solutions for asset owners.

This research focuses on the asset owners, since their business models are like to be affected the most by adoption of Industry 4.0 components. The reason for this is that the lifecycle, management and operations of the assets will change due to the increased possibilities associated with Industry 4.0.

The last step in the case study selection process was to focus on owners of industrial assets with a clear production task. Production here is defined as the process of turning a feedstock of some sorts into one or more different products. The choice for production systems has been made, because CPS enable the autonomous exchange of information through value networks can trigger independent control and fundamentally improve industrial production processes (Hermann et al., 2016; Kagermann et al., 2013).

## 1.6 RESEARCH DESIGN

This section will introduce the design of the research and the structure of this report. It can be seen as the blueprint for the collection, measurement and analysis of data that is deemed necessary to give a grounded answer to the research question.

Considering this research question: *“How can the impacts of the adoption of Industry 4.0 components on the value proposition, value creation and value capturing characteristics of the business models of owners of industrial production systems in the Dutch oil and gas industry be determined and assessed?”* the study can be considered **exploratory** in nature. An exploratory study is “a valuable means of finding out ‘what is happening; to seek new insights; to ask questions and to assess the phenomena in a new light’” (Saunders, Lewis, & Thornhill, 2009 - p59). According to Sekaran & Bougie, (2013), an exploratory study should be done when little facts are known about a situation or phenomenon. During this study, the little information that is available in the shared domain of Industry 4.0 and business models has to be combined to create a ‘theoretical’ framework in order to answer the research question. Since the purpose goal of the study is to *search for* a tool or framework to determine and assess the impacts of the adoption of Industry 4.0 components on the various business model elements of owners of industrial production systems in the Dutch oil and gas industry, it fits the description of exploratory studies given by Sekaran & Bougie (2013). A consequence of making the choice for this type of research is that qualitative methods for empirical research are more effective than a quantitative approach. Various qualitative research methods have been utilized in an attempt to achieve an empirically relevant and scientifically appropriate research design. However, using a qualitative research approach, the construct validity of the ‘theoretical’ framework cannot never fully be determined (Cronbach & Meehl, 1955). In other words, the question whether the framework (or construct) in this study actually measures what is it intended to measure is not irrevocably answerable. Any observed impacts on the business models of the cases under study could be the consequence of a wide variety of instances and developments, which are not necessarily ‘part’ of Industry 4.0. For this reason, multiple qualitative

research methods are chosen for this study. Using these methods and activities complementary to each other, an attempt is made to:

- i) Build a framework which is refined by not only the researcher using multiple scientific and professional literature sources, but also by discussing the framework with selected experts and ;
- ii) Explore the functionality of the framework by applying it to four real-world cases using three research methods complementary to each other (desk study, survey and semi-structured interviews).

This thesis is divided into four distinct parts. In Table 1, an overview is given of the contents of these four parts of the thesis. Also, Table 1 depicts the interrelation between the parts of the thesis and the six research steps that have been executed (A through F). Each of these research steps has different goals, tasks and data collection and research activities. In the remainder of this section, the research parts and steps are described in more detail. In section 1.7, the various methods that have been used to execute the six research steps are elaborated upon.

Part I consists of three sections. Section 1 contains an introduction to the research problem, the problem statement, the guiding research questions, the relevance and scope of the research and the methodology. Section 2 features a description of the theoretical grounding and concepts used in the study. Also, section 2 contains a summary of the expectations expressed in scientific literature regarding desired business model characteristics for industry 4.0. These desired characteristics are essential to the study since they form the starting point for the building of the framework (which is the primary deliverable of the study). In section 3, the real-world setting in which the framework has been used is described. The section entails an analysis of the Dutch oil and gas industry according to the value chain and its institutional characteristics. Part II of the thesis entails a description of the conceptualization of impact on business models and the building and evaluation of the framework, as described in section 4. The basis for the framework is formed by the 1) the expectations regarding appropriate business model characteristics for Industry 4.0 as was found in the literature review (section 2) 2) an extended literature review focused on the creation of a framework depicting five different appearances of these business model characteristics and 3) the opinions and ideas of six experts in the field of business models and Industry 4.0. Part III contains a description of the findings from the four case studies. Section 5 features the application of the refined framework on four cases. A case in this study should be understood as a business model of the ecosystem of asset owners of industrial production systems. Three of these cases within the Dutch oil and gas industry have been studied (upstream, midstream and downstream) and one case in the Dutch manufacturing industry. This fourth case was added to explore the content validity of the framework in a business context outside of the oil and gas industry. The goal of these case studies is twofold:

- To apply the theoretical framework to a real world situation in order to test the validity of the concepts and functionality of its contents (whether the framework can actually be used to determine and assess impacts of Industry 4.0) in this context and;
- To utilize the framework to gain insights into the current state of business models and to potentially identify impacts on these business models caused by Industry 4.0.

The main purpose of part III of the thesis is to describe the attempts that were done to use the framework in real-world settings. In the evaluation part, the findings from the conceptualization and demonstration parts are discussed, and evaluated to reflect on the design of the framework itself and the results that were obtained by using it in the case studies. Additionally, part IV features a reflection upon the research itself and the limitations of the framework.

Table 1 - Research design

Part	Research Steps	Section	Goals and tasks	Data collection and research activities
I. Introduction	A. Preliminary analysis	1	Exploring research scope, goals, questions and methods	Desk research
	B. Literature review	2,3	Defining research scope, providing theoretical grounding for study and conceptual framework	Desk research, literature review,
II. Conceptualization	C. Extended literature review	4	Provide theoretical grounding for appearances of business model characteristics, building framework	Literature review
	D. Expert interviews	4	Discussion and refining of conceptual framework	Semi-structured interviews with Industry 4.0 and Business Model experts
III. Demonstration	E. Case study analysis	5	Using the framework to evaluate three business models in the Dutch oil and gas industry and one in the manufacturing industry with the aim of identifying impacts of Industry 4.0 on business models.	Desk research, Electronic questionnaire, semi-structured interviews with SMEs
IV. Evaluation	F. Synthesis	6, 7	Discussion of results, answering research questions, formulating recommendations based upon findings, reflection on research methods and findings	Comparison of findings from conceptualization and case study analysis. Observing use and function of framework

## 1.7 METHODOLOGY

The methodology consists of six research steps, being a preliminary analysis, a literature review, an extended literature review, expert interviews, case studies and synthesis. Each step is supported by different data collection and research activities. The methods that were chosen in order to complete these six research steps are discussed in the remainder of this section.

### 1.7.1 PRELIMINARY ANALYSIS

In the preliminary analysis, relevant literature was selected through desk research and literature study. These preliminary studies were performed to gain a better understanding of the Fourth Industrial Revolution and business models. The results of this activity were the selection of the theoretical grounding, concepts and the research domain. The choice was made to take the business model as unit of analysis, which has the resource-based view (RBV), capability-based view (CBV) and transaction cost economics (TCE) as theoretical groundings. The chosen research domains are Industry 4.0 and the oil and gas industry, wherein the case studies were limited to owners of industrial production systems in the upstream, midstream, downstream sections of the oil and gas industry and steel sector.

### 1.7.2 LITERATURE REVIEW

The literature review consisted of an extensive desk research and large study of academic literature. The first goal of the literature review was to choose a definition and conceptualization of the business model. Therefore, the scientific databases Google Scholar and Scopus were surveyed for theoretical literature about the relevant topics: *business model*, *ontology*, *business model theory*, *industry 4.0*, *industrie 4.0*, *internet of things*.

Secondly, the literature review was used to create a list of desirable business model characteristics for Industry 4.0. In order to create this list, the following queries were used in order to find empirical literature about earlier research in this field of study in the aforementioned databases of scientific publications: *value creation*, *value capturing*, and *value proposition* in combination with *industry 4.0*, *industrie 4.0*, *internet of things*, *IoT*, *IIoT*.

Thirdly, the literature review was used to define the institutional context of the Dutch oil and gas sector. A selection of available theoretical literature on the oil and gas value chain and business models is used to structure a description of institutional structure of the Dutch oil and gas industry. Using the structure proposed in section 3, the *institutional factors* that characterise the business and market context of the cases under study are discussed in section 5. This step was added to the research as a sample control to evaluate whether any impacts on business models that are identified in the cases under study can be potentially caused by institutional factors that do not have anything to do with Industry 4.0.

### 1.7.3 EXTENDED LITERATURE REVIEW

During this research step, the theoretical concepts and the research domain of Industry 4.0 were integrated into a framework. By looking into the theoretical concepts and their application in multiple practical cases, possible interactions between those concepts can be explored when the assumptions of a single theory do not satisfy the real-world observations. This resulted into a framework, which is the conceptual design discussed in section 4. This conceptual Industry 4.0 Business Model Impact Framework contains the predicted business model characteristics that are deemed appropriate for Industry 4.0 (which were found in the literature review and are introduced in section 2), and corresponding appearances. These appearances are examples of operational processes that are designed to realize the business model characteristic. The five appearances are used to create scales wherein the first shows the characteristic in a form that is deemed less desirable for Industry 4.0, and the fifth shows the most desirable and suitable form according to Industry 4.0 business logic. Several sources have been used for this activity, including scientific publications and method books.

### 1.7.4 EXPERT INTERVIEWS

Six expert interviews were conducted to deepen the authors' understanding of the topics and to evaluate and improve the conceptual framework. The data collection was done during semi-structured interviews, where interview guidelines were sent to the interviewee beforehand. A convenience sampling approach was used, where experts were considered to be actively developing and sharing knowledge in the domain of Industry 4.0 and business models. For this reason, the majority of the interviewed experts are active in academics.

Since the aim of the interviews was to *refine* a conceptual theoretical framework, it does not classify as theory building as described by Glaser & Strauss (1967). Therefore, the steps of integrating the theoretical constructs into a new model was not done in this research step alone. This process of *building* the framework was done iteratively during the research steps B, C and D. This is in line with the iteration step described by Spiggle (1994). Refutation was done by taking a step-by-step approach during the expert interview process. With the first two interviews, a deeper understanding of the concepts was achieved. During the third, fourth and fifth interviews, the contents of the framework



and their theoretical foundations of the descriptions of the different appearances of the business model could be discussed and refined. Finally, the sixth interview was used to reflect on the content validity of the framework on a company which is not an asset owner, but a service provider. This interview led to the conclusion that the cases that were to be studied should focus on the former group.

Table 2 - characteristics of the experts consulted for the validation and partial creation of the framework

#	Expert Name	Occupancy
1	Egbert-Jan Sol	Director Program Bureau at Smart Industry, the Dutch Fourth Industrial Revolution
2	Fred van Houten	Professor Design Engineering at University of Twente
3	Stefan Wiesner	Research Scientist at BIBA, Bremer Institute for Production and Logistics
4	Christian Gülpen	Director Industrie 4.0 at RWTH Aachen
5	Christian Burmeister	Doctoral Researcher at RWTH Aachen
6	Karel Crombach	EMEA Industry Director at Microsoft Corporation

Figure 1 shows schematically the interrelations between research steps B, C, D and E. These are the research steps aimed at the building and application of the framework in this study. The literature review resulted in a list of desired business model characteristics for Industry 4.0. During the extended literature review, five different appearances of these business model characteristics were searched for and ranked according to their desirability for Industry 4.0, taken into account the business logic of Industry 4.0. During the expert interviews, the conceptual model was evaluated and discussed with several experts to refine the Industry 4.0 Business Model Impact Framework that could be used to analyse the cases under study.

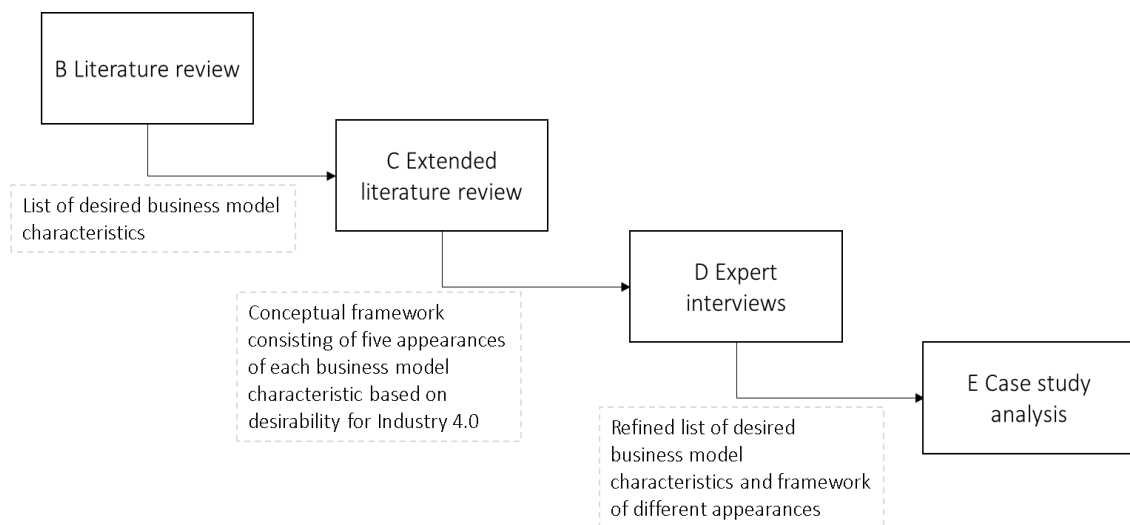


Figure 1 - Interrelations between research steps B, C, D and E

### 1.7.5 CASE STUDY ANALYSIS

As described in the introduction of this thesis, the high topic complexity of the Industry 4.0 paradigm results in uncertainties among manufacturing firms. The firms have difficulties relating the concepts and opportunities to their own specific domain. This uncertainty is an important barrier in the realization of Industry 4.0 principles at these companies. To overcome this barrier, the framework in this study should enable the identification and assessment of impacts of adoption of Industry 4.0 components on current business models. Using the framework, the current capabilities of firms in the oil and gas industry can be evaluated and expected developments of the business model can be documented.

Doing this analysis, using the framework, should enable the firms to plan and coordinate measures towards the realization of business models that are appropriate according to Industry 4.0 business logic. However, whether the framework is useful for companies in developing specific measures towards successful realization of these business models cannot be determined within the scope and timeframe of this study, as this would require for example longitudinal case studies.

Nonetheless, case study analysis is conducted within this study to examine the *practical utility* of the framework. Utility in this case refers to the usefulness of the theoretical framework. The framework consists of constructs and variables and relations between them. Constructs are explanatory variables that cannot be observed directly. Variables are operationalized constructs, intended to allow measurement of the constructs. To evaluate the utility of the framework, the following criteria are used (Bacharach, 1989):

- Scope of the variables and constructs. The variables must sufficiently tap the domain of the constructs, while the constructs must tap the domain of the phenomenon in question;
- The explanatory potential and predictive adequacy of the relationships.

The case study analysis is designed to enable these evaluations. However, the predictive adequacy of the relationships of the framework could not be evaluated since it requires multiple observations of the same phenomenon at various points in time.

In order to 1) evaluate the practical utility of the framework and 2) gain insights into business model dynamics related to Industry 4.0 in the Dutch oil and gas industry, four case studies were conducted. The framework was used to evaluate three business models in the Dutch oil and gas industry and one in the steel industry with the aim of identifying impacts of Industry 4.0 on business models. The choice was made to do multiple case studies to explore the scope of the variables and constructs of the framework and its exploratory potential. Examining multiple cases has certain advantages and disadvantages (Voss, Tsikriktsis, & Frohlich, 2002):

- Advantages are augmented external validity and multiple cases help guard against observer bias;
- Disadvantages are that more resources are needed and there is the consequence of less depth per case.

A case in this study should be understood as a business model of the ecosystem of asset owners of industrial production systems. The purpose of the case studies is to evaluate the utility of the framework to evaluate the business models in the cases, wherein the framework is applied to define and assess impacts of Industry 4.0. For this reason, it is more important to test the pragmatic validity of the framework in multiple real-world settings than to conduct fewer more in-depth case analyses. The guidelines for using case research suggest by Voss et al. (2002) were followed. They suggest the following steps in the in the case study analysis process: 1) developing the research framework, constructs and questions 2) choosing cases 3) developing research instruments and protocols 4) conducting the field research 5) data documentation and coding 7) data analysis.

When case study research is used for theory evaluation, it is typically used in conjunction with survey-based research in order to achieve triangulation of the results (Voss et al., 2002) Using this triangulation approach, different methods are used to study the same phenomenon in order to avoid sharing the weaknesses of the different methods. Because of this advantage of triangulation, and due to time constraints within this study the choice was made to use a survey in addition to the case study interviews with Subject-matter Experts (SMEs) working at the cases under study. This triangulation step was added to increase the *internal validity* of the results.

Due to the sectoral and geographical scope of the study, upstream gas, midstream oil and gas and downstream oil. This choice was based upon multiple criteria for sampling as described in section 5.2.1.

As a *sample control*, the institutional factors found during the literature review were evaluated for the cases under study. Additional desk research was done for this control step. The aim of this control step was to evaluate whether any observed business model impacts could be caused by factors that are not featured in the construct model (framework). This is also the main research step aimed at the testing of *nomological validity*.

The external validity of the results was improved by using an interview protocol, improving replication logic in the multiple case studies (Yin, 1994). The reliability of the findings was improved by developing a structured documentation process and a database (Yin, 1994).

#### 1.7.6 SYNTHESIS

During this research step, a comparison of findings from conceptualization and case study analysis was done. In this research step, sub question 5 of this research will be answered. Using the criteria for testing practical utility, the functionality of the framework within the case study analysis is discussed. Furthermore, the scientific added value of the results was evaluated by reviewing the emergent theory against the existing literature. Also, the limitations of the framework are discussed using multiple observations from the previous research steps.

## 2 LITERATURE REVIEW

*The framework that is created originates from results of available literature sources. In this section, the literature upon which the framework is based is presented. In section 4, the creation of the framework itself is described. The different theoretical concepts and domains that form the basis of the impact framework are described in this section. Firstly, an introduction to the business model is provided. After this, an overview of different business model definitions is given. Hereafter, common business model ontologies and their usage in relevant research fields are described. What follows is an overview of the technological essence of Industry 4.0. Hereafter, the in academic literature predicted suitable business model characteristics for Industry 4.0 for owners of industrial production systems are described. In this section, the following sub-question is answered:*

1.      *What are frameworks and methods that could aid in determining the impacts of Industry 4.0 on business model characteristics in the oil and gas industry?*

### 2.1 BUSINESS MODELS

Business models are templates of ways companies can create, deliver and capture value (Osterwalder, 2004; Teece, 2010). The business model is, like all models that are created to simplify reality, a simplified description of what is happening in a firm, making it visible, manageable and analyzable (Osterwalder, 2004). In accordance with Osterwalder (2004) the business model in this study is considered to be the blueprint of a company’s money earning. This money earning logic is not to be confused with the company’s strategy or its organization and processes. No consensus has been achieved in literature on the nature of the interrelations between strategy and business models. Figure 2 shows this issue in three distinct layers. The figure depicts the business model as a translation of the company’s strategy into a blueprint for money earning logic. The business model can then be implemented into the process layer, where the logic is ‘operationalized’.

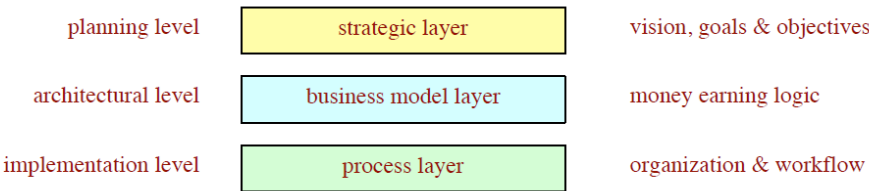


Figure 2 - Business layers indicating the difference between strategy, business model and business processes (Osterwalder, 2004)

The theoretical basis for the concept of business models comes from multiple management theories, among which the resource-based view, transaction cost economics and the capability-based view. These three theories differ in the sense that they each have different goals. TCE sees the firm as a governance structure rather than a production function, by taking the transaction as the unit of analysis (Williamson, 1998). Business models can be evaluated using the TCE perspective by examining governance structures that minimize the cost of transactions. Using this perspective, firms can assess whether will want to ‘make or buy’ a good or service. Furthermore, the TCE can be used to study horizontal and vertical integration, corporate finance, the organization of work and all sorts of contractual relations of firms. The RBV allows firms to address their competitive advantage through key strategic issues like diversification , resource allocation, mergers & acquisitions and market barriers (Wernerfelt, 1984). Using the RBV, firms can aim for a competitive advantage by possessing unique resources. Using the CBV, the *differences* between firms can be studied in terms of their capabilities. Capabilities can be defined as a high level routine that, together with its implementing input flows,

confers upon an organization's management a set of decision options for producing significant outputs of any kind (Hoopes & Madsen, 2008). In other words, capabilities are organizational routines that, with can use the necessary input to produce a certain result. A specific type of 'dynamic' capabilities is frequent in the business model literature, as it describes the capabilities that are required for successful BMI (Teece, 2010). Another perspective on business models is the activity systems perspective (Zott & Amit, 2010), which describes the design of business models as a the interweaving of a set of independent activities performed by the firm itself or by its suppliers, partners and/or customers. The interdependencies between these activities then become a system of activities, describing the business model. All of these perspectives suggest different *representations* and *definitions*. In sections 2.1.1 and 2.1.2, these representations and definitions are discussed and reviewed with the goal of formulating which perspective is chosen for this study.

The logic of a business model is to establish unique combinations of a firms' capabilities and available resources. Having found these combinations, the next step is to find the most efficient way of structuring the transactions between the firm and its suppliers, partners and customers (DaSilva & Trkman, 2014). In order to grasp the money earning logic of a business model, the underlying mechanisms through which business models influence outcomes must be understood (Zott et al., 2011). Examples of these mechanisms are: advantageous costs structures and competitive advantage (Teece, 2010), value chain deconstruction and reconstruction (Timmers, 1998), pricing systems and revenue models (Rappa, 2001). Also, when dealing with new or emerging technologies, business models can help create and capture value from the implementation of these technologies (Chesbrough & Rosenbloom, 2002). The business model is therefore sometimes defined as the connector between technological innovation and value creation (Baden-Fuller & Haefliger, 2013; Chesbrough & Rosenbloom, 2002). Business models should primarily be seen as analytical tools or frameworks that are suitable for the recognition of challenges and opportunities new technologies , as well as the identification of capabilities required to gain economic value from them (Osterwalder, 2004).

Because Industry 4.0 encompasses many technologies and applications, it relates to multiple research domains. Examples of such domains are Cyber-Physical Systems, Product-Service Systems, Internet of Things and manufacturing systems. This implies the boundary-crossing nature of the necessary Industry 4.0 Business Model Impact Framework, and complexities associated with the aggregation of the results of previous studies. In order to gain a comprehensive and reliable answer to the research questions, the complexity should be decreased in the sense that the business model should clearly be defined and the logic for combining different ontologies has to be described.

### 2.1.1 BUSINESS MODEL DEFINITIONS

The emerging literature on business models is scattered with definitions about the nature of the concept. (Teece, 2010) defines the business model as a *management hypothesis* describing customer needs, how they want these needs to be fulfilled and how firms can be organized to fulfil them whilst making a profit. Others consider the business model to be an articulation of how companies create and capture value from technological innovation (Chesbrough & Rosenbloom, 2002).

The business model concept is described in different academic fields of study, such as strategic management (Amit & Zott, 2001; Linder & Cantrell, 2000; Shafer, Smith, & Linder, 2005). In this field, the concept is studied to focus on the implementation of strategies. Another field of study where the concept is used, is Information Systems (IS) (e.g. Bouwman, Faber, Haaker, Kijl, & Reuver, 2008; Osterwalder, Pigneur, Clark, & Smith, 2010). In the IS field, the research into the concept is focused on the design of business models.

The business model is defined differently by various scholars. Examples of these definitions are shown in Table 3.

Table 3 - Examples of Business Model Definitions

Author(s)	Definition
(Osterwalder, 2004)	“A conceptual tool that contains a set of elements and their relationships and allows expressing a company’s logic of earning money. It is a description of the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, in order to generate profitable and sustainable revenue streams” (p.15)
(Shafer et al., 2005)	“A representation of a firm’s underlying core logic and strategic choices for creating and capturing value within a value network” (p.202)
(Morris et al., 2005)	“A concise representation of how interrelated set of decision variables in the areas of venture strategy, architecture, and economics are addressed to create sustainable competitive advantage in defined markets” (p.727)
(Amit & Zott, 2001)	“A business model depicts the content, structure and governance of transactions designed to create value through the exploitation of business opportunities” (p.511)
(Osterwalder et al., 2010)	“The business model is the rationale of how an organization creates, delivers and captures value” (p.14)

The definitions of the business model differ between the previously mentioned research fields. From the strategic management perspective, the business model is considered to be a collection of *activities* that companies use to create and capture value from technological innovation (Chesbrough & Rosenbloom, 2002). In line with Osterwalder (2004), the business model is seen as the ‘glue’ between the company’s strategy and its operations, making it a blueprint for the operationalization of the strategy. Therefore, the definition by Osterwalder (2004) is chosen.

The above-mentioned scholars have described the business model as composing of different elements. Although many different conceptualizations have been made, commonalities between them can be found. A frequently used choice to distinguish business model elements is to separately formulate the value proposition, value creation activities and value capturing models (Johnson, Christensen, & Kagermann, 2008; Zott et al., 2011). This distinction can be made to decrease the complexity of the study and create a high-level overview of the business model.

The business model elements can be differentiated into:

- Value proposition
  - Drivers of customer value and unique offerings of firm
- Activities of value creation
  - Resources, capabilities and processes required to deliver the offering. Starting from partner/supplier relationships to sales channels
- Models for value capture
  - Underlying cost structure and revenue formula, used to determine profitability and economic sustainability

To clarify the *elements* featured in the business model definition by Osterwalder (2004), the choice is made to distinguish a business model into a value proposition, activities of value creation and models for value capture. The choice for this division into three elements has been made because existing representations of business models, or ontologies, can nearly always be deduced to these three elements. Because the specific representation of a business model often varies, it is convenient for this

study to use the more generic distinction of the three business model elements. The ontologies that are described in section 2.1.2 and their relation to the three business model elements are shown in Table 4.

## 2.1.2 BUSINESS MODEL REPRESENTATIONS

Many business model representations exist, each having its own drawbacks and benefits. One of the goals of this literature review is to discuss and aggregate expectations regarding business model characteristics that are appropriate for Industry 4.0 business logic. However, due to the many different representations of elements and their relationships, the aggregation of these expectations is not straight-forward. In order to cope with the differences in these representations, the most common ontologies are evaluated with the purpose of establishing a logical representation of how they can be compared. In Table 3 the commonly used ontologies are mapped according to their usage in Industry 4.0 related research domains. Because the available literature on business models for Industry 4.0 is scarce, no single ontology has been identified as the most frequently used or most appropriate in the research domain. For this reason, various ontologies for business models could be chosen for this research. However, crucial characteristics like the level of analysis (e.g. firm level or business ecosystem) vary between the ontologies. In order to avoid the switching of the level and scope of analyses, thus compromising the results, an overview of the relations between the various ontologies has to be made. For this reason, various ontologies (or representations) of business models are reviewed in the remainder of this section.

Ontologies in the research field of business models are perspectives on the business model concept, and do not refer to the philosophical study of the nature of being, becoming, existence or reality. Ontologies can be used as a tool in the process of finding alternatives to map business models (Osterwalder, 2004). A distinction can be made between the European and American schools of business model research. The European school has a focus on the design of business models and on ontologies (Bouwman et al., 2008), whereas the American school focuses on classifications of business models in specific sectors (Chesbrough, 2003).

A popular ontology is the Business Model Canvas (BMC) (Osterwalder et al., 2010). The business model is composed of nine different elements as shown in Figure 3.

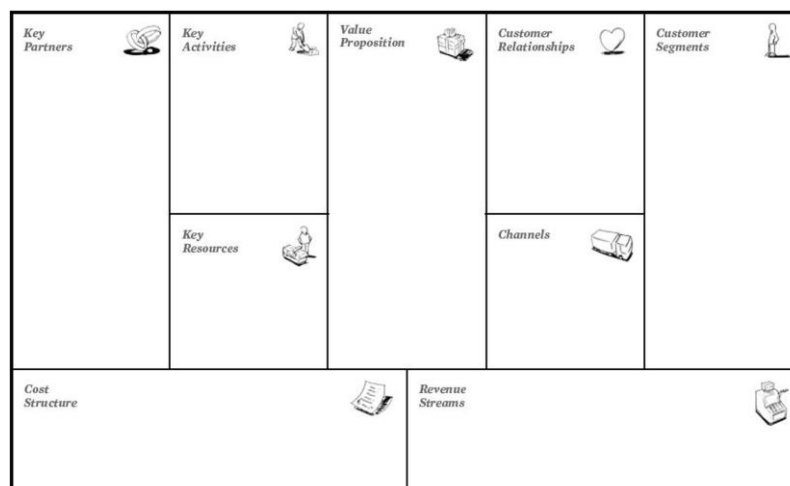


Figure 3 - The Business Model Canvas (Osterwalder, 2004)

The nine elements of the BMC are divided into four categories:

- Value proposition: product;
- Customer interface: target customers, distribution channels, relationships;
- Infrastructure: resources, core competencies, partner network;
- Financials: cost structure, revenue model.

The BMC allows managers alike to brainstorm about different types of business models for their firm. The visual interface of the canvas helps them to identify the different elements of the BMC within their company. Because of the elements, it is easy to experiment with different business models using the BMC (Bouwman et al., 2012). Another advantage of the BMC is that it is widely used across various industries. This could be the result of the generic nature of the canvas. A drawback of the BMC however, is the lack of opportunities it provides to place the individual firm in a (value) network or ecosystem of companies.

Another example of a business model ontology is the STOF model. The model was initially designed for innovation for mobile services. The model contains four domains (Bouwman et al., 2008); service, technology, organization and finance. Even though the focus of the model was intended to be on mobile services, the authors argue it can be adopted in broader fields of business and academia. The STOF model (Figure 4) entails the following elements:

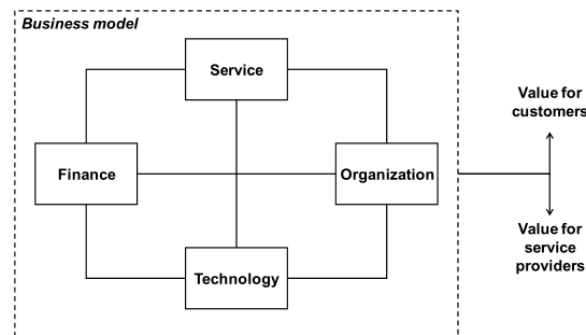


Figure 4 - The STOF Model (Bouwman et al., 2008)

- Service domain: focus on delivery of value to end customers (proposition). The value in question is perceived by customers, and is often influenced by other domains like technological capabilities and contracts.
- Technology domain: focus on technological functionality, infrastructure, architecture and elements.
- Organization domain: focus on process within and with external to the organization. Internal processes have a focus on resource management and allocation, the external processes have a focus on collaboration within the network of the company.
- Finance domain: focus on revenue models and investment decisions.

