Abstract

Manufacturing companies are currently facing impactful challenges regarding concepts such as Industry 4.0 and Cyber-Physical Systems. For the oil and gas industry however, no literature is available on the potential impact of adoption of Industry 4.0 components on business models. For this purpose, this paper proposes a conceptual framework to identify and assess these impacts. The framework was created and refined with six experts during semi-structured interviews. Furthermore, the refined framework was used to conduct case studies of business models in the upstream, midstream and downstream sectors. The case studies are based on desk study and semi-structured interviews with SMEs from the oil and gas industry in the field of Industry 4.0. The main goal was to extend the technology dominated focus of literature on Industry 4.0 by including a framework that can be used to assess and evaluate business model dynamics related to Industry 4.0. In three categories "Value Proposition, Value Creating Activities" and "Value Capturing Models", ten business model characteristics and examples of their operational appearances are depicted in the framework. Using the framework, a total of 20 impacts could be identified on the business models of the three case studies in the Dutch oil and gas industry. Based on this study, the companies in the Dutch oil and gas industry can be recommended to focus on the creation of value networks and the offering of new services and products.

Keywords: Industry 4.0, Cyber-Physical Systems, Internet of Things, Value Chain, Business Model, Oil and Gas, Manufacturing, Case Study
1. Problem Outline

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 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.

Recently, a new wave of technological developments is expected to impact business models throughout various industries. 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 companies (Teese, 2010; Zott & Amit, 2010).

This new wave of technological developments, that is also one of the most important drivers of the need to reevaluate the business model by industrial firms, is "Industry 4.0". This is a paradigm enabled by multiple intelligent technological developments that shows the potential to radically and fundamentally change production processes and value creation. The concept Industry 4.0 (or Industrie 4.0) refers to the fourth industrial revolution, the previous revolutions 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 essence of Industry 4.0 is the introduction of Cyber-Physical Systems (CPS) into the industrial systems (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 machines, materials and products along the value chain (Porter & Heppelmann, 2014; Rudtsch, Gausemeier, Gesing, Mittag, & Peter, 2014). Specific cases of CPS, being combinations of these innovative technologies, are referred to as Industry 4.0 components in this study. Furthermore, 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.

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).

However, because of the novelty of Industry 4.0 and lack of proven use cases, it is unclear what the operational and monetary benefits of the adoption of Industry 4.0 elements are and to what extent this will impact the way current business models in the oil and gas industry. The tool or method 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.

Also, 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. The scientific problem addressed by this study is thus the lack of understanding of Industry 4.0 related business model dynamics in asset owners using continuous (bulk) production processes. For this reason, the chosen research domain is the Dutch oil and gas industry, where various business models of asset owners are studied. Because a systematic evaluation of these business models for their appropriateness for Industry 4.0 business logic cannot be done using available tools or frameworks, the research objective is to develop such a method. Consequently, the research question is: “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?”

Due to the lack of previous systematic research on this topic, a qualitative and exploratory research design is used. Using literature review and expert interviews, a conceptual framework was built and refined. Then, a comparative case study in the Dutch oil and gas industry enabled the testing of the nomological validity and practical utility of the framework. From the case studies, practical recommendations for asset owners in the Dutch oil and gas industry could be made. In section 6 of this paper, the results of one of the case studies are described in detail. Also, the overall key findings of the case studies are summarized.

2. Theoretical background

The adoption of Industry 4.0 components should be accompanied by the design of an appropriate and related business model. The framework that resulted from the study needed to capture the technical characteristics of Industry 4.0 related innovations and translate these into business model characteristics, to enable asset owners in the Dutch oil and gas industry to determine and assess what part of their business model will be impacted. To explain the theoretical groundings for the framework (or construct), for this reason, the interpretation of the business model concept that is chosen for this research is described consequently.

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, & Roussel, 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.

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 theoretical groundings for the framework (or construct). For this reason, the interpretation of the business model concept that is chosen for this research is described consequently.

