The Convergence and Integration of Operational Technology and Information Technology Systems

A case study in the Oil and Gas sector

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Preface

Dear reader,

The report you are currently reading is the final chapter of my education at the Delft University of Technology. The reason I came to Delft was to become a Mechanical Engineer, in which I currently hold a Bachelors degree. The reason why I stayed in Delft however was different, I enjoyed the student life of Delft to the fullest, got involved in running my own company and finally even setup another company to the point I almost forgot why I came to Delft in the first place. Because of my interest in entrepreneurship I was hesitant to start my Masters degree. Luckily I came across my Master Management of Technology. A Master that focuses more on the social and business aspects of technology instead of educating students to become a 'die-hard engineer' who sleep on their calculus book. The contents and courses of the Master appealed to me and challenged me in other ways than my Bachelor did. I am therefore very proud, but also relieved, to finish my studies in Delft in search of my next adventure!

In this preface I would like to thank everyone who showed interest or supported me during my graduation research. I would like to thank my first supervisor Rob Stikkelman in particular for having the patience to guide me through a period that took quite a while longer than originally planned. I would also like to extend my thanks to my graduation committee, professor Marijn Janssen and Aad Correlje for taking the time to review my work. A special word goes to Jules and Lauren, two friends who provided feedback and coaching in the final stage of writing this report. Finally a word of thanks to all my friends and family who have provided me with support and distraction during this intriguing period of my life!

Ruben Kranendonk

Executive Summary

Societal pressure, a competitive sector and a low oil price force Oil and Gas Companies to constantly reduce costs and optimize productivity and efficiency. While the physical hardware is near its technological potential, this conservative sector has plenty of opportunities to improve digitally. Smart sensors, connected equipment and advanced analytics tools could provide valuable insights into processes and can help predict and prevent equipment failures. The real-time available flow of data from these connected devices can notably enhance decision-making, but this does require that the traditional worlds of Information Technology (IT) and Operational Technology (OT) converge. Operational Technology controls all physical processes on production sites while Information Technology controls the flow of (digital) information. IT/OT Convergence aims to bring both technologies together by connecting field equipment like pumps, valves and compressors with computers in the office environment. This allows stakeholders to track the condition of equipment and production output real-time. Together with remote control equipment, companies in the Oil and Gas Sector can eliminate the need for humans at remote and dangerous production sites. While IT/OT Convergence has also proved itself in other sectors, the Oil & Gas Sector is slow to implement this technology. Therefore the main research question that will be answered in this report is:

What blocks the convergence and integration of Information Technology and Operational Technology in the Oil and Gas sector and what are the requirements to integrate the technologies?

To investigate why companies are hesitant to implement the convergence, this research conducted a case study into the control systems of compressors. The control systems of compressors generate and process tremendous amounts of data and therefore these pieces of equipment can benefit substantially from IT/OT convergence. To acquire insights, the researcher interviewed seven experts from major companies in the Oil and Gas Sector. Among these experts there are four users of IT and OT systems and three suppliers of these systems. The goal of the case study was to find relationships between factors that influence the implementation of IT/OT convergence. To grasp the relations between these factors, the DeLone and McLean Model for Information System Success (D&M Model) has been used. The D&M Model has three input variables, representing properties of IT/OT systems, which can be adjusted: System Quality, Information Quality and Service Quality. These input variables influence the other factors in the diagram and eventually lead to a change in Net Benefits for the company. The interviews with the experts revealed that the implementation of IT/OT convergence led to more factors and relations. The D&M Model has therefore been expanded to a causal diagram (Figure 1) to visualize how these factors affect each other.

The causal diagram is tested with three different scenarios, 1: improving the System Quality, 2: improving the Information Quality and 3: improving the Service Quality. The impacts these adjustments have are in line with the outcomes expected by the experts. Furthermore, the diagram suggests that IT/OT convergence can definitely have a positive impact (Net Benefits) on companies in the Oil and Gas Sector. The positive impacts on Net Benefits are in the form of reduced costs and risks, improved productivity and efficiency.

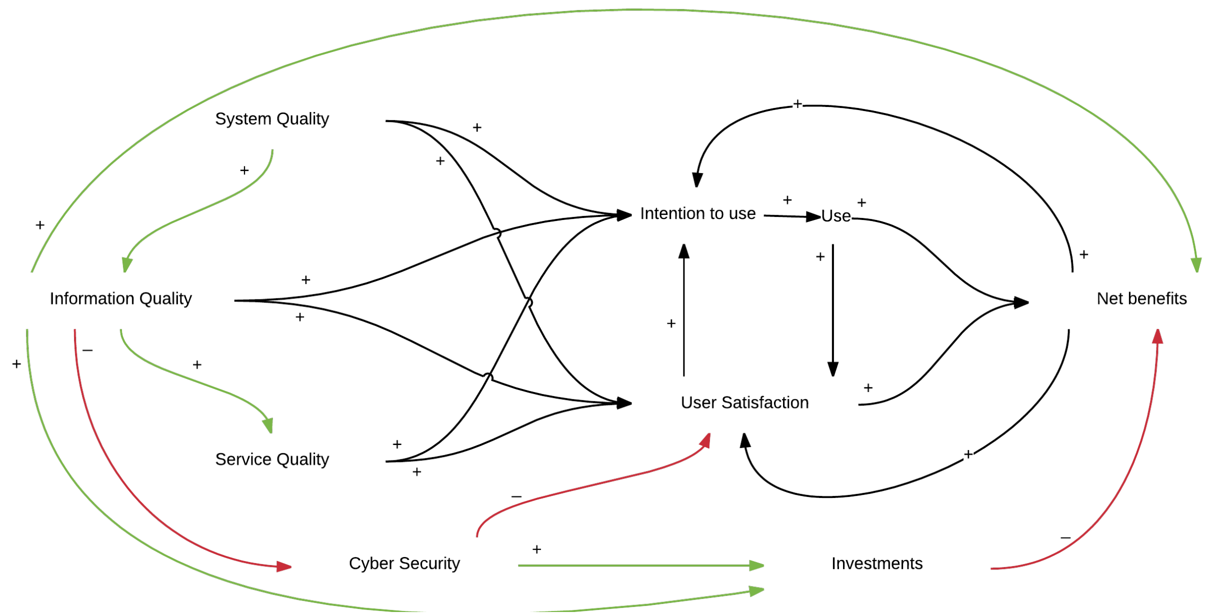

Figure 1: Causal Diagram displaying how properties of IT/OT systems (System Quality, Information Quality and Service Quality) can lead to Net Benefits for companies.

The convergence is however not being implemented as a result of a number of IT/OT barriers. IT/OT barriers are organizational and technological barriers that prevent both technologies from converging and integrating. From the non-academic literature, three different categories of barriers have been identified: Business Silos, Cultural and Skills Differences, and Technological Differences. The experts have confirmed these barriers during the interview and the definitions of these barriers are a valuable contribution to academic literature and for companies trying to achieve IT/OT convergence.

Business Silos represent the different departments that are in place in companies operating in the Oil and Gas Sector. Different goals, responsibilities, ownership, management and difficult communications between these departments all avert IT and OT into converging and integrating.

Cultural and Skills Differences are complications caused by the different skills and cultural habits of people working in the IT and OT departments. These people often have different educational backgrounds, working habits, responsibilities and impact on their working environment. These differences also prevent the convergence and integration.

Technological Differences origin from historical differences between the technologies, but also from the different functions for which they are built. OT is often specifically designed equipment to perform a single task with strict safety requirements in harsh environments. IT is designed to perform multiple tasks in a controlled environment (offices). Due to the different designs, both technologies are often not compatible with each other. In the past, OT tried to ensure safety with physical measures, by preventing remote access and keeping all control local. IT on the other hand tries to enable collaboration, open but secure access and remote control.

Interviews with experts on these barriers revealed that the barriers are linked to each other and reinforce each other. This makes the categories of barriers impossible to solve one at a time. Furthermore, Oil and Gas companies cannot afford any downtime of their equipment because this will lead to lost profits. To overcome the barriers while keeping the equipment running requires a step-by-step roadmap for implementation. With solutions provided by the experts and industry specialists from a leading consulting firm, a roadmap has been developed to guide companies in achieving IT/OT Convergence. This roadmap can be of significant business value for Oil and Gas companies that want to stay competitive. The roadmap consists of the following steps:

1. Check the maturity of the organization regarding IT/OT convergence, setup a well-planned project plan.
2. Convince the whole organization of the value of IT/OT convergence, from managers down to users, everybody must realize and believe in its value.
3. Find feasible (pilot) projects that quickly show tangible results as an example or best practice.
4. Integrate IT and OT departments and setup common governance model.
5. Stakeholder management and communication, to keep all involved parties informed of the progress, the value it creates and the opportunities it offers.

The causal diagram reveals how IT/OT systems can be adjusted to have a positive impact on companies. The roadmap can aid companies in overcoming the barriers that prevent IT and OT from converging. How all findings from this research are related to each other can be seen in Figure 2. This diagram reveals how factors influence each other when investments are made in either the System Quality, Information Quality or Service Quality of IT/OT systems. The diagram can be of aid for companies willing to invest in IT/OT convergence.

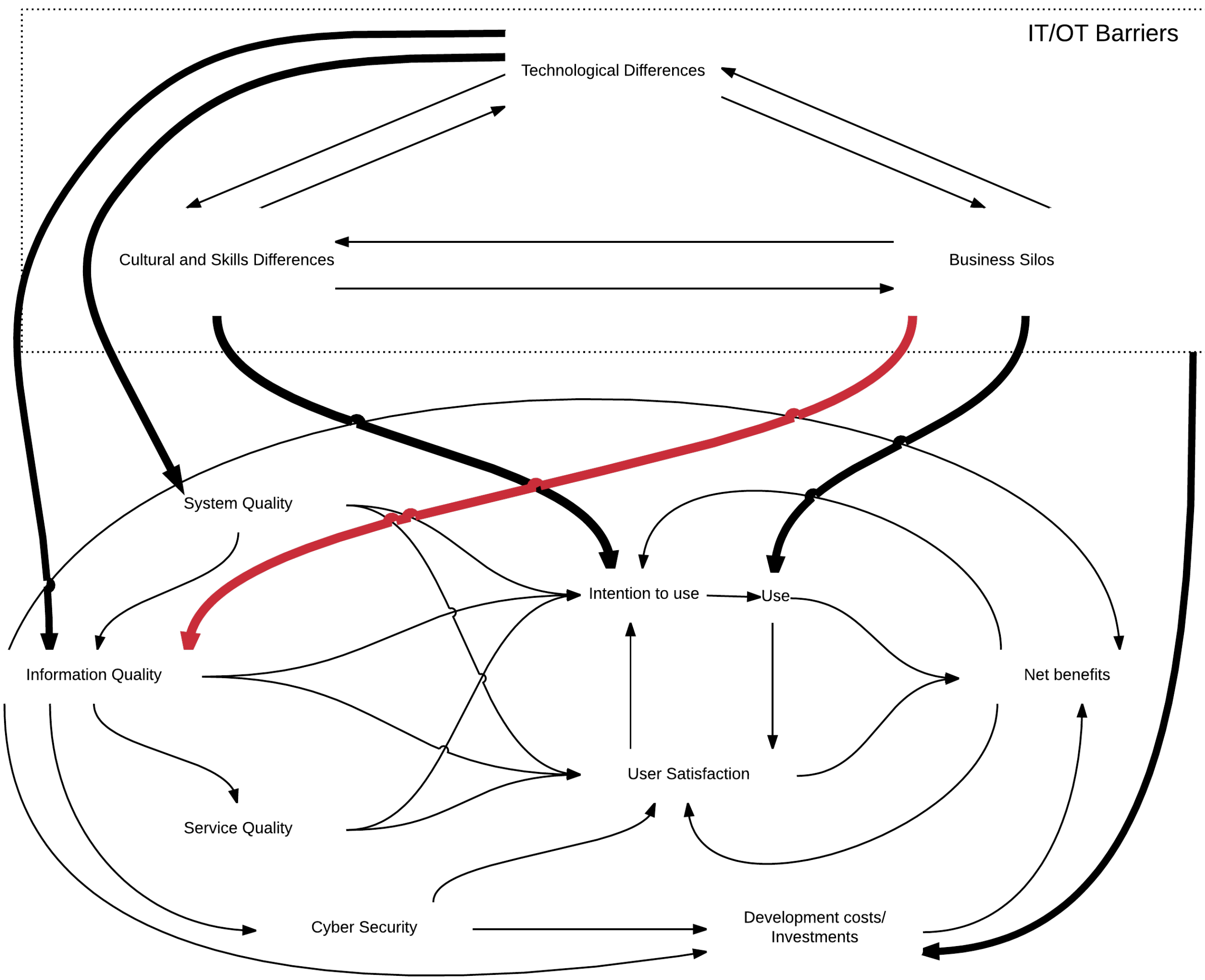

Figure 2: Causal diagram how IT/OT Barriers block the implementation of IT/OT convergence.

To conclude the answer to the main research question is:

The convergence and integration of Information Technology and Operational Technology in the Oil and Gas Sector is blocked by ‘IT/OT barriers’. The barriers reinforce each other and consist of organizational- and technological barriers, which complicate the integration of IT and OT. These barriers can be divided into three different categories, Business Silos, Cultural and Skills Differences and Technological Differences. To overcome the barriers and successfully integrate IT and OT a roadmap provided by this research can be used.

The novelty of the topic and findings of the study present a number of interesting directions for future research:

- Long-term study into the impact of IT/OT convergence, to measure the actual impact of the convergence over time.
- Investigate real IT/OT convergence implementation case, this research exposed the fact implementation is difficult since the companies cannot afford downtime. Researching a real-life case is therefore an interesting direction.
- IT/OT convergence as an enabler for the Internet of Things (IoT). IoT is considered ‘the next big thing’, the Oil and Gas Sector however must first achieve IT/OT convergence and integration. The link between these technologies and IoT in this specific environment is very interesting to investigate.
- Further investigation into the IT/OT barriers to define sub-categories or find out how much the barriers contribute exactly to the misalignment of IT and OT
- Investigate the merging of IT and OT departments. Merging these departments offer other benefits besides enabling IT/OT convergence but is a very complex problem.
- Validate developed model, the relationships are confirmed by the experts but could be validated to see how strong these relations are.

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1 Introduction

Companies and organizations continue to strive for production methods that are more efficient, flexible, with less risks and costs. Furthermore, our current society is more aware of the negative effects humanity has on the environment. These factors including the aftermath of the economic crisis forces all sectors to continuously rethink their business strategies and production methods.

The Oil and Gas sector is no different. Additionally, the Oil and Gas sector has exploited most easy to access hydrocarbon fields and must focus on remote and difficult to reach sites for access to crude oil and gas. Transferring people and equipment to these sites can be very costly. Alongside the costs, these sites often face difficult weather conditions that can cause safety hazards and an increased burden on the equipment. Since humans account to 60% to 80% of all incidents and accidents on site (Boschee, 2014), Oil & Gas companies want as few humans on site as possible. Companies therefore are forced to rely more and more on reliable and remote controlled equipment. Data from the equipment will become more valuable since if predictions on maintenance and lifecycle could increase the reliability, safety and output. In a time where everything is connected and “The Internet of Things” is seen as the next disruptive technology, data is considered as valuable as oil and sensors and communication tools are better and cheaper than ever; it is strange that the Oil and Gas Sector is slow to follow these disruptive trends.

The convergence and integration of Informational Technology and Operational Technology (IT/OT convergence and integration) is a strategy that will enable companies to become more efficient and flexible by connecting and converging IT and OT equipment while reducing operating risks and costs. IT/OT convergence and integration brings the two traditionally separated worlds of IT and OT together. The OT domain monitors and controls all physical equipment on production sites. The domain of IT is more involved in controlling, monitoring and processing the flow of information. The convergence and integration of these domains allows companies to benefit from strengths and advantages of both technologies.

In different journals, sector experts, research institutes and consultants consider IT/OT convergence in the Oil and Gas sector as the next crucial technological advancement to stay competitive. The current uncertain oil price forces these companies to become more efficient and innovative. Furthermore, IT/OT convergence has proven itself in other sectors similar to the Oil and Gas sector so it is expected to have a positive impact on this sector as well. What blocks the adoption of IT/OT convergence in the Oil and Gas Sector is therefore an interesting topic to study and is one of the main problems this research will cover. Since other sectors already apply the principle, the scope of the research will be limited to the Oil and Gas sector. Hence, the goal of this research is to find out why IT/OT convergence is not yet applied in the Oil and Gas sector, to explore the topic of IT/OT convergence and integration and to find how IT/OT convergence can be achieved.

1.1 Background, Problem and Research Questions

This paragraph provides an introduction and background to the the problem statement of this researchnd This section elaborates on key stakeholders, definition of IT and OT and introduces the opportunity that the gathering of data offers. Finally, the societal and academic relevance of the problem will be described. The context and background of the problem will then lead to the research questions that will be answered in this report.

1.1.1 Operational Technology (OT)

OT is typically associated with field-based devices used for monitoring and controlling specific processes. The collective of OT systems is often called Industrial Control Systems (ICS). OT systems communicate between devices or device-to-computer with relatively little human interaction. OT encompasses certain field devices and the control applications such as programmable logic controllers (PLCs), distributed control systems (DCSs) and instrumentation measurement systems. These operational assets are becoming smarter over time and use more technologies that were traditionally in the domain of the information technology (IT). OT is often employed for specific functions and quite controlled by specific operations personnel (Enose, 2014). In the Oil and Gas Sector OT is in control of all the production equipment, from valve control to safety systems and control systems for compressors.

1.1.2 Information Technology (IT)

IT is traditionally linked with back-office information systems for conducting business-type transactions, such as cost and tax accounting, billing and revenue collection, asset tracking and depreciation, human resource records and time-keeping, and customer records (Taylor, 2012). Whilst OT systems are controlled by a few users only, IT systems are controlled by many. Due to the wide array of uses and application areas, IT systems have gone beyond their boundaries and there is a profound increase in quality. Enhanced enterprise applications- the ERPs, asset management systems, workforce management systems, geographic information systems, outage management systems, along with other real-time monitoring and productivity enhancement tools have taken dominance in the workplace. IT has always been developed independent and separately of the OT equipment. Within IT, manual data entry is often involved, and the computing resources have tended to be located in offices, server rooms and corporate data centres (Enose, 2014).

The differences between the two technologies, IT and OT, how these are managed and what impact the technologies have is considered a key problem contributing to the misalignment of IT and OT (ATOS, 2012; Harp & Gregory-Brown, 2015; Taylor, 2012).

1.1.3 Stakeholders Concerning IT/OT Convergence

The role, interests, power position or relationship between the different stakeholders involved in the problem could present a cause of the problem. After preliminary research and discussing the topic with industry specialists, the following important and influential stakeholders are identified and listed in Table 1. In this table their interest and power position presented which will reveal any issues between involved parties that could be a cause for the problem.

Table 1: Stakeholders With Interest in IT/OT Convergence

Stakeholder	Role	Interest	Power
Decision Makers in Oil and Gas companies (Managers)	Customer	High	High
Suppliers of IT/OT systems	Supplier	High	Medium to low
Users (within Oil and Gas companies) of IT/OT systems	Users	Medium	Low

Decision Makers in Oil and Gas Companies (Managers)

The decision makers in Oil and Gas companies are the main stakeholders regarding IT/OT convergence, these companies have a need to improve performance, reduce risks and costs and enhance decision-making. Main driver for these companies are in the end costs so they prefer to achieve all these gains with as limited investment as possible. Since these companies make the final decision on whether to implement IT/OT Convergence or not, they have the most influence.

Suppliers of IT/OT Systems

The different suppliers of IT/OT systems are another important stakeholder, as they supply the technology that enables the integration and convergence of IT and OT. They do however rely on the decision of their customers (companies in the Oil and Gas Sector), when this decision is made they can have influence on the implementation but their power position is therefore medium to low. The focus of the suppliers is not on a sustainable future but on maximizing sales, whether in services or in products sold. Because they rely on the Oil and Gas Companies, their interest in the matter is very high.

Users of IT/OT Systems

The actual users of IT/OT systems themselves, the operators and engineers who work with the systems are a third stakeholder. Their interest in the matter is medium; employees often prefer the way they are working at the moment instead of learning to work according to new procedures or with new systems unless the systems provide major benefits for the employees themselves. As the user of the systems they are informed of changes of these systems but they are rarely involved in the decision making process, they simply have to accept the needs 'from above'. Hence their power position is low.

The key stakeholders regarding IT/OT Convergence are clearly the suppliers and the buyers (managers) of these systems. Regarding the adoption of IT/OT Convergence their views will probably be opposite since suppliers will try to push customers into using new systems where customers will try to expand the lifetime of the current systems as long as they can. Furthermore, companies in the Oil and Gas sector tend to be conservative on adopting new technologies while the suppliers are often early adopters. This should be taken into account when gathering data from different sources for this research.

1.1.4 Data Captured at Oil and Gas Production Sites

Oil and Gas production sites generate tremendous amounts of data that is only used locally to control different equipment and processes. Figure 3 displays a typical production site with various pieces of equipment. The process starts at the production wellheads where the mixed stream of oil, water and gas enter the system through a pipeline. This part of the process is often named the gathering system and the process is called pre-completion. The rest of the diagram is called the Gas and Oil Separation Plant (GOSP) with the goal to separate the hydrocarbon stream into clean, marketable products. The process of the GOSP is called the post-completion process. A detailed description of the various steps and processes is not relevant for the research and can therefore be found in Appendix A Gas Processes.