The CSOFT model (Heikkilä, Heikkilä, & Tinnilä, 2008) is a business model ontology that has an emphasis on long-term services between businesses. The model stresses the importance of customer relationships in business networks. The model can be used to form joined business models between firms, with the customer relationship a central element (Figure 5).



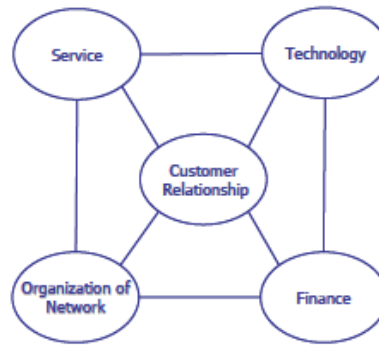


Figure 5 - CSOFT Model (Heikkilä et al., 2008)

The CSOFT is at first appearance very similar to the STOF model. However, these ontologies show important differences. The differences arise in the prescribed interpretation of the five elements of the CSOFT model:

- The customer relationship: focus on long-term customer relationships. These relationships are jointly owned by the involved parties in the network
- The service: the element that creates the value for the customer
- The organization of the network: defines the roles and responsibilities within the business network
- Finance: focuses on cost issues and revenue sharing
- The technology: refers to mainly ICT-related support to the delivered services

Another example is the Magic Triangle developed by scholars of the University of St. Gallen (Gassmann et al., 2013). The Magic Triangle (Figure 6) can be used to sketch out existing business models and experiment with new ones (Bilgeri, Brandt, Lang, Tesch, & Weinberger, 2015). It can be used as a substitute for the BMC, according to personal preference. A strength of the Magic Triangle for this research is its use in research into business models for IoT. This research domain is related to that of business models for Industry 4.0.



Figure 6 - St. Galler Magic Triangle (Gassmann et al., 2013)

In Table 4, the business model ontologies used in the empirical literature associated with Industry 4.0 are shown. The Business Model Canvas for instance, is used at to describe product-service systems (e.g. Barquet, de Oliveira, Amigo, Cunha, & Rozenfeld, 2013), Cyber-Physical Systems (e.g. Wiesner, Padrock,

& Thoben, 2014), Internet of Things (e.g. Bucherer & Uckelmann, 2011), manufacturing service ecosystems (e.g. Wiesner et al., 2014) and mass customization (e.g. Fritscher & Pigneur, 2009). More frequently used in the specific evaluation of business models for ICT services is the STOF Method (Vos & Haaker, 2008), while networked business models have been analyzed using the CSOFT method (Heikkilä et al., 2008). In order to design business models for IoT, (Gassmann et al., 2013) developed the Magic Triangle.

Table 4 - Business Model ontologies used in the research domains associated with Industry 4.0

Business Model Ontology					
		Business Model Canvas	STOF Method	CSOFT Method	St. Gallen Magic Triangle
Research Domain	ICT Services		X		
	Industrial Product-Service Systems	X			
	Cyber-Physical Systems	X			
	Networked Business Models			X	
	Business Models for IoT	X			X
	Manufacturing Service Ecosystem	X			
	Mass Customization	X			

For the purpose of decreasing the complexity of the results, the theoretical constructs of the four discussed ontologies have been analyzed by re-iteratively dimensionalizing and integrating as proposed by (Spiggle, 1994). Doing this, the different constructs of the ontologies could be categorized under the three business model elements as discussed in section 2.1.1. The result of this dimensionalization process is shown in Table 5. For the remainder of this study, the choice is made to use these three elements as level of aggregation as the business model ontology. This is common starting point for business model research (Baden-Fuller & Haefliger, 2013; Casadesus-Masanell & Ricart, 2010; Johnson et al., 2008; Zott et al., 2011).

The choice for this ontology allows for the comparison of opinions on desirable business model characteristics. The depiction of the business model into these three elements provides a high-level overview of the business model, which allows for the comparison of the results of various studies that use different business model ontologies. Also, the high-level ontology decreases the complexity of the constructs and variables of the framework and the relations between them.

Table 5 - Business Model Ontologies and Linkages to Elements

		Ontology			
		BMC	STOF	CSOFT	Magic Triangle
Element	Value proposition	<ul style="list-style-type: none"> <li>Value proposition</li> </ul>	<ul style="list-style-type: none"> <li>Service</li> </ul>	<ul style="list-style-type: none"> <li>Service</li> </ul>	<ul style="list-style-type: none"> <li>What?</li> </ul>
	Value creation	<ul style="list-style-type: none"> <li>Customer interface</li> <li>Infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>Technology</li> <li>Organization</li> </ul>	<ul style="list-style-type: none"> <li>Customer relationship</li> <li>Organization of network (1/2)</li> <li>Technology</li> </ul>	<ul style="list-style-type: none"> <li>Who?</li> <li>How?</li> </ul>
	Value capture	<ul style="list-style-type: none"> <li>Financials</li> </ul>	<ul style="list-style-type: none"> <li>Finance</li> </ul>	<ul style="list-style-type: none"> <li>Organization of network (2./2)</li> </ul>	<ul style="list-style-type: none"> <li>Revenue</li> </ul>

In Table 5, the four ontologies that have been discussed earlier in this section are compared to the high-level ontology that is chosen for this study. The several elements of the BMC, STOF model, CSOFT model and the Magic Triangle are categorized into the three elements of the chosen ontology (value proposition, value creation and value capture). Table 5 was created by dimensionalization and categorization of theoretical constructs featured in the various ontologies. The table has been used to structure and compare the results of previous research in the field of Industry 4.0 business models, which is described in sections 2.2 and 4.

## 2.2 INDUSTRY 4.0

Because of the boundary-crossing nature of Industry 4.0, the concept is challenging to define. In Germany, where it was first introduced, several associations and institutions from the public and private domain cooperated in the creation of a *reference model* for Industry 4.0. This reference model describes the fundamental aspects of Industry 4.0 and is intended to assist in the implementation of Industry 4.0 components. Industry 4.0 components can be defined as specific cases of CPS (Grangel-González et al., 2016). The reference model is called the Reference Architecture Model for Industry 4.0 (RAMI 4.0) and is shown in Figure 7. The model describes the connection between IT, manufacturers/plants and product life cycle through three dimensions (Grangel-González et al., 2016). The left vertical axis reflects the perspective of IT projects, which are usually highly complex. Therefore they are commonly broken down into different components, like business, information, integration, assets etc. The left vertical axis represents the product life cycle. Two main concepts of the product life cycle are *type* and *instance*. The right horizontal axis shows the location of functionalities and responsibilities within a hierarchical organization. RAMI 4.0 builds upon existing industry standards for data management during product life cycle (IEC 62890), enterprise control system integration (IEC 62264) and process control (IEC 61512).

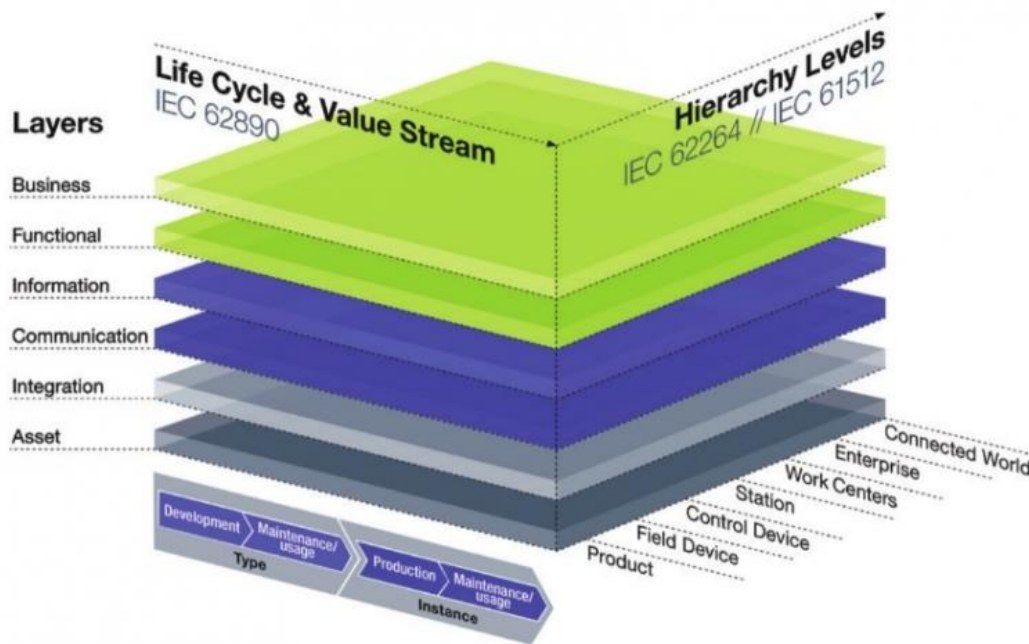


Figure 7- The Reference Architecture Model Industrie 4.0 (Hankel, 2015)

The technical characteristics of Industry 4.0 have been the focus of various studies in the previous three years. The two crucial subsets of Industry 4.0 are Internet of Things and Cyber-Physical Systems. These concepts determine the technical possibilities, but also the business logic of Industry 4.0 components. For this reason, the available literature on business models for IoT (e.g. Bilgeri, Brandt, Lang, Tesch, & Weinberger, 2015; Westerlund et al., 2014) and CPS (Jazdi, 2014) have been used as a starting point for this research.

Ubiquitous availability of real-time and accurate data enables companies to align their processes with others that extend their interconnected supply chain. This creates possibilities to establish cross enterprise linkages and flexible integration along value chains and multiple companies, enabling new networks that create value (Burmeister et al., 2015).

CPS are networks of computers, sensors and actuators that can be embedded in materials, devices or machines and are connected to the internet (Burmeister et al., 2015). The technology in CPS can be divided into multiple layers (Fleisch, Weinberger, & Wortmann, 2015; Porter & Heppelmann, 2014):

- A device or physical layer with added logical capability through sensors and actuators;
- A network layer enabling communication;
- A content layer containing the data and meta-data;
- A service layer for the functionality of the CPS.

The implementation of CPS in industrial production systems will enable the alignment of processes within firms, but perhaps more crucially, also outside firms. This way, multiple companies can be integrated flexibly along the value chain, essentially creation value networks (Burmeister et al., 2015).

## 2.3 INDUSTRY 4.0 BUSINESS MODELS

In this section, the results of the second step of the literature review as described in section 1.7.2 are discussed. The goal of this step of the research was to find and aggregate the expectations regarding a business model that is desirable for the creation and capturing of value according to Industry 4.0

business logic. During phase of the study, theoretical and empirical literature was surveyed, wherein specific keywords (see section 1.7.2) were used in various scientific (on-line) databases. Non-peer reviewed publications were excluded from the review and only publications written in English were included. Descriptions of business models, business model characteristics, business model dynamics and descriptions of the three business model elements in the context of Industry 4.0 and related research domains as discussed in section 2.1.1 were entered into a spreadsheet. Using dimensionalization and Table 5, these descriptions of desirable Industry 4.0 business model characteristics were categorized.

The technological possibilities characterizing Industry 4.0 enable firms to change the way they create and capture value. The products and services they offer can be innovated and new forms of collaboration and knowledge sharing will change the way the firm competes drastically. The literature on these business model innovations for Industry 4.0 is limited and is characterized by overlaps with literature on IoT and technological enablers like Additive Manufacturing and Big Data. In order to create a framework that enables firms to gain insight into the impacts of Industry 4.0 on their business model, the expected business model characteristics for Industry 4.0 are gathered and structured according to the value proposition, value creation and capturing elements.

The available descriptions of suitable Industry 4.0 business model characteristics from the literature review are described subsequently. These descriptions of business model characteristics have been used to create the impact framework, as described in section 4.

### 2.3.1 VALUE PROPOSITIONS FOR INDUSTRY 4.0

The following business model characteristics were found in the literature study to describe appropriate value propositions for Industry 4.0:

- Optimal resource utilization and smart control. Modular and configurable products (Jazdi, 2014)
- New services based on data and information, connected supply chain (Shrouf, Ordieres, & Miragliotta, 2014)
- Combining existing services with available services from other enterprises (horizontal and vertical integration) (Pisching et al., 2015)
- Highly customized products (Piller, Weller, & Kleer, 2015)
- Comprehensive service business & end-customer focus (Burmeister et al., 2015)
- Product-service hybrids (Wiesner et al., 2014)

### 2.3.2 INDUSTRY 4.0 AND VALUE CREATION

Value creation within the Industry 4.0 paradigm is mostly themed around the ecosystem or network perspective. The integration of processes between parties along the value chain will become increasingly possible. However, the business models of firms in these value networks should be designed to enable the co-creation of value. The business model characteristics describing value creating activities for Industry 4.0 that were retrieved from the literature review are the following:

- Connected supply chain (Shrouf et al., 2014)
- End-to-end engineering and horizontal and vertical integration can have a significant increase (Schlechtendahl, Keinert, Kretschmer, Lechler, & Verl, 2014)
- Combining existing services with available services from other enterprises (horizontal and vertical integration) (Pisching et al., 2015)
- Big data collection (Shrouf et al., 2014)

- Connected information flows, close customer relations, short time-to-market, high efficiency, high scalability, high availability, preventive maintenance (Burmeister et al., 2015)

### 2.3.3 INDUSTRY 4.0 AND VALUE CAPTURING

As for the value capturing characteristics of a business model, less indications can be found in the available literature. Some indications mentioned are:

- Value appropriation from data/digital structures, variabilization of prices and costs (Burmeister et al., 2015);
- Cost and risk sharing through innovative revenue structures (Wiesner et al., 2014)

## 2.4 CONCLUSIONS

In order to answer the guiding sub-question, this section had three goals. Reflecting on the sub-question: *What are frameworks and methods that could aid in determining the impacts of Industry 4.0 on business model characteristics in the oil and gas industry?* The results of this literature review are used in multiple ways in the remainder of the study. Firstly, the definition of the business model concept by Osterwalder (2004) is used in the empirical research steps: “A conceptual tool that contains a set of elements and their relationships and allows expressing a company’s logic of earning money. It is a description of the value a company offers to one or several segments of customers and the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, in order to generate profitable and sustainable revenue streams” (p.15). Secondly, a framework was created (Table 5) to enable the comparison between various business model ontologies (or representations). In order to decrease the complexity of the results of the study, as well as the communication towards the respondents of the empirical research steps, the high-level business model representation of three business model elements, being the value proposition, value creating activities and value capturing models. Thirdly, the various characteristics of business models that are deemed appropriate for Industry 4.0 according to peer-reviewed (academic) empirical and theoretical literature are listed in this section. These characteristics will be used to create a representation of a business model that is deemed most appropriate for the business logic of Industry 4.0. Using these characteristics, the framework (as discussed in section 4) could be built.

### 3 THE DUTCH OIL AND GAS INDUSTRY

*This section contains a description of the factors that determine value creation and capturing in the Dutch oil and gas industry, according to the concept of the value chain. This leads to a description of the characteristics of the upstream midstream and downstream sectors according to its institutional factors. The specific institutional factors of a company will determine what strategy will be economically viable. In this chapter, the institutional factors that characterise the upstream, midstream and downstream oil and gas industry are discussed. This information is used and specified for business models in the Dutch oil and gas industry in section 5. The insights from this section will thus be used to guide and structure the research into the institutional characteristics of the cases under study. The following research questions are thereby answered:*

2. *How is value created and captured in the upstream, midstream and downstream sectors of the Dutch oil and gas industry?*
  - 2.1. *What are the current market conditions in the upstream, midstream and downstream sectors?*
  - 2.2. *What are current business models in the upstream, midstream and downstream sectors?*

As described in section 2.1, the business model is defined as a template of ways companies can create, deliver and capture value (Osterwalder, 2004; Teece, 2010). In order to gain insights into the differences in business models in the oil and gas industry, the ways value is offered and created are introduced in this section. To give an overview of the loci and nature of value creation, the value creation process is systematically described in the remainder of this section.

For this study, the oil and gas (or petroleum) industry is described according to its value creation processes. Through value chain analysis as introduced by Porter & Millar (1985), the various activities that are required to gain value from a product or service in the oil and gas industry are identified. The various stages of production and distribution can be classified into the three main steps of the value chain. The analysis can both be done for individual firms, clusters or networks or firms or (inter)national industries. These networks usually involve suppliers, distributors, sellers and customers and are called value systems by (Porter & Millar, 1985).

#### 3.1 THE OIL AND GAS VALUE CHAIN

The oil and gas industry encompasses a range of different activities and processes which jointly contribute to the transformation of underlying petroleum resources into useable end-products valued by industrial and private customers (Wolf, 2009a). These different activities are inherently linked with each other (conceptually, contractually and/or physically), and these linkages might occur within or across individual firms, and within or across national boundaries.

In this section the key activities within the oil and gas industry are described. The concept of the value chain is used to structure the industry.

Figure 8 depicts the oil and gas industry value chain, with its essential stages:

1. Exploration
2. Production
3. Processing
4. Refining
5. Transportation
6. Marketing

This linear process is often distinguished into three subsections of the value chain. These sections are all associated with their respective *activities*. The first is *upstream*, consisting of the exploration (development) of oil and gas resources and production. The second is *midstream*, which consists of transport & storage, and some minor gas processing (sweetening). The third is *downstream*, consisting of the refining of oil, petrochemicals and marketing and distribution. The petrochemical industry is an integral part of the chemical industry. The prefix 'petro' is used to limit the system to those firms, plants and installations that use petroleum-derived feedstock. Generally, the petrochemical industry consists of large-scale continuous process plants.

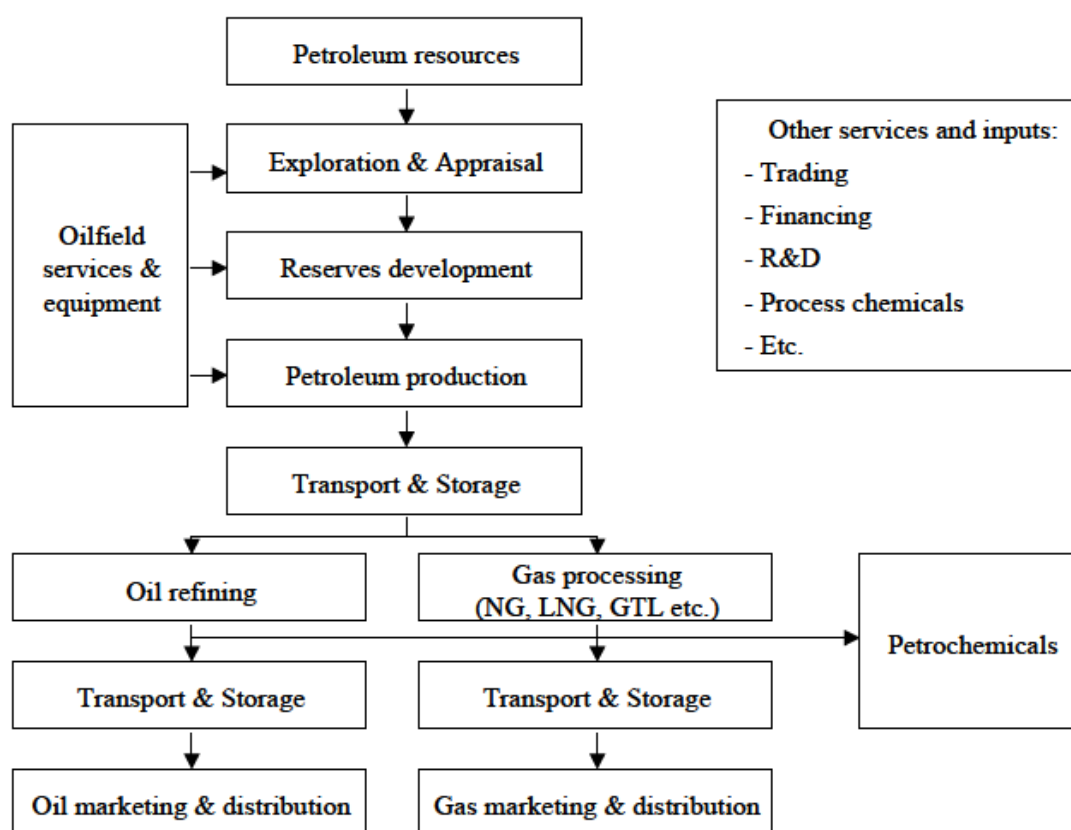


Figure 8 – Petroleum Industry Value Chain (Wolf, 2009a)

Firms can cover one or more activities in this value chain. When a firm is involved with multiple activities, typically vertical integration is done. Vertical integration refers to the integration of successive activities, for instance exploration & processing or transportation & storage. The degree of vertical integration on a national scale is often limited by regulatory and licensing tools. Firms can also engage in horizontal integration, meaning the increase of business scale. The degree of horizontal integration is limited by the volume of available natural resources and the size of domestic markets.

Within the Dutch oil and gas industry, certain activities of the value chain are more dominantly present. The upstream oil (E&P) activities for instance, are typically located in large oil producing, nationally owned companies (OPEC). The Netherlands is not a part of this group. However, the country does own a large amount of natural gas resources. The oil and gas companies in the Netherlands are large traders in both oil and gas. This trading is mostly done through pipelines in the case of gas, although Liquefied Natural Gas (LNG) is also increasingly being traded. Like oil products, LNG is mostly transported from abroad in tanker ships and stored in terminals on shore. For LNG, the value chain is similar to other natural gas, except for the fact that liquefaction is done before long-distance transport in dedicated ships, hereafter the LNG is re-gasified after disembarking (Nunen, Speranza, & Bertazzi, 2009).



### 3.2 SOURCES OF VALUE IN THE OIL AND GAS INDUSTRY

The process of value creation is used to illustrate the differences in business models along the oil and gas value chain. The value that is created along the chain comes from different potential sources or factors. These factors are (Wolf, 2009a):

1. *Exogenous context and conditions.* Many market variables are not within the power of the actor. This can be described as being exogenous to the actors' decision-making power. However, these exogenous factors can affect value creation. Examples are:
  - The quality and quantity of natural resources within the geographical borders of the land the actor has authority (including geographical properties). This determines the availability, cost structure and technical complexity of production (upstream);
  - The position of the land the actor has authority and of its resources. This determines access to domestic and international markets, including accessibility through infrastructure like roads, rivers ports etc.;
  - The structure of the domestic economy, determined by the balance of output, trade incomes and employment. The economic structure leads to a certain dependence on the oil and gas industry, which varies between countries.
2. *The participating companies.* Within the upstream oil and gas sector, these are mostly national oil companies (NOCs) like the Nederlandse Aardolie Maatschappij (NAM) and private oil companies (POCs) like Exxon, Chevron and Shell. In the midstream sector, the resources are traded and shipped by companies like Vitol and stored by companies like Vopak. In the downstream sector, the oil is refined and marketed and sold by firms like Q8 and BP and the gas is processed and distributed by companies like Total and Q8. Also part of the downstream sector are producers of petrochemicals like AkzoNobel.

The owners and operators of oil and gas production or processing installations have a clear role in the value creation process, but the process is also determined by for instance service or capital providers. Examples of sources of value creation are:

- Cost efficient operations. This includes exploration, production, refining and marketing as well as overhead spending and investment efficiency;
  - Technical efficiency and excellence. This boosts recovery rates of sources, lower fuel losses, the yield of higher quality products;
  - Benefits that can be achieved from horizontal integration and concentration (economies of scale) and vertical integration (transaction costs);
  - Strategic choices like asset ownership and selection, domestic and export market participation etc.
3. *The organization and institutional properties of the sector.* Policy decisions and the values, culture and ability and willingness to perform well are key determinants of this factor. Examples of sector organization amongst the companies themselves and top-down governance mechanism are:
    - Capital allocation decisions between different stages of the value chain. Examples are free and competitive markets, market entry restrictions and regulation;
    - Licensing policy for activities like exploration, production, refining, sales and trading etc.;
    - Taxation system including subsidies;
    - More specifically, petroleum and industrial policy, both commercial and non-commercial objectives.
    - Contract types and revenue sources

### 3.3 UPSTREAM VALUE CHAIN

The upstream value chain consists of the activities exploration and production (E&P). The value creating process associated with these activities will be subsequently described in this section.

Oil and gas are the primary hydrocarbon resources. Crude oil is not a consistent product in the sense that its consistency and colour vary from light and almost gaseous to heavy and sludgy. For this reason, crude oil is usually distinguished on its density according to the guidelines of the American Petroleum Institute (API) (Martínez-Palou et al., 2011). Usually light crude oil is classified when it exceeds an API gravity<sup>2</sup> of 38 degrees, and heavy when it has an API gravity of 22 degrees or less. Besides density, crude oil can also be classified according to its Sulphur content. When the crude contains more than 1 percent of Sulphur, it is considered sour. When this is not the case, the batch is referred to as sweet (Wolf, 2009a).

Gas can be recovered from separate sources (or bubbles). These deployments are called non-associated gas. When the gas is found in solution of crude oil, it is referred to as associated gas. Usually, the produced gas consists primarily of methane (or pure natural gas), as well as natural gas liquids (NGLs) like propane, butane and ethane (Wolf, 2009a). The amount of NGLs mixed with the gas determines whether it is classified wet or dry (Nelson & Sommers, 1982). Alongside these methane and NGL products, water and carbon dioxide are found in the gas reservoirs.

A lot of gas reserves have no real commercial value because (Wolf, 2009a):

- They have been found by accident during the exploration for oil;
- Transportation of gas is more intricate and expensive than oil since it has to be done by pipeline or dedicated liquefied natural gas (LNG) containers.

Finding oil and gas reserves that are suitable for exploration is usually done through a survey of the soil using magnetometers, in combination with surface photography. Once a potentially interesting patch of land has been found, more detailed subsurface analysis is done through reflection seismology, which is greatly more expensive (Hübscher & Gohl, 2014). Once the data from these exploration activities is analysed, test drillings are done at high potential hydrocarbon deposits.

Once deposits have been found that are suitable for large quantity production (usually verified by appraisal wells), infrastructure for full-scale production is built. This infrastructure includes the facilitation of the transport of hydrocarbons to processing facilities or more long-distance transportation.

Recently, the increased scarcity of conventional hydrocarbons has increased investments in production of unconventional reserves in shale formations (Shuen, Feiler, & Teece, 2014). These formations are porous sediments that contain natural gas, NGLs and crude oil. Other unconventional resources (non-shale) are: tight gas, coal bed methane, oil sands and heavy oil (Shuen et al., 2014). This development towards more unconventional resources requires a new set of technologies and processes like hydraulic fracturing (fracking).

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<sup>2</sup> API Gravity can be calculated as:  $API = (141.5 / SG) - 131.5$  where

API = Degrees API Gravity

SG = Specific Gravity (at 60°F) ("API Gravity," n.d.)

From a value perspective, the upstream E&P activities are characterized by (among others) (Shuen et al., 2014):

- Long development times. It usually takes five years from the start of exploration to full-scale production;
- For geographically challenging reserves, this can be a lot longer;
- Uncertainties in production and flow;
- Operational risks of damaging reservoirs;
- High capital intensity;
- Trade-offs between stranded assets and cost-intensive complex recovery;
- Depletion of traditional (onshore and shallow-water) reserves.

### 3.4 MIDSTREAM VALUE CHAIN

After production, crude oil and gas is to be processed at dedicated facilities before being marketed and distributed. Along this process, the products are usually stored for various reasons. These reasons include trading and speculation, as well as assuring security of supply.

The storage of crude oil is done in large (in the range of 20-100 meter radius) tanks. The transportation of crude oil can be done by rail, road (inside trucks), water (tanker ships) or pipeline. The crude oil is always transported to a refinery. Crude oil is typically transported from the top oil producing countries via ocean tankers from i.e. the United States, Saudi Arabia, Russia and China ("World's top oil producers," n.d.) to major hubs for import and trading. These hubs have extensive storage and loading facilities. Examples are the ports of Rotterdam and Singapore, the Houston Ship Channel and the Louisiana Offshore Oil Port (Wolf, 2009a). Refineries are typically located in the vicinity of import hubs, in order to decrease transportation costs. After refining, crude oil products can be transported in the same ways as the crude base product.

Natural gas can be stored in both dedicated man-made tankers and terminals, as well as in natural (depleted) reservoirs, salt caverns and aquifers. Natural gas can be transported in both gaseous and

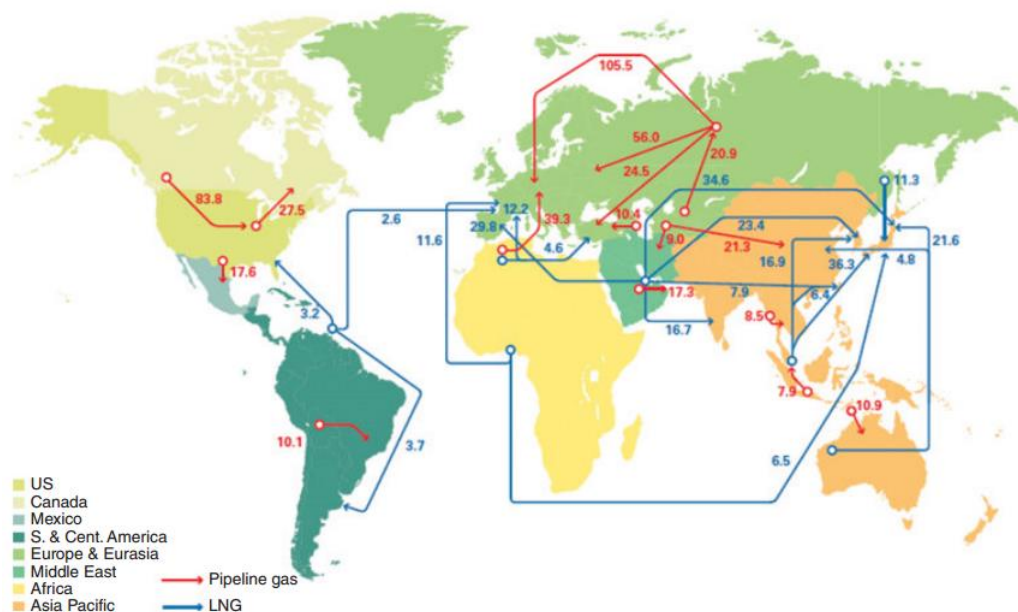


Figure 9 – Major gas trade movements 2012 (Roncoroni, Fusai, & Cummins, 2014)

liquid state. NGLs can be transported via both road (tanker trucks) and pipeline, but dry methane gas

only by pipeline. Due to the necessity for powerful compressors along the pipeline, dry gas cannot be transported over deep sea beds (Wolf, 2009a). This characteristic makes the long-distance transportation unfeasible. Recently, the infrastructure for the transportation of liquefied natural gas (LNG) has undergone strong developments.