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

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,
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.

3. Industry 4.0 – Definition and opportunities

According to various academics and practitioners, it is no longer the question whether the fourth industrial revolution is taking place (BCG, 2015; Grangèl-González et al. 2016; Jazdi, 2014; Schlechtendahl, Keinert, Kretschmer, Lechler, & Verl, 2014; Schuh, Potente, Wesch-Potente, Weber, & Prote, 2014). The notion of CPS is inseparably linked to Industry 4.0. In addition, many other terms are used to describe Industry 4.0. The most frequently used is the IoT (Brettel, Friederichsen, & Keller, 2014). Industry 4.0 is also sometimes referred to as the Industrial Internet of Things (IIoT) (Grangèl-González et al., 2016). For this study, it is assumed that IoT or IIoT are not the same as Industry 4.0. Industry 4.0 is regarded to be a result of CPS connected to the (Industrial) Internet of Things, whereas the IIoT is the connection of industrial products, components and machines to the Internet. This combination together with a consolidated Internet protocol and network infrastructure is believed to have a strong disruptive character (Kagermann et al., 2013; Westerlund, Leminen, & Rajahonka, 2014). 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 component can be defined as specific cases of CPS (Grangèl-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 1. The model describes the connection between IT, manufacturers/plants and product life cycle through three dimensions (Grangèl-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).

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 (e.g. 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, Luettgens, & Piller, 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).

4. Research Design

The how featured in research question indicates the need to create a tool or framework to explore impacts on the business models within the Dutch oil and gas industry. For this purpose, a conceptual framework to identify and assess these impacts was created in the course of the research. The following research steps have been consequently been carried out:

- A preliminary analysis to create an understanding of the Industry 4.0 domain;
- Literature review, to select the theoretical constructs used in the framework;
- An extended literature review, aimed at the collection of variables to measure or ‘operationalize’ the constructs of the framework;
- Six expert interviews, to refine and determine scope of constructs and variables of the framework;
- Multi-method case study analysis, according to the methodology of Voss, Tsikritskis, & Frohlich (2002), to evaluate the practical utility and normological validity of the framework, and to gain in-depth insight into business model dynamics in the Dutch oil and gas industry.

The first step consisted of the exploration of domain complexities and analysis of the gap of existing methods and tools to determine and assess impacts of adoption Industry 4.0 components. The constructs and variables were selected during an extensive systematic literature review of English literature. The literature did provide insights into the constructs of a business model that is suitable for the Industry 4.0 business logic. However, the constructs could not yet be measured. In an iterative process between expert interviews and extended literature review into the constructs and variables, the conceptual framework was built and refined. The constructs and variables of the framework were re-iteratively categorized, dimensionalized and integrated as proposed by Spiggle, (1994) to create the conceptual framework. The creation of and logic behind the conceptual framework is described in more detail in section 5. The experts were selected based upon their knowledge of Industry 4.0 related business model dynamics. The
face-to-face or telephonic semi-structured interviews with interviews used a draft version of the conceptual framework as guideline and lasted between 60 and 90 minutes. Furthermore, case studies of business models in the upstream, midstream and downstream sectors were done. The multi-method case study analysis entailed two steps i) desk research and ii) semi-structured interviews. The desk research was aimed at exploring the institutional factors that determine the creation and capturing of value in the specific section of the value chain of the business model (upstream, midstream or downstream), which entail the: i) exogenous context and conditions, ii) the participating companies and iii) the organization and institutional properties of the sector as described by (Wolf, 2009). The semi-structured interviews with Subject-matter Experts (SMEs) in the field of Industry 4.0 at the case companies used the conceptual framework as guideline, with the question list shown in Appendix A as support. The case studies sampling was based on the following criteria:

- Currently operated ecosystem business model;
- Asset owners;
- Diversity of value chain activities;
- Different context, organization and institutional properties;
- Willingness to contribute.