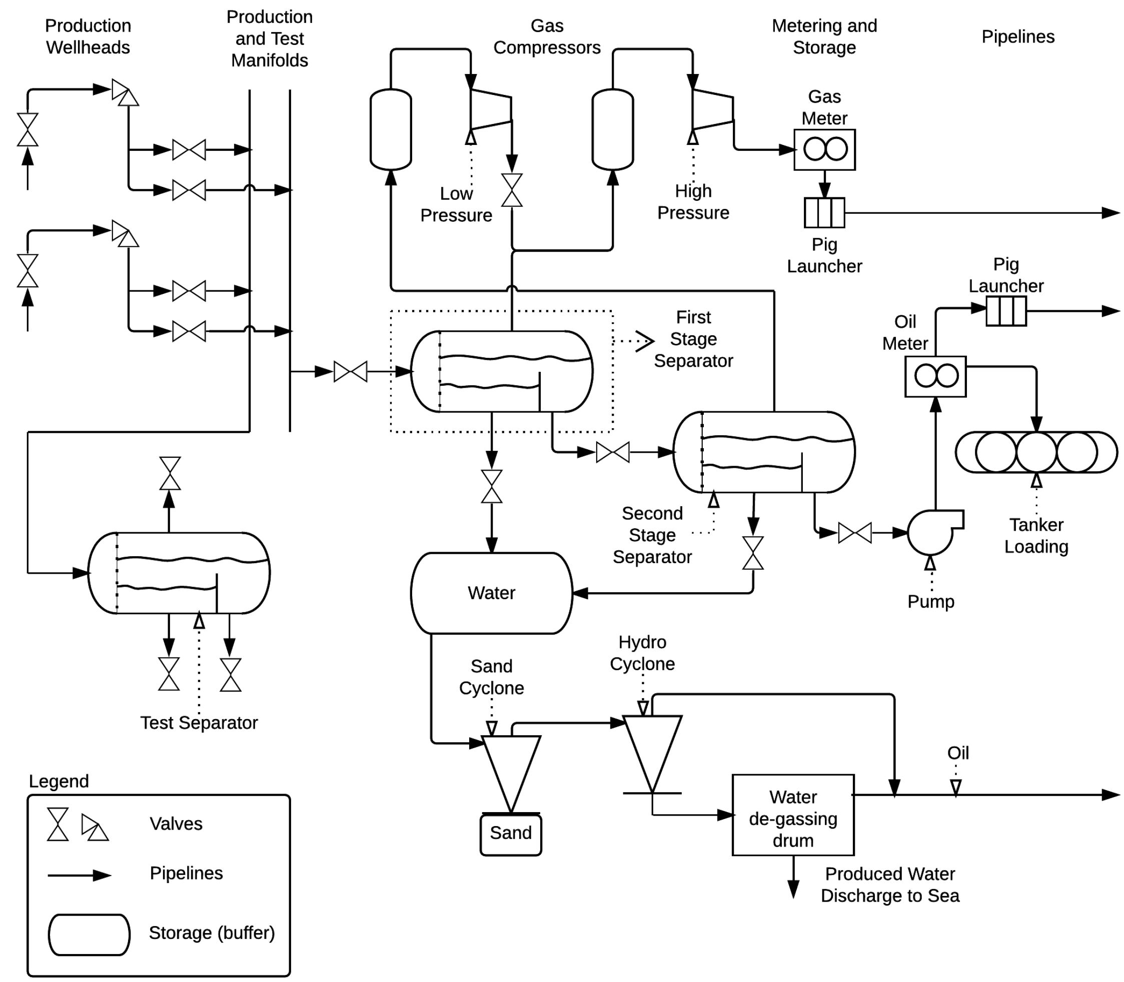

Figure 3: Gas production process.

The data that is generated at all these production steps is relevant, since all the different pieces of equipment (e.g. wellheads, separators, compressors, cyclones and the different safety devices) that are in place constantly measure a large number of different variables. These variables include a.o., liquid levels, pressures, volumes, flow speed, temperature, vibrations, humidity and rotation speed. For certain equipment these variables are measured every 5 milliseconds (0,005 seconds) generating 200 data-points every second. This data is used to control vital processes that may cause harm to the environment or people in the vicinity and is therefore stored locally without any outside interference.

To summarize, this data could be of value for the Oil and Gas Companies with today's advanced analytics tools and this is a huge opportunity for the Oil and Gas Sector. (Van't Spijker, 2014).

> *"Data is the new oil" (Van't Spijker, 2014)*

1.2 Problem and Goal

It is unknown why IT/OT convergence is not applied in the Oil & Gas sector whilst the benefits of this convergence are known and it is successfully implemented in other sectors (Harp & Gregory-Brown, 2015). Preliminary research and background information does suggest that the contrast between IT and OT is at the core of the problem. The research goal is therefore to investigate the potential performance improvement of the current IT and OT systems on the one hand. The second goal is to identify the blocking factors of IT/OT convergence and address potential solutions for these 'IT/OT barriers'. This research aims to provide a recommendation at whether there should be invested in implementing IT/OT convergence in the Oil & Gas sector. To achieve the final goal, it should be firstly investigating the potential performance improvements of the current IT/OT systems in the Oil and Gas sector, and subsequently identifying the blocking factors of IT/OT convergence. The problem is summarized in the following sentence:

The problem is that the IT/OT convergence has great potential, has proven itself in other sectors, but is not being applied in the Oil & Gas Sector and it is unknown why it is not being applied and how to implement IT/OT convergence.

1.3 Academic and Societal Relevance

This research extends the limited published literature on IT/OT Convergence, and aims to provide useful recommendations to companies in the Oil and Gas Sector on how to overcome IT/OT barriers. IT/OT convergence is a rather new trend in manufacturing with limited existing research, making it an interesting topic for research. The fact that the Oil and Gas sector is very capital intensive and has a huge environmental impact makes the study also relevant for society. Preliminary research into the subject resulted in little to no academic papers into the subject. Most knowledge on the topic can be found in-house at companies, within different research institutes and in specialized magazines. Various research institutes and consultancy companies like Gartner, IDC and Accenture see IT/OT convergence as one of the biggest trends in the Oil and Gas sector during the following years making it an interesting topic for companies.

1.4 Research Questions

From the general problem statement, its academic and societal relevance and the background information on the topic, the main research question for this is thesis is:

What blocks the convergence and integration of Information Technology and Operational Technology in the Oil and Gas sector and how can these barriers be eliminated to integrate the technologies?

To be able to answer this main research question, the following sub-questions are answered first:

1. How do the current IT/OT systems perform, can IT/OT convergence and value to the Oil and Gas Sector?

Although the concept of IT/OT convergence has been proven in other industries, there is no evidence if it can be applied to the Oil and Gas Sector. Investigating whether IT/OT convergence is an improvement and looking into the performance of the current system is an important step to take, as a negative outcome could eliminate the need for IT/OT convergence.

2. What technological barriers prevent the integration and convergence of IT and OT?

While it seems that technology these days can solve everything, the background of the IT and OT domain are vastly different which could block the convergence of these worlds. Investigating if there are technological barriers preventing the convergence and integration of IT and OT is therefore an important part of this research.

3. What social/organizational barriers prevent the integration and convergence of IT and OT?

Next to technological barriers IT, social or organizational factors could be the cause for the misalignment between the worlds of IT and OT. These social and organizational barriers are therefore critical to research.

4. How can the barriers be eliminated to successfully integrate and convergence IT and OT in the future?

When the problems and barriers for IT/OT convergence have been explored it is interesting to determine how this integration and convergence of IT and OT can be accomplished. The convergence and integration could be crucial for Oil and Gas companies in order to stay competitive so methods or technologies to eliminate these barriers can be invaluable.

1.5 Structure report

The next chapter discusses the methods used to conduct the research and provides a motivation for applying these methods. After the methodology, the findings from the extensive literature research are presented in chapter 3. With all knowledge found in the literature, a case study is developed and presented in chapter 4 to gather data for this research. The findings from the case study will be discussed in the same chapter. In chapter 5 the results from both literature and the case study will be compared, combined and discussed. After discussing the acquired results, the conclusions on the research will be drawn in chapter 6. Recommendations for future research can be found in the conclusions chapter. After the conclusions, a brief personal reflection on the research period is enclosed.

2 Methodology

This chapter will describe the different scientific methods used and steps taken to answer the research questions. First a schematic overview of the research framework is presented that will be used to guide the researcher and reader of this report through the different research steps. Next a detailed description of the different research steps, methods and execution will be presented. These different steps will finally be used to develop the final research framework at the end of this chapter.

2.1 Schematic Overview Research Framework

A schematic overview of the steps required to take in order to answer the research questions can be found in Figure 4: Schematic Overview Research Framework. Below the framework, the different steps are described in more detail. A resulting, detailed and filled diagram can be found in Figure 5: Detailed Research Framework, a detailed version of the first framework.

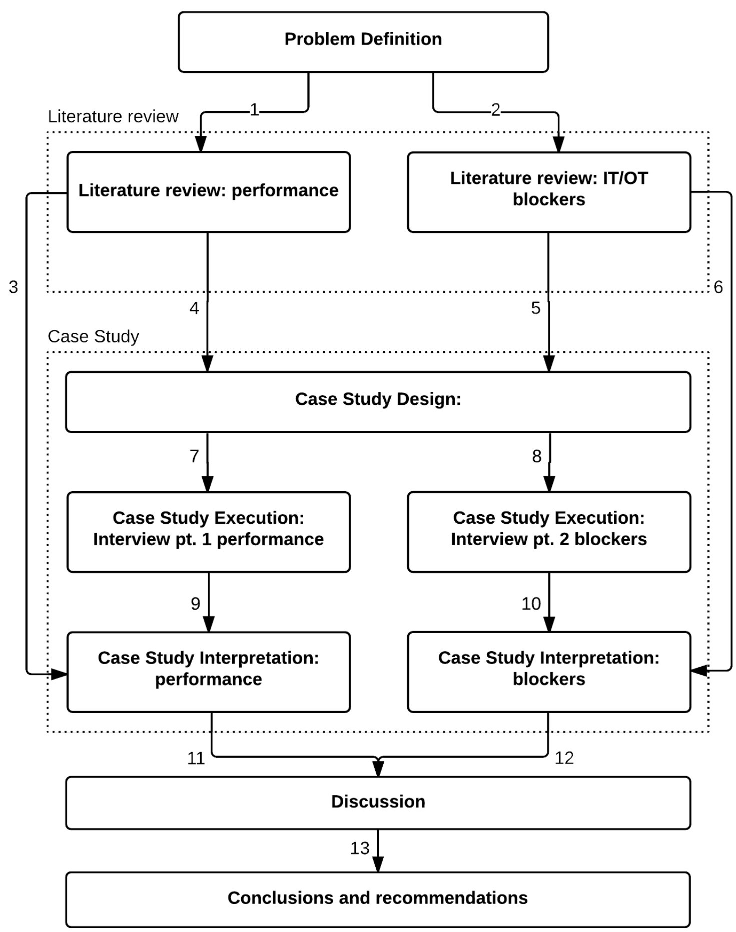

Figure 4: Schematic Overview Research Framework

The framework starts with the research problem, which has been derived from the preliminary research and background on the topic. The main problem: "Potential improvement of IT/OT performance is not being exploited due to IT/OT barriers", consists of two different parts: 1) the "Potential improvement of the performance of current IT/OT systems" and 2) "IT/OT barriers". These problems will be treated separately but equally throughout the research. For both problems a literature study is conducted with different goals for their respective problem: “Prove that the performance of current IT/OT systems can be improved”, “Find a scientific model to measure the performance/impact of IT/OT systems” and “Find all current known IT/OT barriers”.

The novelty of research on IT/OT Convergence and recommendations to cope with these “IT/OT barriers” favours an explorative, qualitative research strategy to gain insights (Velde, Jansen, & Anderson, 2004). To fully grasp the concept of IT/OT Convergence a case study is designed to study the barriers in detail and generate in-depth knowledge on the topic. In this case study, multiple companies and stakeholders are involved to enable a certain level of generalization. The results from the literature study will be used as input for the case study.

Data for the case will be gathered with interviews with various experts from different stakeholders in the sector. The interviews will be based on the insights gathered from the literature review. During the interpretation of the case, the results from both sources, literature and interviews, will be compared using triangulation. The discussion will evaluate all findings and discuss what conclusions could be drawn from the acquired results and interpretation. Finally the conclusions are drawn and recommendations for future research are presented.

These steps lead to the framework in Figure 4. The following paragraphs will motivate and elaborate on all different steps and methods in order to give body to the final research framework that will be presented at the end of this chapter in Figure 5.

2.2 Model for evaluating Information Systems

To assess whether IT/OT convergence can increase the performance of the current IT and OT systems, a literature review is conducted to find sectors comparable to the Oil and Gas sector where IT/OT convergence has successfully been applied. Since IT/OT convergence is a rather novel concept the scope of this part of the literature research will therefore not be limited to academic literature (Scopus, Web of Science) but include other resources as well. Sources like Google Scholar, Professional Research Institutes (Gartner, IDC), publications by sector specialists and consultancy companies but also Google search and Wikipedia will be considered. To be able to measure the impact of IT/OT convergence for future research, the literature study will also find a scientific model that can be used to measure the impact or performance of IT/OT systems. The model will be selected on the following criteria:

- **Ease of use** (few variables), the model will also provide insights for business users so an overly complicated model is unnecessary and only prevents business users from using it.
- **Clear explanation of the input variables and relations**, to enhance the usability as well. Unclear relations and factors lead to uncertain conclusions.
- **Publishing date** (more recent is preferred), the most recent model take current technological possibilities into account, older models can be out-dated.
- **Model leads to positive impact on the organization**, not an individual. The goal of IT/OT convergence is to have impact on organizations, not on single users (unless the connection between user and organization is proven as well).

Keywords that will be used for searching:

Information Technology (systems), Operational Technology (systems), Information Systems, Performance, Success, Evaluation, Effectiveness, Impact, Acceptance, and obviously combinations between keywords like: IT Systems Success, OT effectiveness etc.

Important note is to exclude non-engineering and computer sciences not related to the topic like Medicines, Art, Biology, and Chemistry. The most relevant and cited models will be compared to each other on the previously named factors. The most suited model will be chosen for this study.

2.3 Exploring IT/OT Convergence and Current known Barriers

The preliminary research into IT/OT convergence and integration proved that the topic is rather new. To acquire knowledge on the topic and to find barriers that are recognized by different sources, not only academic sources will be consulted.

Keywords that will be used for all sources will be:

Information Technology (and acronym IT), Operational Technology (and acronym OT), integrating (integration), convergence (converging), blockers, barriers, impediments, and combinations of these words like: IT OT integration, IT OT convergence, IT OT blockers, IT OT barriers, IT OT impediments.

Again excluding non-engineering and computer sciences not related to the topic like Medicines, Art, Biology, and Chemistry. Results from these search queries will be filtered by citations, date and keyword relevance.

2.4 Case Study Design

The number of major operators that can be used to gather research material in the Oil and Gas sector is limited. According to Yin (2009) a qualitative case study is best suited for research where quantification is difficult. In the case of the Upstream Gas sector, both the number of suppliers of IT/OT systems as well as the number of users is constrained so a qualitative case study is best suited for this research. The valuable in-house knowledge these companies possess may be of such value that they are not willing to cooperate. Case studies focus more on intensive, in depth data/knowledge generation instead of broad. The research could be of value for the companies in the Upstream Gas sector, which will provide access to experts within companies.

The case study aims to find why IT/OT convergence is not being implemented, explore the barriers for IT/OT convergence and integration, find solutions for these barriers and refine a model to be able to measure the impact of IT/OT systems. Most knowledge on the topic of IT/OT convergence is in the minds of experts at different Oil and Gas companies, an interview with these experts is a good method to achieve both case study goals. Extracting this knowledge however is difficult since most of these companies are very protective of their human capital and knowledge. Large-scale surveys are therefore not an option because the number of respondents will not be sufficient to draw a valid conclusion. Additionally, the research aims to acquire as much knowledge as possible on the topic of IT/OT convergence and therefore in-depth-interviews are the best method for acquiring data.

IT/OT convergence can be applied on every piece of equipment in a production plant. To be able to compare the current IT/OT systems a case study with clear boundary limits, focussing on a specific IT/OT system supporting a specific process will be set up. The process selected as the case must be a crucial process in the Oil and Gas sector. Furthermore, the process is preferred if current literature suggests that the process can be improved by IT/OT convergence and integration. Exploring drivers for IT/OT convergence and questioning on the topic of IT/OT barriers at multiple companies will ensure a descent representation of the sector since the number of companies in the sector is small. The case study design is therefore a single-case-study that will interview experts from multiple companies and backgrounds to gather data.

Selecting the specific case to study is essential for the research and the impact of the results. The IT/OT system that will be selected must generate or process a sufficient amount of data or information. This to ensure that IT/OT integration/convergence can have a positive effect on the system or process. The system must have ample impact on production during operation or breakdown, this to ensure that the current system is up-to-date and optimized compared to other systems in place. The system should also support a crucial process in the Oil and Gas sector, again to ensure that the system is checked and updated regularly. Finally the system must, preferably, be found at many/most sites in the Oil and Gas sector. These criteria are also crucial to ensure that there will be enough available stakeholders to interviews but also to be able to generalize the findings for the rest of the sector.

Selection of the participants will be done with the goal to have a decent representation of the companies in the Oil and Gas sector. To get a viable impression of on the different views in the sector, both suppliers and users of IT/OT systems will be invited to participate. Criteria for the interviewees themselves will be experience with the specific case and knowledge of IT/OT convergence and integration. Participants who are currently working on, or have worked on an IT/OT convergence project have preference.

The method for data collection for the case study will be in-depth semi-structured interviews. The questions asked in the interview will reflect the knowledge gathered from the literature review before. A semi-structured interview in which the questions are formulated beforehand, but with sufficient flexibility for unexpected answers to come up (Velde et al., 2004). The interviewer can cover a certain amount of topics but allows the interviewee to put focus on certain aspects/topics. The researcher can control the interview by asking for motivation on statements made by the interviewee. In-depth semi-structured interviews therefore provide more detailed information on specific ideas and concepts. During the interviews, the researcher must avoid influencing the opinion of the interviewee. Since the main problem is split into two different parts, the interviews and interpretation will be separated as well.

The exact design of the case study and the interview questions is dependent on the literature study. The following research steps will therefore use the results from the literature study as input. Results that will be used for the interviews are the DeLone & McLean Model for IS Success (D&M Model) which will be introduced in chapter 3.2.3 and the barriers that are introduced in chapter 3.3. The case that will be selected and elaborated on in chapter 4 revolves around the control systems of compressors.

2.5 Interview Setup Part 1 – Performance Current Systems and Measuring Model

The first part of the interview addresses the following problem: “Potential improvement of the performance of current IT/OT systems”. This problem can be separated into two separate goals:

1. Prove that the performance of current IT/OT systems can be improved
2. Find and possibly expand a scientific model to measure the performance/impact of IT/OT systems in the Oil and Gas Sector

The interview will start with questioning the performance indicators, how these impact each other, where they can be improved and how this can be achieved. Next an explanation of the model is presented and how it is used, the input variables and how these are related.

The first goal is achieved by asking questions on how and where the performance can improve without mentioning IT/OT convergence. The D&M model is then introduced and the interviewee is asked how the sub-variables of the model can improve. The interviewee is asked to elaborate on how these variables are related to each other in order to obtain the complex relationships needed to setup the causal diagram. Afterwards, IT/OT convergence is then introduced and the interviewee is asked to name all the advantages and disadvantages to a current scenario. Finding sector specific variables is done with open questions to find out if any other variables could be included. Finally, the weights of the different variables are determined by open questioning. The interviewees are asked which variables are more important than the other, and to motivate this choice.

Sub-variables of D&M model found in the literature relevant for the specific case and will be discussed in interviews are the following:

- System Quality: Uptime, data-accuracy, reliability, and response times.
- Information Quality: Availability, completeness, consistency, timeliness, and usability.
- Service Quality: Responsiveness, accuracy, reliability, and technical competence.

2.6 Interview Setup Part 2 – Validate and Expand Barriers from Literature

The objective of second part is to validate barriers found in the literature and to find other barriers not mentioned in the literature. The interview will start with questioning the definitions of IT and OT in the Oil and Gas sector. Afterwards an assumed definition will be given to continue with the rest of the interview. The interviewee is then asked to describe barriers of IT/OT convergence without given a definition of these barriers. With the definitions of the different barriers from the literature review, the interviewer will then check if the interviewee names all the barriers. If the interviewee names any unknown barriers, the interviewer will ask for an elaborate explanation. When the interviewee does not name certain barriers, the interviewer will feed a description of these barriers to see if the interviewee does recognize these barriers. After treating all barriers, the interviewer will ask how strong the barriers are compared to each other to find out which is the most difficult to overcome. The interview will finish by asking for possible solutions and examples how the barriers can be overcome. The goal is to identify implemented and proven solutions. Possible theoretical solutions that have not been tested in practise will also be discussed. This part of the interview is open and the interviewer should avoid giving definitions early on but letting the interviewee come up with their own unbiased view on the barriers and solutions.

2.7 Interview Procedure

During the interview, the researcher will only present definitions of certain concepts when this is crucial to answer questions. The researcher will try to acquire the unbiased view of the interviewee since differences in definitions could be the root of a certain problem. The researcher will therefore ask the interviewee for their definition of the different concepts that are handled and only correct them when this is needed to answer further questions. When the interviewee presents new concepts or definitions, the researcher will ask the interviewee to elaborate and give examples to fund this view. The complete interview script that is used by the researcher can be found in Appendix C.

2.8 Analysis and Interpretation – Performance Current Systems and Measuring Model

The results from the first part of the interview on the current IT/OT systems will be used to find relationships between variables that influence the performance of IT/OT systems. Interpretation will be done with triangulation by comparing findings from the literature with the results from the interviews. The combined results will be used to setup a causal diagram. This diagram will provide a visual representation on how the different variables impact each other and how IT/OT convergence can lead to benefits for the company (De Haan, Willemse, de Heer, Vos, & Bots, 2015). The diagram will also show insights in why the concept of IT/OT convergence is not being implemented. The relationships from the interviews will be transformed into a causal diagram using the DeLone & McLean Model for Information System Success (D&M Model) as a basis. This model and the selection method will be elucidated in chapter 3.2.