The growth of the LNG market has changed the dynamics in the natural gas markets. Building pipelines requires high up-front investments, and non-producing countries are usually not the owner of the pipe network in their country (Wolf, 2009a). As is shown in Figure 9, major gas producing countries are Russia, Norway, the United States and Qatar. However, the Netherlands is also a global top gas producer (Roncoroni, Fusai, & Cummins, 2014).

Due to the aforementioned high associated costs of piped transport, investments have to be backed up by long-term commitments (grid parity contracts) between producers and consumers. This long-term contract investment (un)certainly mechanism has a strong interlinkage with the short-term spot price market for natural gas. For instance, when spot prices are lower than long-term parity contracts, consumers (i.e. energy companies) will be prone to buy at the spot market. Due to the volatility of the spot markets and the long lead times of natural gas infrastructure investments, there will be no incentive for additional infrastructure. When spot prices are higher than long-term contract prices, the higher demand for parity contracts will lead to additional investments in infrastructure. However, when capacity rises more than the demand, prices on the spot market will drop below the parity contracts again.

This dynamic (and asymmetric) risk dispersion in natural gas systems makes highly complex markets. Furthermore, the long-term commitments and ownership of infrastructure issues between multiple countries make the natural gas market highly susceptible to geopolitical issues (Victor, Jaffe, & Hayes, 2006).

### 3.5 DOWNSTREAM VALUE CHAIN

The downstream value chain of the oil and gas industries show significant differences in the i.e. the production, processing, distribution and marketing activities. For this reason, the two segments of the petroleum value chain are discussed separately.

#### 3.5.1 OIL REFINING, MARKETING AND DISTRIBUTION

In the downstream section of the oil and gas value chain, the refining and marketing of petroleum products are the main activities. Before it can be consumed, crude oil needs to be processed (or refined) using a distillation process. The resulting products can be classified into heavy (waxes, base oil, bitumen, heavy oil), middle (kerosene, heating oil) and light distillates (gasoline, naphtha, butane). The main energy related end-uses for distillates from crude oil are (International Energy Agency, 2015):

- Heating;
- Power generation;

- Transportation

Furthermore, the oil products can be used for non-energy purposes, for instance in the petrochemical industry. These end-uses all have different markets which are susceptible to different threats of competing fuels. Transportation and non-energy markets have a specific need for certain hydrocarbons, leading to low vulnerability of fuel substitution. Power generation and heating however, can be done using many other hydrocarbons and non-carbon energy carriers.

The refining of oil is done by the distillation process. During this process, different lengths of hydrocarbons are separated and converted into petroleum products with a higher value. The refining usually consists of different process stages, including separation, conversion and treatment of crude oil products. Refining starts with a process of heating and separation in a distillation column, as shown in Figure 10.

Because crude oil varies greatly in consistency and composition, the market value differs between reservoirs and batches. Light and sweet crudes are more suitable for the production of valuable products like gasoline than heavier and more sour crudes.

The refining business is characterized by profitability that is sensitive to marginal changes in product supply and demand (Wolf, 2009a). Profitability is determined by the gross refining margin (GRM) (Gary & Handwerk, 1975):

- $GRM = \text{received revenues} - (\text{costs of feedstock} + \text{labour costs} + \text{maintenance costs} + \text{working capital costs})$
- GRM excludes non-capital costs like depreciation

The marketing of oil products entails the distribution and sale through petrol stations or wholesale, depending on the target market. The margins for marketing are typically determined by subtracting spot price of gasoline from the pump price (pre-tax). These margins are typically stable and profits at petrol stations is increasing through sales of non-petroleum products (Wolf, 2009a).

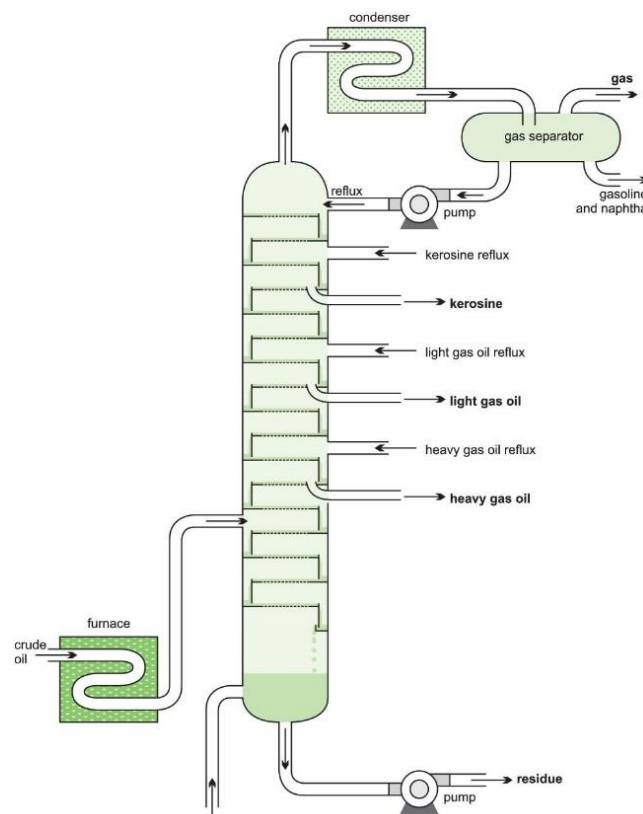


Figure 10 - The fractional distillation of crude oil ('Distillation', n.d.)

### 3.5.2 GAS PROCESSING AND MARKETING

After the production of gas, it has to be processed before it can be transported through a pipeline network. This processing entails the extraction of NGLs and contaminants like H<sub>2</sub>O and CO<sub>2</sub>. These impurities are further processed into valuable constituents and then sold at the market. Natural gas is usually distributed to consumers via pipelines operated by utility companies. However, many oil and gas companies are involved with the long-distance transport and transmission of natural gas. This can entail the direct delivery to large industrial users or an involvement in the ownership and operations of transmission pipeline networks. Furthermore, oil and gas companies are projected to become increasingly involved with the transport and trading of LNG (Wolf, 2009a).

### 3.5.3 PETROCHEMICALS IN THE VALUE CHAIN

Chemicals that use natural gas and crude oil as feedstock are referred to as petrochemicals. These petrochemicals make up for approximately 40% of the chemical market globally (Wolf, 2009a). Olefins and aromatics are the primary groups of base petrochemicals. Olefins include butadiene, propylene and ethylene. Aromatics include xylenes and benzene. 99% of all plastics are derived from oil and natural gas, where most of them are manufactured using naphtha feedstock ("Total Refining & Chemicals - What is petrochemicals?," n.d.). Other examples of products made from oil and gas feedstocks are electronics, paints and tires.

The petrochemical industry is strongly interlinked with the oil and gas industry because the economic and operational benefits of locating petrochemical plants and refineries close to each other. Furthermore, these petrochemical plants often have feedstock transported by pipelines from oil refineries and gas processing plants.

## 3.6 HORIZONTAL AND VERTICAL INTEGRATION

Companies in the oil and gas industry can attempt to gain operational and economic benefits from the integration along the value chain. This integration process can be both horizontal and vertical, and usually generates incremental value (Wolf, 2009a). The micro-economic foundation for these forms of restructuring of the business is diverse.

*Horizontal integration* most often entails the expansion of production capacity for a single product type, thus gaining economies of scale (Eikeland, 2007). The benefits of economies of scale are acknowledged along the entire value chain, but in particular within the activities of exploration and production. The scale can help companies in the industry to better investors and sustain long-term (contractual) relationship with partners like governments. Through *horizontal integration*, a dominant market position can be obtained and sustained.

*Vertical integration* revolves around the existence of market imperfections. Neo-classical economic theories conceptualize this integration type as a strategic response to market power problems in throughout up- mid- or downstream markets. From a transaction cost economics (TCE) perspective, the market power issues are acknowledged, but also takes into the analysis the costs of mediating transactions through market arrangements and bureaucratic costs associated with internal organization (Eikeland, 2007). Reducing these transaction costs requires specific investments for both the buyer and the seller, which changes both the attributes of the *ex post* bargaining space, but also complicates the effects of outside opportunities on *ex ante* investment decisions (Joskow, 2010). *Vertical integration* can also be viewed from a strategic management perspective, in the form of risk management. Regulatory interventions like liberalization may change the market structure and change the loci of (future) value along the value chain. Diversification across value chains and energy sectors revolves around economies of scope. The idea of this strategic choice is the increased efficiency of the distribution and marketing of multiple energy-related products instead of only one.

### 3.7 CONCLUSIONS

Reflecting on the guiding sub-questions for this section:

2. *How is value created and captured in the upstream, midstream and downstream sectors of the Dutch oil and gas industry?*
  - 2.1. *What are the current market conditions in the upstream, midstream and downstream sectors?*
  - 2.2. *What are current business models in the upstream, midstream and downstream sectors?*

It can be concluded that value creation and capturing is done according to a different business logic in the upstream, midstream and downstream sectors of the Dutch oil and gas industry. There are various institutional factors that determine the value creation and capturing processes. According to the structuring of these factors as proposed by Wolf (2009a) the institutional context of the studied cases can be compared: 1) *Exogenous context and conditions*, 2) *The participating companies*, 3) *The organization and institutional properties of the sector*. This step in the comparison is added in an attempt to evaluate whether any observed impacts on the business models under study could be caused by institutional factors that are not associated with Industry 4.0. The business models of asset owners in the Dutch oil and gas industry are characterized by: cost efficient operations, technical efficiency and excellence, benefits that can be achieved from horizontal integration and concentration (economies of scale) and vertical integration (transaction costs), and strategic choices like asset ownership and selection, domestic and export market participation. Decisions about these strategic issues can be used to explain the current state of the business models studied in section 5.

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## PART II - CONCEPTUALIZATION

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## 4 CONCEPTUALIZING INDUSTRY 4.0 COMPONENTS AND BUSINESS MODELS

*In this section, the expectations for appropriate business models for Industry 4.0 as described in section 2 form the starting point for the development of the framework. Firstly, the conceptualization of Industry 4.0 components that was used during the case study analysis is presented. Hereafter, a description of the reasoning and considerations behind the creation of the framework is given. In this section, the following sub-question is answered:*

3. *What are business model characteristics that are appropriate for Industry 4.0 and how can impacts on these characteristics be determined?*

### 4.1 INDUSTRY 4.0 COMPONENTS

Industry 4.0 does not consist of a fixed set of technologies, processes, stakeholders and institutions. However, the Industry 4.0 *components* as described in section 2.2 can be conceptualized. Industry 4.0 components are described in literature as follows: “an Industry 4.0 component can be a production system, an individual machine or station, or an assembly inside a machine. Each Industry 4.0 component constitutes a specific case of a CPS” (Grangel-González et al., 2016, p2).

In order to evaluate and assess the adoption of Industry 4.0 components in the Dutch oil and gas industry, a conceptual model of Industry 4.0 components has been created. This conceptual model is used to *inform* the participants of the case studies about the nature of CPS. Furthermore, the technical diversity of Industry 4.0 was expected to cause difficulties regarding inclusion and exclusion of specific technologies and solutions. In the remainder of this subsection, the creation of the conceptual model for Industry 4.0 components is described.

In order to align the concept of Industry 4.0 between the different respondents of the study, a conceptualization of Industry 4.0 components has been made. This conceptualization was presented to all interviewees to give an idea of the technical nature of Cyber-Physical Systems and at what levels of aggregations the creation and/or adoption of CPS will affect their assets. The model was built using a grounded theory approach suggested by Spiggle (1994). Even though the model has various levels, the concepts featured must still be understood as different levels of analysis. Due to this, the conceptual model is not theoretically accurate. However, the choice was made to use the conceptual model regardless of this weakness, since it is only intended to provide respondents of the study with a simplified depiction of CPS.

Figure 11 represents the conceptual model of Industry 4.0 components as used in this study. The inner ring consists of three elements, being IT, OT and Digital Supply Chain. These three elements, although they show a certain extent of overlap can be regarded to be the most important domains in which technological innovations related to Industry 4.0 can be categorized. Using Industry 4.0 components, the Information Technology (IT) and Operations Technology (OT) domains within and between firms can be integrated (or converged). The IT domain in this context is In order to expand the integration and automation benefits this merging of IT and OT offers, digitalized supply chains expand these improvement throughout networks of companies.

Shown surrounding the inner ring are the so-called enabling technologies. Technological developments in the fields of Autonomous Robots, horizontal and vertical system integration, Additive Manufacturing, Augmented and Virtual Reality, Simulation, Artificial Intelligence and analytics, Industrial Internet of Things, Cybersecurity and Cloud and Blockchain technology continue to enable the realization of Industry 4.0 (BCG, 2015; Brettel et al., 2014). These enabling technologies can, but do not have to be

integrated into Industry 4.0 components. Any combinations of these enabling technologies can be featured in Industry 4.0 components, their integration can be done through hardware and software systems from the OT domain and communication between the technological elements can be facilitated through IT protocols.

Combinations of elements from the inner two rings create the specific cases of CPS. During the design of these Industry 4.0 components, four design principles that will enable their optimal operations have been identified by (Hermann et al., 2016):

- Interoperability of humans, equipment, assets and CPS components enabled by standards;
- Decentralized decision making through embedded computers. By embedding computers into items, equipment, products and other assets enable these elements of CPS to make decisions on their own;
- Information transparency in CPS and aggregation of sensor data enable the creation of virtual copies of physical systems;
- Technical assistance for human operators by aggregating data into comprehensible information to enable informed decision-making. Autonomous CPS also assist human in conducting undesirable tasks that are straight-forward, exhausting or unsafe.

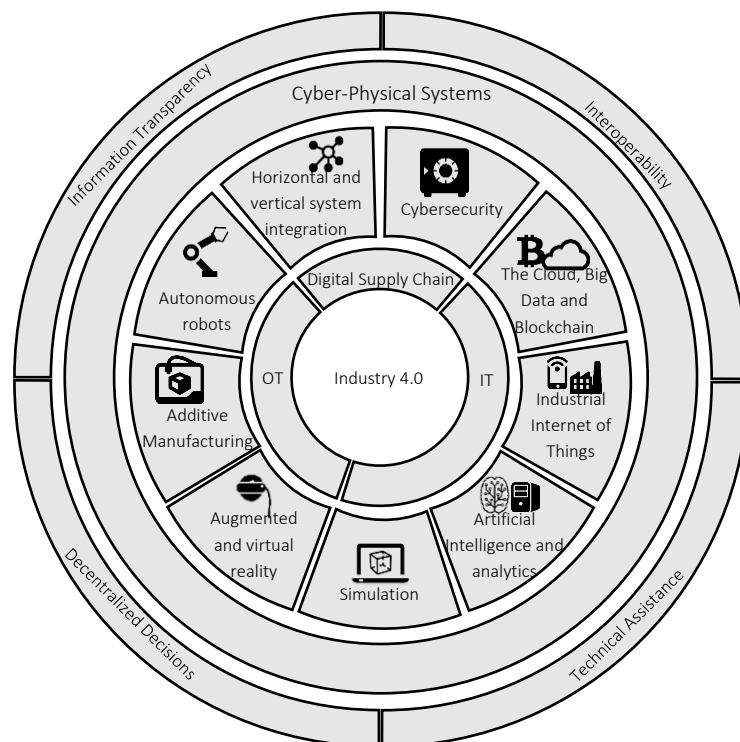


Figure 11 – Conceptual model of Industry 4.0 components. The model has been used as a visual support to explain the CPS concept during the case studies.

These design principles are cross-domain, in the sense that they incorporate technical characteristics, technology traits, business activities and operational protocols.

The conceptual model shown in Figure 11 was used during the case studies, as a visual support in the explanation of CPS to the respondents (when necessary). The model is theoretically inaccurate, because the relations between the concepts can be contested due to their differences in nature. However, the analysis of the case study results is not based upon the depiction of the concepts as shown in the figure.

## 4.2 CONCEPTUALIZING IMPACT OF INDUSTRY 4.0 ON BUSINESS MODELS IN THE OIL AND GAS INDUSTRY

The goal of the Industry 4.0 Business Model Impact Framework within this study is to determine and assess the impact of adoption of Industry 4.0 components on business models. In order to determine the impact, a description of degrees of impact had to be created. The literature offers insights into the desirable Industry 4.0 business model characteristics, which can be considered to be the ideal situation. The choice is made to create a five-point scaled model, where 1 represents a business model that is not at all appropriate for Industry 4.0, and 5 the desired situation as described in the available literature. The steps in the scale represent appearances of the specific business model characteristic. The framework was built and refined according to the steps shown in Figure 1. The literature review provided a list of business model characteristics that are desirable for the creation and capturing of value according to the Industry 4.0 business logic. During the extended literature review, this list of characteristics was refined using a grounded theory approach (Spiggle, 1994). Concepts were compared and categorized to create a final list of 10 characteristics (note that the conceptual model contained thirteen characteristics). During the extended literature review, appearances of these characteristics were searched using academic databases. The queries used in Scopus and Google Scholar for this extended literature review are combinations of: *differentiation, customization, products, services, product-service offering, capturing value from data, CPS value, vertical integration, innovation, open innovation, horizontal integration, value system, revenue sources, blockchain, smart contracts, dynamic contracts, industry 4.0, industrie 4.0, CPS, IoT, IIoT*.

Theoretical literature was reviewed to create five appearances of the business model characteristic, and rank them according to their ability to effectively create and capture value according to Industry 4.0 business logic. This process is described in the remainder of section 4.2. Furthermore, the framework was refined by discussing it with experts in the fields of business modeling and Industry 4.0.

From the literature review it can be concluded that whichever definition or ontology for business models is chosen, the value proposition, value creating activities and value capturing methods can often be distinguished as core elements. From the literature it also becomes clear what an Industry 4.0 business model can and will probably consist of. For these reasons, the Industry 4.0 Business Model Impact Framework consists of three elements, being the value proposition, value creation and value capturing. In these three elements (as shown in section 3.1), the expected business model characteristics that are suitable and appropriate for Industry 4.0 found in academic literature are clustered and shown (as introduced in section 2.3). This section features a description of the extended literature review and the expert interviews that were the data collection methods upon which the framework has been created.

To create the intended impact framework, an approach to 'operationalize' the business model characteristics has to be developed. The choice is made to create a five-step scale wherein the five appearances of the business model characteristic are ranked upon their suitability for Industry 4.0 business logic. The resulting scales are ordinal, thus any conclusions on results generated with the model can only be based upon ranking. However, various academic sources from fields of study like computer science, engineering, operations research and information systems have been used to describe five appearances of the business model characteristic, ranked upon appropriateness to create and capture value according to Industry 4.0 business logic. These appearances will be which will be introduced consequently. During the design process of the framework, a conceptual model was created and discussed with six experts during interviews.

A description of the experts is shown in Table 2. Experts one and two were consulted for their thought leadership and steering role in Smart Industry, the Dutch equivalent of Industrie 4.0. The third, fourth and fifth experts are German, and were consulted for their scientific contributions in the field of business models for Industry 4.0. Their publications were used to create parts of the conceptual framework, which made them appropriate for feedback on the framework. The sixth expert was consulted for his experience with business modelling in various sectors.

The interviews lasted between 60 and 120 minutes and were, if possible, conducted face-to-face, or by telephone. The interviews were all recorded and summarized. The data analysis process was inductive and based upon the approach suggested by Spiggle (1994). The steps that were done during the data analysis were the categorization, abstraction, comparison, dimensionalization, integration, integration and refutation of data. The starting point was the categorization of data into the thirteen business model characteristics featured in the conceptual framework. This was followed by abstraction of these categorized data into the three business model elements (value proposition, value creation, value capturing) by reflecting on their accordance with the chosen theoretical definitions. During the dimensionalization of the data, polar aspects like capabilities, resources, processes, and offerings were uncovered. Comparisons of the data collected from the interviews were done after each interview to look for similarities and controversies within between the data.

The conceptual framework can be found in Appendix A0. The refined framework can be found below. The discussion with led to the rephrasing and reorganization of some characteristics and to the discovery and formulation of new characteristics. The interviews were conducted according to an interview guide, shown in Appendix A0.1. The questions that guided the expert interviews are:

- Do you agree with the division of the business model into these three elements?
- Do you think that the business model characteristics are a good indication of changes caused by Industry 4.0?
- Do you feel the impacts scales are appropriate, realistic and relevant?
- What is your opinion on the practical use of the framework?

A summary of the interviews is shown in Appendix A0.2. The inputs and contributions from the experts are mentioned in the description of the framework in the remainder of this section.

#### 4.2.1 INDUSTRY 4.0 BUSINESS MODEL IMPACT FRAMEWORK – VALUE PROPOSITIONS

The characteristics shown in section 2.3.1 show overlap. For the value proposition characteristics (Table 6) the suitable business models described in section 3.3.1 were combined to create three categories. As the two of expected the business model characteristics dealt with smart, customized, configurable products (Jazdi, 2014; Pillar et al., 2015), the characteristic 1.Differentiation and customization was formulated. Since the offering of additional services and finding appropriate offerings of products and services was another trend in the literature (Burmeister et al., 2015; Pisching et al., 2015; Shrouf et al., 2014; Wiesner et al., 2014), the characteristic 2.Product-service offering was created.

In the conceptual framework, three categories were classified. These categories were differentiation and customization, end-user centricity and product-service offering. After the interviews with Expert 1 and Expert 3, it became apparent that end-user centricity was inherent to differentiation and customization. Therefore, the end-user centricity was removed from the framework. Expert 2 pointed out that in the manufacturing industry, a shift is made from product focus to production process. The value propositions of firms are changing, but appropriateness of business model is different for every company. Therefore the measurement of appropriateness for Industry 4.0 is not straight-forward. This point of critique was discussed with interviewees 3, 4 and 5. During these interviews, there was a

consensus that the scale for product-service offering appropriately reflects the shift from product to service in the manufacturing industry. However, it is strictly applicable to asset owners of (industrial) production systems.

Table 6 - Value propositions for Industry 4.0

Business model characteristics	Value proposition					Sources
	1	2	3	4	5	
1.Differentiation and customization	Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	One-of-a-kind production	(Piller et al., 2015; Tseng & Piller, 2003) Interviews Expert 1 & Expert 4
2.Product-service offering	Products	Products + services for functionality	Products + services for functionality and availability	No product offering, but manufacturing as a service (MaaS)	OEM as solution provider for end-user, no production done	(Barquet et al., 2013; Bustinza, Parry, & Vendrell-Herrero, 2013; Herterich, Uebernickel, & Brenner, 2015; Mikusz, 2014) Interviews Expert 2 & Expert 3

#### Characteristic 1. Differentiation and customization:

To create a ranking of appearances, literature on Mass Customization (Tseng & Piller, 2003) and business models for fully personalized products using Additive Manufacturing technology (Piller et al., 2015) has been used. These sources describe the development of appropriate differentiation and customization propositions for additive manufacturing and mass customization. Since these two offerings do not cover the full nature of the propositions that can be offered by Industry 4.0, the suggestions from Expert 1 and Expert 4 were used to modify the contents and descriptions of the five appearances. The most desirable characteristic is deemed to be completely customized and uniquely production. This is a one-of-a-kind product or service, tailored fully to the client's wishes. The steps shown in the scale are created by following the logic that customization and personalization add increased customer perceived value to products and services (Tseng & Piller, 2003). The reasoning behind the steps in the scale is that from one to five, the offerings are increasingly created specifically for a customer and the customer is increasingly integrated into the design and production process through services like online platforms.

#### Characteristic 2.Product-service offering

The other characteristic in this section of the framework is the product-service offering by firms. What is referred to here, is the extent to which the products and/or services offered by a firm are complementary to each other and aimed at the tighter integration with customer and suppliers (Bustinza et al., 2013). Various scholars have written about Product-Service Systems (Barquet et al., 2013; Mikusz, 2014), also in combination with CPS (Wiesner et al., 2014). Besides selling products, manufacturing companies compete by offering product-related services throughout the product lifecycle (Herterich et al., 2015). The service business is an increasingly important source of revenue. Examples of such services are maintenance, repair and overhaul (MRO) services as well as technical support. This trend of 'servitization' has led to more interlinked and combined product-service hybrid in industry. Mikusz (2014) argues that Cyber-Physical Systems should be understood as Industrial PSS and (Barquet et al., 2013) show different PSS types and corresponding business model types.

The steps in between the five appearances are based upon the conceptual model of PSS by (Barquet et al., 2013), as shown in Figure 12. Interviewee Expert 3 pointed out that the PSS is an older concept, recently re-applied in the light of Industry 4.0. He suggested that the fourth and fifth appearances could be changed using more modern concepts like Manufacturing as a Service and OEMs as solution providers instead of manufacturers or fabricators.

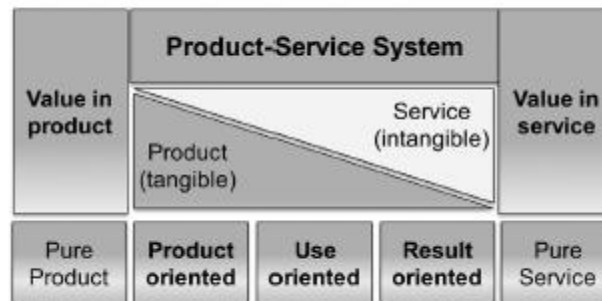


Figure 12- Product-Service System (Barquet et al., 2013)

#### 4.2.2 INDUSTRY 4.0 BUSINESS MODEL IMPACT FRAMEWORK – VALUE CREATION

To create the conceptual framework for the second category (Table 7), the findings from the literature review as described in section 3.3.2 were used to create five additional business model characteristics. Characteristic 3.Data collection was suggested by (Shrouf et al., 2014). Characteristic 4.Data usage, efficiency, scalability and availability was created to summarize some of the suggestions by (Burmeister et al., 2015). The characteristic 5.Innovation process was created to reflect the short time-to-market required in Industry 4.0 (Burmeister et al., 2015). The characteristic 6.Value network centrality (ecosystem) refers to both the horizontal and vertical integration (Schlechtendahl et al., 2014) as to the combination of services with those from other enterprises (Pisching et al., 2015). Characteristic 7.Horizontal integration (networking) was based upon the connected information flows described by (Burmeister et al., 2015) and the connected supply chain described by (Shrouf et al., 2014). Characteristic 8.Vertical integration to CPS is created to reflect the notion of vertically integrated into CPS (Kagermann et al., 2013; Schlechtendahl et al., 2014). None of the interviewees disagreed with these characteristics, however not all of the descriptions of the appearances featured in the conceptual framework were found appropriate and fitting. How these descriptions were changed are discussed at the explanation of the relevant characteristics.

Table 7 - Value creation activities for Industry 4.0

Business model characteristics	Value creation					Sources
	1	2	3	4	5	
3.Data collection	(Occasional) manual data collection	Sensors installed, data integration is not possible due to inconsistency	Network of connected sensors installed	Network of sensors, interoperable with for example RFID and Cloud storage	Network of sensors, RFID, Cloud storage and computation, connected to Manufacturing Execution System	(Gubbi, Buyya, Marusic, & Palaniswami, 2013)
4.Data usage, efficiency, scalability and availability	Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	Adaptive assessment of equipment health in cyber-physical spaces	Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management	(Lee, Kao, & Yang, 2014)
5.Innovation process	Linear design process, no end-user interaction, no prototyping, long time-to market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	Iterative design process, (early) end-user feedback, prototyping	Usage of (un)structured data for product life cycle improvement, short time-to-market	Interview Expert 4 Interview Expert 1 Interview Expert 3
6.Value network centrality (ecosystem)	No partnerships or exchange of services, traditional buyer-seller relationships	Ad-hoc exchange of services and aligning of activities, communication and information exchange	Incidental but recurring exchanges, alignment of company goals and activities for mutual benefits	Service exchange, co-production along the value chain (coordinated)	Alignment of goals, workflow, creation and design and sharing of responsibilities	(Frow, Nenonen, Payne, & Storbacka, 2015; Herrala, 2011; Lusch, Vargo, & Tanniru, 2009) Interview Expert 3
7.Horizontal integration (networking)	Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	Internal communication and collaborative network with either supplier or end-user (external)	Functional collaboration network, data availability through network	(Brettel et al., 2014; Rai, Patnayakuni, & Seth, 2006)
8.Vertical integration to CPS	Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MES systems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)	(Kagermann et al., 2013) Interviews Expert 2 & Expert 3

### Characteristic 3.Data collection

The global availability of real-time data enables sophisticated analysis and intelligent control of the industrial production environment (Shrouf et al., 2014), which significantly extends today's possibilities

and may represent a disruptive technological change (Burmeister et al., 2015). The steps of the five appearances are based upon (Gubbi et al., 2013), who argue that data collection maturity within the domain of IoT moves from asset level, to plant (or factory) level, to enterprise level. Furthermore, they argue this integration is enabled by technologies like Radio-frequency Identification (RFID) and cloud storage.

#### Characteristic 4.Data usage, efficiency, scalability and availability

The usage of data in CPS can be done on five levels (Lee, Ardakani, Yang, & Bagheri, 2015), which form the steps in the five appearances. These levels refer to the collection and usage of data. The first level can be regarded to be highly manual and throughout the levels, the autonomy and intelligence of assets increases. The first level is the connection of equipment data to local data servers through sensors. The second level is the integration, aggregation and interpretation of the various equipment data points. The third level is the usage of the available equipment information for prognostics and equipment health. The fourth level extends the analysis of equipment with product quality reasoning and human operator evaluation. The fifth level represents the optimal usage of data within a CPS, where self-optimization and autonomous operations are possible.

Table 8 - Five Levels of CPS integration in a band saw machine (adapted from Lee et al., 2015)

Levels of CPS	Characteristics
1. Connection level	<ul style="list-style-type: none"> <li>• Sensors and actuators</li> </ul>
2. Data to information level	<ul style="list-style-type: none"> <li>• Sensor data is translated to control parameters</li> </ul>
3. Cyber level	<ul style="list-style-type: none"> <li>• Adaptive health assessment of assets</li> <li>• Utilization based prognostics</li> </ul>
4. Cognition level	<ul style="list-style-type: none"> <li>• Quality and condition check</li> <li>• Product quality reasoning</li> <li>• Human operator evaluation</li> </ul>
5. Configuration level	<ul style="list-style-type: none"> <li>• Self-optimization of the machinery for: <ul style="list-style-type: none"> <li>○ Efficiency requirements</li> <li>○ Quality requirements</li> </ul> </li> </ul>

#### Characteristic 5.Innovation process

The characteristic was discussed with interviewee Expert 1, who said innovation is going so fast that companies cannot do it alone. Expert 4 referred to the literature on open innovation and the use of both structured and unstructured data during the process. Expert 3 remarked that the scale chosen resembled more closely a design process than an innovation process, after which the wording was altered.