The SMEs were selected using a convenience sampling approach and employment in the Strategic Apex as described by (Mintzberg, 1993). The results of the semi-structured interviews with SMEs were twofold. Firstly, impacts of Industry 4.0 on the business models could be determined by, for each construct, comparing the different variables of the theoretical framework that described the current business model best with the variable that describes the desired business model. Using this as-is vs. to-be overview, general insight into the business model dynamics of the case studies could be obtained. However, using the triangulated results of the in-depth descriptions of the business model dynamics and the desk research, an assessment of the determined business model impacts could be done. Furthermore, a cross-case analysis revealed the extent to which the framework can be used to determine and assess impacts on business models of other companies in the manufacturing industry. This cross-case analysis and the triangulation of desk research and interview results enabled the evaluation of the nomological validity of the framework. Further synthesis of all of the research steps and results allowed for the evaluation of the practical utility of the framework.

5 Conceptual Framework

The technological possibilities characterizing Industry 4.0 described in the section 3, 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. These business model characteristics were found in a systemic literature review of peer-reviewed articles. Using literature from 2013-2016 that was scanned and selected using the following queries in Google Scholar and Scopus: value creation, value capturing, value proposition in combination with industry 4.0, industrie 4.0, internet of things, IoT, IIoT. The result of this review was a list of business model characteristics that are deemed appropriate for the creation and capturing of value according to Industry 4.0 business logic. Using a grounded theory approach (Glaser & Strauss, 1967), the characteristics were grouped to create a list of thirteen.

Using an extended literature review, multiple appearances of these business model characteristics were searched in literature using combinations of the following queries in the aforementioned databases: 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. What resulted was matrix with business model characteristics and for each five appearances, which was discussed with the experts to establish its theoretical constructs. The goal of these expert interviews was to refine the conceptual framework, its business model characteristics and to rank their appearances based upon their appropriateness for Industry 4.0 business logic. This should create a systematic approach to evaluate existing business models of asset owners in the Dutch oil and gas industry. Resulting from the iterative process of building and refinement using building blocks from literature and discussing with experts, was the refined conceptual model shown in Figure 2. The conceptual model features ten business model characteristics and five appearances per characteristic, ranked on appropriateness for Industry 4.0 business logic. Using this matrix, impacts on business models can be determined by looking for the appearance which best describes the current business model, and subsequently looking for an appearance for the same characteristic which describes their desired business model.

The available descriptions of suitable Industry 4.0 business model characteristics from the (initial) literature review are described subsequently. After this, the creation of the list of appearances and their ranking is elaborated upon.

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, Padrock, & Thonen, 2014)

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 et al., 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)
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)

Based upon the first literature review and the above-mentioned business model characteristics for value propositions, value creation and capturing, five variables were described using an extended literature review. These research steps resulted in a conceptual framework, which was refined using six expert interviews. The result of this iterative process are the refined framework in Figure 2. The process of building this framework (using a grounded theory approach) is described in the remainder of this section.

Characteristic 1. Differentiation and customization:

To create an scale of variables, literature on Mass Customization (Tseng & Pillar, 2003) and business models for fully personalized products using Additive Manufacturing technology (Piller et al., 2015) has been used. 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 & Pillar, 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. This trend towards one-of-a-kind production was elaborated upon by two of the experts.

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, Parry, & Vendrell-Herrero, 2013). Various scholars have written about Product-Service Systems (Barquet, de Oliveira, Amigo, Cunha, & Rozenfeld, 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, Uebemickel, & Brenner, 2015). The service business is an increasingly important source of revenue according to three of the experts. Examples of such services that the experts explicated 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.

Characteristic 3. Data collection

The global availability of real-time data enables sophisticated analysis and intelligent control of the industrial production environment (Shroff et al., 2014), which significantly extends today’s possibilities and may represent a disruptive technological change (Burmeister et al., 2015). The steps of the variable scale are based upon (Gubbi, Buyya, Marusic, & Palaniswami, 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, Aridakani, Yang, & Bagheri, 2015), which form the steps in the variable scale. 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.