Next to the analysis of the causal diagram, analysing the D&M Model will hint how to apply the model in this specific case and how the model can be used in future research. Insights may provide sector specific variables that should be included in the model when it is used in this specific sector.

2.9 Analysis and interpretation – IT/OT barriers

The second part of the interview will result in a list of IT/OT barriers. These barriers are divided into categories found in the non-academic literature. A new category is proposed when a certain barrier does not fit in the categories. The goal of this categorization is to give a funded academic definition of these categories based on the barriers that are identified by the experts. Triangulation will be used to declare this final definition that is based on definitions from the literature as well as definitions from the experts. Finally a set of solutions for these barriers proposed by the experts will be presented that will provide a roadmap for companies trying to achieve IT/OT convergence.

2.10 Discussion, Conclusions and Recommendations

In the discussion, any conflicting findings will be elaborated on to be able to present a final conclusion. The findings will finally be used to answer the different research questions. Discrepancies between findings will be taken into the recommendations with suggestions on how to avoid this in future research. The recommendations will also suggest parts of the topic that could be interesting for future research.

2.11 Final Research Framework

The elaborate steps and methods described above are filled into the original research framework in Figure 4. This results in a detailed research framework that will guide the researcher through all different steps. The final research framework can be found in Figure 5 below. The outline of the report, in which chapters the different sections can be found, can be found below the detailed version of the research framework.

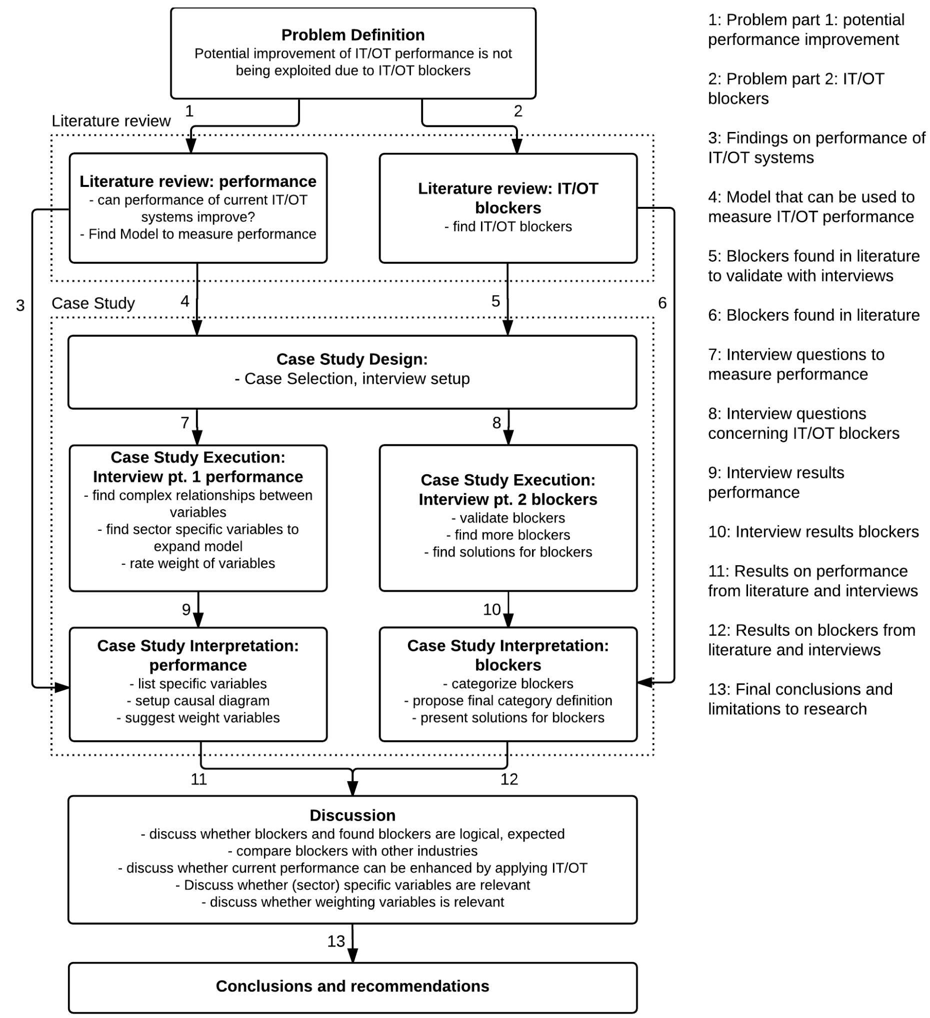

Figure 5: Detailed Research Framework

The results from the literature study will be presented in the next chapter 3. These results will be used to setup the case study in chapter 4. The results from the case study will be presented in chapter 4. Chapter 5 will contain the discussion of the different results from the case study and the literature. In chapter 6 the conclusions will be presented together with recommendations for future research.

3 Results literature study

The background information and preliminary literature research provided a funded research problem and questions. To obtain all current knowledge on the subject of IT/OT convergence, a thorough literature study is conducted. This chapter will present important information on the subject that will be used during the rest of this research. The possible performance benefits of IT/OT systems are investigated by looking at different sectors in paragraph 3.1. In paragraph 3.2 a model will be selected that can be used to measure the performance of IT/OT systems and function as a basis for a causal diagram of complex relations. Finally in paragraph 3.3 the barriers for IT/OT convergence that are found in different types of literature are presented.

3.1 Literature review – Performance Benefits IT/OT Convergence

Preliminary researched revealed that IT/OT Convergence can lead to significant improvement but this has not been confirmed for the Oil and Gas Sector. Different sectors have successfully implemented IT/OT convergence and exploit the benefits of the convergence. This chapter will present sectors that are similar to the Oil and Gas Sector where IT/OT convergence has successfully been implemented. Predictions and trends on IT/OT Convergence that will impact the Oil and Gas Sector will also be presented to forecast whether convergence will improve performance in this specific sector.

3.1.1 Similar Sectors with Successfully Integrated and Converged IT and OT

Three sectors that are similar to the Oil and Gas Sector where IT/OT Convergence has successfully been implemented are the Electrical Distribution-, the Manufacturing- and the Mining sector. Table 2 presents the similarities between the sectors to see on which levels the different sectors can be compared.

Table 2: Sectors similar to the Oil and Gas Sector where IT/OT Convergence has increased performance.

Sector	Differences and Similarities with Oil and Gas Sector
Electrical Distribution	+ Cost intensive + Large Scale + Few suppliers and clients + Huge investment costs and long Return On Investment (ROI) + Potentially dangerous (equipment) + Highly dependent on IT and OT - No production, only distribution
Manufacturing	+ Cost intensive + Highly dependent on IT and OT + Potentially dangerous (equipment and raw materials) + High investment costs and long Return On Investment (ROI) - Customer driven (in general) - Lots of suppliers and customers (in general)
Mining	+ Cost intensive + Highly dependent on IT and OT + Dangerous (equipment and raw materials) + Big environmental impact + Huge investment costs and long Return On Investment (ROI)

The major similarity between the sectors is the fact that all sectors rely highly on IT and OT, have high investment costs and a long Return On Investment (ROI). Table 3 to 5 presents the impacts of IT/OT Convergence in the different sectors together with predicted impacts in the Oil and Gas Sector. Table 3 presents the impacts for the Electrical Distribution Sector.

Table 3: Impacts of IT/OT Convergence and Integration in the Electrical Distribution Sector (Taylor, 2012).

Impacts of IT/OT Convergence and Integration	Case Before Integration	Root of Problem	Applicable to Oil and Gas Sector*
Informed stakeholders	Uninformed stakeholders	No real-time availability of data, weekly/monthly reports	Yes
Data availability	Scattered data	Only critical process data available, often not real-time	Yes
Smart-grids	'Dumb' grids	Electrical distribution grids react to problems instead of preventing problems	Yes, in the form of smart fields or e-fields.
Outage prevention	Reactive maintenance	Plants react to problems instead of preventing them	Yes, preventive maintenance prevents unforeseen outages
Smart metering	'Dumb' meters	Old meters only measure and forward data, no analysis of data	Yes
Improve system performance	Lower performance	Process parameters are fixed in an operating window, not adjustable.	Yes
Reduce costs	Higher costs	Inefficient processes, reactive maintenance costs more since equipment needs to be replaced more often instead of repairing	Yes
Improved customer satisfaction	Lower Customer satisfaction	Customers have no access to critical data, only receive the end product	Yes
Better decision making (through data analysis, pattern recognition)	Difficult decision making	Due to limited availability of data, decision making is complicated	Yes

In Table 4, the impacts for the Manufacturing Sector are displayed.

Table 4: Impacts of IT/OT Convergence and Integration in the Manufacturing Sector (Namboodri, 2013).

Impacts of IT/OT Convergence and Integration	Case Before Integration	Root of Problem	Applicable to Oil and Gas Sector*
Higher revenue	Lower revenue	Downtime and unforeseen complications	Partly, since uptime and production capabilities are already optimized
Reduced operating costs	Higher operating costs	Inefficient processes, reactive maintenance costs more since equipment needs to be replaced more often instead of repairing	Yes
Improved asset utilization	Poor asset utilization	Unforeseen complications	Yes
Reduced engineering to order cycle	Long engineering to order cycle	Installation, commissioning and debugging of stations takes time	No, Oil and Gas sector produces continuous instead of batch and has no product differentiation
Agility with Efficiency, to shift capacities and meet new demands	Sluggish and inefficient	Combination of problems above	Yes, agility is not the most crucial factor in the Oil and Gas sector but efficiency is important
Speed with Security, to enhance global operations with secure remote access	Slow and insecure	Combination of problems above	Yes, the ability to react to (dangerous) complications is very important in the Oil and Gas Sector
New Business Models, to enable valuable services via machine-to-machine networks	Same business models	Technology is saturated, only possible to improve incremental	Yes, this is already tested by equipment suppliers who lease their equipment and provide a number of hours uptime instead of selling the equipment.

The final sector with similarities to the Oil and Gas Sector is the Mining Sector. The different impacts of IT/OT convergence for the mining sector are presented in Table 5.

Table 5: Impacts of IT/OT Convergence in the Mining Sector (Andai, 2015).

Impacts of IT/OT Convergence and Integration	Case Before Integration	Root of Problem	Applicable to Oil and Gas Sector*
Insights for business process improvement	No comprehensive process improvements	Limited availability of data, scattered data and no tools to analyse data	Yes
Prioritize work (prevent outages)	Critical processes first	No grounded prioritization of processes	Less applicable to continuous production sites in the Oil and Gas sector
Improved inventory Management	Bad inventory management	Inability to track and follow equipment	Yes
Model Predictive Control (predicts soil composition)	Poor idea of soil to mine	Not being able to access real-time data	Yes, the Oil and Gas sector deals with different soils as well
Quality improvement	Poor quality products	Not being able to access real-time data to adjust system parameters	Yes
Asset optimization	Poor asset utilization	Inability to respond to unforeseen complications	Yes

*Source: (Dayal, Akatsu, Gupta, Vennelakanti, & Lenardi, 2014; Edwards, Ishaq, & Johnsen, 2011). Predictions for the Oil and Gas sector include: improved decision making, reduced risks and costs, positive environmental impact, improved efficiency, raised production levels, raised recovery rates, improved flexibility and advanced analysis and forecasting.

Gains from integrating and converging IT and OT observed in literature often result from the enhanced decision-making enabled by IT/OT convergence. Most of these gains are general benefits that apply to all different sectors. Certain impacts like Smart-grids for electrical distribution and Model Predictive Control for Mining however, are sector specific. The differences between the sectors seem minor which suggests that IT/OT Convergence could also have a positive impact in the Oil and Gas Sector. Since the other gains are not sector specific, the Oil and Gas sector could probably benefit from them as well. The following sources underpinning this idea are:

IT/OT Convergence in the Oil and Gas Sector (Mahoney & Roberts, 2013)

- Opens opportunities for enhanced value-chain-wide information and process connections
- Adds value and timeliness through enhanced information for better decisions
- Creates the potential for negative consequences of attempts to "lie with metadata," or how some will try to fool auditors, regulators and others by using fabricated metadata
- Increases cyber-security risks and the greater incidence of inadequate access controls against cyber-attacks in OT environments

Impacts of IT/OT Convergence (Mahoney & Roberts, 2013)

- IT/OT convergence creates new business opportunities for enterprises, but also brings risks, requiring leadership review and action.
- The heterogeneity of IT and OT physical technologies, applications, skills and management practices creates barriers to interactions and increases cost and risk that CIOs must address.

- Growth of IT/OT interaction and convergence require CIOs to install and operate stronger management processes for OT configuration and security.
- IT/OT convergence crosses typical organizational boundaries of budgets, authority, reporting lines and cultures, requiring CIOs to work with OT leaders and others to identify and resolve the issues this creates.

McAvey (2015) argues that IT/OT convergence can lead to the following business Impact: "Oil and gas companies will see improved performance across all elements of their businesses as a result of effective management of IT/OT convergence. Performance improvements will come from better information and decision making in the areas of asset management, production, safety and sustainability. In addition, IT/OT convergence will help oil and gas enterprises manage risk, whether from better visibility or simply more effective management of mission-critical OT systems." (McAvey, 2015)

"Executives in the Oil and Gas sectors see integration becoming even more critical to connect the various technological disciplines and innovations with people and processes." To them, integration is vital to delivering "the right information on demand to the right people at the right time for better decision making." (Edwards et al., 2011)

3.1.2 Drivers for IT/OT Convergence and Integration

Drivers of the convergence of IT/OT are a.o. economic pressure, societal pressure and the potential improvements the convergence vows to offer. The economic pressure results from from globalization and intensifying competition due to a current low oil price. IT/OT convergence can lead to benefits for different sectors, from manufacturing to pharmaceutical, from food to telecommunication and utilities. Specific benefits will be different per sector but common benefits gained from the convergence are described below.

Enhance Monitoring, Control and Decision Making

Decisions in organizations are often made based on data gathered from various equipment and sensors. Integrating, converging or connecting these sensors, machines and IT equipment will allow for better strategic decisions due to more timely and accurate information. The convergence will improve automation, provide insights into processes and allow for direct control of operations. (Harp & Gregory-Brown, 2015)

Cost reduction

Due to the application of standards, similar technologies and governance for IT and OT, costs (operational expenditures) can be reduced. Inventory levels can be adjusted more quickly, thus inventory utilization is optimized leading to an improvement in plant asset turnover. Inventory turnover itself is improved as well since more data is available to managers, allowing better forecasting future demand (Anderson, Banker, Menon, & Romero, 2011).

Risk reduction

IT/OT security issues can jointly be addressed with an integrated approach. This provides security against intrusions from outside the company and this leads to central security governance throughout the company. Risk reduction is also achieved by applying IT operations management skills, processes and technologies, which allows OT to be monitored and managed better. Further risk reduction comes from minimizing internal errors in OT software through version control, patching and upgrading by using tools derived from managing IT products (Steenstrup, 2011).

Enhanced performance

The integration of IT and OT will save time and costs by allowing smooth transition of newly developed products into existing manufacturing operations. Convergence also allows value-chain-wide information and process connections with (near) real-time data for better decision-making. This increased visibility of information will allow more effective management of mission-critical OT systems.

Flexibility gains

IT/OT convergence leads to transparency concerning costs and cost structures and will therefore provide better site efficiency. The available information allows for better and faster decision making processes, increasing the flexibility of the company. Increased insights will also allow for manufacturing to shift between locations (‘produce anywhere’) (ATOS, 2012).

Operational Excellence (OE)

Operational Excellence is a philosophy of the workplace where problem solving, teamwork, and leadership results in the on-going improvement in an organization. The process involves focusing on the customers' needs, keeping the employees positive and empowered, and continually improving the current activities in the workplace. Operational Excellence is a concept that is often liked with IT and OT since these are both ‘enablers’ and ‘drivers’ for OE. Continuous improvement is a component of OE that has one of the strongest links since this is enabled by real-time data-driven decision-making. Predictive maintenance and advanced analytics are also concepts made possible by IT and OT (Liker & Franz, 2011; Rai, Patnayakuni, & Seth, 2006).

Comparing the different sectors together with the predicted trends from multiple sources, IT/OT Convergence and Integration could definitely improve the way companies in the Oil and Gas Sector operate. Integrating and converging IT and OT does not affect sector specific processes but enhances the performance of the companies in general. A major impact of IT/OT convergence is improved decision-making where all companies in different sectors could benefit from.

3.2 Literature – Models for Measuring IT/OT performance

When IT/OT Convergence is proved to have a positive impact on organizations in other sectors, it is not sure whether it will have the same impact on the Oil and Gas Sector. To explore how IT/OT convergence can impact Oil and Gas organizations, a scientific model that measures the impact of information systems will be used. This model can also be used to explore complex relationships between variables and form a basis for a causal diagram. This causal diagram can be used by companies that need to decide on investments regarding IT and OT systems.

Academic literature presents an abundance of scientific models that can be used for measuring and evaluating IT/OT or Information Systems (IS Systems). This paragraph presents the best fitting models for this research, compares them and motivates which model will be used in this study. At the end of this chapter a conclusion is drawn on the relevance/applicability and added value of this model.

The selection criteria for the model are: ease of use (few variables), clear explanation of the input variables, publishing date (more recent is preferred) and the Model should lead to positive impact on the organization. Motivation for these selection criteria can be found in the Methodology chapter.

3.2.1 Summary of Scientific Models

The four most relevant and quoted models found in scientific literature are taken into account for further analysis. The models together with their authors and number of citations are presented in Table 6. Below the table the models are elaborated and light is shed on criticism towards the specific model. The models are also rated on the various selection criteria from ++ (excellent) to -- (inferior) compared to the other models. Finally a motivation for the best model is presented.

Table 6: IS Success, Impact, Evaluation and Effectiveness Models/Frameworks.

Name	Author	Citations
Unified Theory of Acceptance and Use of Technology (UTAUT)	(Venkatesh, Morris, Davis, & Davis, 2003)	6111
IS Success Model (D&M Model)	(DeLone & McLean, 2008)	5630
IS Impact Measurement Model (ISIM)	(Gable, Sedera, & Taizan, 2008)	331
IS Effectiveness Framework (ISEF)	(Grover, Jeong, & Segars, 1996)	241

Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003)

The Unified Theory of Acceptance and Use of Technology (UTAUT) is a unified model built from 8 known models for technology acceptance. The model incorporates a total of 8 different but interconnected variables that influence use behaviour, preceded by 41 independent variables. The model is very well described and all constructs/variables are well explained in different sources. The model is applied and validated by several studies, both literature as field studies (Verhoeven, Heerwegh, & De Wit, 2010; Williams, Rana, & Dwivedi, 2015).

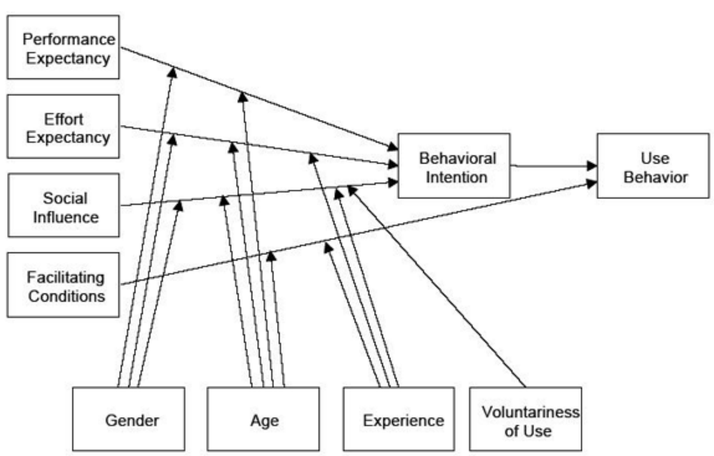

Figure 6: Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003)

Although one of the most advanced and cited models in the list, the model is due to the number of input variables complex to use, especially when using qualitative input. Furthermore, the model leads to Use Behaviour instead of the preferred impact on the organization.

Critics of the model state: “UTAUT is a well-meaning and thoughtful presentation,” but that it presents a model with 41 independent variables for predicting intentions and at least 8 independent variables for predicting behaviour,” and that it contributed to the study of technology adoption “reaching a stage of chaos.” (Bagozzi, 2007).

Table 7: Rating of Unified Theory of Acceptance and Use of Technology model.

Selection criteria	Score	Motivation
Ease of use	0	Abundance of variables makes model difficult to use for a visualization of complex relationships and an indication of the impact. The variables influencing other relations, makes the model complex as well.
Clear variables	++	All variables are described thoroughly and clear
Publishing date	+	Published between 10 and 15 years ago.
Leads to impact organization	-	The model leads to individual Use Behaviour, with no link to organizational impact.

Information System Success Model (Petter, DeLone, & McLean, 2008)

The DeLone & McLean Model for IS Success (D&M Model for IS Success) is the one of the most cited and used model for the evaluation of Information Systems (Urbach, Smolnik, & Riempp, 2009). From the first version in 1993 the model was praised and widely used. In 2003 they posted an update that included another variable to meet modern standards. The model presents a clear framework and the variables are well explained. In the updated version of 2003, DeLone & McLean validated their model by reviewing over 100 articles that tested the association between the different variables.

Critics of the model satirize the model for the fact that the researchers do not propose a method for empirical validation (Mukherjee, 1992). Countless individual researchers did however prove the relationship between the variables, allowing DeLone & McLean to update the model and validating their model. Other critics only address the original version of the model, being to focused on products and not on services (Pitt, Watson, & Kavan, 1995) and the variable "Use" is often seen as a very complex variable (Seddon, 1997). DeLone & McLean used all the criticism to update their model, eliminating any flaws found previously.