#### Characteristic 6.Value network centricity (ecosystem)

A value network is a spontaneously sensing and responding spatial and temporal structure of largely loosely coupled value proposing social and economic actors interacting through institutions and technology, to: (1) co-produce service offerings, (2) exchange service offerings, and (3) co-create value (Lusch et al., 2009). The co-creation of value can be done through various activities (Frow et al., 2015): (1) co-conception of ideas (e.g. crowd-sourced solutions at InnoCentive); (2) co-design (e.g. customization of Dell Computers); (3) co-production (e.g. DIY clinics at Home Depot); (4) co-promotion (e.g. Harley Davidson brand community); (5) co-pricing (e.g. pay-what-you-want restaurants); (6)



codistribution (e.g. Unilever's use of 'last mile' local women distributors in India); (7) co-consumption (e.g. Wet Seal's online users); (8) co-maintenance (e.g. Tesco customer engagement for trolley recovery); (9) co-outsourcing (e.g. Apple's co-outsourcing of 'apps'); (10) co-disposal (e.g. technology companies' recycling initiatives); (11) co-experience (e.g. adventure holidays); and (12) co-meaning creation (e.g. on-line gamers' shared meanings within a virtual world). The above-mentioned characteristics of a value network form the basis of the list of appearances. During the interview with Expert 3, the maturity of value networks can also be characterized by the frequency of collaborations and interactions. This frequency ranges from ad-hoc to full alignment of essential workflow elements. This remark has been implemented in the description of the appearances.

#### Characteristic 7.Horizontal integration (networking)

To exploit the flexibility potential of collaborations, the supply chain has to be designed to allow adaptation of routes and schedules. For high agility, the inventory levels and lead times within the value chain have to be decreased (Brettel et al., 2014). An integrated digital supply chain should not only have optimized physical flows, but also integrated information and financial flows (Rai et al., 2006). When standards enable the integration of information flows, physical objects can communicate with each other. This can lead to full CPS that enable optimized physical flows and financial flows follow (Kagermann et al., 2013). This full integration of the supply chain leads to the ability for end-to-end engineering.

#### Characteristic 8.Vertical integration to CPS

For the creation of the scale that corresponds to this characteristic was based on the IT pyramid and the concept of CPS as described by (Acatech, 2015; Kagermann et al., 2013). The integration of the various architecture layers associated with Industry 4.0 and CPS enables the efficient and disruptive operations of industrial production systems. The RAMI reference framework is designed with the purpose of enabling multi-dimensional integration of CPS as shown in Figure 7.

#### 4.2.3 INDUSTRY 4.0 BUSINESS MODEL IMPACT FRAMEWORK – VALUE CAPTURING

For the third element of the business model (Table 9), little suggestions on appropriate business model characteristics could be found. During the interview with Expert 3, the suggestion came to conceptualize the sources of revenue and rank them from appropriate for Industry 4.0 to less suitable. This suggestion led to the creation of characteristic 9.Revenue sources. Characteristic 10.Smart contracts using Blockchain was suggested by Expert 1, who explained that the Blockchain overthrows every aspect of administrative procedures and mutual alignment of processes.

Table 9 -Value capturing models for Industry 4.0

Business model characteristics	Value capturing					Sources
	1	2	3	4	5	
9.Revenue sources	Traditional sales (buyer-seller)	Sales based on data gathered from internal processes and historical transactions	Product and/or service transaction with extensive service to increase functionality and availability	Data-based transactions, for instance pay-per-use models	As-a-Service revenue model (fully data-based)	(Porter & Heppelmann, 2014)  Interview Expert 3
10.Smart contracts using Blockchain	Traditional legal contract	Dynamic contracts	Digital currency exchange	Peer-to-peer smart contracts	Blockchain used for coordination of monetary, physical and data flows	(Battaglini & Lamba, 2015)  Interview Expert 1

#### Characteristic 9.Revenue sources

In their article in the Harvard Business Review, (Porter & Heppelmann, 2014) described that traditional buyer-seller contracts will be extended with additional services, and will shift towards transactions based fully on service and usage data. The logic of this shift was explained by Expert 3 as certain types of revenue sources might be more appropriate for Industry 4.0 business logic than others.

#### Characteristic 10.Smart contracts using Blockchain

The Blockchain was identified as crucial enabler in Industry 4.0 by Expert 1. In order to create the scale for this characteristic, the literature on Dynamic Contracts by (Battaglini & Lamba, 2015) was combined with suggestions by Expert 1.

### 4.3 OBSERVATIONS AND CONCLUSIONS

During the expert interviews, several observations were done regarding the content validity of the framework and its practical relevance. Expert 1 did not expect that the business model characteristics of firm in the oil and gas industry will change due is limited due to the small margins in production and capital intensity. This leads to limited space for innovations and high path-dependency. However, Expert 1, Expert 3 and Expert 5 acknowledged the relevance in real-world settings. This led to the further motivation for trying to determine and assess any business model impacts in the oil and gas industry. Another observation was that both Expert 2 and Expert 1 mentioned the change of business logic for Industry 4.0 is caused by a shift from economies of scale or scope to economies of networking. Expert 5 pointed out that the framework could potentially be used to look for certain patterns in business model appearances. Certain combinations of appearances could be successful in certain industries or sectors. To uncover such successful patterns, the case study analysis using the framework could be extended to multiple industries. This recommendation could not be included into this study due to time and resource constraints. However, this remark did lead to the conceptualization of the framework as an architecture for business model design, where certain value propositions can be linked to certain value capturing models through the six value capturing activities like schematically shown in Figure 13.

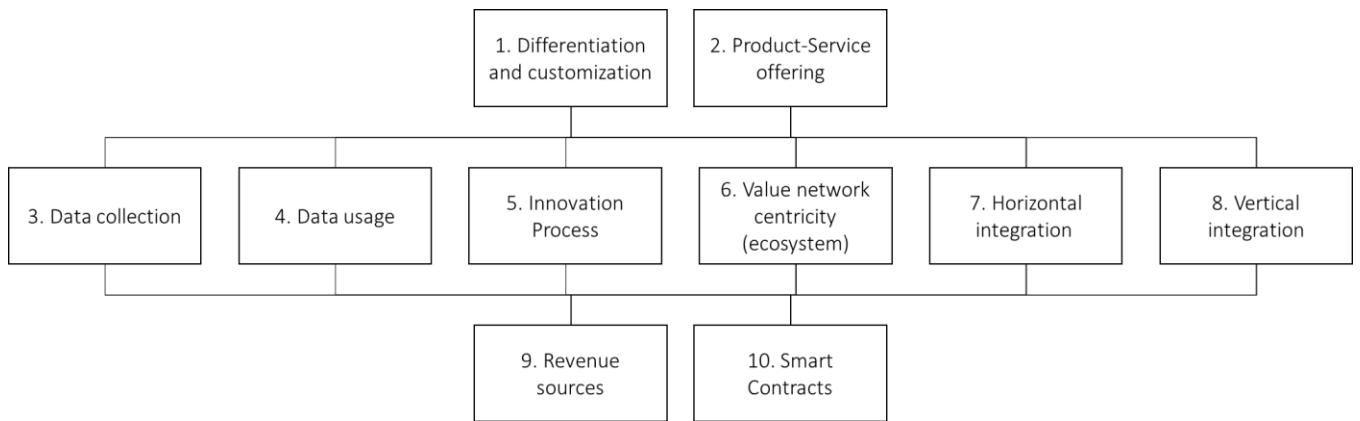


Figure 13 - Conceptual depiction of interactions and dynamics between the ten characteristics of the Industry 4.0 Business Model Impact Framework

Reflecting on the sub-question guiding this section of the thesis: *“What are business model characteristics that are appropriate for Industry 4.0 and how can impacts on these characteristics be determined?”*, it can be suggested that ten business model characteristics are deemed appropriate for the business logic of Industry 4.0. Furthermore, it is hypothesized that impacts on these characteristics can be assessed by empirically examining longitudinal dynamics between various appearances of these characteristics. This can however only be tested by testing predictive adequacy, which falls out of the scope of this study. The scope of the constructs and variables of this framework and its explanatory potential, have yet to be tested. This process of demonstration and testing is described in section 5 of this thesis.

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## PART III – CASE STUDY ANALYSIS

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## 5 RESULTS

*This section describes the empirical analyses and their results aimed at determining impacts of Industry 4.0 on business models in the oil and gas industry. Firstly, the argumentation for the choice of respondents of the questionnaire and the SMEs is given. Secondly, the process for the questionnaire and the results from this research are shown. Thirdly, the results from the four case studies are described. The guiding sub-question for this section is:*

4. *What are operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry (e.g. labor intensive, unhealthy, unsafe or ineffective operations)?*

### 5.1 CASE STUDY DESIGN

In order to test the content validity of the framework, four case studies were conducted. These case studies are intended to uncover business model changes (also called impacts) caused by Industry 4.0. Because the scope of the research is the Dutch oil and gas industry, three of the case studies meet this requirement. The fourth case study serves as a benchmark, and does not meet this requirement. This is explained in more detail in section 5.2.3.

#### 5.1.1 CASE STUDY STRUCTURE

The research framework for the case studies is the framework as presented in section 4 of this thesis. The guiding research questions during the case study were: *“How can the impacts of the adoption of Industry 4.0 components on the value proposition, value creation and value capturing characteristics of the business models of owners of industrial production systems in the Dutch oil and gas industry be determined and assessed?”* and *“What are operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry (e.g. labor intensive, unhealthy, unsafe or ineffective operations)?”* These questions are the main research question and the fourth sub-question that are answered in this thesis.

Next, the research instruments and protocols were developed. This started with the design of the survey, as discussed in section 5.2.4. The framework was used to create a list of questions that had the goal of uncovering the current state of the business model of the respondent. The open questions had to be answered by choosing one of five answers, each corresponding to one of the five appearances of a business model characteristic as featured in the framework. Using these result, the opinion of the SME given during the interview could be triangulated. Next, the interview protocol for the SME interviews was written. The reliability and validity of case research data will be enhanced by a well-designed research protocol (Yin, 1994). The interview protocol was designed to serve as a checklist to make sure all of the topics were covered, but also to address triangulation of the results from the desk study and survey.

The field research was conducted by purposive sampling using the theory of Mintzberg (1993). The respondent selection is described in more detail in sections 5.1.2 and 5.2.4. The data collection in the field research was done through an electronic survey and semi-structured interviews with SMEs at the four companies under study. The semi-structured interviews lasted between 60 and 90 minutes and were conducted at the plant site. The discussion was guided by the framework as described in section 4 of this thesis. Issues relating to the value proposition, value creating activities and value capturing models of the case were explored in these discussions. The introduction of each business model characteristic was followed by an introduction of the survey responses regarding the relevant characteristic. Discrepancies between survey responses and interview discussion were noted and elaborated. All SME interviews were recorded and transcribed.

After the transcription of the interviews, the data was coded into categories as proposed by (Glaser & Strauss, 1967). These categories were pre-defined, as they were the business model characteristics featured in the framework. The analysis of these categorized data was done both within the case and cross-case. The in-case comparison was done by visualizing the observed impacts in a simplified version of the framework, using arrows and colors. The cross-case analysis was done by pairwise comparison of the results.

#### 5.1.2 KNOWLEDGE REQUIREMENTS FOR THE CASE STUDIES

The evaluation of a business model is the examination its evolution or direction(s) of development. The actions of a company that determine this evolution of the business model can be seen as the strategy translation of the company's strategy into operational processes. However, no consensus regarding the interrelations between strategy and business model is reached in the academic literature. To evaluate business models in the case studies, the employees of companies which are actively involved with its strategy are therefore deemed most suitable for interviewing. To distinguish different types of employees within an organization, the Mintzberg model is used (Mintzberg, 1993). In Figure 14 the organizational model by Mintzberg is shown. The model depicts the five key parts of an organization, being:

1. *The strategic apex*: consists of top management and its support staff. In the oil and gas industry these are C-level executives, Presidents, Vice-Presidents, Senior Managers and similar functions. Their role is to define the goals and mission statement of a company. They are also responsible for the alignment of company objectives with its mission and goals. Furthermore, this part of the organization is responsible for the establishment and maintenance of the relationships with its macro-environment (network);
2. *The operating core*: consists of the workers who actually carry out the tasks within the organization. This part includes plant operators and site workers and lower level engineers;
3. *The middle line*: consists of middle and lower level management. In the oil and gas industry these are Group Heads/Leaders, Assistant Managers and Supervisors. This part of the organization forms a bridge between the strategic apex and middle operating core. It needs to interpret the expectations and plans of the strategic apex and translate these into the work done by the operating core;
4. *The technostructure*: consists of analysts like engineers, researchers, accountants and planners. In the technostructure, systems are designed to guide the process of work. The technostructure is thus directly associated with the operating workflow;
5. *The support staff*: consists of specialists that support the organization outside of the operating workflow. In the oil and gas industry, these roles are fulfilled by for example employees from the R&D department, legal department and PR. Their efforts are aimed at the improvement of efficiency and effectiveness of the operating core, middle line and strategic apex.

Preferably, the evaluation of business models in this study should be done in cooperation with employees from the strategic apex or middle line. In the strategic apex, the management decisions that determine the business model are made. In the middle line, employees are aware of these management decisions and objectives, since they need to translate them onto the operating core.

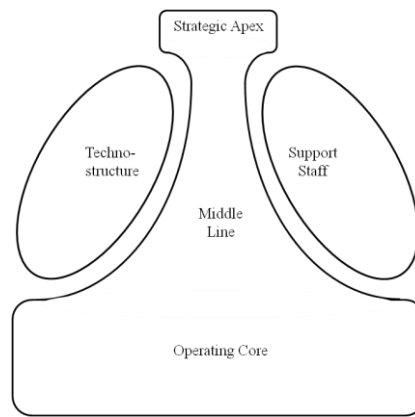


Figure 14 -Mintzberg's Organizational Model (Mintzberg, 1993)

Due to time constraints within this research, the case studies could not be done by interviewing multiple employees from one company. For this reason, as well as due to time constraints from employees from the strategic apex in the Dutch oil and gas industry, the choice was made to include an electronic survey in the research. This survey is intended to serve as a triangulation method for the opinions of the subject-matter experts (SME's) that were interviewed, complementary to the required desk study. Because the framework has not been applied to real-life cases before, the application of these two data different gathering techniques has the additional benefit of testing their appropriateness for empirical business model evaluation.

The following two subsections contain a description of the two separate research steps, beginning with the case study interviews with SMEs. Hereafter the results gathered through the case study interviews with SME's are described.

## 5.2 CASE STUDY INTERVIEWS AND SURVEY

### 5.2.1 CASE STUDY SELECTION AND SAMPLING

The case study analysis in this study is *comparative* in nature. Because of the various differences in both the *exogenous context and conditions* and the *organization and institutional properties of the sector* as described in section 4.2, a single case study would not lead to generalizable results for the Dutch oil and gas industry. The choice is made to conduct three case studies, each within one of the main distinguishable steps of the value chain. The Industry 4.0 Business Model Impact Framework consists of multiple levels of analysis and aggregation, and combines multiple theories. It can be expected that the different characteristics of the Framework have different relevance between companies with a different business context and organizational and institutional properties. Therefore, it is expected that the different case studies will show business models with different maturity and appropriateness for Industry 4.0. The case study selection is based on the following criteria, to warrant a broad range of industry insights and presence of different concepts from the Industry 4.0 Business Model Impact Framework:

- *A specific and currently operated business model:* all cases should be executed with a single business model in mind. For most companies in the oil and gas industry, not a single business model can be identified. Usually, different business units can be identified, aimed at the offering of a single or a few value chain activities and has its own suppliers, customers and technologies. The appropriateness of a business model can only be evaluated when a single business unit or business model is analysed. If this is not done, the results of the case study could be non-representative since only best or worst practice example could be mentioned

by the respondents. In order to evaluate a business model, it should be used in practice by at least one company.

- *Asset owners*: The business model should be operated by the owner of assets. As could be concluded from the expert interviews, the framework is merely suitable for the evaluation of business models of asset owners, not for those of service or technology providers.
- *Different value chain activities*: different value chain activities should be chosen for case studies. This will contribute to finding interactions between the various activities in the value chain and the appropriateness of business models for Industry 4.0.
- *Different context, organization and institutional properties*: All of the cases fall within the geographical scope of this research (the Netherlands). However, by exploring cases where different value chain activities are executed, different exogenous context, conditions and organization and institutional properties of the (sub)sector can be reviewed.
- *Willingness to contribute and availability of information*: Sufficient data on business models, investment decisions and strategic considerations should be available through publicly available documents and interviews with employees of the companies.

As mentioned before, three cases in the oil and gas industry were chosen. This enables the comparison of the upstream, midstream and downstream business models. However, since Industry 4.0 originates from the manufacturing industry and most of the available research is focused on this industry, the choice is made for a reference case. To enable a comparison, the manufacturing case should resemble the scale and operations of the oil and gas industry. For this reason, the chosen reference case is a business model from a steel manufacturer. The guideline for the conduction of case study interviews can be found in Appendix B.

### 5.2.2 STRUCTURE OF THE RESULTS

A case study protocol has been used to conduct the interviews for the case studies (appendix). The case studies start with a summary of the characteristics of the company operating the business model. Due to its frequent use in business and especially the oil and gas industry, the essential processes of the ecosystem business model are mapped according to a SIPOC tool. The SIPOC tool enables a (simplified) summary of the business processes by considering sources (S), inputs (I), process (P), output (O) and customer (C). This way of depicting a business model is not to be confused with the chosen (high-level) ontology of business models. SIPOC is merely a tool to show the collection of processes that is considered to be a part of the business models that are studied. The chosen ontology however, shows the value propositions, the specific processes that create value and the models for value capturing.

Hereafter, the results of the industry questionnaire show the estimate of the state of the business models in the specific part of the value chain. In the subsequent sections the chosen business model is described, followed by the evaluation of the ten business model characteristics described in the framework shown in section 4. The three business model elements (value proposition, value creation activities and value capturing models) are used as a guiding structure of the analysis and observations of the chosen business model.

In the case studies, an ○ indicates the current state of the business model according to the questionnaire and case study interview. A ● indicates the desired state of business models in the light of Industry 4.0 as discussed during the case study interview. The arrows indicate the difference between the two, hinting at possible impacts on business models caused by Industry 4.0. Additionally, interesting observations and reflections discussed during the interviews are presented.



### 5.2.3 CASE CHARACTERISTICS AND QUALITY

The following cases were selected using a purposive sampling approach:

- Upstream Gas
- Midstream oil and gas
- Downstream oil
- Bulk Steel Production

The upstream, downstream and manufacturing cases all meet the requirements discussed in section 5.2.1. The midstream case study however, is different from the other three use cases due to the lack of actual production in the scope of the business model. It can be expected that this affects the evaluation of the first two characteristic of the framework. However, the value chain activities carried out in the in the midstream sector of the Dutch oil and gas industry (transportation and storage) do not contain a clear production step. This drawback of the midstream case study should be taken into account during the analysis of the results. However, the added benefit of including the case study is that a more complete interpretation of the industry can be done.

The case studies that have been analyzed can all be characterized as business-to-business (b2b), as both suppliers and consumers are not individual end-users. In the upstream, downstream and manufacturing case studies, many of the suppliers and customers were even internal to their own enterprise. This characteristic should be taken into account when interpreting the results.

In all of the case studies, the products that are handled are bulk and liquid or gaseous. This has as a consequence that the possibility of creating smart products as described in section 4.2.2 could not be featured in any of the cases under study. Literature on Industry 4.0 and value creation often describes the creation and use of smart products, where embedded computers in products change the operations and business models of companies. However, for all of the case studies this aspect of Industry 4.0 will not be applicable.

It can be argued that the cases do not represent a full picture of the oil and gas value chain since only upstream gas, midstream oil and gas and downstream oil are featured. However, not all of these steps could be featured in the study due to the geographical scoping. In the Netherlands, upstream oil is only incidentally produced and most of the crude oil is imported from abroad. Because the import of oil is a trading affair and does not involve an industrial production system, the upstream oil case was excluded from the study. In the downstream gas sector of the Netherlands, gas is merely transported towards the end-users via a piped network. Within the downstream gas sector, no production is done in the sense that the gas is not chemically altered or refined. Due to this it is assumed that the downstream gas sector in the Netherlands does not contain any industrial production systems.

### 5.2.4 ELECTRONIC SURVEY

To gain an overview of the current state of business models in the Dutch oil and gas industry, a survey was sent to 178 employees from the strategic apex from asset owning companies. The survey was done in the form of an online questionnaire.

The online questionnaire was built using the tool Typeform ([www.typeform.com](http://www.typeform.com)). The reason for choosing the Typeform tool was its user friendliness and availability on computers as well as mobile devices. The 18 questions in the questionnaire can be divided into three categories:

1. 5 Questions about the respondent, their job and their area of work (both open-ended and closed-ended);

2. 3 Questions aimed at the respondent's expectations of the impact of Industry 4.0 on their business model (closed-ended);
3. 10 Questions based on the framework, aimed at uncovering the current status of their business model (closed ended).

The results of the third category questions are used as the starting point for the case study interviews with SME's.

#### 5.2.4.1 Data collection

A link to the questionnaire was sent e-mail via to a client list supplied by the facilitating consulting company. Since no statistical analysis is required in order to answer the research question of this study, the rules for sample sizing are not relevant for the questionnaire.

The sampling process was done by selecting from a client list of >500 people, the asset owners based on the company they work for and hereafter the people from the strategic apex based on their job title (for job title examples see introduction to section 5).

#### 5.2.4.2 The questionnaire

The first category questions are straight-forward in the sense that the respondent is asked to fill in general information about themselves. The information includes name, job title, company of employment, value chain position (upstream, midstream, downstream) and value chain activities they are involved with.

The second category questions are *Likert items*, which is question type using an ordinal scale to measure the respondent's attitude towards a certain issue. Table 10 shows the questions of the second category, and their characteristics.

Table 10 – Questions and characteristics for the second category questions

Question number	Question	Level	Scale	Scale
5	The Fourth Industrial Revolution, also known as Smart Industry, affects the way my company adds value to its customers.	Ordinal scale (5-point)	1 Disagree	5 Agree
9	The Fourth Industrial Revolution changes the way my company creates value for itself and its customers.	Ordinal scale (5-point)	1 Disagree	Agree
16	The Fourth Industrial Revolution affects the way my company captures value.	Ordinal scale (5-point)	1 Disagree	5 Agree

Questions of the third category also use an ordinal scale, but can be called *Likert scales* because the scale consists of different items. The questions that were formulated for this part of the questionnaire

are shown in Table 11, the answers corresponding to the questions are the levels of the framework shown in Tables 6, 7 and 9.

Table 11 - Questions and characteristics for the third category questions

Question number	Question	Business model characteristic	Level
6	What types of products and/or services does your firm or business unit offer to its clients?	1	Ordinal
7	Are the products and services you offer complementary to each other i.e. how would you characterize the offering to your client?	2	Ordinal
10	How is operational data from the production process collected at your firm or business unit?	3	Ordinal
11	How does your firm make use of available production/process (and collected) data?	4	Ordinal
12	Which of the following best describes your firms' innovation process?	5	Ordinal
13	How does your firm interact and collaborate with suppliers, end-users and/or competitors?	6	Ordinal
14	Is the production data shared within the ecosystem (along the supply chain), i.e. inter-company?	7	Ordinal
15	Does your firm have a functional Cyber-Physical System?	8	Ordinal
17	How does your firm create revenue?	9	Ordinal
18	Does your firm make use of dynamic contracts or Blockchain technology to register transactions and keep track of physical and data flows?	10	Ordinal

#### 5.2.4.3 Data processing and coding

Due to the sample size of  $N < 31$ , no statistical analysis could be done with the survey results. The results can be merely used as individual opinions. To get a better idea of the different answers provided by the respondents, the results from the upstream, midstream and downstream sections of the oil and gas industry were grouped and their arithmetic means were calculated. These results should not be regarded to give an accurate overview of the business models in the oil and gas industry, merely as an indication.

#### 5.2.4.4 Inputs from survey for the case study interviews

Due to the aforementioned limitations in the questionnaire results, the interpretation of them should be limited within this study. Figure 15 depicts the means of all of the 25 respondents, as well as the means of the 7 respondents from the upstream sector, the 8 respondents from the midstream sector and the 10 respondents from the downstream sector. The survey was conducted in July 2016 and

should be looked upon as a snapshot or momentary observation. The response rate of the survey is  $(25 / 178) * 100\% = 14\%$ . The initial response rate was 8%, which was increased by the use of one reminder via e-mail.

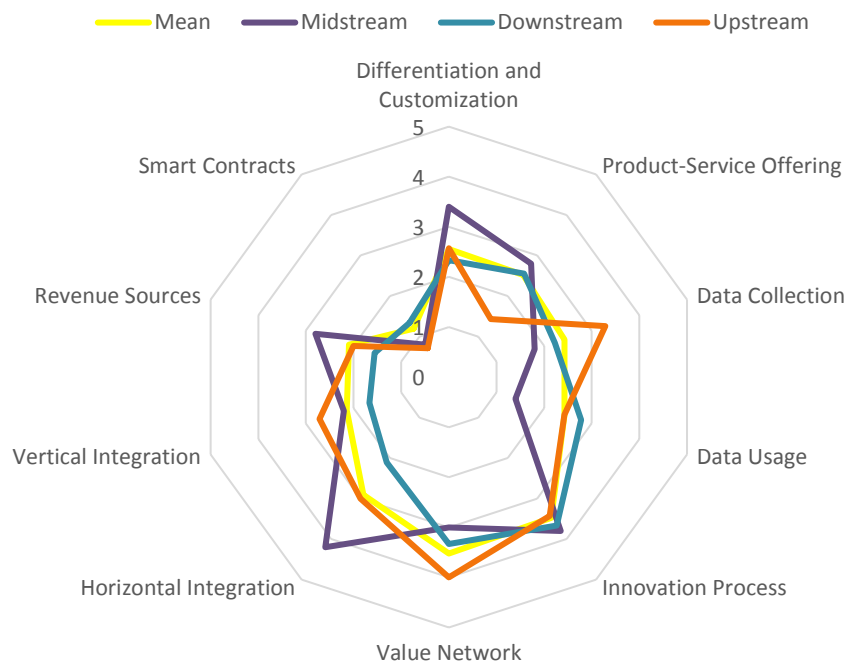


Figure 15 - Questionnaire results for Dutch oil and gas industry. Total sample size = 25 (7 upstream, 8 midstream & 10 downstream)

Using these results, the SME interviewees were presented with an indication of the current state of the business models in their part of the value chain. This is based upon the meaning of the estimations of the questionnaire respondents regarding the appearance of the business model characteristic they found most fitting for their current business model. These estimates were presented to the SMEs during the case study interviews.

The purpose of the questionnaire was to provide the SMEs with an indication of the business models in their part of the value chain, and not to do statistical research. Therefore the estimates (shown in Table 12) will only be used during the SME interviews as a way to introduce the business model characteristic. No conclusions and/or recommendations are based upon the results of the questionnaire.

Table 12 - Estimates of survey respondents on current appearances of business model characteristics in the Dutch upstream, midstream and downstream oil and gas industry. The appearances relate to the variables 1 to 5 chosen for each characteristic as depicted in Tables 6, 7 and 9.

Characteristic		Appearance 1	Appearance 2	Appearance 3	Appearance 4	Appearance 5
1. Differentiation and customization				A, C	B	
2. Product-service offering		A		B, C		
3. Data collection			B, C	A		
4. Data usage		B	A	C		
5. Innovation process				A	B, C	
6. Value network centricity (ecosystem)				B, C	A	
7. Horizontal integration (networking)			C	A	B	
8. Vertical integration to CPS			B, C	A		
9. Revenue Sources			A, B	C		
10. Smart contracts		A, B, C				
A	Upstream					
B	Midstream					
C	Downstream					

## 5.3 CASE STUDY ANALYSIS - RESULTS

### 5.3.1 CASE 1 – UPSTREAM

#### 5.3.1.1 Company summary

Table 13 - Summary of upstream company characteristics (source: company web page)

Headquarters location	
Market segment	Upstream
Value chain activities	Development, Production, Processing
Founded in [year]	
Company shareholders	
Employees (global) [number]	
Revenues [billion €]	unknown
Production gas [million cubic metres]	
Production oil [million cubic metres]	
Products	Exploration and production of natural gas and oil
Services	Storage capacity for oils, gas and chemicals. Blending, heating, cooling, unloading, loading.



[REDACTED]

The company attempts to use modern, safe and appropriate methods and techniques to drill, produce and clean natural gas and oilfields. This is done both onshore and offshore. Due to the potential environmental effects of their activities, many resources are spent for the optimal preparation of these activities. Maximizing safety is herein their philosophy.

At this upstream company, an experienced business improvement lead was interviewed at the company headquarters.

### 5.3.1.2 Market description

In line with the value creation factors as defined by (Wolf, 2009b), the upstream company is characterized by the following:

#### 1. *Exogenous context and conditions:*

- The Dutch subsurface contains 25% of Europe's total natural gas reserves. This is the largest share of all European countries. This has led the Netherlands to be the largest natural gas producer in the European Union. The Netherlands is mainly relying on imported oil, since relatively little oil can be produced from the 44 oil field in the country.
- The technical complexity of production is moderate since the (simple) Slochteren field is the main source of production, but more hard-to-reach or nearly depleted sources are currently being exploited. Also the geopolitical situation regarding the Groningen gas fields in relation with seismic activity is increasing the complexity of production in this area.

[REDACTED] The Dutch government issues licenses to explore and produce natural gas and oil at certain geological locations. Because of this, the Ministry of Economic Affairs can be regarded to be the owner of the products [REDACTED]

#### 2. *The participating companies*

- The Dutch upstream sector consists of exploration and production participations, whereby multiple commercial parties collaborate with the state owned company EBN (Energiebeheer Nederland). In these participations, the EBN usually is 40% shareholder, where the rest of the shares are owned by companies like the NAM, GDF Suez, Total and TAQA.
- Due to the structure of these participations, the upstream company benefits most from cost efficient operations as well as technical efficiency and excellence strategies.