Characteristic 5. Innovation process

The characteristic was discussed with three interviewees, who said innovation is going so fast that companies cannot do it alone. Furthermore, the experts referred to the literature on open innovation and the use of both structured and unstructured data during the process. Another expert 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 centrality (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, Vargo, & Tanniru, 2009). The frequency of interactions between partners in the network was added to the variables after discussion with an expert.

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, Patnayakuni, & Seth, 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

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 according to one of the experts. For this reason, end-to-end engineering was included in the narrative of the framework.

Characteristic 9. Revenue sources

An expert suggested that a categorization of types of revenue sources may provide different variables to measure the degree to which revenue sources are appropriate for the Industry 4.0 business logic. 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. Based on these ideas, the variables for characteristic 9 were described.

Characteristic 10. Smart contracts using Blockchain

The Blockchain was identified as crucial enabler for Industry 4.0 by the interviewed experts. In order to create the scale for this characteristic, the literature on Dynamic Contracts by (Battaglini & Lamba, 2015) was combined with suggestions by interviewees.
These variables are feature according to their accordance with Industry 4.0 business logic. The choice of constructs and variables, as well as their describes, is based upon literature review and six expert interviews. The ten business model characteristics are depicted on the left. These are ranked on an ordinal scale of 1 to 5, with 1 being the lowest and 5 being the highest. The rankings are based on their perceived importance in the context of Industry 4.0 business models. The values capture the potential impacts on business models in the Dutch Oil and Gas Industry.
6. Case studies in Dutch oil and gas company

Example of in-depth case study results

In this section, the results obtained from the case study of a Dutch upstream gas company are presented. The company is involved with the exploration for and production of natural gas in Dutch territories, both on and offshore. The desk study of the company website and annual reports resulted in several institutional factors, unrelated to Industry 4.0, that could determine the value creation and capturing process for the case study. The list of these factors can be found in Appendix B.

During the interview with an experienced business improvement executive, the following impacts were identified:

1. 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.
2. 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.
3. The streamlining of the innovation process is done by increasing the interaction with the (internal) end-user and prototyping.
4. The horizontal integration of the upstream company is increasing, due to innovations like the collaborative work environment.*
5. In the field of vertical integration, additional steps can be expected due to recent efforts in database coupling and IT system integration.

The SME interview thus resulted in five proposed impacts. In order to evaluate whether these business model dynamics are actually caused by Industry 4.0, a triangulation with the results of the desk research was done. This triangulation was done by pairwise exploration of causal linkages between the institutional factors and the observed impacts. For the upstream case study, this resulted in the following concern regarding an impact:

- **The technical complexity of the specific resources operated by the 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 the 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 (this is indicated with an * in the list of observed impacts).**

Key findings of case studies

In a similar way, case studies were done for midstream and downstream companies. The nomological validity of the framework was tested by: 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. The internal validity of the results was evaluated using multiple sources of evidence, by cross-examining desk study results and interview data. A total of 20 impacts was identified and assessed during three case studies. A cross-case comparison enabled the closer examination of practical utility. 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 for this part of the framework, the internal validity is not confirmed. 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.

Based on the empirical results gathered using the framework, two observations were made regarding the appropriateness 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.

8. Discussion

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.

**Interpretation of key findings**

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. This simplification may lead to the different interpretation of the key findings of the research. Also, the study was conducted by a single researcher. Therefore empirical results that were generated using the framework could be subject to the interpretation of the theoretical constructs by the researcher.

**Implications for the oil and gas Industry**

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 decentralized 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.

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 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.

**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 method to 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 variable scales 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 determining and assessment of impacts of Industry 4.0 on existing business processes in the oil and gas industry, due to the explanatory power of the framework. This new method or tool to assess business model dynamics is therefore of added value scientifically.

**References**


Appendix A – List of questions used during SME interviews

- 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?

Appendix B – List of institutional factors determining the value creation and capturing processes of the upstream case study.

[Available upon request]