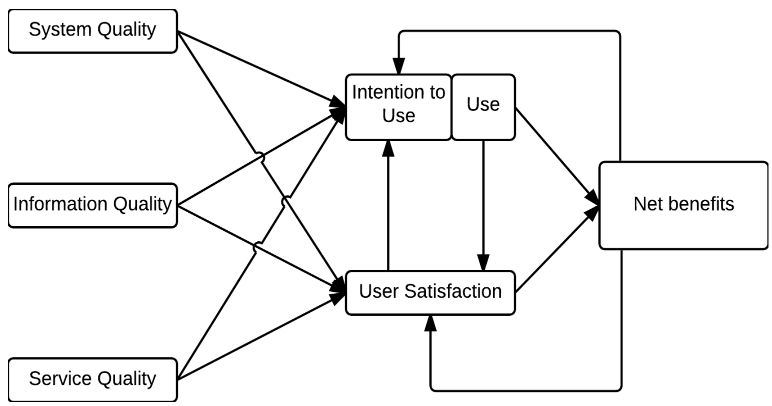

Figure 7: DeLone and McLean Model for IS Success (Petter et al., 2008)

Table 8: Rating of DeLone & McLean Model for IS Success

Selection criteria	Score	Motivation
Ease of use	++	All relationships are straightforward and impact each other. There are no variables that influence relationships and the total number of variables makes the model easy to use.
Clear variables	++	The variables of the model are all clear and well described.
Publishing date	++	Published within the last 10 years
Leads to impact organization	+	The model measures net benefits for the organization.

IS Impact Measurement Model (Gable et al., 2008)

The IS Impact Measurement Model builds on the D&M Model for IS Success. The model is however expanded by factors that have impact to date, and factors that take anticipated benefits into account. This model is therefore very suitable for organizations that want to measure the impact of an Information System while it is being implemented or recently has been implemented. Certain benefits take time of these IS systems can take time before the benefits can be measured and this model takes that into account and tries to

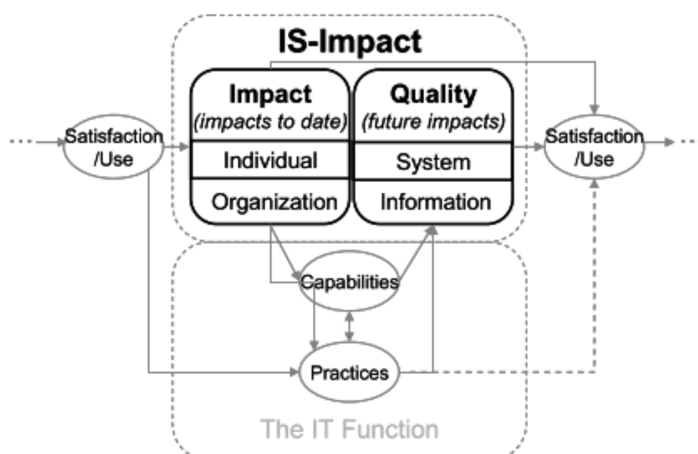

Figure 8: IS-Impact Measurement Model (Gable et al., 2008).

measure the impact that the IS system could have.

The creators of this model have derived the model from data gathered from the Australian public sector and question whether it is generalizable. Other critique on the model names certain measures like "individual impact" and "organizational impact" to ambiguous (Steinhüser, Smolnik, & Hoppe, 2011).

Table 9: Rating of IS Impact Measurement Model.

Selection criteria	Score	Motivation
Ease of use	-	One of the variables, future impacts is difficult to measure, especially for new technologies like IT/OT convergence.
Clear variables	++	The
Publishing date	++	Published within the last 10 years
Leads to impact organization	-	Model leads to satisfaction and use for users, not impact for organizations.

IS Effectiveness Framework (Grover et al., 1996)

Grover's article tries to build a model for IS Effectiveness inspired by the D&M Model but with a more solid theoretical backing. Grover separates individual and organizational impacts but the sub variables influencing these measures are elaborate. The model is not often named, criticized or referred to. The different measures in the model is based other literature, making the measures itself not very clear.

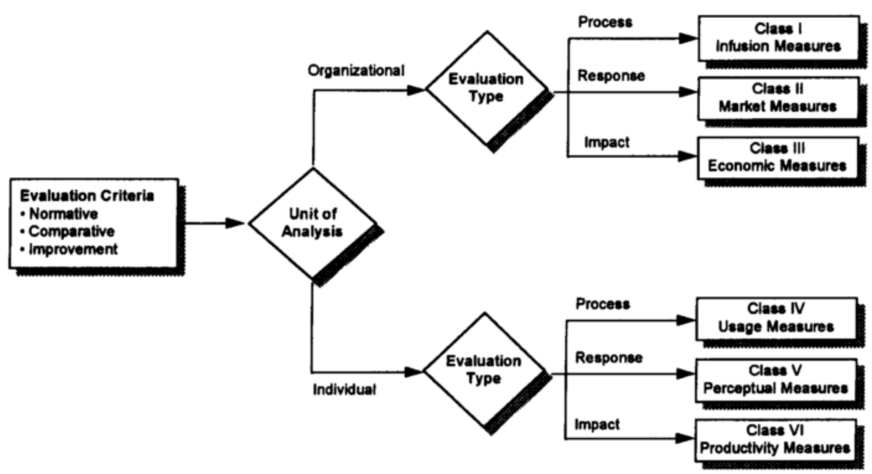

Figure 9: IS Effectiveness Framework(Grover et al., 1996).

Critique on the model is the definition of the domain of IS Effectiveness and the context in which the criteria are used (Grover et al., 1996).

Table 10: Rating of the IS Effectiveness Framework.

Selection criteria	Score	Motivation
Ease of use	-	The framework only provides a way to look at IS effectiveness but no ways of measuring.
Clear variables	+	The different classes to look at IS systems are well defined but again no measurement method.
Publishing date	-	Published in 1996
Leads to impact organization	+	The 3rd class, Economic Measures, when looking at the organizational impact describes the productivity or financial gains for an organization.

3.2.2 Model Selection

The rating of the different IS models that were introduced in the previous are combined in Table 11.

Table 11: Combined scores of different IS models.

	Ease of use	Clear variables	Publ. date	Impact to organization	Average score
UTAUT	0	++	+	-	0/+
D&M Model	++	++	++	+	++
ISIMM	-	++	++	-	0/+
ISEF	-	+	-	+	0

All models found in literature refer, try to expand and/or contribute to the D&M model for IS Success while keeping the same basis. The D&M Model clearly stands out regarding the selection criteria. Considering its popularity, clear structure, well-described measures, ease of use and recent update to fit modern needs, the D&M model is the best suitable model for further analysis in this research. Based on the information found in literature, the D&M model is mentioned as the best suitable model for this case. The following quotes support this claim:

- A study comparing the predecessor of the UTAUT, the Technology Acceptance Model (TAM), D&M Model for IS Success and the IS Impact Measurement model suggested that: “the D&M model is one of the best models to measure organizational impact or benefits”. The TAM on the other hand is hinted to be the most popular to study individual willingness to use technology (Mukherjee, 1992).
- Another study clearly named the D&M Model for IS Success, its updated version and the TAM as the predominant models used for IS evaluation although the TAM model is more often used to in the context of IS adoption (Dörr, Walther, & Eymann, 2013).
- In the article that proposed the IS Effectiveness Framework, DeLone & McLean’s model is praised for its structure, the IS Effectiveness Framework only tries to expand and complement the model (Grover et al., 1996).
- An article that builds on Gable’s IS Impact model, again the D&M Model for IS Success is praised for its “clear framework and validated measures” (Steinhüser et al., 2011).

The IS Effectiveness Framework could have been an option as well but since the measures must be gathered from 100 different articles, which makes the model very difficult to use. Furthermore, the model separates individual and organizational impacts, which are important selection criteria.

In the following paragraph the D&M Model is explained in detail to be able to use the model in the interviews.

3.2.3 Detailed description D&M Model

The model depicted in Figure 10 shows the connection between the different concepts in the model. The source for the definitions of the concepts of the model is the original article by (Petter et al., 2008). The arrows between the variables represent a proved positive correlation between the variables. The main input variables “System Quality”, “Information Quality” and “Service Quality” will be used to setup questions for the interview, while the organisational impact will be the result. For example, when the System Quality is increased, the Intention to Use increases, which will in turn lead to an increase in Use and that is linked to an increase in Net Benefits.

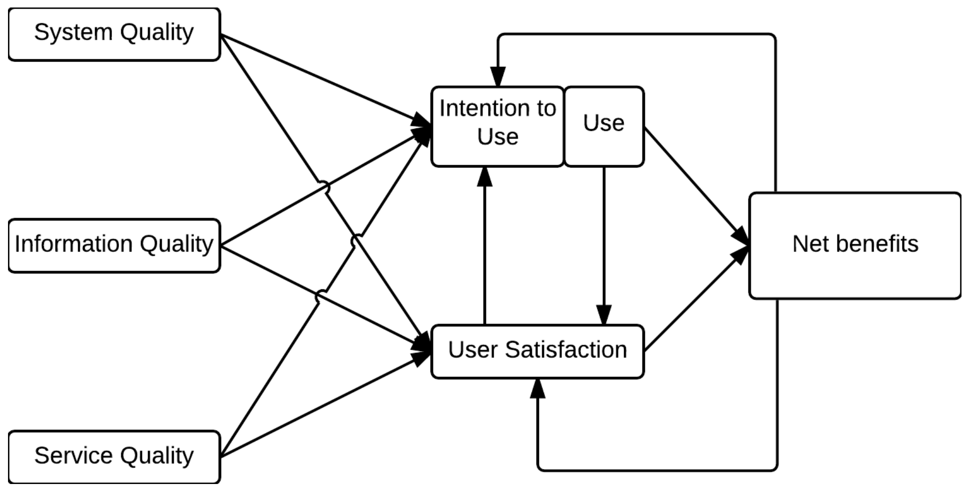

Figure 10: DeLone and McLean model of Information System success, source: (Petter et al., 2008)

System Quality describes the desirable characteristics of an information system. For example: ease of use (usability), uptime, system flexibility, system reliability, adaptability, data accuracy, data currency, database contents, access, user requirements, system features, system, efficiency, integration, customization and ease of learning, as well as system features of intuitiveness, sophistication, flexibility and response times.

Information Quality encompasses the desirable characteristics of the system outputs; management reports, web pages and graphs. For example: importance, availability, relevance, format, understandability, content accuracy, conciseness, completeness, consistency, timeliness, and usability.

Service Quality is the quality of the support that system users receive from the IS department and the support personnel. For example: responsiveness, accuracy, reliability, technical competence, and empathy of the personnel staff. SERVQUAL, adapted from the field of marketing, is a popular instrument for measuring IS service quality. (Pitt et al., 1995)

Intention to Use and Use, the degree and manner in which staff and customers utilize the capabilities of an information system. For example: amount of use, frequency of use, nature of use, appropriateness of use, extent of use, and purpose of use.

User satisfaction, Users' level of satisfaction with reports, Web sites, and support services. For example, the most widely used multi-attribute instrument for measuring user information satisfaction can be found in (Ives, Olson, & Baroudi, 1983).

Net benefits, the extent to which IS are contributing to the success of individuals, groups, organizations, sectors, and nations. For example: improved decision-making, improved productivity, increased sales, cost reductions, improved profits, market efficiency, consumer welfare, creation of jobs, and economic development. (Brynjolfsson, Hitt, & Yang, 2002) have used production economics to measure the positive impact of IT investments on firm-level productivity.
The variables from the D&M Model described above are used during the interviews to explore relationships and find other factors that influence the integration and convergence of IT and OT. The model will then form a basis for a causal model that will be used to visualize the relationships between these different factors. The causal

diagram will help to interpreted and explore the factor and how they affect each other. The D&M model itself will be tested to find out whether it can be used to assess IT/OT converged systems. The next chapter explores the blocking factors for IT/OT convergence recognized in the literature.

3.3 Literature – IT/OT Barriers and Misalignment

Previous paragraphs presented the advantages of IT/OT convergence and how to measure the benefits. IT/OT converge is however not being implemented due to certain barriers and a misalignment between IT and OT. Barriers of IT/OT convergence encompass all organizational or technological aspects that can hinder the convergence and integration of IT and OT. This chapter will present the barriers found in the literature and possible solutions for these barriers and this misalignment. In Table 12 below these barriers, found in literature, are listed and a definition of all the barriers is given afterwards. Important note is that all these barriers are found in specialist literature and other non-academic sources. This research will contribute to academic literature by investigating these barriers providing a definition from the input of the experts.

Table 12: Barriers for IT/OT convergence from literature.

Source	Barrier for IT/OT Convergence
(ATOS, 2012)	Technology Misalignment Cultural Aspects Ownership and Governance
(Harp & Gregory-Brown, 2015)	Technological differences: Environmental Compatibility Skills Shortage Security Organizational differences: Business Silos Culture Clash Risk Tolerance
(Taylor, 2012)	Technological differences Business Silos
(Edison, Brantley, & Edwards, 2011)	Organizational Silos

3.3.1 IT/OT Barriers in the Oil and Gas Sector found in literature

The categories of barriers below are found in the literature. The barriers described influence the Oil and Gas Sector but often apply to other similar sectors as well.

Technology Misalignment (ATOS, 2012)***:*** OT was traditionally designed according to specific requirements and typically has to function in harsh environmental conditions, like high/low temperatures, moisture dust and vibrations. IT equipment is generally used in safe and clean office environments. Furthermore, IT has developed tremendously over the past 30 years where in the beginning IT could not meet OT standards and requirements. For example, communication with thin-Ethernet cabling was unreliable, fragile and costly. Nowadays TCP/IP and Wi-Fi allow safe, secure and cheap wireless communication.

Misalignment also comes from the choice engineers had to make between time-sharing Operating Systems (for IT) and real-time Operating Systems (for OT) since there were no architectures available to do both at the same time (at a reasonable cost). Since the capacity of these systems has grown, traditional IT Operating Systems are being used and integrated in the OT environment more and more.

These constraints led to specific OT standards for communications, security and process integration. Most standards are developed and adopted by large OT players.

Cultural Aspects (ATOS, 2012)***:*** People working in OT departments are usually sector specialist like mechanical engineers in a machinery company or geological engineers in drilling companies. These specialists are educated in engineering schools and universities where they are not only schooled in methods and procedures but also adopt behaviour, engineering traits and other cultural aspects. IT professionals often have commercial or computer sciences backgrounds and have no interest and experience in 'real-world' OT techniques. They are however very adaptable to changing environments, because they were forced to keep up with the latest trends and concepts since IT has been evolving rapidly the last 20 years. These differences between IT and OT caused an organizational separation between the two domains. On one hand the production-oriented world of OT and on the other the commercially-oriented world of IT. The technologies and platforms used in both domains however are becoming more and more similar, thus the skills of employees are also converging.

Ownership and Governance (ATOS, 2012)***:*** At the moment, IT and OT equipment is 'owned' by different departments and different people are responsible for the equipment. IT is often 'owned' by the CIO and centrally managed by an organization of hardware, software and infrastructure specialists. All systems in different business units are owned by this organization to ensure harmonization. The CIO is therefore responsible for all IT-related strategies and sets company-wide standards for software and hardware products and the way the infrastructure is managed. OT on the other hand is managed by local business units or productions managers in a decentralized fashion. Since most sites are unique as well, harmonization between business units or production sites is rare. Targets, goals and objectives can also differ from one unit to the other, but are often focussed on direct business outputs. A central governing organisation to cover the definition and execution of company-wide OT strategies is rare. This, together with the different goals and paths IT and OT have taken the recent years, is partly the result of the organisational silos.

Technological differences – Environmental (Harp & Gregory-Brown, 2015)**:** IT equipment is mainly located in clean and controlled environments with failsafe systems and support staff nearby to response to irregularities. IT has developed during the last 20 years to deliver faster and more reliable data processing in the business sector. IT transformed organizations by transfer speeds, storage capacity, fault-tolerant architectures and protocols. Processing power has been doubling every 18 months and will continue to do so according to Moore's law (Moore, 1998), allowing hand-held devices to contain more processing power than the entire U.S. National Space Agency had in the 1960s.

OT generally has different requirements, priorities and resides in vastly different environments. OT equipment is often subject to extreme pressures, humidity and temperatures. OT systems are expected to function without human intervention for years or even decades across wide geographical distances. Where IT equipment is obsolete within two to five years, OT is designed to last in harsh manufacturing, refining and outdoor conditions for 10 up to 50 years. OT is often designed to fulfil specific functions or tasks with exceedingly high reliability metrics. Since OT equipment often controls large, costly and dangerous equipment, the impact of failures is severe and thus the reliability and integrity of the OT system is essential.

Technological differences – Compatibility (Harp & Gregory-Brown, 2015)***:*** The entire hardware and software sector has benefitted from international computing and networking standards. The standards allow interoperable information and processing technologies to be created and updated continuously. While compatibility is focussed on, it is expected that this will not always be achievable and thus redundant systems are often in place and are considered a basic cost of doing business. OT works in an operational space without crashing systems and often cannot function in a business environment, while IT is not setup to function in OT environments. Safety and limitations of OT systems is something IT developers tend to underestimate.

Technological differences – Skills difference (Harp & Gregory-Brown, 2015)***:*** The need for reliability and 'proven concepts' has driven OT to be a late adopter of new technologies in the Oil and Gas Sector. Equipment in operating plants if often older than those used in enterprises, which leads to a vastly different skillset required to operate both. IT equipment must keep up with performance and safety requirements by constantly updating and upgrading while OT is driven by stability and interoperability demands. The skills needed to operate this equipment therefore differ as well. IT specialists are constantly learning new operating systems and coding languages to be able to work with the latest technologies. Since OT personnel makes use of specific technologies for a longer period of time while ensuring reliability, experience is more important. This results in an older, higher paid OT workforce where their IT counterparts are often younger and paid less.
Furthermore, OT workers often have a background in traditional engineering disciplines like mechanical, civil or industrial. These workers have been educated in how to approach and accomplish projects and solve problems. While IT specialists often have engineering degrees as well, they speak another language. These differences in skills and language contribute to communication and planning difficulties.

Technological differences – Security (Harp & Gregory-Brown, 2015)***:*** OT equipment can often be found in restricted, remote area's with an abundance of physical security. Control mainly happened manually so the systems where not exposed to that many risks. IT is more mature in the area of network safety because since the invention of the Internet, systems have been under attack. Application of the IT security principles in the OT domain is not possible however since even small disruptions in the network can cause equipment to go into an unwanted safety shutdown. OT can definitely learn from IT on this topic but IT specialists must take the risks, impacts and effects into account as well as the working environment.

Organizational differences – Business Silos (Harp & Gregory-Brown, 2015)***:*** IT builds and maintains all equipment in the office domain and the Chief Information Officer or the Chief Technology Officer is responsible for this domain. IT can support the OT department but the divisions are not integrated. Manufacturing, generation and distribution systems are owned, controlled and monitored by the OT department. Responsibility for this equipment often lies with the Strategy Officer, Chief Operations Officer, President of Utilities.
The OT department does require IT services but they often train and maintain their own "IT staff" which is separated from the other IT personnel. Reorganizing these divisions will force deconstruction and validation of budgets, evaluation and justification of employee numbers, restructuring of supervision-and-report charts as well as other implications that may arise.

Organizational differences – Culture Clash (Harp & Gregory-Brown, 2015)***:*** IT departments often have a supporting role within larger enterprises with a focus on costs. While they do establish own policies and rules, particularly regarding security, their main goal is to service others. Outages are planned and scheduled during off-peak times and agreed on with service agreements. OT on the other hand revolves around the core business of a company. Outages are seldom and result in a crisis with huge losses, which trigger emergency procedures and responses to restore normal operations.
OT specialists are traditional engineers that evaluate their work against a zero-fault expectation. They focus on bringing the chances of potential threats and unforeseen scenarios as close to zero as possible. A crash of an OT system might bring lives in danger and breakdowns can also have tremendous cost impact with facilities ranging from 10 to hundreds of millions of dollars per day.

"Due primarily to the driving need for reliability, OT is the classic late adopter, often taking on new technology only once it has matured and any bugs have been addressed." (Harp & Gregory-Brown, 2015)

The departments clearly place different emphasis on avoiding failures because the impacts are so drastically different. IT failure can lead to lost-data that usually can be back-upped, power loss or network failures but almost never cause human injury or death. The possibilities of IT have evolved in such a way that almost all systems are designed redundant with back-up servers, power generation and network equipment. Because of the cost intensity of OT equipment this is often not possible and therefore the systems must be as reliable as possible.

Organizational differences – Risk Tolerances (Harp & Gregory-Brown, 2015)***:*** In enterprises that rely heavily on the flow of accurate information like financial companies, the IT department has a lot to say in the boardroom. For other sectors, the OT department usually has the biggest voice and impact at the bottom line. As mentioned the impacts of OT failures are far more severe and often have the potential to endanger people's lives. Furthermore, society often relies on OT equipment to function. When a gas or electricity network goes down, the company is charged with huge fines whereas a downtime of an email-client only damages the reputation of the company. OT is therefore very careful on implementing IT risk avoidance measures like network scanning, patching, firewalls and anti-virus software to avoid malware, data theft and malicious attacks. These are all daily routine of the IT department but due to historic failures OT still distrusts IT.

Business Silos (Edison et al., 2011)***:*** Because of the different departments within organizations, the data acquired is owned by different people and it is very difficult to transfer this between the different business silos. Certain crucial data that is needed for both departments is often measured multiple times, each with own time intervals and accuracy. These walls are held in place by people who are afraid to lose their job, through cultural differences and safety procedures.

General differences (Taylor, 2012) between IT and OT considering purpose, operating environment, input data, output, owners and connectivity can be found in Table 13.

Table 13: Differentiating information technology and operational technology (Taylor, 2012).