#### 3. *The organization and institutional properties of the sector.*

- The Netherlands has licensing policies for both exploration and production of oil and gas.
- The license for exploration includes the permission for test drilling. These exploration licenses are offered through a public tendering procedure. The tenders are evaluated by the Ministry of Economic Affairs, consulted by TNO, EBN and Staatstoezicht op de Mijnen (SodM), which is a supervisory organ of the Ministry aimed at the safety of production, storage and transport of natural resources. Only when the parties that have won the tender can prove the economic viability of production at the site (after test drilling) the procedure for production can be started.

- The licensing procedure for production is mostly similar to the one for exploration. The winning party must engage in a collaboration with the EBN, so the Dutch government can participate in the profits from production. Before a drilling installation can be built, an Environmental Impact Report has to be issued.
- The mining law contains the regulatory context wherein the upstream company can attempt to achieve profits through exploration and production projects. The Dutch government does not produce gas. However, the state-owned company EBN is obliged to participate in any activity within the upstream field. Furthermore, the oil and gas is subject to taxation of up to 50%. The profit share of the EBN and the taxation schemes for license owners lead to residual profits of a maximum of 30% for the upstream company (dependent on the percentage of participation).
- The upstream company has one customer of gas, which is GasTerra. Therefore, the great majority of revenue originates from GasTerra, guided by long-term contracts (>10 years).

### 5.3.1.3 Business model description and characteristics

For the evaluation of the business model, only the natural gas activities of the upstream company are considered. The input for the SIPOC table for this business model was created through desk research and the SME interview, described in Appendix A1. Table 14 shows the evaluated business model within this case study.

Table 14 - SIPOC table for upstream business model

Supplier	Inputs	Process	Output	Customer
<ul style="list-style-type: none"> <li>• Dutch government</li> <li>• Technology developers</li> <li>• Service suppliers</li> </ul>	<ul style="list-style-type: none"> <li>• Geological information</li> <li>• Natural gas specifications</li> <li>• Production and exploration standard</li> <li>• Work schedule and</li> </ul>	<ul style="list-style-type: none"> <li>• Exploration</li> <li>• production</li> </ul>	<ul style="list-style-type: none"> <li>• Natural gas</li> <li>• Natural gas specifications</li> <li>• Natural gas reserve specifications</li> </ul>	<ul style="list-style-type: none"> <li>• GasTerra</li> </ul>

Within the upstream sector of the oil and gas industry, seven professionals from the strategic apex and middle line filled in the questionnaire. Characteristics of the respondents are shown in Table 15, and the results are shown in Figure 16.

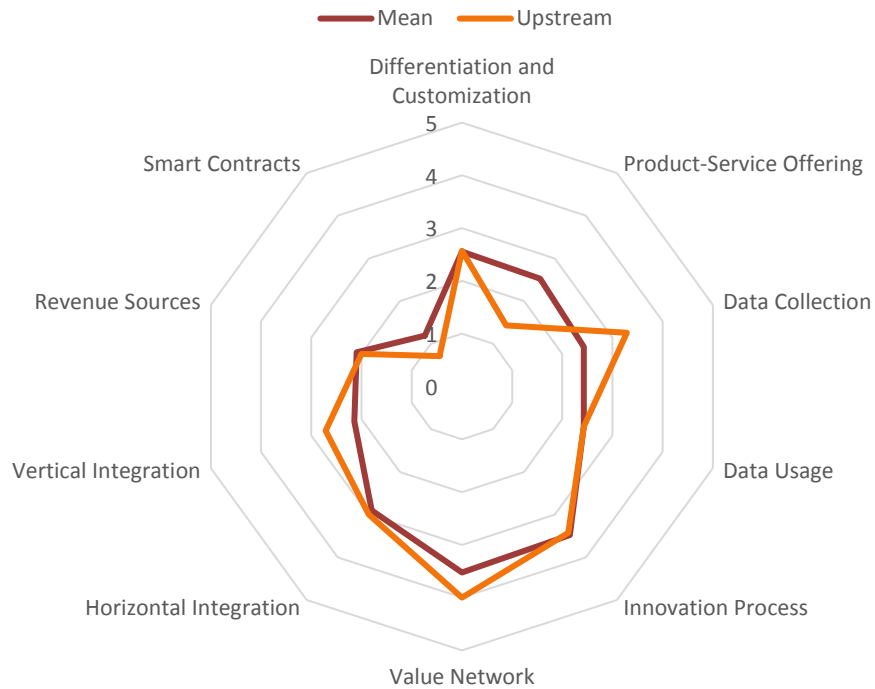


Figure 16 - Questionnaire results for upstream oil & gas. Mean represents the arithmetic mean of the 25 respondents per characteristic. Upstream represents the arithmetic mean for the 7 respondents from the upstream oil and gas industry. These results are not case-specific.

The results shown in Figure 16 we established by meaning the estimates of the questionnaire respondents. The results show the estimate level on the ten business model characteristics from the framework, by all of the 24 respondents as well as from the seven employed in the upstream sector. The estimates from this last group were rounded to whole integers and then used as input for the case study interviews, indicating the as-is situation of the business models in the upstream sector.

Table 15 - Background information on questionnaire respondents in the upstream oil & gas

Questionnaire respondent #	Job title	Value chain activities
1	Manager Strategy	Corporate functions
2	Manager IT	Corporate functions
3	Senior advisor	Exploration & Production
4	Strategy advisor	Exploration & Production
5	Business Improvement Lead	Exploration & Production
6	Production programming lead	Exploration & Production
7	Senior manager	Exploration & Production

#### 5.3.1.4 Value Proposition

During the interview with the SME (described in Appendix A1) at the upstream company, it became clear that the SME did not expect the business model to change fundamentally. The SME has over thirty years of experience in the upstream oil and gas and believes that the activities will remain the same for decades to come, but the ways of working are and will be impacted by Industry 4.0.

##### Characteristic 1 – Differentiation and customization

The differentiation and customization of the offerings are not required, since the only product is natural gas, the only variables are the characteristics like density, caloric value and wetness plus the volume that is produced. The task for the upstream company is to deliver gas with the same consistency to its



customer GasTerra, of which they cannot change the requirements. Due to this lack of dynamics in the product offering, the case study is at the first level for characteristic one. This has as a consequence for the company that when the natural gas resources are depleted, the company will cease to exist.

In response to the question whether the developed technologies are an additional source of revenue, the SME responded negatively: “The sales of innovative technologies is done more and more, but here we often deal with internal customers. Therefore it is not part of the business model as a revenue source”.

Characteristic 1 – Differentiation and customization				
○● Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	*Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	One-of-a-kind production

#### Characteristic 2 – Product-service offering

In addition to the offering of this uniform product, the only service that is provided to the customer is the information related to the gas characteristics and volume. This is mentioned by the SME as plan of gas sales. Although the SME did not fully agree on this, the second level for characteristic 2 is deemed most appropriate for the chosen business model. For this category, the same counts as for the first. The static and long-term relationship between the producer and the customer will lead to a lack of change on this characteristic in the future.

Characteristic 2 – Product-service offering				
Products	○● Products + services for functionality	Products + services for functionality and availability	No product offering, but manufacturing as a service (MaaS)	OEM as solution provider for end-user, no production done

For characteristic one, the assigned level deviates from the average score from the questionnaire (indicated with an asterix). This can be considered to be a direct effect of the case study choice. The upstream company is a joint-venture aimed at the exploration and production of the Dutch natural gas (and some oil) reserves. The way the company was created, entails that by definition it has only one supplier (the Dutch government) and one client (currently GasTerra). Therefore the lack of impact of Industry 4.0 on the value proposition of the company is not a controversial result.

### 5.3.1.5 Value Creation

#### Characteristic 3 – Data collection

Partly due to the high amount of offshore projects, data collection is mostly done electronic and remote. The most advanced (PI) technology available at this point is used for this at the upstream company. The SME acknowledge that their ability to monitor for instance production volume, temperature and asset integrity leads him to the conclusion that the fourth level is most appropriate for characteristic three.

Recent efforts - an example is the [REDACTED] project – are aimed at the usage of the available data to further automate the production systems. This is a step towards level five, but this has not yet been achieved due to issues regarding data integrity.

Characteristic 3 – Data collection				
(Occasional) manual data collection	Sensors installed, data integration is not possible due to inconsistency	*Network of connected sensors installed	○ Network of sensors, interoperable with for example RFID and Cloud storage	● Network of sensors, RFID, Cloud storage and computation, connected to Manufacturing Execution System

#### Characteristic 4 – Data usage, efficiency, scalability and availability

With regard to the fourth characteristic, the ability to predict future performance of assets is deemed crucial, especially for the offshore part of the [REDACTED] business. The [REDACTED] project has enabled the use of Asset Performance Analytics (APA) to predict breakdowns. This is an example of preventive maintenance. Condition-based maintenance (maintenance when need arises) has been done for many years at the [REDACTED]. These analytics technologies are used to increase efficiency (and autonomy) of operations. The autonomy of certain assets has been achieved in for instance underground gas storages (autonomously starting up and shutting down based on demand and supply). The estimation of the SME is that the third level is currently fitting with the operations at [REDACTED]. The SMEs expectation is that the fourth level can be achieved when projects like [REDACTED] are expanded within activities in the company. Level five is deemed inappropriate for the future operations of the company, due to the aforementioned data verification issues: “Everything revolves around data and data quality. Garbage in is garbage out we always say. We do a lot with data verification. How do determine what data is accurate? That is a big challenge. We try to create models find this out for us”.

Characteristic 4 – Data usage, efficiency, scalability and availability				
Equipment connected to local data server (i.e. centralized system)	*Sensory data and machine level data can be converged	○ Adaptive assessment of equipment health in cyber-physical spaces	● Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management

#### Characteristic 5 – Innovation process

Innovations in the context of characteristic 5 are regarded to be “finding new ways of working” by the SME. The way this is approached within the [REDACTED] has been increasingly structured over the past five years. The company is using the ideas of Lean Manufacturing to increase efficiency and decrease waste of resources. The end-user in these process innovation projects is often an internal client (mostly other departments). This process however, can still be improved according to the SME: “We are not yet using prototyping and end-user interaction as much as we should.”

Characteristic 5 – Innovation process				
Linear design process, no end-user interaction, no prototyping, long time-to market	Design process with a few iterations, no end-user interaction, prototyping	○ Iterative design process, little end-user interaction	● Iterative design process, (early) end-user feedback, prototyping	Usage of (un)structured data for product life cycle improvement, short time-to-market

#### Characteristic 6 – Value network centrality (ecosystem)

Within the network of the company, contact with third parties is frequent and exists at many levels. With these third parties, service are exchanged and collaboration is done to achieve efficient production. Due to the longevity of these collaborations, these collaborations are coordination through so-called Collaborative Work Environments (CWE). Through CWE, different business units and companies can exchange information and control assets. This is the result of efforts in the previous three years. Because of the innovations like the CWE, the sharing of data and exchange of services and co-production can be optimized. However, the SME mentioned mostly collaborations between internal departments exist. Therefore, the fifth level of characteristic 6 is not deemed appropriate for current or future operations at the ■■■.

Characteristic 6 – Value network centrality (ecosystem)				
No partnerships or exchange of services, traditional buyer-seller relationships	Ad-hoc exchange of services and aligning of activities, communication and information exchange	Incidental but recurring exchanges, alignment of company goals and activities for mutual benefits	○● Service exchange, co-production along the value chain (coordinated)	Alignment of goals, workflow, creation and design and sharing of responsibilities

#### Characteristic 7 – Horizontal integration (networking)

Regarding characteristic 7, the SME remarked the following: “Here we are really moving towards five at the ■■■. We have a functional collaboration network with data availability through network. We are doing this. With third parties and end-users. Even though the end-user is 90-95% of the time internal.” This process could be so streamlined due to the fact that only one customer existed during the whole lifetime of the ■■■.

Characteristic 7 – Horizontal integration (networking)				
Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	○ Communication between machinery as well as with smart products and items (internal)	● Internal communication and collaborative network with either supplier or end-user (external)	● Functional collaboration network, data availability through network

#### Characteristic 8 – Vertical integration to CPS

The vertical integration of the assets and IT architecture at the ■■■ is gaining a lot of attention. An example is the increased coupling of databases and IT, in order for ‘things’ like machinery, pipelines and IT systems can communicate with each other. Three is deemed appropriate for the way things are done at this point in time. However, due to knowledge spill-overs from other subsidiaries of the co-owners of the ■■■, it can be expected that more advanced vertical integration will be achieved in the future. Again, for this characteristic, the quality of data is mentioned as crucial hurdle in making steps towards the right of the scale.

Characteristic 8 – Vertical integration to CPS				
Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	○ Sensors and actuators integrated with control and production management system	● Sensors and actuators integrated with control and production management and MES systems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)

#### 5.3.1.6 Value Capturing

##### Characteristic 9 – Revenue sources

For the ninth characteristic, the SME was short and clear in his opinion: “For the ■■■, this is truly one. For other countries, where there is a service contract, this is of course different. But here in the Netherlands, this is traditional.”

Characteristic 9 – Revenue sources				
○● Traditional sales (buyer-seller)	Sales based on data gathered from internal processes and historical transactions	Product and/or service transaction with extensive service to increase functionality and availability	Data-based transactions, for instance pay-per-use models	As-a-Service revenue model (fully data-based)

##### Characteristic 10 – Smart contracts

Like for the previous characteristic, the SME did not estimate any other contract type than the traditional legal contract will be used in the lifetime of the ■■■.

Characteristic 10 – Smart contracts				
○● Traditional legal contract	Dynamic contracts	Digital currency exchange	Peer-to-peer smart contracts	Blockchain used for coordination of monetary, physical and data flows

#### 5.3.1.7 Observations and remarks

After the evaluation of the business model using the framework, the opinion on the lack of change in the business model of the SME did not change. The SME remarked that the value proposition (what is done) and value capturing (how you make money with this) does not change fundamentally. However, the ways of working (activities for value creation) do change tremendously. This is enabled by the technological developments associated with Industry 4.0. In a way, Industry 4.0 even strengthens the fundamental value proposition of the ■■■.

Five impacts on business models have been identified in this case study. These impacts are:

- The changing modes of data collection, by using collected data for Asset Performance Analytics. This is a big step towards using the data in the MES.

- The usage of data is also impacted by Industry 4.0 in the sense that the quality of data can be verified in better ways due to increased computing power and analytics. This means more data can be used for predictive and preventive maintenance.
- The streamlining of the innovation process is done by increasing the interaction with the (internal) end-user and prototyping.
- The horizontal integration of the upstream company is increasing, due to innovations like the CWE.
- In the field of vertical integration, additional steps can be expected due to recent efforts in database coupling and IT system integration.

In order to validate the results of the SME interview, triangulation was done with the desk research results as described in section 5.3.1.2. The purpose of this validation step was to explore whether the institutional factors that influence value creation and capturing within the business model under study have a causal relationship to the observed impacts on business model characteristics. A visualization of this process is shown in appendix C1. The following influence of institutional factors on the observed impacts can be described:

- The technical complexity of the specific resources operated by upstream company also determines the profitability of its projects. The observed impact on the horizontal integration of its business model can potentially be influenced by this. Due to the long-term contracts, the ownership structure of the E&P projects and the limited parties involved, the parties have well-developed institutions for collaboration, co-production and networking. Especially in the case of upstream company, the investments that are made to create innovative (digital) networking platforms like the collaborative work environment, can be done with very low risk due to these institutional factors. Therefore, the impact on the horizontal integration characteristic in this case study cannot be fully attributed to Industry 4.0, and so the impact is not considered valid in this case study.

Table 16 - Summary of impacts in upstream case study. Visual depiction of the business model impacts as discussed in the case study interview. Invalid impact indicates a compromise of the internal validity of the results due to a suspected influence of institutional factors on the observed impact.

Characteristic	Appearance 1	Appearance 2	Appearance 3	Appearance 4	Appearance 5
1. Differentiation and customization	•				
2. Product-service offering		•			
3. Data collection				----->	•
4. Data usage			----->	•	
5. Innovation process			----->	•	
6. Value network centricity (ecosystem)				•	
7. Horizontal integration (networking)			----->		•
8. Vertical integration to CPS			----->	•	
9. Revenue Sources	•				
10. Smart contracts	•				
Current level					
Desired level					
•					
Invalid impact					

### 5.3.2 CASE 2 – MIDSTREAM:

#### 5.3.2.1 Company summary

Table 17 - Summary of midstream company characteristics (source: Annual report 2015)

Headquarters location	
Market segment	Midstream
Value chain activities	Storage
Founded in [year]	
Company shareholders	
Employees (global) [number]	
Revenues [billion €]	
Storage capacity [million cubic metres]	
Products	None
Services	Storage capacity for oils, gas and chemicals. Blending, heating, cooling, unloading, loading.

[REDACTED]

The evaluation of the international Hub Terminal business model operated by [REDACTED] was done during an interview with the manager Terminal IT & Automation at the company headquarters [REDACTED]

### 5.3.2.2 Market description

In line with the value creation factors as defined by (Wolf, 2009b), [REDACTED] is characterized by the following:

1. *Exogenous context and conditions.*
  - Due to the fact the Netherlands has a net surplus of natural gas (production exceeds consumption), the demand for natural gas (liquid) storage is limited in the country. Therefore, the midstream company's portfolio of storage terminals in the Netherlands mostly handle crude oil and petroleum products.
  - The company has strategic positions for its oil terminals, mostly in the Rotterdam port area and also one in the port of Amsterdam and one in Vlissingen. Through these positions, [REDACTED] has access to major shipping routes, roads and railroads. Furthermore, in the Rotterdam area the terminals are located in the vicinity of the petrochemical industrial cluster (its customers).
2. *The participating companies.*
  - In the midstream sector of the Netherlands, [REDACTED] main competitor is [REDACTED]. When the value chain activity *storage* is used as only considered, its main competitors would be the upstream and/or downstream companies which have their own storage infrastructure.
  - [REDACTED] has a global way of working and this has led to its operational excellence. The safety and integrity of products and assets is of vital importance to the company. To maintain this operational excellence, [REDACTED] has developed 75 global standards.
3. *The organization and institutional properties of the sector.*
  - Storage of oils, gases and fuels is regulated by the Activities Decree. [REDACTED] is a company which needs an All-in-one permit for Physical aspects for the environmental aspect of its business. Because of this, it is obliged to notify the Ministry of Infrastructure and the Environment of most of its business activities.

### 5.3.2.3 Business model description and characteristics

[REDACTED] has four types of terminals, being ([REDACTED] Annual Report, 2015):

1. Major hubs, supporting intercontinental product flows
2. Import and distribution terminals in major markets with structural deficits
3. Terminals facilitating growth in global gas markets
4. Industrial and chemical terminals in the Americas, the Middle East and Asia

During the interview with the SME at [REDACTED] (described in Appendix A2), it became clear that all of these terminal types have different business models. Furthermore, the technical maturity and networking possibilities differ between different geological locations. Therefore, the choice is made to evaluate type 1 terminal (major hubs) in the Netherlands. [REDACTED]

The input for the SIPOC table for this business model was created through desk research and the SME interview, described in Appendix A2. Table 14 shows the evaluated business model within this case study.

Table 18 - SIPOC table for midstream oil Hub terminal business model

Supplier	Inputs	Process	Output	Customer
<ul style="list-style-type: none"> <li>• IOC</li> <li>• NOC</li> <li>• Traders</li> <li>• Service suppliers</li> <li>• Technology suppliers</li> </ul>	<ul style="list-style-type: none"> <li>• Characteristics of liquids</li> <li>• Storage, mixing, blending, heating, cooling demands</li> <li>• Working standards</li> <li>• Global product flows</li> </ul>	<ul style="list-style-type: none"> <li>• Handling</li> <li>• Storage (and additional services)</li> </ul>	<ul style="list-style-type: none"> <li>• Oil (crude &amp; products)</li> <li>• Petrochemicals</li> <li>• Biofuels</li> </ul>	<ul style="list-style-type: none"> <li>• IOC</li> <li>• NOC</li> <li>• Traders</li> </ul>

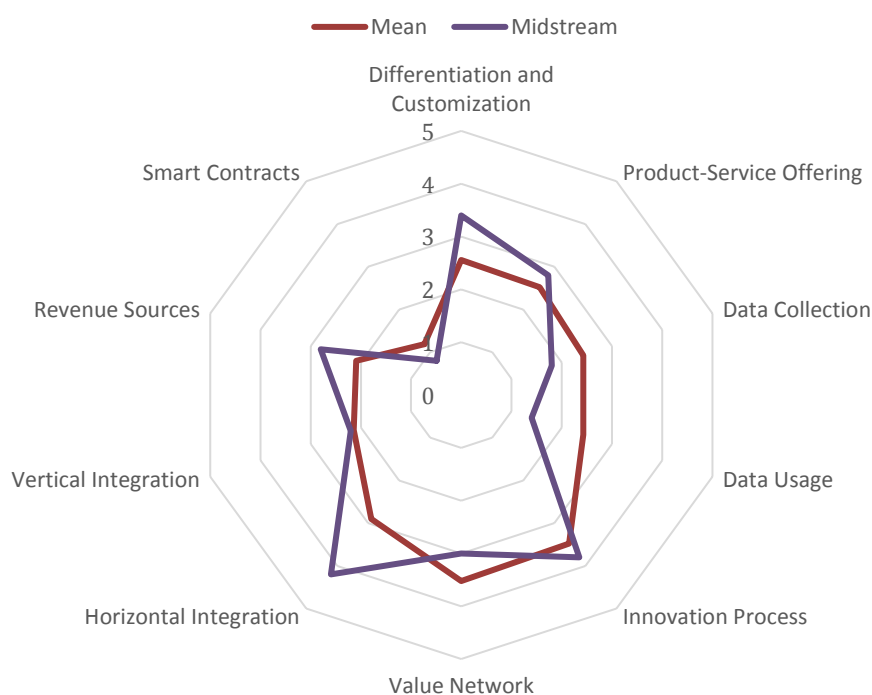


Figure 17- Survey results for midstream oil & gas. Mean represents the arithmetic mean of the 25 respondents per characteristic. Upstream represents the arithmetic mean for the 8 respondents from the midstream oil and gas industry. These results are not case-specific.

Based on the questionnaire conducted among (c-level) executives in the oil and gas industry, an indication of the current state of business models could be obtained. The result of the questionnaire are shown in Figure 17. The scores obtained for the midstream oil and gas sector were established by meaning the results of the estimations given by seven professionals in the industry, shown in Table 19.



Table 19 - Background information on questionnaire respondents in the midstream oil & gas

Questionnaire respondent #	Job title	Value chain activities
8	Managing Director	Transportation
9	Manager	Storage
10	C-level executive	Storage
11	Global Group President	Storage
12	Manager	Transportation
13	C-level executive	Storage
14	Manager	Storage
15	Director	Storage

### 5.3.2.4 Value Proposition

#### Characteristic 1 – Differentiation and customization

The SME of █████ started the interview by explaining they see two areas application for Industry 4.0 technologies and ways of working. The first area of application is maintenance (i.e. condition-based maintenance), and the other is the integration of the supply chain. Regarding the second application area the SME stated the following: “I will give you an example. In the past, our relationship with the client had a more physical element. Because when you have a pipeline connecting you and your customer, the customer will not walk away so easily, this had our strong preference. That has relatively high investment threshold. Whilst nowadays, the replica of the physical pipeline is now the administrative binding of the client. We are now looking for collaborative platforms and try to work with the same supply chain documents, the same freight letters and so on. So you see that we are now establishing customer relationships through the digital world.” This indicates the tighter client relationships using customer-oriented services. This indicates the shift from the third to the fourth level in characteristic 1. This is underpinned by the SME as follows: “We need to be more flexible and informative towards our clients. If an international tanker is docked and pumping for about a day, it doesn’t say that you don’t have to say anything all day. We can talk about more services, like any formalities that have to be taken care of. The skipper also has to purchase food and beverages for the crew. We could supply these services but are currently quite passive in this sense”. The fifth level is not deemed appropriate for █████, since it does not produce anything itself.

Characteristic 1 – Differentiation and customization				
Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	○ Diverse product and service offering, supply driven production	● Customization possible through end-user-oriented services	One-of-a-kind production

#### Characteristic 2 – Product-service offering

Regarding the second characteristic, the lack of manufacturing done by the company automatically classifies the company at the fifth level.

Characteristic 2 – Product-service offering				
Products	Products + services for functionality	Products + services for functionality and availability	No product offering, but manufacturing as a service (MaaS)	○● OEM as solution provider for end-user, no production done

### 5.3.2.5 Value Creation

#### Characteristic 3 – Data collection

The low estimate of the questionnaire respondents at the second characteristic surprised the SME. The SME acknowledged the level of technical excellence varies greatly among the terminals, even in the Netherlands. About this characteristic the SME recognizes a great opportunity and necessity for change: “we have to be at level five. We are networking more and more. But we are also more and more doing RFID and cloud storage. And yes, we want to use this not so much in manufacturing but in the chain”.

Characteristic 3 – Data collection				
(Occasional) manual data collection	○ Sensors installed, data integration is not possible due to inconsistency	Network of connected sensors installed	Network of sensors, interoperable with for example RFID and Cloud storage	● Network of sensors, RFID, Cloud storage and computation, connected to Manufacturing Execution System

#### Characteristic 4 – Data usage, efficiency, scalability and availability

Characteristic 4 is interpreted by the SME as the technical basis for more advanced maintenance. Due to this, he states: “I don’t think we have to be at level five for this one. See for us, maintenance is more of a necessary evil. It is not our core business, so it would be strange to be at the full right here.”. Nevertheless, a shift is expected by the SME: “It does have an impact however, I think adaptive assessment of equipment health in cyber-physical spaces will help us tremendously. If you offer your raw data, which we will start offering As-a-Service, and offer analytics As-a-Service, we can start predicting. This generates warnings for upcoming outages or generates work packages for maintenance. This would fall under category three, so I think that is where we need to be.”

Characteristic 4 – Data usage, efficiency, scalability and availability				
○ Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	● Adaptive assessment of equipment health in cyber-physical spaces	Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management

#### Characteristic 5 – Innovation process

During the interview, characteristic 5 was interpreted as the development of innovative services. This can also entail the development of new ways to approach clients. More and more unstructured data like satellite data, shipping documents and global product flows are analyzed to offer competitive prices for storage. The establishment of a dedicated innovation department, including data analysts marks the shift from the fourth to the fifth level in this characteristic.

Characteristic 5 – Innovation process				
Linear design process, no end-user interaction, no prototyping, long time-to-market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	○ Iterative design process, (early) end-user feedback, prototyping	● Usage of (un)structured data for product life cycle improvement, short time-to-market

#### Characteristic 6 – Value network centrality (ecosystem)

For the Dutch Hub terminals, the volumes are large and clients often recurring. Therefore, this terminal type has mature relationships with its clients and suppliers. This was explained by the SME as follows: When we take the Dutch Hub terminals, I think we are doing service exchange and co-production. If you have a client that loads more than 300 trucks per day, of course you have more than incidental service exchanges. Completely different orders come in than when a partner comes for loading every once in a while". Within [REDACTED], this way of working at the Dutch Hub terminals forms an example for other terminals around the globe. Furthermore, the fourth level is the desired level for [REDACTED].

Characteristic 6 – Value network centrality (ecosystem)				
No partnerships or exchange of services, traditional buyer-seller relationships	Ad-hoc exchange of services and aligning of activities, communication and information exchange	Incidental but recurring exchanges, alignment of company goals and activities for mutual benefits	○● Service exchange, co-production along the value chain (coordinated)	Alignment of goals, workflow, creation and design and sharing of responsibilities

#### Characteristic 7 – Horizontal integration (networking)

As was mentioned at the description of characteristic 1, [REDACTED] is hoping to tighten its relationships with clients through digital innovations. The SME is of the opinion that this can only be achieved when the terminal is fully owned by [REDACTED]. For the largest clients (key accounts) of [REDACTED], the desire is to be at level five for characteristic 7.

Characteristic 7 – Horizontal integration (networking)				
Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	○ Internal communication and collaborative network with either supplier or end-user (external)	● Functional collaboration network, data availability through network

#### Characteristic 8 – Vertical integration to CPS

The vertical integration of the assets and IT systems is the primary responsibility of the interviewed SME. The SME is working at the company for five years and is seeing the level of integration grow more or less along the appearance list of characteristic 8. The shift from the current level (overall) to the fifth level is already being realized. This is illustrated by the SME's following statement: "At least one of our terminals is here. Once the ship embarks on the dock, we only have to identify the ship and put the hose in it. The rest is automated fully."

Characteristic 8 – Vertical integration to CPS				
Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	○ Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MES systems	● Vertical integration (control, production management, manufacturing and planning and corporate planning systems)

### 5.3.2.6 Value Capturing

#### Characteristic 9 – Revenue sources

For characteristic nine, the SME is recognizing a shift in operations: “In the Netherlands we are surely at the second level, and are moving towards managed (fourth level). We should be able to do this because we own all of the terminals here.” This is illustrated by the following practical examples: “Data-based transactions or pay-per-use models we do. We do not only send invoice for the rental of our assets, but also for instance issue contracts based on how many trucks we have loaded or how many times the terminal was filled. So in Europe, this one is applicable to our business.”

Characteristic 9 – Revenue sources				
Traditional sales (buyer-seller)	○ Sales based on data gathered from internal processes and historical transactions	Product and/or service transaction with extensive service to increase functionality and availability	● Data-based transactions, for instance pay-per-use models	As-a-Service revenue model (fully data-based)

#### Characteristic 10 – Smart contracts

The international Hub terminals of [REDACTED] need to be cost competitive. The SME relates to this as being “price fighters”, which he relates to the first level of characteristic 10. The SME refers to the shift towards more dynamic contracts, but calls this development market driven. When a client is unsure about its business developments, [REDACTED] is willing to put a certain margin in the volume and duration of the contract.

Characteristic 10 – Smart contracts				
○ Traditional legal contract	● Dynamic contracts	Digital currency exchange	Peer-to-peer smart contracts	Blockchain used for coordination of monetary, physical and data flows

### 5.3.2.7 Observations and remarks

The SME notices the commonalities between conventional maturity models like CMMI and the framework. The terminology from the CMMI model (ad-hoc, managed, defined, quantitatively managed and optimized) could be used to improve the use of the framework as a stand-alone evaluation tool.

Eight impacts on business models have been identified in this case study (see Table 20). These impacts are:

- A higher level of differentiation and customization through customer-oriented digital services.
- More advanced data collection through the use of RFID and Cloud storage. More autonomous operations through data input in the MES.
- More usage of data through increasing data analytics capabilities. In the maintenance domain, the assessment of equipment health and condition-based and preventive maintenance are the desired level of data usage.
- The increased use of unstructured data for the development of innovative pricing methods.
- The increase of horizontal integration through data sharing with large clients.
- The increase of vertical integration by increased systems integration and automation.
- The move towards data-based transactions and pay-per-use models
- The increasingly dynamic nature of contracts with customers

The impacts were examined for any causalities with institutional factors as described in section 5.3.2.2. However, as shown in Appendix C2, no interrelations between institutional factors and observed impacts could be found. The reason for this could be that the SME regarded the impacts from a technological opportunity perspective, where technology provides the firms with innovative strategies and ways of working. This examination was done to validate the observed impacts for the midstream case.

Table 20 - Summary of impacts in midstream case study. Visual depiction of the business model impacts as discussed in the case study interview.

Characteristic	Appearance 1	Appearance 2	Appearance 3	Appearance 4	Appearance 5
1. Differentiation and customization			----->		
2. Product-service offering					•
3. Data collection		----->	----->		----->
4. Data usage	----->	----->	----->		
5. Innovation process				----->	----->
6. Value network centricity (ecosystem)				•	
7. Horizontal integration (networking)				----->	----->
8. Vertical integration to CPS			----->	----->	----->
9. Revenue Sources		----->	----->	----->	
10. Smart contracts	----->	----->			
Current level					
Desired level					
•					
Current and desired level					

### 5.3.3 CASE 3 – DOWNSTREAM:

#### 5.3.3.1 Company summary

Table 21 - Summary of downstream company characteristics (source: Annual report 2015)

Headquarters location	
Market segment	Downstream
Value chain activities	Refining
Founded in [year]	
Company shareholders	
Employees (global) [number]	
Revenues [billion €]	
Refining capacity [tonnes / year]	
Products	Gasoline, diesel, kerosene, lubricants, LPG, fuel oil, polyols and chemical solvents
Services	Storage capacity for oils, gas and chemicals. Blending, heating, cooling, unloading, loading.

the technology manager of the refinery was interviewed as SME.

#### 5.3.3.2 Market description

In line with the value creation factors as defined by (Wolf, 2009b), is characterized by the following:

1. *Exogenous context and conditions.*
  - The refineries location is a driver for its scale. Its location grants the access shipping routes, railroads and roads. Also, the low density of population in the area allows for expansion and the construction of external pipelines.
2. *The participating companies.*
  - In the refining sector, cost efficient operations are the most important driver for profits. Also technical efficiency and excellence can lead to profit maximization, through optimal resource usage, based on current market values of refining products.
  - is a highly integrated company, with business units on both the supply and customer side. This high level of integration reinforces the cost efficiency and technical excellence due to alignment of goals and workflow as well as openness with respect to resource characteristics, capacity and market conditions.
3. *The organization and institutional properties of the sector.*
  - The refinery is subject to laws regulating noise nuisance, air pollution and environmental hygiene. Any building activities on the terrain must be granted permission based on the General Environmental Law (WABO).
  - Increasingly, European refineries are subject to EU emission regulations. These regulations will potentially force a cap on production at the refinery, pressuring profitability.

### 5.3.3.3 Business model description and characteristics

For the purpose of this study, the evaluated business model is considered to be only the petroleum refinery of the [REDACTED] complex.

The input for the SIPOC table for this business model was created through desk research and the SME interview, described in Appendix A3. Table 14 shows the evaluated business model within this case study.

Table 22 - SIPOC table for downstream petroleum refining business model

Supplier	Inputs	Process	Output	Customer
<ul style="list-style-type: none"> <li>Trading department of Xxxxx</li> <li>Service suppliers</li> <li>Technology suppliers</li> </ul>	<ul style="list-style-type: none"> <li>Characteristics of crude</li> <li>Crude oil</li> <li>Working standards</li> </ul>	<ul style="list-style-type: none"> <li>Distillation (separation)</li> <li>Conversion</li> <li>Treatment</li> </ul>	<ul style="list-style-type: none"> <li>Gasoline</li> <li>Diesel</li> <li>Kerosene</li> <li>Lubricants</li> <li>LPG</li> <li>Fuel oil</li> </ul>	<ul style="list-style-type: none"> <li>Supply department of Xxxxx</li> </ul>

Based on the response of nine professionals from the downstream oil and gas industry, an indication of the current state of the business models could be made (as shown in Figure 18).

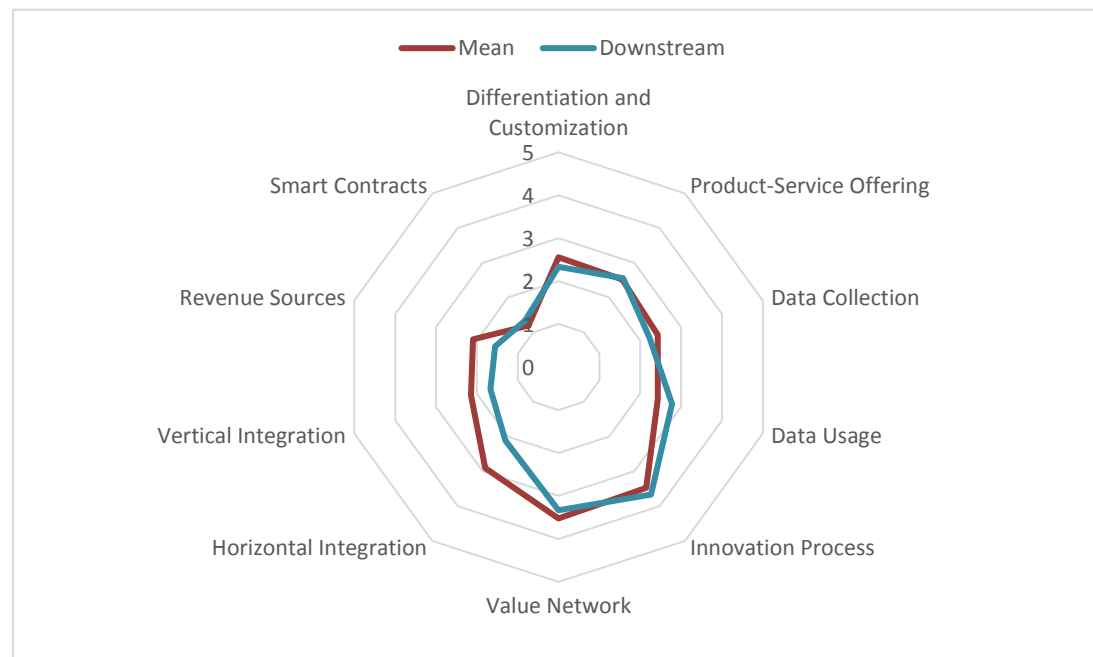


Figure 18- Survey results for downstream oil & gas industry. Mean represents the arithmetic mean of the 25 respondents per characteristic. Upstream represents the arithmetic mean for the 10 respondents from the downstream oil and gas industry. These results are not case-specific.

The scores obtained for the downstream oil and gas sector were established by meaning the results of the estimations given by ten professionals in the industry, of which the characteristics are shown in Table 23.

Table 23 - Background information on questionnaire respondents in the downstream oil & gas

Questionnaire respondent #	Job title	Value chain activities
16	Logistic manager	Storage
17	Global division head	Marketing
18	Partner	Storage
19	Portfolio manager	Refining
20	Innovation advisor	Refining
21	Optimization lead	Transportation
22	General Manager	Marketing
23	CEO	Transportation
24	Enterprise Architect	Refining
25	Manager	Refining

### 5.3.3.4 Value Proposition

#### Characteristic 1 – Differentiation and customization

Refineries are traditionally seen as production locations. According to the SME, the [REDACTED] refinery is so advanced and flexible, that its full potential in terms of production and efficiency is not understood at the trading and supply divisions. The new role of the refinery is a collaborating party that has the common purpose of optimizing production for current market positions. For category 1, the SME sees a shift from levels one or two towards level three. The SME explains that the products made in refineries are heavily regulated in terms of specifications. The challenge for the refinery is: “to try to meet these specifications at the most cost-efficient way”. The variety is caused by the flexibility to make different products. The product specifications are not determined by the refinery itself, but by the supply department of [REDACTED]. The lack of integration with the supply department limits the shift towards level four and five for characteristic 1. According to the SME, the appearance list for this characteristic, closely resembles the journey the refinery is making at the moment.

Characteristic 1 – Differentiation and customization				
	○	●		
Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	One-of-a-kind production

#### Characteristic 2 – Product-service offering

Manufacturing-as-a-service is not done in the petroleum refinery business of [REDACTED] according to the SME. Information is shared between the various stages of the value chain. This information has commercial purposes, but also helps to optimize integrity and functionality of the assets. However, information on the usage and functionality of the sold products is not offered to the clients. For this reason, level two is deemed most appropriate for characteristic 2.

Characteristic 2 – Product-service offering				
	○●			
Products	Products + services for functionality	Products + services for functionality and availability	No product offering, but manufacturing as a service (MaaS)	OEM as solution provider for end-user, no production done



### 5.3.3.5 Value Creation

#### Characteristic 3 – Data collection

The product flows within the refinery are constantly monitored and assessed within the refinery. According to the SME, this data is mostly used to detect any supply or flow problems, and to solve disturbances in the supply due to external factors or breakdowns. Data is also used for yields from feedstocks. Data collection is highly important at the refinery. The following statement by the SME indicates that the level five of characteristic three has been achieved at the site: “within the factories themselves, standard process control is present, but also optimizers on top of this. Due to these optimizers, the operators do not have to intervene in the production parameters because these optimizers facilitate the continuous steering of production activities for maximum production of the desired products.

Characteristic 3 – Data collection				
(Occasional) manual data collection	Sensors installed, data integration is not possible due to inconsistency	○ Network of connected sensors installed	● Network of sensors, interoperable with for example RFID and Cloud storage	Network of sensors, RFID, Cloud storage and computation, connected to Manufacturing Execution System

#### Characteristic 4 – Data usage, efficiency, scalability and availability

At the refinery, condition-based maintenance and preventive maintenance allow the adaptive assessment of the assets in cyber-physical spaces. The functionality of the equipment is of utmost importance. The chance of failure should be minimized by several contingency measures. Human intervention in this process is very limited. The equipment has a high level of autonomy and local intelligence. The equipment has a self-check system for integrity and health. The production management system automatically alters production to prevent incidents with the specific equipment. This level of data usage is deemed fitting with the fourth level of characteristic four. Full autonomy of operations is still limited by data integrity and occasional low equipment health.

Characteristic 4 – Data usage, efficiency, scalability and availability				
Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	○ Adaptive assessment of equipment health in cyber-physical spaces	● Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management

#### Characteristic 5 – Innovation process

The innovation at the refinery can be interpreted in terms of equipment innovation, process innovation (automation) or diversification assets to diversify the refineries' products. The innovation that fits the jargon used for this characteristic suits best for [REDACTED]. During the interview with the SME, no appropriate level could be determined. For this reason, the level based on the questionnaire respondents is chosen for this characteristic.

Characteristic 5 – Innovation process				
Linear design process, no end-user interaction, no prototyping, long time-to-market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	○● Iterative design process, (early) end-user feedback, prototyping	Usage of (un)structured data for product life cycle improvement, short time-to-market

#### Characteristic 6 – Value network centrality (ecosystem)

As described in section 5.3.3.3, the refinery has suppliers and clients that are internal to the company. Due to this, the value network of the refinery is mostly within [REDACTED]. The SME acknowledges the changing role of the refinery in the value chain and its closer integration with both the trading and supply departments. More frequently, employees from these departments convene to align goals, workflow etc. Because clear cut-off points between the responsibilities and tasks of these different departments still exist, level five is not yet achieved for characteristic 6. However, the SME's expectation is that this will happen in the future.

Characteristic 6 – Value network centrality (ecosystem)				
No partnerships or exchange of services, traditional buyer-seller relationships	Ad-hoc exchange of services and aligning of activities, communication and information exchange	Incidental but recurring exchanges, alignment of company goals and activities for mutual benefits	○ Service exchange, co-production along the value chain (coordinated)	● Alignment of goals, workflow, creation and design and sharing of responsibilities

#### Characteristic 7 – Horizontal integration (networking)

For characteristic 7, more openness between the refinery and its suppliers and customers is being created. An example is the integration of the market trend data from the supply department and the current state of the refinery assets leads to collaborative decisions on production. However, full availability of all data throughout the network is not desirable according to the SME: "this is such a complex company, all available data will be a complete overload. Transparency is desired, but to a certain extent."

Characteristic 7 – Horizontal integration (networking)				
Independently operating machinery and/or production units (internal)	○ Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	● Internal communication and collaborative network with either supplier or end-user (external)	Functional collaboration network, data availability through network

#### Characteristic 8 – Vertical integration to CPS

The different departments within the refinery convene on daily basis to discuss the current affairs of the various assets and flows. The SME refers to the large complexity of the site as reason for the lack of full vertical integration: "At asset and plant level, this is comprehensible. But when you move to the

site or complex level, it is impossible to combine all of the sensor data into something comprehensible.” An optimizer at the site level is not yet possible due to the complexity the model needs to deal with.

Characteristic 8 – Vertical integration to CPS				
Sensors and actuators not integrated with IT systems	○ Sensors and actuators integrated with control system	● Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MES systems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)

### 5.3.3.6 Value Capturing

#### Characteristic 9 – Revenue sources

Profits at the refinery are made by optimizing margins based on dollars per barrel of crude oil. These profits are virtual in the sense that the refinery does not sale its refined products. The parameters and sales data used to determine this profit margin are continuously monitored. The data this process provides is used in attempts to maximize future profits. This mechanism for revenue maximization is most fitting with the second level of characteristic 9. Due to the lack of actual transactions between the refinery and its suppliers and customers, no shift in this scale can be expected.

Characteristic 9 – Revenue sources				
Traditional sales (buyer-seller)	○● Sales based on data gathered from internal processes and historical transactions	Product and/or service transaction with extensive service to increase functionality and availability	Data-based transactions, for instance pay-per-use models	As-a-Service revenue model (fully data-based)

#### Characteristic 10 – Smart contracts

Within the enterprise, flexibility of contracts is increasing. This is illustrated by an example by the SME: “When we order a certain crude, we make an agreement with the trading department that they are allowed to supply a different crude for the same price. When market and asset conditions change, it might be more profitable for the enterprise to give our crude to another refinery. We then make less margins, but the enterprise could increase overall margins.” This indicates the move from a legal contract of buying a certain good for a certain price, to the purchasing of value for the enterprise.

Characteristic 10 – Smart contracts				
○ Traditional legal contract	● Dynamic contracts	Digital currency exchange	Peer-to-peer smart contracts	Blockchain used for coordination of monetary, physical and data flows

### 5.3.3.7 Observations and remarks

RFID tagging of the products in the refinery is not possible. Furthermore, the use of cloud storage is not deemed safe enough for the site.

Within this downstream case study, seven impacts are identified:

- The increased differentiation of product offerings due to flexibility of the refinery. This is enabled by technological advances and changing relationship between the refinery and its (internal) suppliers and customers.
- The increased collection of data and interoperability of for instance product flow data and asset integrity monitoring.
- The increased reliability of asset self-assessment (combined with data verification) leading to higher levels of autonomy of the refinery's operations.
- The higher level of openness between the refinery and its supplier and customer. The different departments within the enterprise are increasingly collaborating, sharing and aligning their work.
- Higher level of horizontal integration, caused by the arising collaboration networks between different departments of the enterprise.
- Higher level of vertical integration due to the (siloe) integration of sensors and actuators at asset and plant level.
- The focus on enterprise value and increased flexibility in contracts instead of the traditional legal contracts.

When considering these impacts and cross-examining them with the institutional factors of this case (see section 5.3.3.2), one could argue that the highly integrated nature of the █████ enterprise affects the arising collaboration networks within the company (thus influencing characteristic 7). However, the SME explicitly mentioned that the degree of integration has not changed within the enterprise, but that it is becoming stronger due to the increased availability of data and digital networking technologies. Also because of this insight, none of the observed impacts are regarded to be influenced by the institutional factors in this case study.

Table 24 - Summary of impacts in downstream case study. Visual depiction of the business model impacts as discussed in the case study interview.

Characteristic	Appearance 1	Appearance 2	Appearance 3	Appearance 4	Appearance 5
1. Differentiation and customization		----->			
2. Product-service offering		•			
3. Data collection			----->		
4. Data usage			----->		
5. Innovation process				•	
6. Value network centricity (ecosystem)				----->	
7. Horizontal integration (networking)		----->			
8. Vertical integration to CPS		----->			
9. Revenue Sources		•			
10. Smart contracts	----->				
	Current level				
	Desired level				
•	Current and desired level				

### 5.3.4 CASE 4 – REFERENCE CASE: STEEL MANUFACTURER

[Available upon request]

The evaluation of the business model during the interview is described in Appendix A4. Three impacts have been identified during this case study:

- The increased interpretation of collected data to understand and assess the equipment and assets. The result of these efforts will be the usage of condition-based maintenance.
- The increased integration of production units by sharing production data, also incidentally with external companies;
- The integration of control units, where the production processes and assets of different production units are monitored and steered. A trend towards further integration is observed.

Table 25 - Summary of impacts in manufacturing case study. Visual depiction of the business model impacts as discussed in the case study interview.

Characteristic	Appearance 1	Appearance 2	Appearance 3	Appearance 4	Appearance 5
1. Differentiation and customization	•				
2. Product-service offering			•		
3. Data collection		•			
4. Data usage		----->	•		
5. Innovation process		•			
6. Value network centrality (ecosystem)		•			
7. Horizontal integration (networking)		----->	•		
8. Vertical integration to CPS		----->	•		
9. Revenue Sources		•			
10. Smart contracts		•			
	Current level				
	Desired level				
•	Current and desired level				

## 5.4 CROSS-CASE COMPARISON OF RESULTS

In order to further examine the practical utility and the nomological and internal validity of the framework, a cross-case comparison has been done (see Table 26). In all four cases, impacts on business models have been observed. Patterns and commonalities were looked for using spreadsheets and charts. Examining these observations between the four cases, conclusions on the framework can be drawn and empirical evidence on the business model dynamics caused by Industry 4.0 in the Dutch oil and gas industry can be explicated:

- No impacts were observed in the product-service offering characteristic. As already described in the problem context (section 1), the *products* in this part of the manufacturing industry are inherently ‘non-smart’ in the sense that no embedded intelligence or connectivity can be added to petroleum products or hydrocarbons. A vital part of product-service systems is the information exchange through products and services creating tighter coupling of producers and customers. The first step towards synchronized PSS is conventionally the creation of smart products. This could be the reason for the lack of observed impacts in the second characteristic.
- On the characteristic for data usage, impacts were observed in all four cases. This is hardly surprising, since the (automatic) collection of data is usually the first step towards optimization and autonomy and thus reliability and cost-reduction.
- For the reference case, only three impacts were observed. These impacts were all in categories in which two or three of the cases in the oil and gas industry reported impacts as well. Besides data collection, also developments of horizontal integration were observed at the reference case. Note that horizontal integration was originally also observed at the upstream case, but discarded due to possible interactions with other institutional factors. Also vertical integration was observed in the reference case.
- For the differentiation and customization category, impacts were observed in the midstream and downstream cases. The difference between the two is that the former deals with a service-based offering and the latter with a product-based offering. Both SMEs recognize a more personalized offering, although different in nature. This indicates that the characteristic and its different appearances can be interpreted in multiple ways.
- Increased collection data was observed in all three cases in the oil and gas industry. The explanations of these observations were all related to the feeling that the technical nature of the assets and products can be better understood through data collection and analysis. The third and fourth characteristic were also always discussed with a certain degree of overlap.
- The innovation process for the upstream and midstream cases are expected to change due to Industry 4.0. The explanations of these dynamics however, vary between the two cases in the sense that the upstream SME regarded innovation as ‘finding new ways of working’, whilst the midstream SME regarded it as the development of innovative services for their clients. This difference in interpretation of the characteristic indicate that the concept of innovation is seen differently between different professionals. However, the characteristic is intended to be generic and applicable to any type of innovation within the firms. The underlying assumption is that innovation is a process that can be managed and has a strong interrelation with a company culture.
- For the value capturing characteristics, a total of three impacts were observed. Overall, the estimations of the appropriate appearances for characteristic 10 were all at the first or second level. However, two impacts were observed which indicates that the increasing flexibility of contracts. Revenue source innovation (characteristic 9) is described frequently as an important source of value capturing in Industry 4.0 business logic. However, only in the midstream case the SME mentioned this as something which the company is looking to pursue.

Table 26 - Cross-case comparison of observed impacts. The rows represent the business model characteristics and the columns the cases. An x indicates an observed impact on a business model characteristic within one case.

Characteristic	Upstream	Midstream	Downstream	Steel	Total
1. Differentiation and customization		x	x		2
2. Product-service offering					0
3. Data collection	x	x	x		3
4. Data usage	x	x	x	x	4
5. Innovation process	x	x			2
6. Value network centricity (ecosystem)			x		1
7. Horizontal integration (networking)		x	x	x	3
8. Vertical integration to CPS	x		x	x	3
9. Revenue Sources		x			1
10. Smart contracts		x	x		2
Total	4	7	7	3	21

## 5.5 CONCLUSIONS

Reflecting on the guiding sub-question of this chapter: *“What are operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry (e.g. labor intensive, unhealthy, unsafe or ineffective operations)?”* multiple conclusions can be drawn:

- Through data collection and usage for analytical purposes, Industry 4.0 components will likely be used for maintenance and operational innovations by the cases under study.
- Due to the importance of safety in the operations of asset owners in the oil and gas industry, innovations that benefit asset integrity and limit human interference are desired by all cases. Increasing autonomy of assets through more intensive monitoring and moving towards predictive maintenance and decentral autonomous equipment is recognized by all three cases in the Dutch oil and gas industry. This indicates that the technical characteristics of a CPS are being created by all three use cases. However, finding the newly possible value propositions and related value capturing models is lacking in the three cases.

Also on the framework itself, some conclusions can be drawn from the case studies. These observations however will be elaborated upon in section 6 of this thesis.

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## PART IV – EVALUATION

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## 6 DISCUSSION AND REFLECTION

*In this section, the results of the empirical research are discussed. Therefore, the considerations during the conceptualization of the business model characteristics and those made during their application in the case studies are compared. This reflective comparison is necessary to give an answer to the main research question. Also, the scientific added value of the framework and its limitations are addressed in this section. Within this section, the following sub question will be answered (note: this sub-question is not guiding for the entire section):*

5. *How can operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry be assessed?*

### 6.1 FRAMEWORK EVALUATION

In all of the case studies, the framework has led to the discovery of impacts on business models. The framework had to be created since no methods or framework to assess the impact of the adoption of Industry 4.0 components on business models was available. One of the challenges in the creation of the framework was the multitude of definitions and ontologies available in literature, each with its own strengths and limitations. In order to decrease the complexity during the research and to enable the comparison of the results and recommendations of previous research, a highly generic depiction of the business model was chosen. The value proposition, value creation and value capturing aspects of a business model were easily deductible from various representations of business models. Furthermore, these three elements were comprehensible to all interviewees during this study.

As described in section 2.1, the theoretical grounding of the business model concepts consists of TCE, RBV and CBV. TCE allows for the evaluation of governance structures by minimizing transaction costs. This perspective is suitable for evaluation of 'make or buy' decisions, where for instance horizontal integration decisions have to be made. However, an important aspect in Industry 4.0 is the ability to create value from the collection, usage and sales of data. The economic rationale behind the creation and capture of value from data has yet to be developed. An important step in the evaluation of business models in the TCE perspective is the determining of potential value from strategic decisions. The (economic) potential value of adoption of Industry 4.0 components the TCE is not deemed appropriate for this research due to the lack of rationale.

The impact of adoption of Industry 4.0 components on business models can also be evaluated using both the RBV and the CBV. Using the RBV, the state of assets and collection and availability of data within a firm can be evaluated. The framework characteristics 1, 2, 3, 4, 8, 9 and 10 describe directly the appropriate *resources* asset owners should have to create and adopt Industry 4.0 components. However, characteristics 5, 6 and 7 describe directly the desired *capabilities* for the operation of Industry 4.0 components. Concluding, the framework combines the two perspectives.

Besides the theoretical nature of the framework, other observations have been made during the research. Firstly, observations on the concepts and variables of the framework are discussed, hereafter the scientific added value and limitations are discussed.

#### 6.1.1 OBSERVATIONS ON CONCEPTS AND VARIABLES

The literature review led to expectations of appropriate value propositions that showed high levels of overlap with one another. In a draft version of the framework, the characteristic *customer-centricity* was included. This characteristic was deemed redundant after the expert interviews do to the fact that

both characteristic 1 and 2 already show an increasing level of customer involvement in the appearance list description.

Mostly because the research on Industry 4.0 value propositions was predominantly done within the manufacturing industry, the choice was made to include cases that involved an industrial production system. Due to the nature of the products in the oil and gas industry (bulk) the appropriateness of the appearances for the business model evolution in the oil and gas industry was uncertain.

Characteristics 3 till 8 are designed to reflect the appropriateness of business processes to enable value creation. Characteristic 3 and 4 refer to the importance of information in the light of Industry 4.0. The collection of more data for instance, is often paired with the increased use of analytics for maintenance purposes. Characteristic 8 (vertical integration) refers to the collection and coupling of information to improve efficiency of operations.

Characteristics 6 and 7 both address the network of the business model owner. Characteristic 6 is designed to reflect the level of alignment of activities between the company and its suppliers. Characteristic 7 is intended to show the extent to which data is shared between the companies in the network.

The innovation capabilities of a firm are mentioned often as key differentiator for Industry 4.0. The capabilities shown in the appearances of characteristic 5 reflect the matureness of these innovation capabilities within the company.

The scientific literature did not offer many indications of changing value capturing models and their appropriateness for Industry 4.0. To gain from the variations in prices and costs, more accurate and flexible pricing and revenue models and contracts are expected. Both characteristic 9 and 10 are weakly funded in scientific literature and are more a result of discussions during the expert interviews.

#### 6.1.2 OBSERVATIONS ON THE UTILITY OF THE FRAMEWORK

The results within this study have been gathered throughout multiple research steps using various methods. The attempted purpose of this multi-method research design was to create a both scientifically rigorous and practically relevant framework. The degree of rigor is discussed in sections 6.1.3 and 6.1.4, whereas its practical relevance is discussed in this section.

Practical relevance is interpreted in this study as the practical utility or pragmatic validity. As discussed in section 1.7.5, the case study analysis was done to evaluate this practical utility of the framework. The following criteria were selected to do so, as suggested by (Bacharach, 1989):

- Scope of the variables and constructs. The variables must sufficiently tap the domain of the constructs, while the constructs must tap the domain of the phenomenon in question;
- The explanatory potential of the relationships.

Referring to scope of the variables and constructs, multiple observations are made. Firstly, the scope of the constructs were a point of discussion during the expert interviews in research step E. Experts 2 and 4 expressed their impression that the list of business model characteristics will never be exhaustive. Their reasoning for this was that the company-specific business and market conditions of companies will always varies greatly and thus no selection of 'desirable' business model characteristics can be applied generically. However, during the process of the expert interviews, saturation of the constructs was achieved. After revision of the selected literature and discussions with the experts, the constructs were limited to the list of ten characteristics.

These remarks led to the insight that during the case study interviews, the SMEs should be asked whether they feel the constructs (in this case: characteristics) did actually capture the full scope of the Industry 4.0 related business model dynamics. None of the SMEs responded negatively to this question. This is of course no proof for the appropriateness of the scope of the constructs in the framework, but it can be regarded to be at least a solid indication. The SMEs were selected based on their knowledge of both technology and strategy and interest in the Industry 4.0 paradigm. Therefore their opinions on the scope of the constructs can be valued. Also, in an attempt to increase the generalizability of the constructs, several sampling criteria were used to delineate in which cases the framework can be applied.

Also regarding the scope of the variables, observations can be made. The variables are displayed as 'appearances' of business model characteristics in Tables 6, 7 and 9. The scope of the variables refers to the extent to which they represent their relating theoretical constructs. This is interpreted as the extent to which the 'appearances' of the business model characteristics describe the current and desired state of the business models in the case studies. The first observation is that out of all four case studies, only three instances existed where the SME felt that none of the business model appearances reflected the business model characteristic in their company:

- During the upstream case study interview, the SME remarked that for characteristic 7, the appearances did not describe a logical path of development, since the specific case does not deal with external clients or suppliers. Because it is a consortium, almost all of the stakeholders are internal. The SME did believe that although internal, the degree of horizontal integration could still be described using the concepts described in the appearances.
- During the midstream case study interview, the SME did not find the logic behind the appearances of characteristic 2 representative for their company. The reason for this is that in the midstream oil and gas sector, no actual manufacturing is done. Because the company is inherently service-dominant, the scope of the variables was not sufficient for this case study. However, this is a direct result of the drawback of the case in terms of the selection criteria as described in section 5.2.3.
- During the downstream case study interview, the descriptions of the appearances for characteristic 5 were not recognized for the company of the SME. Since the innovation processes is typically managed within a separate business department within the large enterprises in the oil and gas industry, the business units that actually do the production are not always aware of them.

These observations indicate that for characteristics 2, 5 and 7, the chosen appearances do not reflect the extent to which these characteristics are present among all firms in the Dutch oil and gas industry. These shortcomings of the three characteristics are isolated in the sense that these observations have all occurred at only one of the four use cases. However, they are a compromise of the scope of the variables of the framework. Besides these three instances, the SME interviews provided no suggestions that the appearances did not properly reflect the business model characteristics of the framework.

The final evaluation criterium for practical utility is the explanatory potential of the relationships between the variables and constructs. Regarding this criterium, it can be remarked that at two out of four interviews, the logic behind the framework had to be explicitly explained at the early stages of the conversation. This is a solid indication that the framework in itself is not a self-explanatory tool for self-assessment. What confirmed this observation is that for the majority of the characteristics, the clarifying questions related to the characteristics (as shown in Appendix B) had to be used. Often, the concepts featured in the descriptions of the appearances had to be introduced by the interviewer, before the SME was confident in expressing expectations regarding the characteristic. Although this is

observation relates more to the narrative of the framework, it can as well influence its explanatory potential.

The explanatory potential is understood in this study as the extent to which the framework was useful in understanding the cases. Various indications were observed that confirmed the usability of the framework in the analysis of the cases. Firstly, all of the SME interviews were concluded by asking whether the framework and related interview were useful. Four out of five interviewees replied by stating that the framework was an insightful tool to gather relevant operational dynamics and their relationship to the strategy of a firm. Also, three out of five interviewees mentioned that the framework and interview clarified the concept of Industry 4.0 for them.

The explanatory power also relates to the extent to which it allows a researcher to explore the cases. Based purely on the results, it can be concluded that in all four case studies relevant business model dynamics (socio-technical transformations) could be identified. Not only could the impacts on business models be *determined*, they could also be assessed due to the depth of the semi-structured case interviews. The interviews allowed for the exploration of company-specific examples that reflect the impacts adoption of Industry 4.0 components in companies in the Dutch oil and gas and steel industry.