	Information Technology	**Operational Technology**
Purpose	Transaction processing Systems analysis and applications Technical and business analytics Human decision support	Asset monitoring and control Process control, metering, and protection Device-to-device communications Server-to-device communications
Operating environment	Corporate data centres Officers and server rooms Control centres	Substations Field equipment Control centres
Input data	Manual data entry Other IT systems Data from OT systems	Transducers and sensors via RTU's and PLC's IED's, relays, and meters Operator inputs and other OT systems
Output	Data summaries Results of analysis and calculations Commands issued to other OT systems	Device control actions Displays of status and alarms Operating logs
Owners	CIO and IT departments Finance Operations (OMS, DMS, EMS)	Operations and engineering managers Line of business managers Maintenance departments
Connectivity	Corporate network IP-based	Process control protocols IP-based, serial, hardwired analogue and digital

3.4 Conclusions Literature Review

Based on the information gathered in the literature, the following conclusions can be drawn:

1. IT/OT convergence is successfully being applied in other similar sectors so it will probably have a positive impact on the Oil and Gas Sector as well,
2. There are a number of different models that can be used to measure the impact information systems have on organizations, the DeLone & McLean Model for Information System Success is best suited for this study,
3. The literature exposed a number of 'barriers' that prevent IT and OT from converging and integrating.

Other similar sectors are the Electrical Distribution, the Mining and the Manufacturing sector. All these sectors have common properties with the Oil & Gas Sector and have successfully implemented IT/OT Convergence. Due to the similarities between these sectors, IT/OT convergence will probably have a positive impact on the Oil & Gas Sector as well.

There are multiple models to measure the impact of information systems. Due to its ease of use, clear described variables, recent update and fact that the model measures impact on the organization instead of the individual, the D&M Model is best suited for this study. The model will be used during the case study in the next chapter to find other factors and relations that impact organizations when IT/OT convergence is implemented. These findings will result in a causal diagram with the D&M Model as a basis to visualize the impact of adjusting different input variables. The model itself will be used to see whether it can be used to measure the impact of IT/OT converged systems. This will lead to recommendations for future research, weighting of different input variables and perhaps other sector specific variables that should be taken into account when using the model in the Oil and Gas Sector.

IT/OT barriers prevent IT and OT from converging and integrating. Different journals, specialist magazines and industry specialists identify a number of barrier categories that share similarities. These barrier categories will be used to see whether the experts agree with these barriers, to find solutions to overcome these barriers and finally to setup a roadmap for companies who want to achieve IT/OT convergence. Furthermore, the definition of the barriers from the experts and the definitions provided by the literature will be combined to give a final definition to aid future research.

4 Case study

The barriers from the literature review, the D&M model and the knowledge of the sector combined will be used to develop the case study. The literature review had two different goals and therefore the case study and the interview to gather data for the case study will also consist of two parts. This chapter will select and motivate the specific case that is used to further investigate the problem statement of this research. After presenting the selected case, the method for selecting companies and experts to interview will be presented. Subsequently the interview setup for both parts will be elaborated on. Finally the interview results will be presented together with the interpretation sorted per subject. These findings and interpretation will be discussed in the next chapter.

4.1 Case and Participants Selection

Selecting the right case is crucial for the research and is done using the following criteria:

The IT/OT system selected for the case must:

- Generate or process a sufficient amount of data or information;
- Have ample impact on production during operation or breakdown;
- Support a crucial process in the Oil and Gas sector;
- Be found at many/most sites in the Oil and Gas sector (preferably).

Preliminary research and conversations with experts from the Oil & Gas Sector unanimously led to the compression process. Most processes in the Oil and Gas sector are slow continuous processes and streams with redundant safety measures. Compressors generate tremendous amounts of data (pressure, temperature, rotation speed, volume, viscosity) and are, due to the high loads and stresses, very vulnerable for failures and maintenance. Since compressor equipment is very expensive and has tremendous impact on the rest of the production site; predicting when and why these machines will fail can reduce maintenance and replacement costs. Other, less valuable equipment is often over-engineered or have back-up equipment on standby for when it fails. Compressors are too expensive to have redundant or backup systems in place. When a compressor fails, the rest of the site often stops producing as well, which leads to enormous losses. To indicate these losses, Andrew, an average Oil platform in the North Sea can produce up to 80.000 barrels per day or € 2.4 million per day at an Oil price of € 30-50 per barrel over 2015*. The data generation, impact on the production site, support of crucial processes and fact that compressors are found on most sites in the sector make the compression process the perfect case to research. Furthermore, due to the tremendous data generation, compressors will benefit vastly from predictive maintenance. Predictive maintenance uses actual data to simulate (predict) future states and failures, allowing mechanics to repair an issue before the machine breaks down. Different research institutes, like Gartner and IDC, see predictive maintenance as one of the major advantages of IT/OT convergence. Compression happens using several types of compressors that are described in Appendix A Gas Processes.

* http://www.bp.com/en/global/north-sea-infrastructure/Infrastructure/Platforms/Andrew.html

Selection of Participants for Case Study

With the specific case selected, the next step is to select participants for the case study. Companies that are suitable for the case must either supply IT/OT systems for the control of compressors or use these systems.

Criteria for the interviewees themselves are:

- Currently works with-, has worked with- or is in charge of the control systems of compressors.
- Is an expert or authority within his/her company on IT/OT convergence and integration
- Has implemented or is currently implementing an IT/OT convergence project
- Speaks English or Dutch

These criteria were met with all the experts. The experts all had (field) experience with compressors and are currently in the position of managing the control systems of compressors or working on IT/OT convergence projects. The profile of the companies that participated are 3 major Oil and Gas companies who use IT/OT systems and 4 key suppliers of IT/OT systems.

As requested by the experts, all interviews are anonymized.

4.2 Case Study Results and Interpretation

With the background information on the topic and the literature study the interviews with the experts have been prepared. The following paragraphs contain the results and interpretation of the data gathered from the interviews with the experts. In these paragraphs, only the relevant results are displayed, the complete summaries of the interviews can be found in Appendix E. The results and interpretation are presented in separate section, following the different sub-problems of the research problem.

4.3 Complex Relations Caused by Integrating and Converging IT/OT

The complex relations stated by the experts combined with the model from the literature are used trough triangulation to setup a causal diagram. The goal of the causal diagram is to understand the impact of the integration and convergence of IT and OT. First, the different relationships found in the interviews are presented. Afterwards, the relationships are used to setup the causal diagram using the D&M Model for IS Success as a basis. Finally a suggestion of different weights for the D&M Model is presented that can be used in future research.

4.3.1 Complex Relations from Interviews

7 out of 7 experts pointed out that the availability of data for the different stakeholders will provide better insights in specific production and business processes. Currently not all data is (real-time) available to all different stakeholders due to various reasons. Making data available allows all stakeholders to analyse the data, use the data with their own models and simulations and suggest recommendations to improve or optimize specific processes. Since most aspects of organisations are linked to each other directly or indirectly, other business units can benefit from the availability of data as well, even though there is no direct link between departments. Hence there is a positive relationship between Data availability, which is a sub-variable of Information Quality, and better insights in processes, which increases in Net benefits.

✚ Data availability (Information Quality) ➔ ✚ Better insights in processes (Net benefits)

7 out of 7 experts agreed that with an improved data availability the service quality would improve since the service department and all other stakeholders can instantly access and analyse the data available. Uncommon problems where the operator cannot resolve the issue are forwarded to maintenance or rotating equipment engineers. If it is even possible, these engineers have to go through complex-, double authorized portals to gain access to the data needed to find the problem, resulting in higher costs. In general, when the availability of this data increases, uncommon errors can be resolved much quicker. An example given by an expert describes how customer service has improved by linking client numbers to the product serial number, the history of complaints and common errors: “Notice how good customer service providers always immediately ask for the serial/customer or type number that relates to your complaint. This way they can immediately look up frequent errors, the history of complaints and probably even more!” The availability of data therefore has a positive impact on the service quality.

✚ Data availability (Information Quality) ➔ ✚ Service Quality

Next to improved analysis of current states, all experts (7 of 7) also agree that improved availability of data will increase the service quality regarding future states or scenarios. When the data collected from the equipment is combined with all historic data, advanced simulations could predict future states of the equipment and hint when certain parts will fail or break. This can transform the current “reactive maintenance” to “predictive maintenance” in the future. One interviewee pointed out that they where running a suppliers simulation next to their own simulation while they performed regular checks. They used the information gathered from the checks to validate whether the models predicted the correct irregularities and findings. When the simulation models did not predict the correct irregularities they fine-tuned the model so it becomes better every time. The organization mentioned that they already look forward to the moment the model’s predictions are correct all of the time since the regular check, de-assembling the whole compressor, is a very costly operation. This operation forces the whole site to shutdown while all engineers work around the clock to de-assemble, check and assemble the compressor.

✚ Data availability (Information Quality) ➔ ✚ Predictive Maintenance (Service Quality)

7 of 7 experts believe when the data is available for the different stakeholders, the system is accessible to people with malicious intent as well. This exposes the system and thus the organisation to threats of cyber security. The experts do diverge on the topic whether the current technology is sufficient to prevent cyber attacks. Experts who provide the technology (control and security systems) believe that the safety and security is guaranteed. Technology users who work with legacy equipment and have more field experience on the other hand can name exceptional scenarios where current technologies fails to provide enough security. A firm argument is the fact that technology and thus hacking capabilities are constantly evolving so you have to update and patch your software constantly as well which is not always possible. The availability of data therefore has a negative impact on cyber security.

✚ Data availability (Information Quality) ➔ − Cyber Security

7 of 7 experts pointed out that the implementation of IT/OT convergence is very costly. Before the data can be used, it must be gathered, transferred and stored in a secure place. The investment cost to achieve this securely has a negative impact on the net benefits. Some experts did mention that most of these systems are already in

place and only need to be organized but all agreed that it does require investment. The scale of the investments and possibilities of technology already in place obviously differs per site. Data availability in general however has a negative impact on investment costs. Major cost factors named are:

6. Investment in measuring, transferring and storing equipment (Capital Expenditures, CAPEX)
7. Losses due to downtime (Operational Expenditures, OPEX)
8. Organization must abandon spare parts, possibly switch to other vendor (CAPEX)
9. General implementation costs (CAPEX)
10. Training and education of personal (CAPEX)

These are the direct CAPEX and OPEX that can be taken into account when implementing IT/OT convergence projects.

✚ Data availability (Information Quality) ➔ ✚ Investment Costs

7 of 7 experts mentioned that an improvement of system quality has a direct impact on the net benefits. Since the IT/OT Systems not only provides the organisation with data that can be turned into information but also controls the compressors or other equipment, the improvement of the System Quality will directly affect the organization.

✚ System Quality (improved data accuracy) ➔ ✚ Net benefits

Data accuracy is a measure of system quality, when the data accuracy drops, the organization will be affected as well according to 6 of 7 experts. Data accuracy also influences the information quality in the form of reports and graphs produced by the system so these variables are linked as well.

✚ System Quality (improved data accuracy) ➔ ✚ Information Quality

4 out of 7 experts indicated that increased cyber security decreases user satisfaction while 5 of 7 agreed that to achieve increased cyber security, investment needs to be done and security must be organized differently. Increased Cyber Security can often be implemented at the back-end of systems with the associated investment costs. It can however also influence users by increasing security with authorisation steps, procedures and protocols that all have a negative affect on user satisfaction.

✚ Cyber Security ➔ ✚ Investment Costs
✚ Cyber Security ➔ − User Satisfaction

Al relationships found in the interviews can be found in Table 14.

Table 14: Causal relationships found in interviews.

Factor	Positive or negative influence	Factor
Data availability	✚	Better insights in processes
Data availability	✚	Service Quality
Data availability	✚	Predictive Maintenance
Data availability	–	Cyber Security
Data availability	✚	Investment Costs
System Quality	✚	Net benefits
System Quality	✚	Information Quality
Cyber Security	✚	Investment Costs
Cyber Security	–	User Satisfaction

4.3.2 Causal Diagram of complex relations

The relationships between the factors are presented in a causal diagram to provide a visual insight into the relations. A causal diagram is used to find alternatives to scenarios and to expose how an abundance of factors influence each other (De Haan et al., 2015). In a causal diagram the different factors that influence each other are indicated by arrows with a ✚ or a – sign, regarding a positive or negative relationship between the factors. The basis for this diagram is the DeLone & McLean Model for information system success that is introduced in chapter 3.2 which is displayed below in Figure 11.

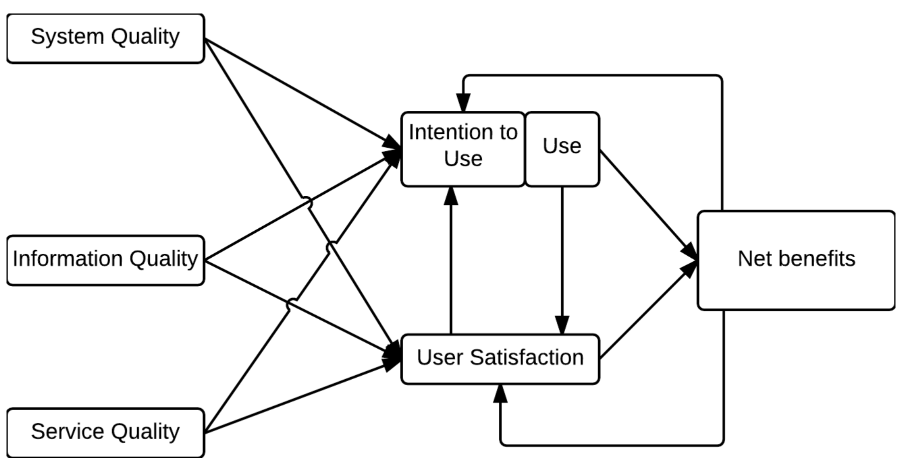

Figure 11: D&M Model for IS Success

The original researchers validated the positive relationships between the factors of the D&M Model during a ten-year update after introduction of the original model. During the update the researchers reviewed over 300 articles that tested and proved the relation between individual factors (DeLone & McLean, 2003). All the causal relations in the base model are therefore positive (marked by a ✚).

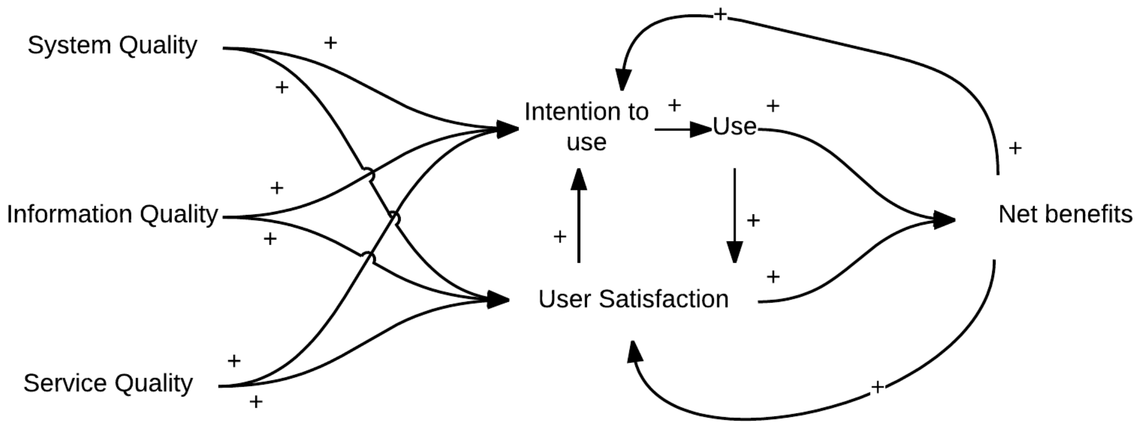

Figure 12: D&M Model in causal diagram form.

Inserting the causal relationships observed in the interviews and presented in the previous paragraph in the causal diagram results in Figure 13.

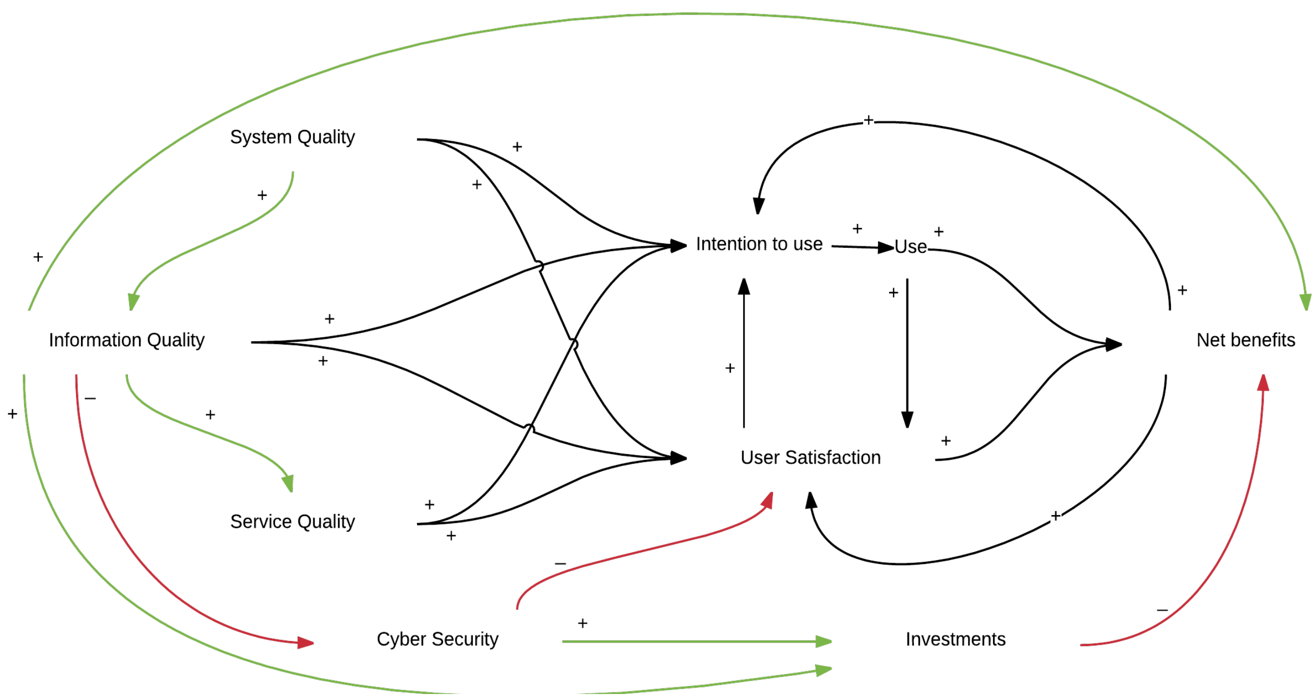

Figure 13: Complex relationships exposed by integrating and converging IT/OT.

The causal diagram exposes a number of interesting facts:

1. An increase in information quality (caused by integrating IT/OT) leads to net benefits for a company

An increase in information quality will result in an increase in net benefits for the organization in the original D&M Model. Increasing the information quality leads to a higher intention to use and user satisfaction, which leads to net benefits. However, the gain from business analytics for other departments has a direct impact on the net benefits as well.

2. The diagram shows which positive impacts (increased intention to use, use, user satisfaction and information quality) need to counter the negative impacts (investments).

The complexity of the business-case to validate IT/OT convergence is exposed by the diagram. Increasing the information quality (data availability) has a positive impact on the intention to use, the use and the service quality. All these variables lead to net benefits and need to outweigh the investments in order to have a positive effect on the organization. However, this does not validate the business case since the positive effects take time before they are noticed while the investments are direct.

3. Original D&M model can be used to measure and compare different cases but not to predict the impact of a 'future scenario'.

This expanded model takes investments into consideration and can therefore rate the benefit gains to the investment costs. The diagram is however specifically designed for IT/OT convergence implementation in the Oil and Gas Sector. Implementing other technologies, for instance to increase System Quality would obviously also require investments and would possibly expose other relationships. Different Scenarios have been used to test the diagram with satisfactory results. The diagram should therefore be redesigned for every case to support complex business-cases around IS systems. For the current case the diagram is a contribution to the D&M Model that can only measure a current state. The diagram can be used to predict future impacts and therewith can be used to provide recommendations for investment decisions.

During the interviews, the experts suggested that if the D&M model is used to measure the exact impact, the variables should be weighted. These findings are presented in the next paragraph.

4.3.3 Weighting variables D&M Model for IS Success

Next to the complex relationships between the different variables, the interviews revealed that the input variables should be weighted differently when the D&M model is used to assess the impact of IT/OT systems. 7 out of 7 experts agreed on the following priority between the variables: 1: System Quality, 2: Information Quality and 3: Service Quality. Motivation for these weights can be found below.

System Quality

The system is rated the most important variable of the D&M Model for IS Success to contribute to net benefits. The main reason presented is the fact that the main goal of the compressor is to have the highest uptime possible. The IT/OT system controlling the compressor therefore has to have the highest uptime as well. The equipment can also trigger dangerous situations for human lives and the environment and therefore has to function perfectly with no exceptions. The dangers in the sector are often sketched by the example of the disaster in the Golf of Mexico.

*"Everybody has become more cautious after the disaster with the Deep Water Horizon in the Golf of Mexico" **

**In February 2010 an explosion on oil-platform Deep Water Horizon caused the biggest environmental disaster in the history of America. The explosion itself was not caused by compressor equipment but it demonstrates the dangerous environment of the Upstream Oil and Gas sector.*

Sub-variables contributing to the importance of system quality that are named most often are availability, reliability and data-accuracy. The availability as a variable contributing to systems quality is notable. The importance of these sub-variables can also be explained by the costs of the compressor-package as a whole. The physical components are often unique one-of-a kind, custom-built products. The software component (the control system) is usually less expensive in comparison to the physical part and can be configured to fit on other compressors as well which makes this part cheaper. Since the availability is dependent on both parts, suppliers do not save on the control system since this does not impact the total price drastically.