Judging only the framework, it can be concluded that its explanatory potential is limited, in the sense that the interviewer had to explain the logic and concepts of the framework in many cases. However, if applied in an appropriate way, the framework can be used to explore case studies in high depth. This does of course require an interviewer with the right knowledge.

A last remark on the explanatory power of the framework is that the generated results cannot be verified without conducting an additional analysis of the institutional factors that could potentially induce the business model dynamics. When an institutional factor not related to the Industry 4.0 paradigm causes a dynamic in the business model characteristics of a company, it is not an 'impact' of adoption of Industry 4.0 components.

These last two remarks also relate to the sub question that is dealt with in this chapter: *How can operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry be assessed?* It can be concluded that the framework can be used to *identify* impacts on business models, but in itself it cannot be used to *assess* these impacts.

The assessment of the impacts requires a more in-depth analysis of the impacts and institutional factors related to the case. So answering the sub question:

- The operational opportunities for improvement using Industry 4.0 components in the Dutch oil and gas industry can be assessed by using the Industry 4.0 Business Model Impact Framework during a semi-structured interview with an SME to discuss these opportunities in depth and use the frameworks logic to map impacts on the current business model. After this, the results of the interview should be verified or questioned using desk research into the institutional factors that are specific to the case under study.

### 6.1.3 SCIENTIFIC ADDED VALUE

The contribution to existing literature from this research is the combination of relevant concepts and theories to gain insight into business model changes in the light of Industry 4.0. The framework that was created provides a novel tool to identify and assess the impacts of adoption of Industry 4.0 components on business models in a generic and comparable way. Impacts were observed in all of the case studies and the SMEs often recognized the steps chosen for the appearances as the evolution within their company. This indicates that the framework could be a valuable tool in the research into

Industry 4.0 driven business model changes. The chosen method of evaluation, using a five step scale, does imply that it is better suitable for the identification of impact of Industry 4.0 on existing business processes in the oil and gas industry.

Within the scope of the current research, the practical utility of this new framework has been evaluated. However, to fully evaluate a new theory, the falsifiability of a theory should also be explored. Defining experiments to explore *construct validity* of the framework and logical and empirical adequacy of the relationships between the constructs and variables would enable this. However, the exploratory potential of the framework is promising, given the results from the four case studies.

The scientific value of the framework as a structure to identify, evaluate and assess business models for the Industry 4.0 paradigm is suggested, yet not empirically validated. The framework has fulfilled its purpose of gaining in-depth insights into the impacts of Industry 4.0 components on business models in the Dutch oil, gas and steel industries. These insights are twofold. On the one hand, the current state-of-development of the business models can be evaluated and compared. On the other hand, the logic of the framework allowed the identification of business model changes (or impacts). The potential of the framework however, is much broader. The framework could be applied to business models of multiple other manufacturing firms to search for successful configurations of business models.

The credibility of the study was improved by describing the chain of evidence of each of the research steps. However, in exploratory and qualitative studies there is always the risk of selection or interpretation bias. This makes the consistency of the results uncertain. Regardless, the wider applicability of the study's findings was explored by applying the framework to a case in the steel industry. This additional case study generated the expected results and in-depth insights into the case study. This indicates that the framework can be applicable to other asset owners of production systems in the Dutch manufacturing industry. The wider applicability can be explored by conducting cross-industry and international case studies.

During the midstream and steel cases, it was mentioned that the value capturing activities closely resembled many of the business processes at the company. A tool that is often used for the evaluation of the maturity of these business processes is the CMMI model. The framework in this research can easily be interpreted as a 'maturity model for business models in the light of Industry 4.0'. However, the extent to which the framework is a maturity model in the definition of the scientific body of literature has to be explored in further research.

The application of the framework in the case study of the steel manufacturer has shown that the framework can also be applied to companies outside of the oil and gas industry. However, the case does resemble the oil and gas case studies in the sense that it involves continuous bulk production. Therefore, this research does not show any indications of the framework being applicable to discrete or batch based production companies.

#### 6.1.4 LIMITATIONS OF THE FRAMEWORK

The framework is intended to give insights into the evolution of business models. Therefore the framework is constructed as a list of appearances consisting of incremental steps in an ordinal scale. However, more radical business model changes/innovations such as the diversification into fully new markets and industries fall outside of the scope of the framework.

Another shortcoming of the framework is the lack of insight it gives into the steps required to move between levels. The goal of the framework in this study is to *identify* business model changes caused by Industry 4.0. However, to analyze these changes in more detail, further research into the nature of the shifts between scales and their requirement in terms of technology and resources is required.

The applications of technologies like 3d printing and robotics are highly company-specific and are therefore not easily processed into a framework generic for the oil and gas industry. Even though the conceptualization of Industry 4.0 shown in section 4 incorporates these and other specific technologies, the framework does not allow the coupling of these technologies with operational opportunities.

The validity of the framework was tested by:

1. Observing whether predictions made about relationships between other variables are confirmed, by evaluating any causality of observed impacts with the *institutional factors* of the case under study (looking for *nomological validity*);
2. Using multiple sources of evidence, by cross-examining desk study results and interview data (looking for *internal validity*).

The first step of the validation was done after the results of the SME interviews were generated. Looking for any interrelationships between observed impacts on business models and the institutional factors determining value creation and capturing for the cases under study. The process was challenging, since the selection of institutional factors includes the risk of leaving important factors out of the analysis. The list of institutional factors was drafted before each interview, and triangulated using new insights into for instance the nature of competition in the section of the value chain gained during the interview. Next, each observed impact was evaluated for possible external influences by the institutional factors in a systematic way, mostly through collective brainstorming. This process is interpretative and perhaps selective. However, this extra step to examine more closely the nature of the observed impacts forces the researcher to critically assess the theoretical hypotheses about impacts caused by Industry 4.0. This is a crucial step in the validation of the model.

Secondly, multiple sources of data have been triangulated to validate the internal results of the cases, but also to conduct a cross-case comparison. The cross-case comparison enabled the closer examination of nomological validity. For instance, characteristics 1 and 5 were interpreted differently by at least two SMEs. Regardless of the difference in interpretation, impacts were still observed. Strictly taken, this interpretation problem indicates that the nomological validity for this part of the framework is not validated. However, it can also be argued that this problem will nearly always occur due to the lack of consensus on the business model concept itself and the high level description of the business logic it represents. This ambiguity makes the business model a slippery concept to study, and decreases the extent to which any empirical evidence can be based upon research using it as unit of analysis.

However, as mentioned in section 1, determining validity using a qualitative and exploratory research approach is never uncontested. The validation steps should be done using a clear chain of evidence. Although efforts have been done to increase both internal and external validity of the research, the risk of bias through selection and subjectivity during data analysis.

## 6.2 PRACTICAL RESULTS

The lack of a unified perspective on the business model formed a challenge during the gathering of empirical findings. The division of the business model into the three elements (value proposition, value creating activities and value capturing models) required no further explanation in all four case study interviews.

The three business model elements each have their own characteristic and nature. Observations regarding the nature of the characteristics have been made. Furthermore, interactions between the different characteristics and elements have been found.

### 6.2.1 VALUE PROPOSITION

The interviewed SMEs recognized the increased interaction with their end-user, although this customer often internal within their enterprise. The wording used for the appearances originates from the business-to-consumer (B2C) manufacturing industry. An important trend in this B2C industry is to create Smart Products that enable interaction between producer and end-user and provide the

producer more information on the product, its use and user. However, the production done in the oil and gas industry only involves bulk liquids and gases. The nature of the products makes them inherently non-smart. This can be considered to be main cause for the low level scores on the value proposition. Another important step in the evolution of the value proposition is the development of a comprehensive service offering, next to the offered products. The services discussed during the upstream and downstream cases only entailed the provision of information. Again, due to the nature of the bulk (liquid and gas) products, no information exchange can be established through the offered product. This hampers the shift in their business models towards the right of the framework.

### 6.2.2 VALUE CREATION

While discussion characteristics 3, 4 and 8, a lot of overlap between the answers of the SME's occurred. The collection of data was illustrated by practical examples that had to do with characteristic 4. The distinction between characteristic 4 and 8 however (maintenance vs. operational excellence) was not observed by the SME's. An observation that was made during the case study interviews is that the fifth level of characteristic 3 (Network of sensors, RFID, Cloud storage and computation, connected to MES) is highly similar to the fourth level of characteristic 8 (sensors and actuators integrated with control and production management and MES systems). During the discussions, it became clear that not every company has a MES, but control and (production) management systems were present in all of the case study companies. This is a surprising result, since a MES is appropriate for the monitoring and steering of continuous production processes, like those in the oil and gas industry. To improve the applicability of the framework for discrete or batch production facilities, the term MES for characteristic three could be altered to control and production management system.

Similar experiences happened during the evaluation of characteristics 6 and 7. Descriptions of characteristics 6 and 7 were often done simultaneously during the interviews. The distinction between the two characteristics was not always clear.

The innovation capabilities described in the framework were not deemed appropriate for the type of innovation required at the downstream and steel manufacturing case studies. In these cases, innovation attempts are made with the goal of improving the internal processes in terms of resource allocation. The appearance list is deemed more appropriate to describe the development of novel products and/or services, where the added value of prototyping and lifecycle analysis is obvious. The nature of the assets and low margins on production in these cases do often not allow for test production. The business units governing the evaluated business model therefore have little space for innovation of the process. However, this does not mean that this type of innovation is not done within their respective enterprises.

### 6.2.3 VALUE CAPTURING

For characteristic 9, the path from traditional revenue sources to fully data based revenue was clear to all SMEs. The third level of this characteristic (products and/or service transaction with extensive service to increase functionality and availability) corresponds directly with the third level of characteristic 2, product-service offering. However, a correlation between these characteristics could not be empirically verified.

During the case studies, the network of some of the companies existed of internal suppliers and customers. In these cases, like at the upstream and steel manufacturing, actual monetary transactions are often not present. The existence of this type of relationships in the company network makes the evaluation of value capturing models using characteristics 9 and 10 challenging.

None of the SMEs were familiar with the Blockchain concept. This is an indication that using this technology for smarter contract types and coordination of monetary, physical and data flows is

currently not on the radar of the companies. Furthermore, a gap is observed between the second and third level of characteristic 10. The step from more dynamic contracts to digital currency is challenging for historically non-digital companies. Furthermore, the added value of using digital currencies like Bitcoin are not evident for the SMEs, until the underlying mechanism of the Blockchain is explained.

#### 6.2.4 OBSERVATIONS FROM PRACTICE

During the three case studies in the Dutch oil and gas industry it became apparent that these companies interpret Industry 4.0 as a way to achieve better operations. Attempts to do so appear in the form of data usage for (predictive) maintenance, increased openness between business departments through digital collaborate work environments.

However, the benefits offered by adopting Industry 4.0 components are not (yet) fully reaped by the companies under study. A number of general remarks can be made on the approach of these oil and gas companies with regards to Industry 4.0:

- Industry 4.0 components can lead to cost reductions, waste reductions and time reductions, but also to the possibilities to develop new products and services. Only in the midstream case study, the development of new services like digital platforms or the offering of analytics as a service to other companies was discussed as a potential business model development. This should be one of the main opportunities of the adoption of Industry 4.0 components for these companies.
- Ubiquitous availability of real-time and accurate data enables companies to align their processes with others that extend their interconnected supply chain. This creates possibilities to establish cross enterprise linkages and flexible integration along value chains and multiple companies, enabling new networks that create value increased customer interaction through digital services (like online platforms). Although all of the case studies estimated their business at a high level on characteristics 6 and 7, their horizontal integration and value networks hardly include parties external to their own enterprise. Value networks and a digital supply chain should theoretically lead to the abolishment of the traditional value chain, and the emergence of value networks. However, only the midstream case study showed signs of more openness and integration with customers using Industry 4.0 components. This openness and integration is an important requirement for the establishment of functional value networks. Even though the midstream case study shows the first steps towards horizontal integration and value networks, the three use cases show an immaturity on this aspect. Redefining the boundary of the company section where product flows and assets are monitored and optimized, asset quality (self-)checks lead to more optimal and reliable operations is discussed in all of the case studies. Even though, the case study companies discuss this step towards horizontal integration, their efforts rarely extend further than their own production unit.

The aggregation of the results of the questionnaire and the case study interviews lead to 27 personal estimates regarding the current status of the business model in the Dutch oil and gas industry. The aggregation of these results is shown in Figure 19. In the figure, the amount of impacts that were identified are indicated per characteristic. Even though the number of respondents does not allow for a statistical analysis, some conclusions can be drawn upon the aggregate results:

- Only one impact was identified in the value proposition characteristics of the case study business model. Even though the products created in the oil and gas industry have not changed drastically in the previous decades, the search for new revenue sources enabled by Industry 4.0 components can still offer high benefits for the companies in the industry.



- The focus on operational excellence and long-term contracts have led to high levels of operational excellence in the industry. The technologies and practices developed within the industry may lead to operational improvements in other industries. Furthermore, commercial offering of the complex models used for advanced maintenance like condition-based maintenance, predictive maintenance and asset self-assessments could provide a new source of revenue for the companies active in industry.
- No impacts were observed in the value network characteristic. The aggregate estimate of the current level the business models had at the time of enquiry (June – July 2016) is the highest of all characteristics. However, this characteristic is defined as follows in section 4.2.2: “A value network is a spontaneously sensing and responding spatial and temporal structure of largely loosely coupled value proposing social and economic actors interacting through institutions and technology”. As discussed in section 5.2.3, many of the customers and suppliers of the sections of the companies under study are internal. The definition of value networks implies that the other parties are largely loosely coupled value proposing social and economic actors, which is not the case with internal clients within the same enterprise. This observation gives reason to suggest that the results based on the evaluation of characteristic 6 are not accurate.

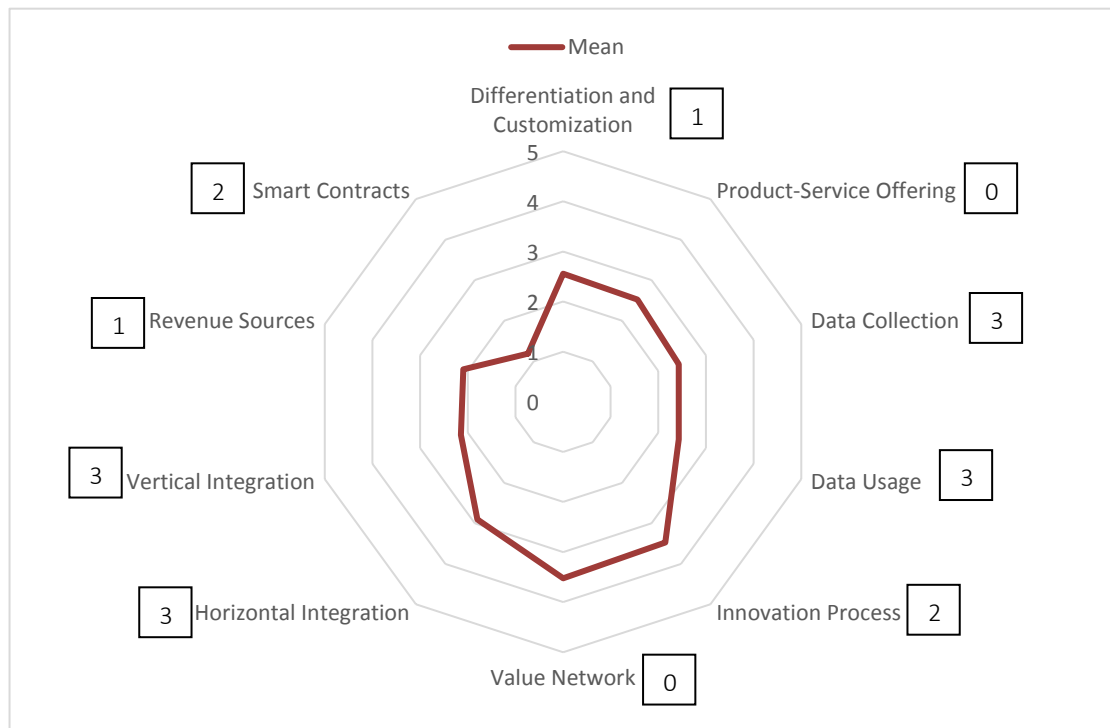


Figure 19 - Aggregate results of questionnaire and upstream, midstream and downstream case studies

## 6.3 REFLECTION

Although the past eight months have been incredibly educational and constructive, both intellectual and social. The path towards the end result has of course had its smoother and rougher patches, but I must say the rougher are most insightful and pivotal. A critical analysis of the project, its results and the chosen methods is no more than appropriate, since it provides myself and the readers with much required insights when interpreting the results, conclusions and recommendations. The critique can be divided into two domains: theoretical and methodological choices.

### 6.3.1 REFLECTION ON THE THEORETICAL CHOICES

Firstly, the choice for the core concepts of this study, the business model and Industry 4.0, proved to be interesting but challenging. The business model is a highly slippery unit of analysis, in the sense that barely any consensus has been achieved in the academic realm regarding its definition, what it consists of or how it can be used. This makes a comparative literature review challenging and requires you to clearly define many assumptions that you make regarding your interpretation of the concept. A commonly used method for this is to start by creating a definition of the business model, usually based on available definitions. Next, different ways of depicting a business model are compared and a selection is made of the ontology that is the most appropriate to analyze the business model.

Each ontology has its advantages and drawbacks when used for analytical purposes. During this process, I had trouble 'fitting' all of the relevant theoretical constructs into an existing business model ontology. Because of the boundary-spanning nature of Industry 4.0, I felt that the choice for a specific ontology would limit the scope of analysis. For this reason, I made the choice for the high-level ontology, making the distinction between the value proposition, value creating activities and value capturing models. This choice has had its benefits and drawbacks, from which I have learned a few lessons.

Firstly, the choice for a high-level ontology consisting of three elements made the process of building the framework easier. However, when I started the design of the framework, I had no real idea on how it would end up. During the process, the idea of linking 'characteristics' and 'appearances' of business models to create links and logic upon which impact can be identified was highly effective for this study. However, because the framework turned out to be a selection of concepts and constructs that has not yet been described in academia or practice, it was 'rough around the edges' for a long time. Firstly, I was unsure what to do with the apparently non-exhaustive list of business model characteristics I ended up with. I was unsure how I could somehow confirm or reject its completeness.

Also regarding framework, I noticed throughout multiple draft versions of the thesis that I made too many assumptions regarding the comprehensiveness of my explanations of the logic behind the framework. Perhaps this is still not fully clear to first-time readers. However, due to the feedback I received on the draft versions, I had to reflect on my narrative of the framework a few times. Due to this, I feel that I have a much better understanding of the framework, its strengths and limitations

Also regarding the theoretical choices, the concept 'Industry 4.0' led to realizations and reflections. Firstly, studying a topic related to Industry 4.0 was truly exhilarating. Because it is a very new but relevant and timely topic, I was able to discuss my research with many highly experienced people. First of all, the experts I have interviewed. Secondly, the many conventions, discussions and events I have visited, especially in the first four months, were a confirmation for me that Industry 4.0 is a valuable topic in both the public and private sector.

Because Industry 4.0 is a vision, a paradigm, a revolution, it took a while for me to properly define it. Having never heard of the term before January of 2016, the literature review required to conceptualize impacts of Industry 4.0 on business models took maybe a little longer than I had planned. What is very interesting to see is that my literature review at the start of the project was rather unfruitful, whereas the use of the same queries in the same databases now leads to many more results. In the academic world, scholars are more and more addressing the lag of management literature on Industry 4.0. Examples are Erol et al. (2016) and Arnold et al. (2016), which also conducted their graduate research into Industry 4.0 related business model dynamics.

### 6.3.2 REFLECTION ON THE METHODS

When multiple theories and comparative case studies are combined to create a conceptual framework, the risk of 'force-fitting' the data into a single theoretical construct arises (Dodier, Ragin, & Becker, 1994). This risk was circumvented by taking a pluralistic view during the conceptualization of the framework. I have tried to remain open since from the creation of the framework until the end of the case study phase I kept looking for possible extension or alteration of the list of constructs in the framework. Since there is no such thing as a perfect model or framework, the risk of force-fitting will always remain present. However, by discussing the appropriateness of the constructs and variables with six experts and five SMEs, the risk of force-fitting of the phenomenon into the theoretical constructs was decreased.

Due to the explorative nature of the research project, the framework was initially designed without a theoretical lens. This choice has led to the discovery of a selection of business model characteristics that may not all have the same theoretical grounding, but are complementary to each other. My belief is that this approach has led to a more holistic view of the critical characteristics of business models for the successful adoption of Industry 4.0 components. However, the explanatory potential of the framework is something I am still not fully pleased with. The chosen methods are intended to be used iteratively, with the goal of continuously improving the generalizability and utility of the framework. However, this leads to the difficult choice of when to stop. Being a person that does not shy away from (r)evaluation of my own products, the overall process was sometimes hampered by my reluctance to proceed before 'getting things right'. Two examples are the delay of the start of the expert interviews because the conceptual framework was not yet completed and the choice to limit the case study interviews to one per case.

Due to the exploratory nature of the study, a question I kept on asking myself during the course of the study was "what can I conclude from all of this?" My concern was that the answer to this question would be limited. To address this problem, taking into account my own time constraints, I made the choice for a questionnaire in addition to desk research and semi-structured interviews for the case studies. In hindsight, I would have either taken more time to think about the role and utility of the questionnaire before sending it or I would have left it out of the study. Since the precise goal of the case studies was not fully clear to me when I sent out the requests for participation in the survey, the use of the results was very limited in the study. Not only because I had a low number of respondents, but also because I had only asked the respondents for their estimation of the current state of their business model. This was not convenient, since the goal of the analysis is to compare the current state-of-development of business models with the desired state-of-development at the case studies.

The conceptual framework had to be created before any empirical research in the Dutch oil and gas industry could be done. The design process was time consuming due to the fact that literature from many fields of study was scanned and examined. The validation of the framework was an essential part of the design process. The six interviews with the experts that were conducted to validate the framework led to valuable insights and allowed for the design of a generic framework, where a potential bias for the case studies was prevented.

During the analysis of the case studies, the process of finding the correct respondents (SMEs) was challenging. Two interviews were conducted that could not be incorporated into the results of the cases, due to the observed lack of technical knowledge of the interviewees. That this happened twice, indicates that the knowledge required to evaluate the business model aspects as well as the technical operations in a company is not available at all employees within the middle line and strategic apex in the oil and gas industry.

## 7 CONCLUSIONS AND RECOMMENDATIONS

*In this section, the conclusions of this research are presenting by answering the main research question. Based on these conclusions, recommendations can be made regarding the practical and scientific relevance of this research.*

*“How can the impacts of the adoption of Industry 4.0 components on the value proposition, value creation and value capturing characteristics of the business models of owners of industrial production systems in the Dutch oil and gas industry be determined and assessed?”*

### 7.1 CONCLUSIONS

The conclusions of this research are twofold. Firstly, conclusions can be drawn upon the design of the framework. Secondly, the application of the framework on case studies within and outside of the oil and gas industry has led to findings and conclusions.

#### 7.1.1 THE INDUSTRY 4.0 BUSINESS MODEL IMPACT FRAMEWORK

The available literature did not provide a specific framework or tool to determine impacts of Industry 4.0 on a business model. For this reason this research provides a framework designed for this purpose. The first step towards the development of such a framework is the identification of expectations regarding appropriate business models for Industry 4.0. Through a literature study, combined with expert interviews, an appropriate business model for Industry 4.0 should show the following ten characteristics:

1. A high level of differentiation and customization with respect to the product and service offering;
2. A comprehensive service offering, in addition to the offered products. The optimal balance between the complementary products and services needs to be found;
3. An automated process for data collection on asset, plant and enterprise level;
4. The use of gathered data for the assessment of equipment condition and health. Examples are condition-based maintenance and preventive maintenance of assets;
5. A well-defined innovation process for both product/service innovations (value propositions) as well as for innovations aimed at new ways of working (operational excellence);
6. A value network of partnerships between the company and its suppliers and customers wherein co-production and development can be done and alignment of workflows and responsibilities is done;
7. Horizontal integration of equipment, assets, plants and suppliers and customers through a digitalized supply chain;
8. Vertical integration through integration of sensors and actuators with control, production, MES and ERP systems;
9. Data-based revenue sources to gain value from the increased importance of information;
10. Smart and flexible contracts

Since the goal of this research is to design a framework that can be used to assess impacts of Industry 4.0 on business models, the above-mentioned characteristics were translated into a scaled impact model. This scaled model takes the expectations of the appropriate business models as desired situation. After this, Literature research and six interviews with experts in the field of Industry 4.0 and business models led to the creation of a five-point scaled description of appearances of each characteristic, ranging from less appropriate for Industry 4.0 to highly appropriate.

This process led to a framework consisting of 50 appearances of business model characteristics that can be used to determine both the current situation of a business model, as well as the desired situation. By comparing the current situation with the desired, impacts of Industry 4.0 on business models of asset owners can be identified. The resulting framework is shown in Figure 20.

The framework was used to evaluate business models in the Dutch oil and gas industry, by conduction case studies in the upstream, midstream and downstream sectors. The data collection for the case studies was done through desk study, an online questionnaire and semi-structured interviews with SMEs.

Impacts on business model characteristics have been observed in all three use cases in the oil and gas industry, as well as in a case study done for a manufacturing company. This indicates that the framework is suitable for the determining of impacts of adoption of Industry 4.0 components on business models of asset owners. However, the business models featured in the case study analyses show many similarities in the sense of production process, asset type and size, network and enterprise structure. Whether the framework is suitable for the evaluation of business models of asset owners that have different characteristics, is studied using tests for nomological validity. The practical utility of the framework was evaluated by examining the scope of the constructs and variables of the framework, as well as its explanatory potential.



Figure 20 - The Industry 4.0 Business Model Impact Framework. The ten business model characteristics are depicted on the left. These are the theoretical constructs of the framework. In order to make these constructs measurable, five different variables were described for each construct. These variables are featured as different ‘appearances’ of the business model characteristic, which are ranked on an ordinal scale of 1 to 5, according to their appropriateness for Industry 4.0 business logic. The choice of constructs and variables, as well as their descriptions and logic of the rankings is based upon literature review and six expert interviews

### 7.1.2 EMPIRICAL FINDINGS USING THE FRAMEWORK

A total of 20 impacts of Industry 4.0 on the three evaluated business models in the oil and gas industry have been identified. In the upstream case, the business model of a natural gas exploration and production company was explored. The following impacts were identified:

- The changing modes of data collection, by using collected data for Asset Performance Analytics. This is a big step towards using the data in the MES.
- The usage of data is also impacted by Industry 4.0 in the sense that the quality of data can be verified in better ways due to increased computing power and analytics. This means more data can be used for predictive and preventive maintenance.
- The streamlining of the innovation process is done by increasing the interaction with the (internal) end-user and prototyping.
- In the field of vertical integration, additional steps can be expected due to recent efforts in database coupling and IT system integration.

An impact on the degree of horizontal integration was also observed in the upstream case study. However, due to interrelationship between this impact and a number of institutional factors that determine value creation and capturing within the scope of the business model. The licensing policy and concurrent long contracts led to decades of collaboration between a limited amount of stakeholders in these projects. This characteristic leads to low investment risks into collaboration and networking tools and technologies. For this reason, this impact could not be validated as caused by the adoption of Industry 4.0 components.

In the midstream case study, a total of eight impacts were identified:

- A higher level of differentiation and customization through customer-oriented digital services.
- More advanced data collection through the usage of RFID and Cloud storage. More autonomous operations through data input in the MES.
- More usage of data through increasing data analytics capabilities. In the maintenance domain, the assessment of equipment health and condition-based and preventive maintenance are the desired level of data usage.
- The increased use of unstructured data for the development of innovative pricing methods.
- The increase of horizontal integration through data sharing with large clients.
- The increase of vertical integration by increased systems integration and automation.
- The move towards data-based transactions and pay-per-use models.
- The increasingly dynamic nature of contracts with customers.

Also in the downstream case study, business model impacts were identified:

- The increased differentiation of product offerings due to flexibility of the refinery. This is enabled by technological advances and changing relationship between the refinery and its (internal) suppliers and customers.
- The increased collection of data and interoperability of for instance product flow data and asset integrity monitoring.
- The increased reliability of asset self-assessment (combined with data verification) leading to higher levels of autonomy of the refinery's operations.
- The higher level of openness between the refinery and its supplier and customer. The different departments within the enterprise are increasingly collaborating, sharing and aligning work their work.

- Higher level of horizontal integration, caused by the arising collaboration networks between different departments of the enterprise.
- Higher level of vertical integration due to the (siloed) integration of sensors and actuators at asset and plant level.
- The focus on enterprise value and increased flexibility in contracts instead of the traditional legal contracts.

Based on the empirical results gathered using the framework, four observations were made regarding the appropriateness of business models for Industry 4.0 components in the Dutch oil and gas industry. The first observation is the lack of development of novel products and services using Industry 4.0 components. The application of Industry 4.0 related technologies are mostly used to increase operational efficiencies and improve maintenance systems in the companies. The second observation is that the companies seem to overestimate their horizontal integration. Horizontal integration in the light of Industry 4.0 is the extension of the company boundaries to actively collaborate with independently operating economic actors. Only in the midstream case the increased interaction with customers through digital innovations was observed. This is an opportunity for the companies in the industry. Also, due to the importance of safety in the operations of asset owners in the oil and gas industry, innovations that benefit asset integrity and limit human interference are desired by all cases. Increasing autonomy of assets through more intensive monitoring and moving towards predictive maintenance and decentral autonomous equipment is recognized by all three cases in the Dutch oil and gas industry. This indicates that the technical characteristics of a CPS (or Industry 4.0 component) are being created by all three use cases. However, finding the newly possible value propositions and related value capturing models is lacking by the three cases.

## 7.2 RECOMMENDATIONS

Having answered the research questions, a number of recommendations can be made. Firstly, for the companies in the industry under study, the Dutch oil and gas industry. Secondly, recommendations for further research can be made.