"System quality is definitely the most important. The system quality is the 'backbone', if this lacks, the information quality and service quality are useless. The system quality directly impacts your revenue.

Reliability for the control system is rated the most important variable contributing to system quality. Reliability and availability are therefore closely connected but definitely different variables. The availability can be high but without a reliable system it is still possible that it will not function.

Data-accuracy is a third and crucial variable contributing to system quality. The system makes decisions based on the data it collects so if this is not accurate, the system could stop or malfunction. The compressor has to work within an operating window so the accuracy does not have to be perfect, as long as the variables stay within the limits it will function. Certain controls within the compressor control system do require such timely action that the data for these controls is crucial. Failure of compressor control systems can damage the compressor itself and surrounding equipment.

Information Quality

The different experts recognize the importance and value of information quality as the second most important input variable of the D&M Model. The compressor's first and most important task is to function. Gathering information is a trend in the sector but this is not a top priority at the moment. Operators, Process-, reliability- and maintenance- engineers do require information for their analysis but they need different information and the information does not have to be real-time. The compressor as a system is mostly controlled by people in the OT domain who prefer not to share any information to others if the cyber-security is risked.

"Information Quality will definitely become more important in the future. Everything is becoming more and more data-driven, from smart-watches that measure every step to sensors in your home."

Concerning sharing information there are different opinions concerning cyber-security. Suppliers are confident their products are safe and impossible to breach while the customers and users do not share this opinion. Most non-crucial information is therefore send to other stakeholders like process-, maintenance- and reliability engineers with a delay.

Service Quality

The service quality is the variable that earns less attention. The equipment should work (high System quality) and the service moments need to be predicted or planned in such a way to keep the highest uptime. In data-intensive processes like the compressor the service quality is highly dependent on the data accuracy and information quality.

"When selecting systems, you first look at the quality of the system, then the information quality and finally you make arrangements on the service quality."

The interviews exposed the complex relationship between factors contributing to net benefits for organizations. When the D&M is used to measure the exact impact and benefits of IT/OT convergence, the interviews revealed that it is wise to weight the different variables since there certainly is an order of importance and impact. The causal diagram suggested that IT/OT convergence can lead to a positive impact for organizations but companies are still cautious to start implementing. This is partly because the business case is difficult to verify, the benefits take time before they can be measured while the investment is direct. Another reason is the fact that the experts named barriers of IT/OT convergence that are in place that are difficult to solve. These barriers will be presented in the next paragraph. The findings on the D&M Model and the Causal Diagram may be applicable only to the current case or scenario. In chapter 5, the researcher will argue whether these findings apply to other scenarios as well.

4.4 Results and Interpretation of IT/OT Convergence Barriers

During the interviews, the experts often mention investment and implementation difficulties as a barrier for IT and OT convergence. Further questioning revealed that these difficulties where more specific than this broad description. This section will therefore introduce a number of categories in order to categorize the IT/OT barriers found in the interviews. The initial findings of the research stated that IT/OT convergence could have a positive impact on organizations. The previous section introduced a causal diagram of relations between factors when IT/OT convergence is implemented. The diagram confirmed the positive impact it can have on organizations but IT/OT convergence is not being implemented everywhere due to certain IT/OT convergence 'barriers'. These barriers are identified in specialized journals but cannot be found in academic literature. From the findings in the literature, first a number of barrier categories will be proposed. The barriers from the interviews will then be divided into the different categories, when a barrier does not fit any of the categories, a new category will be introduced. Based on the results from the interviews, the final definition of these categories will be presented. During the interviews, the experts also mentioned a number of solutions to solve specific barriers or to achieve IT/OT convergence and integration in general. These solutions are presented in the form of a roadmap in paragraph 4.5.

4.4.1 Categorization of IT/OT Convergence Barriers

In order to comprehend all barriers found in the interviews, categories will be introduced. These categories are based on the categories found in the specialized literature. The categories of barriers found in the specialized literature can be found in Table 15 together with a proposed category. For this research as few categories as possible has been selected in order to simplify the problem and keep the barriers manageable. Literature research also proved that the barriers could be summarized in three different barriers so in order to keep overview on the barriers, few categories will be proposed. During the interviews the experts found it difficult to group the barriers but always gave examples from three specific categories, which will be elaborated afterwards.

Table 15: Categories of barriers found in literature and the proposed category

Source	Barrier category	Proposed category
(ATOS, 2012)	Technology Misalignment Cultural Aspects Ownership and Governance	Technological Differences Cultural and Skills differences Business Silos
(Harp & Gregory-Brown, 2015)	Technological differences: Environmental Compatibility Skills Shortage Security Organizational differences: Culture Clash Risk Tolerance Business Silos	- Technological Differences Technological Differences Cultural and Skills differences Technological Differences - Cultural and Skills differences Technological Differences Business Silos
(Taylor, 2012)	Technological differences Business Silos	Technological Differences Business Silos
(Edison et al., 2011)	Organizational Silos	Business Silos

All sources categorize the barriers around the themes technology and organizational differences. ATOS (2012) also named the cultural aspects as a barrier category, while Harp & Gregory-Brown, (2015) distributes the cultural differences in the two main categories. The other sources do mention the cultural differences as a hurdle to take into account but do not provide an exact definition of this barrier. The barrier cultural differences is well described in the paper by ATOS (2012) and Harp & Gregory-Brown (2015) and preliminary research and interviews revealed that these cultural differences definitely block the convergence of IT/OT, therefore it is taken into account as well. The background of the cultural differences lies partly in the education of the IT and OT people and therefore the cultural aspects also include the skills differences between these domains. The barrier category for these differences will therefore be cultural and skills differences. Risk tolerance is a barrier that Harp & Gregory-Brown (2015) file under organizational difference. The difference between the risk tolerances between IT and OT however originates from the different impact the technologies have. OT failure can have tremendous impacts where IT equipment often only impacts productivity. The risk tolerances are therefore added to the technological differences category.

The three categories that will be used to categorize the barriers from the interviews are:

- Technological Differences (TS)
- Cultural and Skills differences (CS)
- Business Silos (BS)

4.4.2 Barriers Identified in Interviews

In the following Table 16, all barriers from the interviews are assigned to their corresponding category. The list of barriers and the motivation for the category can be found in Appendix D. Some barriers may fit in multiple categories if they contain elements of several categories. All barriers fitted in the proposed categories.

Table 16: Barriers from interviews assigned to categories.

Barrier Category	Barriers	Times mentioned
Technological differences (TS)	#103, #104, #105, #106, #201, #202, #302, #304, #305, #402, #404, #502, #503, #601, #603, #604, #701, #704	18
Business Silos (BS)	#101, #102, #104, #105, #106, #201, #301, #304, #305, #402, #404, #501, #503, #504, #601, #602, #603, #604, #605, #606, #702, #703	22
Cultural and Skills differences (CS)	#102, #104, #105, #201, #301, #302, #303, #304, #305, #401, #402, #403, #505, #601, #603, #701, #702, #703	18
Investment and Implementation difficulties (II)	*#105, #106, #402, #403, #503, #504, #605, #701, #704*	*9*

The table suggests that the original three categories of barriers (TS, GO and CS) that were derived from the literature are indeed contributors to blocking IT/OT convergence and integration. Barriers that fit in the categories are mentioned an equal number of times except for the Business Silos, suggesting that each category contributes equally to the misalignment of IT and OT and thus blocking the convergence.

Rejected Category: Investment and Implementation difficulties

During the categorization of the barriers, ten barriers explicitly stated the investment and implementation difficulties as something that can block the convergence and integration of IT and OT. The investments and implementation difficulties however refer to overcoming the other barriers, TS, GO and CS so this barrier is not added to the list of barriers. Experts explaining barriers from this category were unable to explain the underlying problem (barrier) and thus named it under “investment and implementation difficulties”.

4.4.3 Final Definition of Barrier Categories

With the findings from the interviews, a final definition can be drafted for the different barrier categories; Technological Differences, Business Silos and Cultural and Skills Differences. This final definition is drafted using triangulation; it is based on the barriers from the literature and the barriers described by the experts during the interviews. These barriers prevent IT/OT convergence and lead to the misalignment between IT and OT, as can be seen in Figure 14. This final definition can be used for further research since these barriers have not been described in any scientific literature before. The categories are not divided into sub-categories since this will only impede the complex misalignment between IT and OT. Furthermore, when these categories were presented at the end of the interviews, all experts agreed that these were the most important IT/OT barriers.

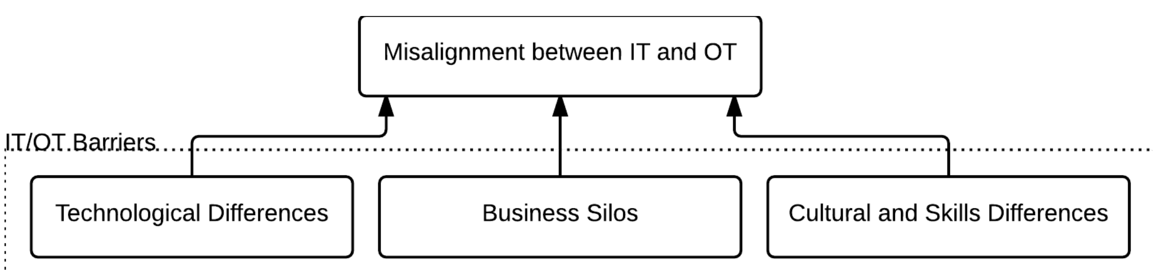

Figure 14: Factors blocking IT/OT Convergence and contributing to the misalignment between IT and OT

Technological Differences

Technological differences encompass everything that is different in the technology between IT and OT. Major differences are the environment, the security and the compatibility between IT and OT due to historical separation. These sub-categories emanate from the technological differences and for this study they are grouped together.

The environment separates the technologies because OT often has to function in harsh environments, with large temperature swings, moisture, different air qualities, high pressures and dusty environments. IT on the other hand is often installed in controlled environments where humidity, temperature and pressure are constant or controlled. This causes OT to be designed in a more rigid, robust manner to maximize reliability and integrity.

The function for which IT and OT equipment is designed differs a lot as well. OT often needs to perform one task according to very high reliability standards, where IT is often designed to be able to perform multiple tasks. Since OT is designed for a single specific task, the equipment is often very expensive and needs to last years to decades. IT's need for faster and more reliable data transfer forces equipment to be replaced between 2 to 5 years. This gap in lifetime of the equipment often leads to compatibility problems as well. Compatibility is a major issue when connecting devices as well, a key principle in IT/OT convergence. While IT equipment can be reset, restarted or updated by with the flick of a switch, OT equipment cannot afford downtime.

Another major difference between the technologies is the impact they have and therefore the security needed to secure the systems. IT often only controls the flow of information where OT controls physical processes that can often be dangerous for people as well. However, since OT systems in general are less accessible by humans, OT has focused on physical security of these systems. IT faced threats from the moment all computers became connected through the Internet and has therefore very advanced cyber-security measures. All these technological differences and constraints have forced suppliers of IT and OT systems do develop different standards. In the Oil and Gas Sector, the OT has a huge impact on costs, the environment and even human lives. Therefore, the sector has become very conservative in adopting new IT technologies. The level of OT technology has therefore saturated due to incremental improvements instead of adopting new, disruptive IT technologies.

Cultural and Skills differences

The cultural and skills differences originate from the technical differences and from the education that IT and OT professionals received. OT professionals are often sector specialists that are educated in engineering schools while IT specialists usually have a commercial or computer science background.

In both domains, different methods and techniques are taught with few overlapping subjects. Engineers are instructed to solve 'real-world problems' that receive little to no interest from IT students (ATOS, 2012). IT problems and solutions on the other hand are seen as black boxes from the eyes of OT specialist.

A major contributor to this barrier again is the impact both systems have on its surroundings; OT is focused on controlling the 'real-world' and failures can harm people or have a huge impact on costs. IT failures often only require a reset and cause, cause downtime and thus cost money as well but in most cases not as severe as the impact OT systems can have. The design basis of these systems is therefore vastly different (technological difference). The education, impact that the systems have and the different goals and needs of the equipment have led to a different culture between the domains where IT people do not speak the language of OT specialists and vice versa.

IT departments are often costs centres that exist to serve other departments as good and as cheap as possible. IT can therefore establish their own policies and rules as long as they are able to serve the other departments; the IT department in the Oil and Gas Sector therefore has a 9 to 5 mentality. Since IT department's main driver is costs, the need for a centralized control and standardized equipment is high, maintenance is planned and according to agreements. OT on the hand is often the core business of a company so they work around the clock, maintenance and unplanned downtime is rare. When downtime occurs, the whole organization bends to the needs of the OT department to get things running again.

Due to the impact of the systems, OT prefers proven concepts to new technologies and even has certain distrust over new tech. The 'old-school' engineers working in OT departments have learned to thrust information and measurements provided by IT systems since certain data simply cannot be processed by humans. The first intuitive check how a compressor is running is still done by simply listening to it, before consulting the data. For 'old-school', experienced engineers this is often a good indication to where the problem lies. The IT department with their equipment becoming obsolete after a couple of years are way quicker to adopt new tech and this is often needed as well since the latest software requires up-to-date hardware as well. Furthermore, lost data in IT departments can often be recovered through backups or fail-safe systems where downtime or human lives cannot be recovered by the OT department.

Working with these vastly different systems requires a different set of skills as well. OT has a need for experience where IT needs adaptable and versatile people. These cultural and skills differences have led to a separation within companies and this resulted in the business silos (different departments) that are in place.

Business Silos

Both the technical differences and the cultural and skills differences have resulted in another barrier that prevents IT and OT from converging, business silos. The business silos are the physical separation of both domains within organizations and encompass governance and ownership difficulties as well. The separation between the domains results in little to none cooperation between departments and even the exchange of information is hampered by these barriers.

In organizations, the IT department is responsible for building, operating and maintaining all information systems that organizations rely on. The equipment that controls the processes and all other manufacturing equipment is 'owned' by the OT department. When the OT department needs IT technology like Wi-Fi to transfer data, it is not clear who is the owner and who is responsible for this technology.

The different goals of the departments result in difficulties as well. The head of the IT department (often the CIO) has a focus of cost reduction, standardization and central-, company wide government. The OT department falls under supervision of the COO and because the OT in companies is often responsible for the organization's core business, has a completely different set of goals. OT often has a profit maximizing strategy per business unit; each business unit is therefore tailored and optimized for its situation. This can result in completely different units although their goals are the same due to a lack of harmonization and governance.

These business silos keep themselves in place due to the hassle it takes to reorganize IT and OT departments. This would require deconstruction and validation of budgets, justification of the number of people working at the departments. Re-establishment of rules, procedures, business processes all need to be reconsidered. This while the current employees are often not in favour of these plans. Their resistance to 'protect' their own department makes the convergence very difficult to implement.

Commonly named issue often named: Conservative Oil and Gas Sector

The experts often pointed out the conservativeness of the Oil and Gas Sector. When asked why the sector is so conservative they explain that the impacts of failures are so substantial (Technological Differences) and the fact that managers in the sector often have an engineering background (Cultural and Skills Differences) and a particular way of working. This issue can therefore be categorized in the proposed barrier categories.

4.5 Roadmap for Implementing IT/OT Convergence and Integration

From the complex relationships found in the case study together with the barriers and solutions for IT/OT Convergence a roadmap is developed, describing how to implement to achieve IT/OT convergence and integration. In this paragraph the steps, solutions and considerations to be able to integrate and converge IT and OT are presented. Since implementation cannot happen from day to day, the solutions are presented in steps the organization must take in order to achieve IT/OT convergence and integration. This roadmap is setup together with consultants specialized in the industry and based on solutions provided by from the literature and tips, solutions and experience from the experts. Implementation of IT/OT convergence is best achieved when a whole site is integrated/converged. All experts agree on this but in practice this almost never happens since the companies cannot afford any downtime. The industry therefore has no clear view on how to approach this problem; this roadmap can help them achieve their goals of achieving IT/OT convergence. During the interviews different cases were encountered where a successful integration/convergence of IT an OT was achieved. The motivation for these projects was different but the way the projects where implemented shared similarities. The roadmap can guide companies into obtaining a competitive advantage over their competition.

One recent project in an urban environment required very high safety standards. Next to the safety standards the organization wanted real-time access to all data for analysis and remote control. Being able to remotely control the site was a method to decrease the number of personal on site that was also formulated as a goal. The design of this project was achieved by getting an IT specialist on board of the team from the start.

Another project named by one of the experts was a hobby project. The manager in charge had a background in IT and ended up being responsible for the OT of a site. With the expertise from both fields he initiated small IT/OT projects. Due to personal interest and expertise the whole site became a pilot project and example for the rest of the organization.

"Both worlds can learn so much from each other but the separation resulting from the organizational structure limits this opportunity."

How to implement new IT/OT convergence projects, experts pointed out a number of steps:

1. Check the maturity of the organization regarding IT/OT convergence, setup a well-planned project plan.

Before starting with IT and OT convergence and integration, the level of convergence must be analysed to find out what and where gains are possible. An IT/OT convergence team must acquire a clear view of what system processes are currently in place. A thorough understanding of what is currently happening with real-time information provided by control systems and SCADA. The team must analyse the supply of IT data and assets, both from IT (historical data, technical data model) and OT (signals, time series historical data). With this analysis a goal and aim needs to be formulated where the company should go.

2. Convince the whole organization of the value of IT/OT convergence, from managers down to users, everybody must realize and believe in its value.

It is key to create company wide support and acceptance for the convergence. This can be done by presenting best practices, successfully implemented projects from the sector, the education of employees and to point out sponsors and advocates of change. These sponsors must support the convergence in every sense and communicate this support to other employees as well.

3. Find feasible (pilot) projects that quickly show tangible results as an example or best practice

This approach calls for the undertaking of pilot projects that promise swift realization, offer tangible and sustainable benefits and represent a comparably low risk for the company (no danger of a production breakdown) and low risk to fail. The team involved in these pilot projects should consist of the best resources the company can provide mixing people from both IT and OT departments. Management should also be closely involved in these projects, as project sponsors and advocates. The purpose of these pilots is to gather experience in IT/OT convergence, to train personnel who can enhance and bring experience to future projects, and deliver positive results that create a positive attitude towards IT/OT convergence. The pilots should act as 'ice breakers' to pave the way for future projects.

4. Integrate IT and OT departments and setup common governance model

Set-up of a common governance model, the model will be the foundation for the integration of both departments. This will imply that all technologies, procedures, policies from both IT and OT departments will be harmonized. The central body will incorporate IT and OT expertise and will define guidelines and rules for both disciplines. Instead of two different departments with their own responsibility, the central body will incorporate all functional units including business process management, application management, technology, and resource sourcing, and infrastructure management. This will result in an overall architecture based on common standards (e.g. ISA 95) that will define the integrated system landscape. After the set-up of the governance model, all duplicate and/or overlapping processes can be harmonized and governed by the policies, workflow and structures defined by the governance model. Next step is to define common Key Performance Indicators (KPI's) to ensure that the implementation is closely tracked and enforced. Control the governance model is very important to keep in mind. Since most benchmark governance models are found in IT, this will probably form a basis for the central body. Ensure that the lack of OT knowhow is compensated by including OT experts in the governance planning team.

The model will be the foundation for the integration of both departments. This will imply that all technologies, procedures, policies from both IT and OT departments will be harmonized. The central body will incorporate IT and OT expertise and will define guidelines and rules for both disciplines. Instead of two different departments with their own responsibility, the central body will incorporate all functional units including business process management, application management, technology, resource sourcing and infrastructure management. This will result in an overall architecture based on common standards (e.g. ISA 95) that will define the integrated system landscape.

5. Stakeholder management and communication, to keep all involved parties informed of the progress, the value it creates and the opportunities it offers.

As emphasized in step 1, the support for IT/OT Convergence from the management is the starting point for all activities but managing the other stakeholders is critical as well. This should include top management like the CEO, CFO, IT management (CIO), OT management (production, unit or operational management). All the management layers should actively support the convergence and act as a sponsor of the change towards the organization. The involvement and support of OT vendors, change officers (internal or external) is another important factor to ensure a successful implementation. Communication should also be carried out to inform, track and gather information about IT/OT convergence projects. Internal communication should target all involved parties and convince them of the benefits of IT/OT convergence/integration. Communication instruments that should be employed:

- IT/OT convergence hotline for questions, problems which will be forwarded to the implementation team
- Management presentations to show support, allowing room for feedback from employees which can be used for future activities
- Internal company page containing info on current and future IT/OT convergence projects, FAQ etc.
- Company Newsletter with insights, views from different stakeholders, general information or specific info from IT/OT convergence projects
- Information kit with hand-outs, presentations, time-line and benefits concerning IT/OT convergence

Consideration: Safety and Security

Key considerations during all steps of the implementation are safety and security measures. Aspects on the topic of security that must be taken into account in order to ensure a safe implementation are described below.

- Security officers should become familiar with OT environments to understand the new control environments that must be protected. Both IT security and OT teams should be trained to become familiar with the risks.
- Educate or hire IT/OT security architect with specific sector knowledge. Architect must be skilled managing and negotiating key governance and architecture decisions across internal teams.
- Current OT management issues must be addressed like: regulatory compliance, upgrades and patches, performing risk assessment across IT and OT. Best practices in risk management and IT security can be leveraged to OT issues.

These steps can be applied to any organization in the Oil and Gas sector that wants to achieve IT/OT convergence. Every organization however is different and therefore careful planning of the implementation is required.

"Security is a critical factor but should not be considered a disadvantage. There are enough systems available that provide perfect security on all different levels."

4.6 Views different stakeholders on barriers and solutions

All the different stakeholders, suppliers as well as users, mentioned the different barriers categories as factors contributing to the misalignment between IT and OT. Implementation IT/OT convergence is the only topic where they disagree. Suppliers tend to see an ideal world where their provided systems can solve all issues and the systems can be implemented in a blink of an eye. Users and managers responsible for IT/OT systems are more realistic and name compatibility, legacy equipment and switching costs as barriers for implementation. They are also more critical on security level, while suppliers claim to have proper and safe and secure technology. This result was expected since the providers of the systems have to put faith in their products and are perhaps a bit more business/sales oriented.

4.7 Other Opportunities and Business Models enabled by IT/OT Convergence

The possibilities IT/OT Convergence can offer in the Oil and Gas sector mostly involve enhanced decision-making, cost reduction through process improvements, risk reduction and an increased flexibility. Experts indicate that condition based monitoring, preventive maintenance, predictive maintenance are all made possible through IT/OT Convergence.

"Convergence is letting the system talk to each other, making sure you gather the right data from both systems in order to make better decisions."

IT/OT convergence enables better, more accurate data to be transferred to different domains. Reliability engineers, maintenance engineers and process engineers can all benefit from this increase of information. At the moment all engineers have access to the data but the real-time availability could allow for faster adjustments. Together with the remote control possibilities IT/OT convergence offer plants could responds faster to situations. For the maintenance of equipment this could mean that the time window where the system will break down can be predicted more precise. This extends the uptime of the systems but it also excludes excessive maintenance during regular checks.

Experts mention that the value of all data from compressors is worth exponentially more than from one single compressor. Compressor manufacturers could therefore chose to take control of the data-flow from compressors in order to predict the maintenance window better, which is crucial for compressors. An extreme scenario was also sketched by a supplier of compressors who believes they could be providing a compressor service in the future instead of a compressor as a product.

"Business models are shifting more and more towards pay for what you use, telecom providers are frontrunners in this field but you see it these days in other sectors as well. Look at Airbnb and streaming services like Netflix and Spotify. It could be possible in the future that we provide a number of hours compression power to the customer while we remain owner. This will make the sector even more competitive as well because it will be cheaper for new entrants to enter the market due to the fact that they don't have to invest tons of money on equipment."

Predictive maintenance can be a significant benefit resulting from the integration of IT and OT. Gathering the complete data-flow and feeding this into different simulation models will allow companies to predict failures instead of reacting on them. These predictions will become better when more data is gathered since the simulation models then take all exceptional scenarios into account as well.

5 Discussion

This chapter will discuss whether the conclusions drawn on the case study apply to the entire Oil and Gas sector or even to other sectors. Also, the limitations of the research will be addressed. Furthermore the chapter will discuss whether the research approach and execution was valid. Lastly any possible biases the findings may have are discussed.

5.1 Generalizability of Case-Study Results

To find out whether the findings of the case study can be generalized, the following questions will be answered: 1: Can the concept of IT/OT Convergence be applied to other equipment in the Oil and Gas Sector? 2: Can the concept of IT/OT Convergence be applied to the whole Oil and Gas Sector? 3: Can the concept of IT/OT Convergence be applied to other sectors?

5.1.1 IT/OT Convergence for other equipment in the Oil and Gas Sector

The case study, compressors in the Oil and Gas Sector, has been chosen since the literature proved that the IT/OT systems controlling compressors could benefit enormously from IT/OT convergence. Compressors are a specific piece of equipment that generates tremendous amounts of data and therefore the availability and analysis of this data, all enabled by IT/OT convergence, could be beneficial for organizations. This study proved this was correct/valid for compressors although the business case can be difficult to corroborate. IT/OT convergence provides enhanced insights, better decision-making and control to equipment so all equipment can benefit from the convergence. The benefits for data-intensive processes are greater compared to normal processes, but all equipment can benefit by eliminating the need for physical interaction; Since people account to 60% to 80% of all incidents and accidents, on site (Boschee, 2014). When integrating and converging IT and OT becomes cheaper, entire production sites will be converged and integrated.

IT/OT convergence enables connected devices, improved performance and decision-making, cost and risk reduction, better and faster insights in data and information, more flexible control of equipment and less people on site. In the remote and harsh offshore environments, less people therefore means fewer costs and fewer risks, which account to costs as well. The enhanced insights will enable the organization to prevent failures by using simulation tools. These simulations however do require as much data as possible so the effect may take time to notice. Again, equipment that does not generate as much data like compressors are therefore more difficult to justify from a business perspective but the concept op IT/OT convergence does apply. The insights obtained by the convergence are valuable for organizations and the cost and risk reduction are worthwhile.

5.1.2 Converging and integrating whole production sites in the Oil and Gas Sector

The previous paragraph argued that IT/OT convergence could be applied to all different separate equipment in the Oil and Gas Sector. Integrating and converging whole production sites therefore has a positive impact on organizations as well. In fact, the benefits of applying IT/OT Convergence to a whole site are even bigger than converging IT and OT for single pieces of equipment.

Connecting all equipment can enable the monitoring and controlling of multiple sites by a single operator when IT and OT are fully converged and integrated. IT/OT convergence enables all equipment and even different sites to communicate and learn from each other, preventing failures, downtimes and other unforeseen errors. Integrating and converging IT and OT for whole sites actually makes more sense because eliminating the need for an operator for one piece of equipment while he still has to check other equipment does not reduce the number of operators in place, just their tasks. Connecting, converging and integrating whole sites will enable 'smart' oil-fields that can function completely autonomously.

An example given by one of the experts stated that if different parameters that are measured at the well (first stage of production) are real-time available for other equipment, they can adjust their production parameters accordingly. A peak in pressure or viscosity at the well-head may cause a compressor to overload in a later stage for instance. When these variables are available, the compressor can be set to a lower speed in order to cope with the pressure peak that is expected. This is one example revealing the benefits of connected devices but gathering, storing and analysing data from all equipment in one place could reveal even more advantages for organizations.

Experts also often refer to advanced analytics and algorithms that can process all data from different sites in order to optimize business and production processes. These simulation and analytics tools could give insights into certain processes that humans simply cannot handle, referring to marginal adjustments of equipment. These marginal adjustments that lead to marginal gains could, over a longer period of time, present huge benefits for companies since the sector is so capital intensive.

Integrating and converging complete sites requires thorough planning. Companies must first analyse the current state of the equipment to see whether the integration is possible at all. When a site utilizes too much legacy or incompatible equipment the investments may not be worthwhile. Some sites have been operating for over 40 years without major upgrades. Connecting younger and more recent equipment is often easier, sometimes equipment only needs a software update.

5.1.3 IT/OT Convergence in other Sectors

One motive to perform this study was the fact that similar sectors already apply the concept of IT/OT convergence. IT/OT convergence can provide benefits to completely different sectors as well. Other sectors that do not produce continuously but in batch could actually benefit even more from the flexibility gains. IT/OT convergence for these sectors could enable them to switch a whole production facility from one product to another with the click of a button, something that required complete overhauls in the past.

"Installation, commissioning and debugging for 10 stations with 12-15 robots takes a couple days, rather than 1-2 weeks." (Namboodri, 2013)

Literature review also disclosed examples of similar sectors where IT/OT convergence has successfully been implemented like the automotive sector. Car manufacturers have online car configurators where customers select the car, customize the paint-job, interior and other options and pay for the car all without interference of a single human. The order is then directly forwarded to the factory and added to the production queue. The examples of successfully integrated IT and OT systems in other sectors are countless, the concept therefore definitely applies to other sectors as well. Production sites that require quality control can also greatly benefit from IT/OT convergence and integration since every step of the production site can be monitored.

5.2 Academic and Business Relevance of Research

The research aimed to contribute to the academic literature by exploring the concept of IT/OT convergence. Furthermore the study promised to provide companies with helpful insights on IT/OT barriers and how to overcome these barriers.

Research Problem, Business Relevance

The topic, IT/OT convergence in the Oil and Gas Sector, is interesting from a business perspective. The sector is capital intensive but under tremendous pressure due to low oil prices and society trying to switch to more sustainable sources of energy. The advantages of IT/OT convergence can therefore bring competitive advantage to companies in the sector. This research provides valuable insights of the benefits of IT/OT convergence, the organizational and technological barriers that prevent integration and how to overcome these barriers. The barriers can aid companies in recognizing issues while the solutions have been used to setup a step-by-step roadmap for companies. Furthermore, the research also suggests how the D&M Model can be used to measure the impact of IT/OT integrated systems. These findings can aid companies in the Oil and Gas Sector to grasp the opportunities that IT/OT convergence offer.

Research Problem, Academic Relevance

The study contributes to academic literature by identifying the barriers that block IT/OT integration and convergence in the Oil and Gas Sector. These barriers have been confirmed by experts from the sector and clearly demark the origin of problems. The complex implementation of IT/OT convergence is also interesting from an academic perspective since the subject is barely explored and this research not only presents the barriers but also solutions and tools companies can use during decision making. The causal diagram and weighting and the conclusions pose a number of interesting future research directions, which will be discussed later. Implementation of new technologies will always be an interesting topic that is on the forefront of science because people have a natural resistance to change. Adopting new technologies of working methods will therefore always cause problems in organizations and remain relevant in the future as well. Regarding IT/OT the technology is not completely new, innovative or disruptive in a particular area; IT/OT convergence mainly brings technologies together. The barriers, causal diagram and organizational issues however can be interesting for future research.

5.3 Research Problem, Methods and Results

This paragraph will discuss whether the selected research methods chosen were correct, whether the execution was sufficient and how valid and valuable the results are based on the methods and execution. The following topics will be addressed during this discussion: Research subject, problem and questions; Research Methods (Case study design and topic, data gathering and interpretation) and the results.

Research Problem and Questions

The problem, IT/OT Barriers and the possible performance improvement of current systems, which was derived from the subject and the context, posed an interesting research problem. The academic relevance resulting from the subject however is still limited; the approach does definitely separate the research from a market research but does not comprise any academic novelty.

The questions resulting from the subject, the context, background and research problem are a logical derivation. The questions allow for interesting insight for both academic as business perspective. Including a scientific model that can be used to measure the impact of IT/OT converged and integrated systems definitely enhances the academic relevance of the research and also has the possibility to aid future research that uses the model in this specific sector.

5.3.1 Research Methods, Case Study

The choice for a qualitative case study in the Oil and Gas Sector was correct since finding companies willing to cooperate proved to be difficult. The case study focussing on a specific process was also well chosen. Roles and specialities in the Oil and Gas sectors are very delineated so researching a broader case would have been near impossible since expertise would have to come from even more different sources. The case itself, IT/OT systems controlling compressors, was also well chosen for a number of reasons: the benefits of IT/OT convergence are the largest for equipment that generates sufficient amounts of data, furthermore Compressor equipment is very costly so insights and predictions in maintenance and failures can reduce maintenance costs dramatically. Preliminary research already suggested that convergence could present major benefits for the control of compressors and all experts agreed on this matter.

5.3.2 Research Methods, Data Gathering

Data for the case study was gathered through interviews with experts. The choice for this method again was adequate due to the limited amount of available companies and thus experts. Setting up the interviews could have been done in more rigor manner; the first two interviews could have been used to adjust the interview setup and focus. Data gathering for the literature review by looking into journals, specialist magazines, research institutes and consultancy reports proved to be a good approach due to limited academic resources covering the topic.

5.3.3 Discussion on Case Study Results

By interviewing both suppliers and users of IT/OT systems, the researcher eliminated possible biases regarding the results. The only dissimilarity between these two groups was on how easy the ‘IT/OT barriers’ are to overcome. The suppliers tend to be more optimistic in implementing new technologies while the users have a more realistic and conservative view. The barriers themselves where recognized by both suppliers and users and all the experts gave an objective view of the sector and the problem.

All experts also agreed on the complex relations between variables and solutions. Experts did occasionally find it difficult to pinpoint the exact cause of certain problems. Due to the fact that the barriers are connected and reinforce each other this is a logical observation in hindsight. Since no contrasting opinions were observed, the number of interviews was sufficient to draw conclusions.

Regarding the group of experts, the managers at Oil and Gas companies and the suppliers provided valuable insights for the research. The actual users that operate the equipment however could have provided insights as well. The managers interviewed often did have field experience and acquired a managerial role afterwards so the insights of the users where represented as well.

5.4 Validity of research

Yin (2009) identified four different tests to establish the quality of empirical research. Construct validity, internal validity, external validity and reliability. These tests are briefly discussed to see whether they apply to this research.

Construct validity is “the degree to which a test measures what it claims, or purports, to be measuring” (Cronbach & Meehl, 1955). Construct validity regarding the barriers and their solutions is ensured by interviewing multiple experts. The researcher combines the definitions from seven experts with the descriptions found in the literature to find a final definition. Furthermore the roadmap that is setup by the researcher, based on findings from literature and suggestions from the experts, has been drafted and reviewed in cooperation with industry specialist. This method of reviewing reports and using multiple sources of evidence is suggested by Yin (2009) to guarantee construct validity.

Internal validity describes whether a causal relationship between two variables is properly demonstrated without interference of some other, unknown, variable. Internal validity is specifically important for the causal diagram. The internal validity for the basis of the diagram, the D&M model, is validated in the literature. The relations proposed by experts have not been thoroughly tested. The suggested relations are logical consequences identified by experts but have not been proved or tested to be correct. Thoroughly testing these could therefore be an interesting research direction for future research.

External validity “deals with the problem of knowing whether a study’s findings are generalizable beyond the immediate case study” (Yin, 2009). The generalizability has been discussed before and the barriers and solutions of IT/OT convergence recognized in this study only apply to the Oil and Gas Sector. Almost all barriers and solutions are specific for the implementation of IT/OT convergence and do not necessary apply to other technological implementation scenarios in the Oil and Gas Sector. The three categories of barriers, Cultural and Skills differences, Business Silos and Technological Differences could be barriers for other technological implementations but this is dependent on the specific case. The concept of IT/OT convergence and its advantages however do apply to other sectors as well; as has been proved by the literature research.

Reliability tests reveal whether the same results will be found when the research steps and its methods are repeated. Regarding the literature review the barrier categories and solutions proposed will be the same from all different literature and non-academic. Companies and people working at these companies are however evolving constantly so perhaps the barriers found in this study are not relevant anymore in ten years. Also, implementing IT/OT convergence could reveal more barriers than this research predicted. Since the experts interviewed for this study agreed on most topics the reliability of obtaining the same results with other experts is high.

5.5 Discussion on IT/OT Barriers

The interpretation of the barriers is done by triangulation and based on the results from literature study and the interviews with experts from the Oil and Gas Sector. The results and conclusions drawn from this interpretation are discussed below to see whether these findings are valid.

Barrier Categories

The barrier categories that are proposed could be intertwined as can be observed in the following example: “An OT engineer tries to explain the inner workings of a piece of OT equipment to an IT specialist since it is not compatible with his laptop and he needs help. The IT specialist does not understand the jargon the OT engineer uses and rejects the help request since it is not his speciality or his departments responsibility.” This small example contains elements from all three barrier categories; Business Silos due to the different responsibilities and departments, Cultural and Skills differences are exposed by the different jargon and speciality while the technological differences cause the incompatibility and the need for help in the first place. Therefore, one could argue that the barriers are intertwined. However, their impact is different: cultural and skills differences and historical technological advancement have contributed to the technological differences in the first place. While the implications caused by the business silos themselves keep the silos in place. The business silos are a self-reinforcing mechanism since the departments resist changing. This is caused by cultural and skills differences, technological differences but also not willing to change or share responsibilities and working methods. This resistance is not typical for the Oil and Gas Sector but can be observed across all industries. Therefore you cannot solve the barriers one at a time but you have to engage the whole problem at once since the barriers reinforce each other. Barriers will often fit in multiple categories as this research showed. The fact that all barrier categories are named as much as the others, suggests that all barriers contribute evenly to the misalignment of IT and OT, by how much exactly is an interesting future research direction.

Rejected Category

The ‘investment and implementation difficulties’ is not considered to be an IT/OT barrier since all categories would fit in this category. Solving the different barriers will always lead to investment and implementation difficulties; otherwise the specific barrier would have been solved already. Experts do mention this when they refer to general complications caused by barriers. When more specific problems or difficulties are described the barriers can always be categorized in a more specific category proposed in this study. The categories are therefore helpful in specifying where specific problem originate.

Conservative Sector

The fact that the Oil and Gas Sector is conservative is explained by the experts due to the impact the sector can have on the environment and society. Companies want to avoid environmental disasters like the Deepwater Horizon Oil Spill at all costs. The conservative attitude origins from safety requirements, risks, societal pressure and at the moment a low oil price. The companies are therefore afraid to experiment with new technologies since this requires investing. Furthermore, most managers in the sector have an engineering background and a way of managing, making decisions and other working methods that are thought to engineers in technical universities. This conservative sector is therefore an issue that originates from the technological differences and cultural and skills differences.

5.5.1 Relations between barriers

The barriers described in the previous section are related to each other, making them very difficult to overcome one-by-one for companies. The barriers in fact reinforce each other, forcing companies to tackle all barriers at once because one by one is futile. How the barriers are is shown in Figure 15 and below the figure the relations are described.

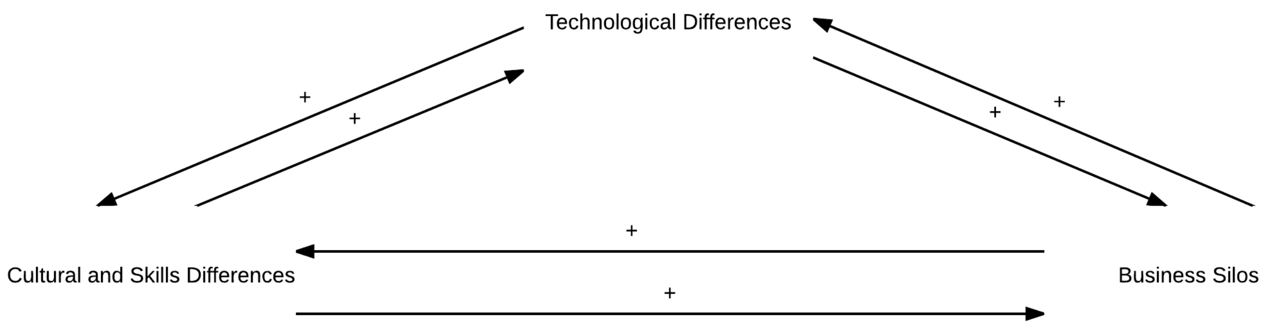

Figure 15: Reinforcing relations between IT/OT Barriers.

Cultural and Skills Differences has a positive impact on Business Silos because companies want to keep the same skilled people in one department. The cultural and educational background of personnel also causes people to stick together and form 'sub-departments'. Due to the fact that people with common cultural or educational background tend to stick together, Business Silos can be formed organically.

Cultural and Skills Differences increase the Technological differences due to the different methods used and ways of working. Examples show that different specialist teams (i.e. aerospace/mechanical engineering students) with the same assignment will provide different solutions for the assignment. Specialists tend to stick with the methods and tools they are good at.

Technological Differences reinforce Cultural and Skills Differences, simply because different types of equipment require different skills to operate and maintain. The two technologies, IT and OT, have diverged to such a level that they require completely different skills.

Technological Differences reinforce Business Silos because different, delimited departments are easier to manage for companies. One department handles IT problems and one department handles OT difficulties. This is line with how the Cultural and Skills Differences strengthen the Business Silos and these are closely related but certainly different. Companies tend to prefer to have specialized departments with specific tasks instead of one department that manages all IT and OT related problems.

Business Silos reinforce Cultural and Skills Differences since the departments have different responsibilities and tasks that require different skills. At the moment an OT engineer cannot function within an IT department. The tasks of the IT department have been delineated and his skills are of no use in this different environment.

Business Silos reinforce Technological Differences as a result of the usage of different tools, methods and proven concepts in the different departments. How Cultural and Skills Differences reinforce the Technological Differences is closely related but these are different in fact; an engineer could prefer a certain tool or method to tackle a problem, resulting from his educational or cultural background, but a department could promote, or force, the use of another tool or method.

Analysing the relations between the barriers it is conclude which barrier was the first to arise. At the moment however these barriers are in place and the fact that they reinforce each other, one way or another, complicates solving them. For new companies/projects or departments the solution is easier, since multidisciplinary teams tackle most of the problems caused by the barriers. Multidisciplinary teams consisting of IT and OT personnel eliminate Cultural and Skills differences by working together and utilizing each other's specialization. Being forced to work together also diminishes the cultural barriers. Technological differences are eradicated since a multidisciplinary team is not limited by its own skills but can employ the skills of both IT and OT specialists. In the current state, OT teams will try to solve all issues with their skills and only ask for help from the other department when there is absolutely no other solution.

"IT is bought by the OT department from the IT department. IT is not asked for advice and is not included in decision-making process, although this is a goal in the future. Decision makers are still in the OT organisation. IT department only provides the service."

The experts also pointed out the advantages of multidisciplinary teams, stating that both departments can benefit from the knowledge and skills spillover. Multidisciplinary teams also ensure a better integration of IT and OT when they work together from the start of a project. In the sector IT is often 'attached' to OT equipment, whereas an integrated solution from the start could have been a better solution.

5.6 Testing Scenarios with Causal Diagram

The causal diagram reveals how a company can achieve net benefits by influencing the three input variables of Information Systems that control compressors, System Quality, Information Quality and Service Quality. In this section the researcher will present different scenarios and how these can influence the net benefits for a company.

The scenarios that are proposed will first be described in detail and afterwards they will be used as input for the causal diagram. The scenarios may change the causal diagram itself by adding relations or influencing factors. The scenario's themselves represent options for companies in order to achieve 'net benefits' in the causal diagram, and therewith form real options for companies. The three scenarios that will be discussed are: Increasing Information Quality by converging IT and OT, Increasing System Quality and Increasing Service Quality.

The causal model that has been setup by interpreting the results from this study can be found in Figure 16 below. The bold arrows added to the model represent the links between the input variables System Quality and Service Quality to the factor Investments. These links are based on the assumption that all improvement for System Quality or Service Quality comes at a price (investment). The sector has been using these systems for decades so quick wins and costless improvements have been explored and therefore improving any Service or System Quality will require investments. The rest of the diagram and its relations are the same and will be used to test the different scenarios.