### 7.2.1 RECOMMENDATIONS FOR ASSET OWNERS IN THE DUTCH OIL AND GAS INDUSTRY

The combined results of desk study, literature review, interviews with Industry 4.0 and business model experts, a questionnaire and interviews with SMEs in the industry lead to the following recommendations:

- The establishment of networks with strategic partners (like technology and service providers), are becoming increasingly important. The safe and secure interconnection of value chains, enables closer and more intensive relationship to suppliers and customers. The creation of value networks with collaborative strategic partners is recommended. The need to develop different ways of collaboration and closer integration of the asset owners with its suppliers and customers is expressed by all SMEs during the case studies. Also, this recommendation follows from the lack of observed impacts on characteristic 6 and the perceived lack of strategy to create strengthen their value networks.
- The investment required to upgrade assets to create Industry 4.0 components should not discourage companies. Industry 4.0 components promise several potential cost reductions. Also, new income sources can be found by the asset owners through the development of new product and service offerings. Also, the cases under study all show degrees of digitalization of assets, more efficient use of data for (self-)optimization and automation. Also, data sharing between business units and stakeholders outside of the current scope of optimization indicates that horizontal integration is already being increased by the firms. Also, coupling of



various IT systems for production control and management, MES and corporate planning clearly indicate the increasing level of vertical integration among the asset owners. This indicates that the firms are already pursuing the creation of Industry 4.0 components in the technical sense. This is a sign that the value creation processes that follows the business logic of Industry 4.0 components are present within the Dutch oil and gas industry. However, the creation of innovative value propositions and related value capturing models should be pursued by the firms in order to gain from the economic benefits of Industry 4.0 components.

### 7.2.2 RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the results, several recommendations for further research can be made:

- Using the framework for the design of new business models, without having to take into account existing business models and structures.
- Further examining the interactions and interrelations between the different characteristics and levels within the framework.
- Applying the framework on different manufacturing cases, where discrete and batch production is done. The different nature of production is expected to require different business processes. The framework could be tested for appropriateness of evaluating these different business processes. Furthermore, the discrete and batch industries more often produce products that can be made 'smart' due to embedded technology. The creation of smart products shows a lot of potential to increase the interaction between the producer and end-user, and opens the door towards new analytics methods for product use, production optimization and product lifecycle analysis. This leads to the expectation that the value propositions and value capturing models within the discrete and batch industries will change. This hypothesis is yet to be verified by future research.

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## APPENDICES

### APPENDIX A0 – THE CONCEPTUAL BUSINESS MODEL IMPACT FRAMEWORK

Business model characteristics	Value proposition					
	1	2	3	4	5	
1. Differentiation and customization	Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	High product/service differentiation / customization, high end-user involvement	(Piller et al., 2015; Tseng & Piller, 2003)
2. End-user centricity	Process-centered orientation	Product-centric orientation	Product-centric orientation with clear end-user strategy	end-user-centric orientation with few end-user interaction channels	End-end-user focus, multiple interaction channels with data collection and analysis	(Shah, Rust, Parasuraman, Staelin, & Day, 2006)
3. Product-service offering	Complete separation of products and service offering	Some additional (product-oriented) service for product(s)	Value-added service(s) offered to related product(s) (user-oriented)	Services aimed at end-user relations to related product offering	Product-Service System (PSS), direct end-user relations, stakeholder engagement	(Barquet et al., 2013; Bustinza et al., 2013; Herterich et al., 2015; Mikusz, 2014)

Business model characteristics	Value creation					
	1	2	3	4	5	
4. Data collection	(Occasional) manual data collection	Sensors and antennas installed, data inconsistency	Network of wireless sensors (WSN) installed	Network of sensors (WSN), interoperable with RFID and Cloud storage	WSN, RFID, Cloud storage and computation, connected to Manufacturing Execution System	(Gubbi et al., 2013)
5. Value network centricity (ecosystem)	No partnerships used for co-production, service exchange or co-creation of value	Understanding of end-user values, strategic partnership exist	Service exchange with partners (e.g. joint ventures), no co-production or co-creation	Service exchange, co-production along the value chain	Service exchange, co-production and clear value co-creation (competency based)	(Frow et al., 2015; Herrala, 2011; Lusch et al., 2009)

6. Innovation process	Linear design process, no end-user interaction, no prototyping, long time-to market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	Iterative design process, (early) end-user feedback, prototyping	End-user centric design process, rapid prototyping (short t-t-m)	(Burmeister et al., 2015)
7. Data usage, efficiency, scalability and availability (for preventive maintenance)	Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	Adaptive assessment of equipment health in cyber-physical spaces	Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management	(Lee et al., 2014)
8. (digital) Supply chain integration	Only physical and financial flows along the value chain	Attempts made for information flows, hampered by inconsistent data	Supplier or end-user information integration	Supplier and end-user information integration	End-to-end engineering (i.e. complete digital supply chain integration)	(Kagerman et al., 2013; Rai et al., 2006)
9. Horizontal integration (networking)	Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	Internal communication and collaborative network with either supplier or end-user (external)	Functional collaboration network, data availability through network	(Brettel et al., 2014; Rai et al., 2006)
10. Vertical integration to CPS	Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MES systems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)	(Kagerman et al., 2013)

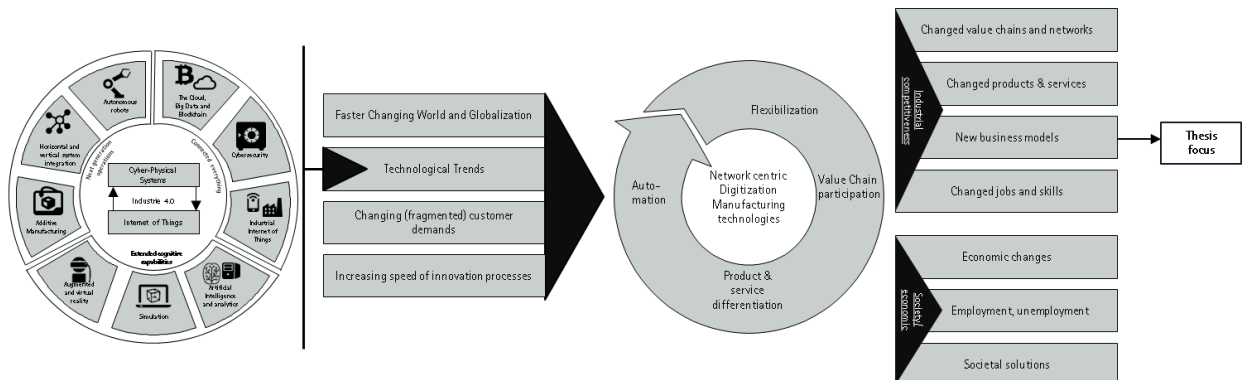
Value capturing

BM Characteristic	1	2	3	4	5	Source(s)
1. Value appropriation from data / digital structures						
2. Variabilization of prices and costs						
3. Value network appropriation						

## APPENDIX A0.1 – EXPERT INTERVIEW GUIDE

The goal of the framework within this study is to measure the impact of adoption of Industrie 4.0 elements on business models. In order to measure the impact, a rationale of degrees of impact has to be created. The literature offers insights into the desirable Industrie 4.0 business models, which can be considered to be the ideal situation. The choice is made to create a scaled impact model, where 1 represents a business model that is not at all appropriate for Industrie 4.0, and 5 the desired situation as described in the available literature.

The following schematic shows an interpretation of Industrie 4.0 and the rationale of its impacts on business models:



In order to create underpinned scales that firms can use to determine the impact of adoption of Industrie 4.0 elements on their business model, various academic sources from fields of study like computer science, engineering, operations research and information systems have been used. In the tables below, the conceptual framework that resulted from the literature review is shown.

In the framework, the following business model elements are distinguished:

- Value proposition
  - Drivers of customer value and unique offerings of firm
- Activities of value creation
  - Resources, capabilities and processes required to deliver the offering. Starting from partner/supplier relationships to sales channels
- Models for value capture
  - Underlying cost structure and revenue formula, used to determine profitability and economic sustainability

In the tables, the left cells of the rows indicate the characteristics of business models that are expected to be impacted by the Industrie 4.0 paradigm. In the cells next to this the impact scales are shown. These impact scales are intended to be practical consequences of Industrie 4.0 on a companies' operations. In the cells on the right, the (academic) sources used to create the impact scales are indicated.

During the interview, I would like to discuss the following points with you:

- Do you agree with the division of the business model into these three elements?
- Do you think that the business model characteristics are a good indication of changes caused by Industrie 4.0?
- Do you feel the impacts scales are appropriate, realistic and relevant?
- What is your opinion on the practical use of the framework?

Business model characteristics	Value proposition					
	1	2	3	4	5	
Differentiation and customization	Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	High product/service differentiation/customization, high end-user involvement	(Piller et al., 2015; Tseng & Piller, 2003)
End-user centricity	Process-centered orientation	Product-centric orientation	Product-centric orientation with clear end-user strategy	end-user-centric orientation with few end-user interaction channels	End-end-user focus, multiple interaction channels with data collection and analysis	(Shah et al., 2006)
Product-service offering	Complete separation of products and service offering	Some additional (product-oriented) service for product(s)	Value-added service(s) offered to related product(s) (use-oriented)	Services aimed at end-user relations to related product offering	Product-Service System (PSS), direct end-user relations, stakeholder engagement	(Barquet et al., 2013; Bustinza et al., 2013; Herterich et al., 2015; Mikusz, 2014)

Sources of predicted impacted characteristics: (Burmeister et al., 2015; Jazdi, 2014; Mikusz, 2014; Pisching et al., 2015; Schlechtendahl et al., 2014; Shrouf et al., 2014; Wiesner et al., 2014)

Business model characteristics	Value creation					
	1	2	3	4	5	
Data collection	(Occasional) manual data collection	Sensors and antennas installed, data inconsistency	Network of wireless sensors (WSN) installed	Network of sensors (WSN), interoperable with RFID and Cloud storage	WSN, RFID, Cloud storage and computation, connected to Manufacturing Execution System	(Gubbi et al., 2013)
Value network centricity (ecosystem)	No partnerships used for co-production, service exchange or co-creation of value	Understanding of end-user values, strategic partnership exist	Service exchange with partners (e.g. joint ventures), no co-production or co-creation	Service exchange, co-production along the value chain	Service exchange, co-production and clear value co-creation (competency based)	(Frow et al., 2015; Herrala, 2011; Lusch et al., 2009)
Innovation process	Linear design process, no end-user interaction, no prototyping, long time-to market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	Iterative design process, (early) end-user feedback, prototyping	End-user centric design process, rapid prototyping (short t-t-m)	(Burmeister et al., 2015)
Data usage, efficiency, scalability and availability (for preventive maintenance)	Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	Adaptive assessment of equipment health in cyber-physical spaces	Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management	(Lee et al., 2014)
(digital) Supply chain integration	Only physical and financial flows along the value chain	Attempts made for information flows, hampered by inconsistent data	Supplier or end-user information integration	Supplier and end-user information integration	End-to-end engineering (i.e. complete digital supply chain integration)	(Kagerman et al., 2013; Rai et al., 2006)
Horizontal integration (networking)	Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	Internal communication and collaborative network with either supplier or end-user (external)	Functional collaboration network, data availability through network	(Brettel et al., 2014; Rai et al., 2006)

Vertical integration to CPS	Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MESsystems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)	(Kagermann et al., 2013)
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Sources of predicted impacted characteristics: (Burmeister et al., 2015; Kagermann et al., 2013; Shrouf et al., 2014; Wiesner et al., 2014)

Business model characteristics	Value capturing					
	1	2	3	4	5	
Data appropriation					Value appropriation from data / digital structures	
Differentiation and customization					Variabilization of prices and costs	
Value network appropriation						

Possible research domains for finding impact scale of value capturing business model elements:

- Blockchain
- Pricing structures and contracts
- Economies of networking

## APPENDIX A0.2 – SUMMARIES EXPERT INTERVIEWS

### FEEDBACK FROM INTERVIEWS

- Interviewee #1: Prof dr. Egbert-Jan Sol
  - Programme director Smart Industry
  - Responsible for Fieldlabs in Netherlands
- Interviewee #2: Prof. dr. Fred van Houten
  - Professor of design science at University of Twente
- Interviewee #3: Dr. Stefan Wiesner
  - Research Scientist at BIBA – Bremer Institute for Production and Logistics
- Interviewee #4: Christian Gülpen
  - Director Industrie 4.0 / Digitalization at RWTH Aachen Technology & Innovation Management
- Interviewee #5: Christian Burmeister
  - Doctoral Researcher at RWTH Aachen
- Interviewee #6 Karel Crombach
  - EMEA Industry Director at Microsoft Corporation

### FEEDBACK ON FRAMEWORK

#### 1. Egbert-Jan Sol

- The fourth industrial revolution will overthrow the manufacturing industry
  - Suppliers will become producers of fully customized products
  - OEMS will become solutions providers to the end-users and abandon production activities
- Remarks on scheme:
  - Add blockchain and increasing speed of innovation processes
- The impact of industry 4.0 on the petrochemical industry is limited due to the small margins in production and capital intensity. This leads to limited space for innovations and high path-dependency. The technologies can be used for incremental improvements of processes (operational excellence) but will not likely lead to new business models.
- The value propositions of OEMs will become focused on same-day production, next day delivery customized products
  - The value propositions of Tier 1-x suppliers will become focused on quality and speed as well as cost-neutral production of unique and customized produce
  - End-user centricity is of paramount importance, but it is intertwined with differentiation and customization → merge the first two categories
- The value capturing in the fourth industrial revolution revolves around the shift from economies of scale to economies of networking
- The value from networks should be distributed among its participants by appropriate agreements and contracts for ownership etc.
  - → The blockchain technology is essential for this (digital) administration in networks for Industry 4.0



- Use and appropriateness of framework: this type of analysis is offered by multiple parties, including TNO. It is a way of creating awareness of business model changes caused by Industry 4.0

## **2. Fred van Houten**

- One-size fits all framework is hardly feasible due to large degree of variation among companies and markets
- Remarks on scheme:
  - Flexibility is lacking
- In manufacturing industry, shift is made from product focus to production process. The value propositions of firms are changing, but appropriateness of business model is different for every company. Therefore the measurement of appropriateness for Industry 4.0 is not straight-forward.
- For the value capturing characteristics of a business model, it could be useful to categorize on the appropriateness of the framework: contract types for suitability for industry 4.0
- The differences between the steps of the impact scales are highly interpretative. This has as consequence that conclusions based on the framework should be done with utmost care.

## **3. Stefan Wiesner**

- Choice for Business Model Canvas was made because of the ease of use and appropriateness in workshop setting
- Remarks on scheme:
  - Display of I4.0 is too technical. It is clearly a socio-technical phenomenon.
- On value proposition
  - Differentiation and customization and end-user centricity are overlapping. Should be merged and customer relationships might belong in domain of value creation
  - The scale for differentiation and product-service can be changed
- On value creation:
  - Value network should be more focused on the nature of collaboration and the instances in which collaboration is done
  - Scale can be changed, sources provided
  - Innovation process is described more like a design process
  - Data usage and supply chain integration show overlap. Preventive maintenance should be removed.
- On value capturing:
  - Try to create a scale based on revenue sources.
  - Profit and risk sharing structures can be distinguished on appropriability for industry 4.0

## **4. Christian Gülpen:**

- Remarks on scheme:
  - Incorporate RAMI
  - Change layout of first circle
  - Second circle is not circular reasoning
  - Organizational change is not included in the outcomes section
- On value proposition:
  - Differentiation and customization is based on articles on 3d printing and customization, this does not cover all off the aspects of Industry 4.0

- Process automation of the customization and differentiation is an important dimension for this characteristic
- End-user centricity is inherent to differentiation and customization
- Process-oriented operations are not unsuitable for industry 4.0, on the contrary! This scale is not appropriate
- The most fitting end-user communication channel for industry 4.0 is a platform
- On value creation:
  - The innovation process scale looks appropriate, the use of different types of data (open, structured etc.

## 5. Christian Burmeister:

### *On Scheme Smart Industry (Industry 4.0 components)*

Technological enablers are not on the same level – hierarchy. The autonomous robots and AM techniques are lower-level pieces of equipment, whereas IIoT & horizontal and vertical integration are more overarching issues or even results of these lower-level technologies (practical). The model is not MECE since there can undoubtedly more technologies or effects/events in the technological domain that can be seen as enabling technologies. Maybe make it more high-level and include just a few examples

The global trends are highly complex socio-technical issues which are intricate and therefore not easily simplified or distinguishable. This list of 4 trends is not MECE and there is also a strong interplay between the elements in the left circle and trends boxes.

Suggestion to remove the middle two unclear and difficultly distinguishable diagrams and create a more clear socio-technical-managerial scheme using different levels of aggregation. The boxes on the right are understandable and should be something to work towards in the explanation of the schematic. Do not create artificial complexity as it will unnecessarily make things more difficult later on.

### *On the distinction of three business model elements*

Totally agree on this division into these three elements. It is done more often and allows you to decrease the complexity and at this level a business model can be understood by all. It is generalizable and appropriate since the existing business model ontologies are not scientifically proven appropriate depictions. Remaining on this high-level, conclusions can be more easily drawn due to this generalizability. This enables any comparisons which are more challenging on a more granular level.

### *On the applicability of the framework*

A lot of commonalities between the BM characteristics of the framework and the research paper by Christian. The way the framework is currently set up is to go from a high-level 'characteristic' to a practical realization of this business model element. The element on the far right would be the most ideal or full I4.0 realization of this characteristic, and the far left would be an as-is or I3.0 realization of this characteristic.

This framework allows for the study into a business model, not so much the BMI process.

### *Business Model, not BMI Process*

The framework can be developed in the following way:

1. Extend and improve list by interviewing experts (10-20) from practice. Look for distinctions in categories and scales between companies and industries (along the value chains)
2. Look at combinations between elements in propositions, creation and capturing that are promising/suitable (clusters)
3. By speaking to experts in different industries and diving into these issues and the appropriateness of the framework (elements) some saturation will occur regarding 1) the generalizability of the framework and 2) the combinations or clusters of business model characteristics and corresponding capabilities that are appropriate in practice. This would be an iterative process!
4. These results would need to be purified/validated by self-assessment of some sorts (i.e. rating each other).

A method to do such a research has been used to look for clusters in open innovation practices and capabilities. Interesting industries for this type of research would be: software/automation, consumer (electronics), automotive, chemicals.

#### 1. Karel Crombach:

- On business model elements:
  - The division into three elements makes sense. However, the elements cannot be separated since they are highly interrelated.
  - Customers of Microsoft are searching for value-added revenue models. For instance, models wherein data-driven sales are done or the sales of services like data analytics.
  - A shift from products to services is observed within the technology providers domain
- On business model dynamics
  - The business models for asset owners is truly different than for technology and service providers. Asset owners will be less likely to shift fully towards the service side, whilst service providers like consultants have different sources of value
  - More integrated business models will arise, wherein vertical solutions are offered by technology providers. 'However, these vertical solutions can also be developed by the asset owners themselves in an attempt to improve operations.

## APPENDIX A1 – INTERVIEW UPSTREAM

[Available upon request]

## APPENDIX A2 – INTERVIEW MIDSTREAM

[Available upon request]

## APPENDIX A3 – INTERVIEW DOWNSTREAM

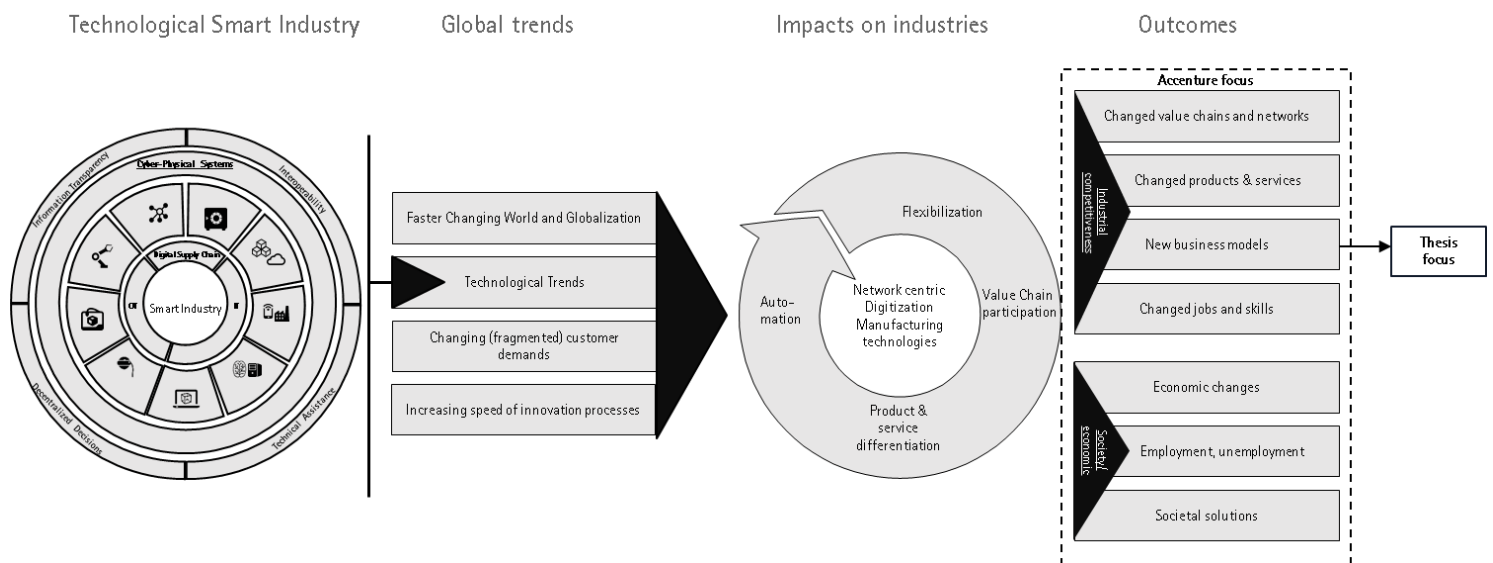
[Available upon request]

## APPENDIX A4 – INTERVIEW STEEL MANUFACTURING

[Available upon request]

## APPENDIX B – CASE STUDY INTERVIEW GUIDE

The goal of the framework within this study is to measure the impact of adoption of Smart Industry elements on business models. In order to measure the impact, a rationale of degrees of impact has to be created. Scientific and professional literature offers insights into the desirable Smart Industry business models, which can be considered to be the ideal situation. The choice is made to create a scaled impact model, where 1 represents a business model that is not at all appropriate for Smart Industry, and 5 the desired situation as described in the available literature. This impact framework has previously been discussed with seven experts in the field of Smart Industry / Industry 4.0 and business models, in order to validate and improve it.



As an introduction to the framework, the following schematic shows an interpretation of Smart Industry and the rationale of its impacts on business models:

In order to create underpinned scales that firms can use to determine the impact of adoption of Smart Industry elements on their business model, various academic sources from fields of study like computer science, engineering, operations research and information systems have been used. In the tables below, the conceptual framework that resulted from the literature review is shown.

In the framework, the following business model elements are distinguished:

- Value proposition
  - Drivers of customer value and unique offerings of firm
- Activities of value creation
  - Resources, capabilities and processes required to deliver the offering. Starting from partner/supplier relationships to sales channels
- Models for value capture
  - Underlying cost structure and revenue formula, used to determine profitability and economic sustainability

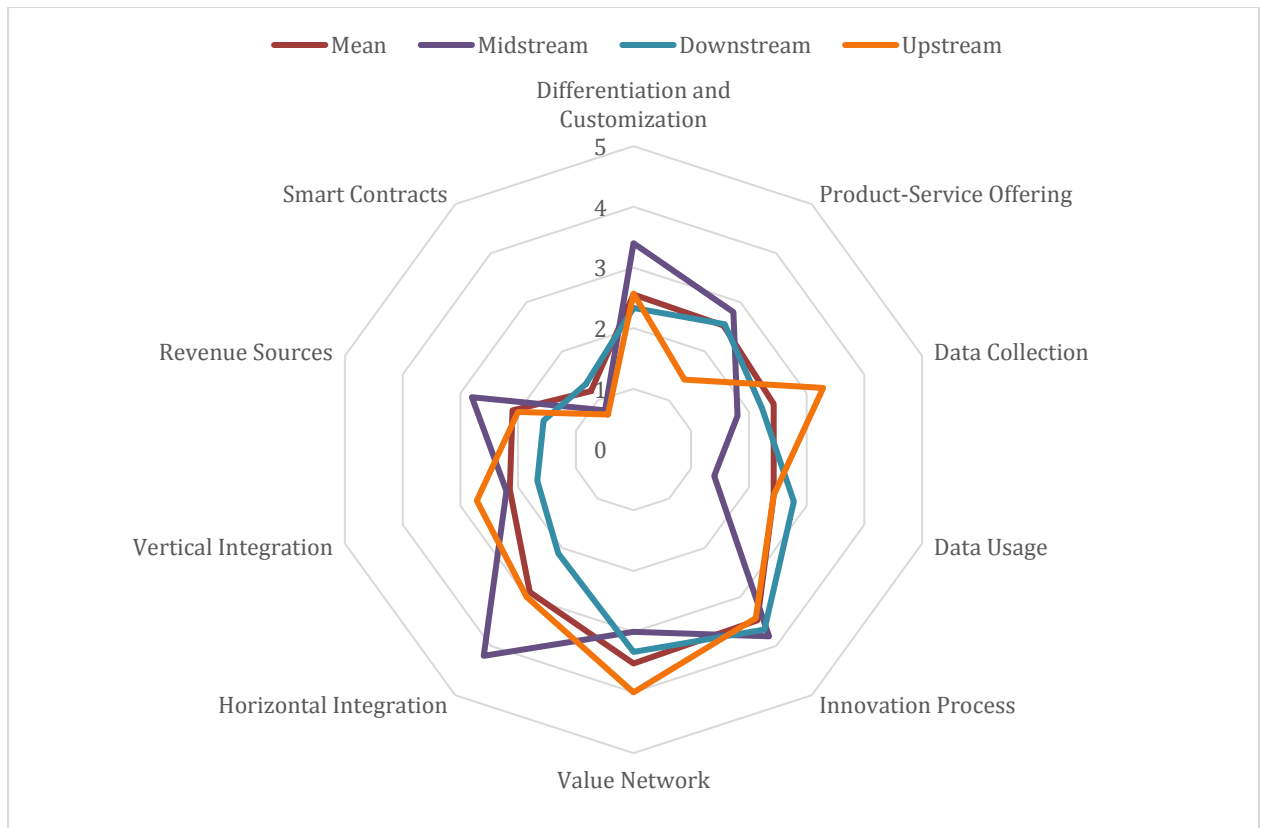
In the tables, the left cells of the rows indicate the characteristics of business models that are expected to be impacted by the Smart Industry paradigm. In the cells next to this the impact

scales are shown. These impact scales are intended to be practical (or operational) consequences of Smart Industry on a companies' operations.

Using the framework, I have done a survey in the Dutch oil and gas industry. In the survey, the following questions had to be answered:

- In what ways do you offer value to your clients?
  1. What types of products and/or services does your firm or business unit offer to its clients?
  2. Are the products and services you offer complementary to each other i.e. how would you characterize the offering to your client?
- In what ways does your firm create value?
  3. How is operational data from the production process collected at your firm or business unit?
  4. How does your firm make use of available production/process (and collected) data?
  5. How is the innovation process managed within your firm?
  6. How does your firm interact and collaborate with suppliers, end-users and/or competitors?
  7. Is the production data shared within the ecosystem (along the supply chain), i.e. inter-company?
  8. Does your firm have a functional Cyber-Physical System?
- How does your firm capture value?
  9. How does your firm create revenue?
  10. Does your firm make use of Blockchain technology to register transactions and keep track of physical and data flows?

During the interview, I would like to discuss the results of this survey with you. I would like to use your business as a benchmark for the oil and gas industry. The following chart shows the results of the survey in the oil and gas industry graphically:



Furthermore, I would like to discuss the appropriateness of business models in your section of the industry for the Fourth Industrial Revolution. The appropriateness can be determined using the framework, which is shown in the three tables that can be found below.

Business characteristics	model	Value proposition				
		1	2	3	4	5
1.Differentiation and customization		Undifferentiated product offering (i.e. uniform products)	Products offered with minor (after-sales) customization possibilities	Diverse product and service offering, supply driven production	Customization possible through end-user-oriented services	One-of-a-kind production
2.Product-service offering		Products	Products + services for functionality	Products + services for functionality and availability	No product offering, but manufacturing as a service (MaaS)	OEM as solution provider for end-user, no production done

Business characteristics	model	Value creation				
		1	2	3	4	5
3.Data collection		(Occasional) manual data collection	Sensors installed, data integration is not possible due to inconsistency	Network of connected sensors installed	Network of sensors, interoperable with for example RFID and Cloud storage	Network of sensors, RFID, Cloud storage and computation, connected to Manufacturing Execution System
4.Data usage, efficiency, scalability and availability		Equipment connected to local data server (i.e. centralized system)	Sensory data and machine level data can be converged	Adaptive assessment of equipment health in cyber-physical spaces	Equipment and components quality and condition check, product quality reasoning, decentralized data processing	Self-optimized decentral autonomous equipment, self-adjustable prognostics and health management
5.Innovation process		Linear design process, no end-user interaction, no prototyping, long time-to market	Design process with a few iterations, no end-user interaction, prototyping	Iterative design process, little end-user interaction	Iterative design process, (early) end-user feedback, prototyping	Usage of (un)structured data for product life cycle improvement, short time-to-market
6.Value network centricity (ecosystem)		No partnerships or exchange of services, traditional buyer-seller relationships	Ad-hoc exchange of services and aligning of activities, communication and information exchange	Incidental but recurring exchanges, alignment of company goals and activities for mutual benefits	Service exchange, co-production along the value chain (coordinated)	Alignment of goals, workflow, creation and design and sharing of responsibilities
7.Horizontal integration (networking)		Independently operating machinery and/or production units (internal)	Communication between equipment in different production stages (internal)	Communication between machinery as well as with smart products and items (internal)	Internal communication and collaborative network with either supplier or end-user (external)	Functional collaboration network, data availability through network
8.Vertical integration to CPS		Sensors and actuators not integrated with IT systems	Sensors and actuators integrated with control system	Sensors and actuators integrated with control and production management system	Sensors and actuators integrated with control and production management and MESsystems	Vertical integration (control, production management, manufacturing and planning and corporate planning systems)

#### Value capturing



Business characteristics	model	1	2	3	4	5
9.Revenue sources		Traditional sales (buyer-seller)	Sales based on data gathered from internal processes and historical transactions	Product and/or service transaction with extensive service to increase functionality and availability	Data-based transactions, for instance pay-per-use models	As-a-Service revenue model (fully data-based)
10.Smart contracts using Blockchain		Traditional legal contract	Dynamic contracts	Digital currency exchange	Peer-to-peer smart contracts	Blockchain used for coordination of monetary, physical and data flows

## APPENDIX C1 - VALIDATION CHART FOR UPSTREAM CASE

Table 27 - Examination of observed impacts and institutional factors for the upstream case

[Available upon request]

## APPENDIX C2 - VALIDATION CHART FOR MIDSTREAM CASE

Table 28 -Examination of observed impacts and institutional factors for the midstream case

[Available upon request]

## APPENDIX C3 - VALIDATION CHART FOR DOWNSTREAM CASE

Table 29 -Examination of observed impacts and institutional factors for the downstream case

[Available upon request]