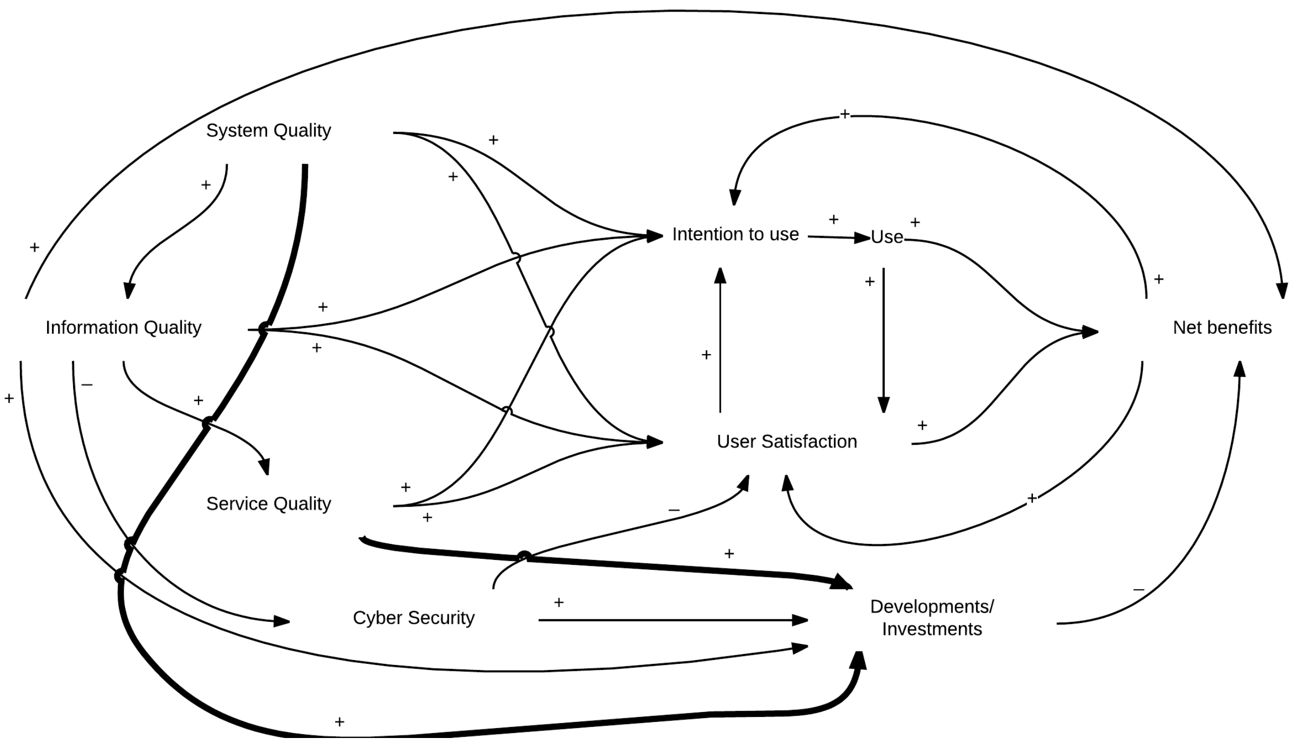

Figure 16: Causal Diagram with added links between investments and the input variables System Quality and Service Quality.

5.6.1 Scenario 1: Improving the Information Quality trough IT/OT Convergence

IT/OT Convergence has been thoroughly discussed in chapter 3 and will therefore require no further introduction here. Implementing IT/OT convergence mainly contributes to an increase in Information Quality. Factors that will increase are data-availability, timeliness of the information, conciseness and completeness of data and the usability of the information. The downside of converging IT and OT can however be a less reliable system. Experts mention that IT systems are instable and unreliable so in this scenario, the increase in Information Quality could result in a lower System Quality. This instability could be prevented by other measures but is worth taking into account since it is the only downside of IT/OT convergence. Plotting this scenario in the causal diagram results in Figure 17 below.

Table 17: Relations influenced by scenario

Added/removed or changed	Factor	Positive or negative relation on	Factor
Added	Information Quality	Negative	System Quality
Removed	System Quality	Positive	Investments
Removed	Service Quality	Positive	Investments
Changed	System Quality	Negative	Information Quality

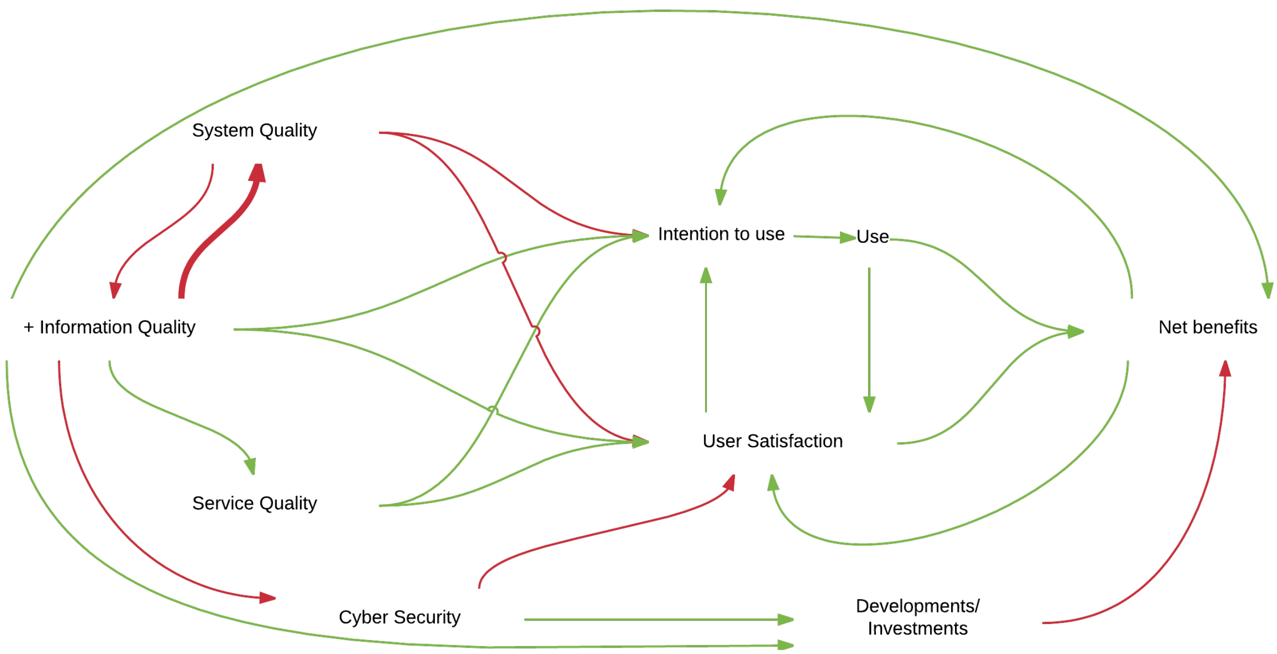

Figure 17: IT/OT Convergence scenario plotted in causal diagram.

From the diagram compared to the normal diagram a self-reinforcing mechanism can be observed that lowers the System Quality when the Information Quality is raised. The improvement of Information Quality, by making the data available and accessible to other users, makes the system and thus the System Quality instable. This instability can cause the Information Quality, which is based on the data provided by the system, to be unreliable as well. Next to this negative cycle, Information Quality has a positive effect on the Service Quality since Maintenance decisions and analysis is based on the Information Quality. Experts have confirmed these observations that are based on the diagram during the interviews. They see the increased risk of Cyber Security and instability of IT systems as great threats resulting from IT/OT convergence and integration. Furthermore, the experts say that predictive maintenance instead of reactive maintenance could present huge cost reductions for companies. The simulation and prediction models rely on the Information Quality so improving this factor will enhance these models, which results in an increased Service Quality.

5.6.2 Scenario 2: Increasing System Quality

Companies can also opt to improve the system quality. Increasing system quality is done by improving reliability, uptime, data accuracy, response time and flexibility of the information system. This can be done by using more expensive components (sensors and other measuring equipment), more rigor software, redundant safety and backup systems that all improve the system quality. Downside to this scenario is the investment that comes with small incremental improvements. Companies have been improving the system quality for decades now and the technology is practically saturated, which will be elaborated in chapter 5.6.4. Furthermore, as mentioned by the experts, the information systems that control the compressors are less valuable than the compressor itself, which is a critical piece of equipment. The control system is therefore often over-engineered with redundant safety systems in place. Since these systems are already optimized, small incremental improvements come with huge investments. The scenario of improving system quality is plotted in Figure 18.

Table 18: Relations influenced by scenario Increasing System Quality

Added/removed or changed	Factor	Positive or negative relation on	Factor
Removed	Information Quality	Negative	Cyber Security
Removed	Information Quality	Positive	Investments
Removed	Cyber Security	Positive	Investments
Removed	Cyber Security	Negative	User Satisfaction

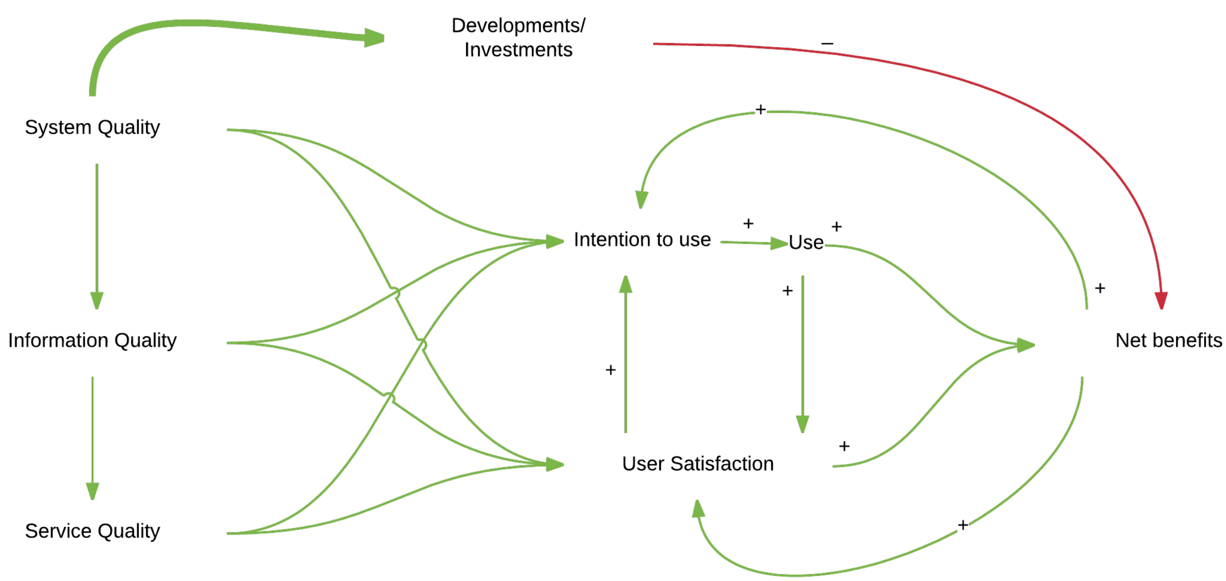

Figure 18: Scenario increased System Quality plotted in causal diagram.

Improving the System Quality results in a highly positive scenario. Improving the system with the use of better, more accurate sensors will result in an improved Information Quality as well. The improved Information Quality then has a positive impact on the Service Quality as in the previous scenario. The outcome is perfectly in line with reality where the System Quality is at the highest level possible; this is also a result of the impact the System Quality has, failures can have tremendous impacts. The positive impact on the rest of the system however also results in companies trying to increase the System Quality. Unfortunately, since the level of System Quality has practically reached its maximum, incrementally increasing the System Quality costs huge investments. This is due to the fact that the technology performance follows an S-Curve as can be seen in Figure 19 on the right; the investments increase exponentially when the technology becomes saturated. The performance/saturation of technology often follows S-Curves where it takes a big initial investment before a technology performs better than the technology it is replacing. When a technology matures, the investments are rewarded by big jumps in performance until it saturates and reaches its technological limit. Reaching the maximum performance again requires huge investments.

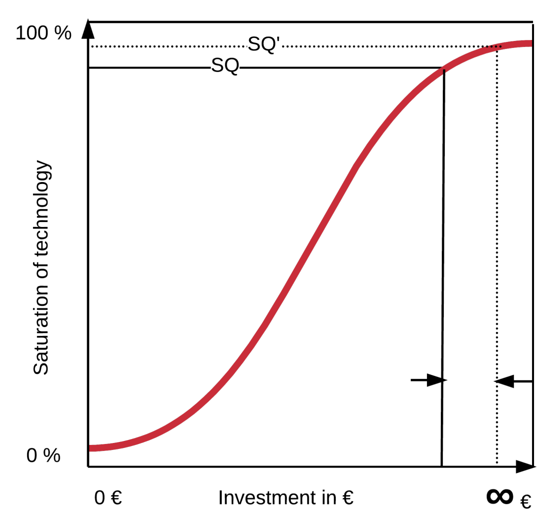

Figure 19: S-Curve technology level of System Quality versus investment.

5.6.3 Scenario 3: Increasing Service Quality

The last input variable that can be adjusted is the Service Quality. The Service Quality can be improved by educating the operator responsible for the control system of the compressor, or demanding better service from supplier of the control system. Factors that can be improved are responsiveness, reliability, technical competence and empathy of the service personnel. The Quality of the Service is often agreed on in a service contract between the supplier and user.

Table 19: Relations influenced by scenario Increasing Service Quality

Added or removed	Factor	Positive or negative relation on	Factor
Removed	Information Quality	Negative	Cyber Security
Removed	Information Quality	Positive	Investments
Removed	Cyber Security	Positive	Investments
Removed	Cyber Security	Negative	User Satisfaction
Removed	System Quality	Positive	Information Quality
Removed	Information Quality	Positive	Service Quality

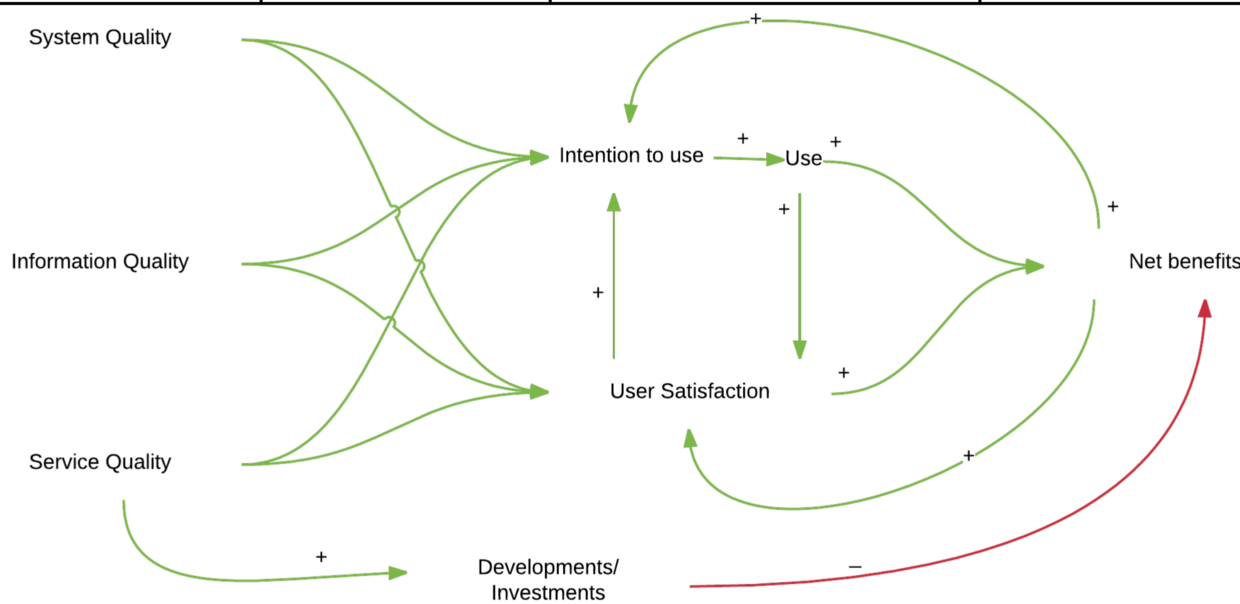

Figure 20: Scenario increased Service Quality plotted in causal diagram.

Service Quality enhances the system, the Intention to Use and User Satisfaction but does not support extra reinforcing mechanisms like the other input variables. Experts name the Service Quality as the least important input variable and the diagram supports this statement. This is partly due to the fact that Service Quality is seen as an out-dated measure, since it reacts to failures where IT/OT convergence should predict failures to prevent them beforehand. Experts point out that if the System Quality and Information Quality are perfect there is no need for Service Quality. The model is therefore quite representative with the real-life scenario where companies mainly focus on System Quality and Information Quality.

"When selecting systems, you first look at the quality of the system, then the information quality and finally you make arrangements on the service quality"

5.6.4 Conclusion Different Scenarios

The proposed scenarios discussed in the previous paragraphs represent extreme choices for companies. The companies have to decide between System-, Information- and Service Quality. Choosing for a combination of improvements is an option as well; or this scenario the reinforcing mechanisms are more difficult to predict. This is due to the fact that the investments required for marginal improvements of the input variables are different. The level of System Quality for instance is already near its limit so marginal gains are very expensive as can be seen in Figure 21. In this figure, the technology level is plotted against the investment required, this line follows an S-Curve. The current level of System Quality (SQ) is at such a high level that an improvement to SQ' requires an enormous investment. The current level of Information Quality (IQ) is much lower and therefore the same increase in technology saturation requires a smaller investment. Improving Information Quality by integrating and converging IT and OT therefore does seem like the best choice. The System Quality is the best choice when you look at the causal diagrams because of the reinforcing mechanisms and the only negative impact is the investment, but again this is so substantial that it is better to improve on other areas.

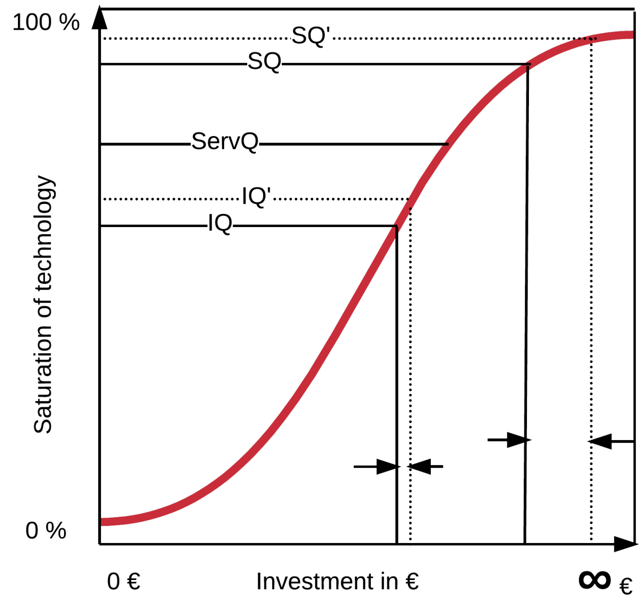

Figure 21: Advancement in technology as a function of investment.

All scenarios described have not been tested with the experts but do present outcomes that match the real situation. The System Quality is at such a high level because it has a positive impact on the rest of the diagram as well. The Information Quality is at a lower level because the possibilities of IT/OT convergence have been discovered recently and the costs of connecting devices, sensors and other equipment have gone down. Service Quality is a measure that is needed for unforeseen failures but when the System Quality and Information Quality are perfect, the Service Quality is a superfluous factor.

5.6.5 Original D&M Model compared to the Causal Diagram

The original D&M Model was not able to take all capture all factors and relations that are influenced by the implementation of IT/OT convergence. Transforming the model into the causal diagram contributed to the research by exposing reinforcing mechanisms and how decisions are made in companies. The original model proved a valuable basis but by expanding the model to the causal diagram, it can be used as a tool for decision-making. When companies want to precisely measure the impact of information systems, the original model is better suited, especially when the suggestions from this research are taken into account.

5.7 Combining Barriers and Causal Diagram

The Causal Diagram shows how IT/OT Convergence can lead to benefits for companies and the barriers in place prevent both technologies from converging. Combining these two aspects could provide a helpful tool for companies that need to make investment decisions regarding information systems. First the different relations that are added to the diagram are explained, afterwards the diagram is presented followed by some conclusions that can be drawn based on the diagram.

Technological Differences to System Quality and Information Quality, these relationships can either be positive or negative. For instance, the differences could be in the form of a very secure site with no outside connectivity, this has a positive impact on the reliability and security of the system but a negative impact on the Information Quality. The other way around, a connected system where all stakeholders are in control and have access to all data is often less reliable and thus a lower System Quality.

Cultural and Skills Differences to Intention to use, this relationship comes mainly from an educational background. For example, engineers who are taught to use specific software tools may have an aversion towards other software tools since they are not familiar with them. This relation could be positive as well.

Business Silos to Information Quality, this relation is negative due to the difficult exchange of information between departments. Different departments can have particular policies for handling data and this impedes the exchange of information between departments. Ownership and responsibility of sensitive data also contributes to this negative relation, owners tend not to share sensitive information because they are to blame when the information is leaked or corrupted.

Business Silos to Use, where the Cultural and Skills differences influence the intention to use, different business departments can block or stimulate the use of certain information systems. This comes from the need for harmonization and cost reduction, departments and often whole companies use the same email clients and other information systems. This relation can therefore be positive or negative.

IT/OT Barriers to Investments, this relation has been discussed thoroughly throughout this report and is based on the investment it costs to solve or eradicate the barriers. While certain aspects of the barriers can be solved by managerial and organizational interventions like setting up transformation and change teams, most measures will simply require investments whether it is in money or time to accomplish.

The result of these relations applied to the causal model can be found in Figure 22.

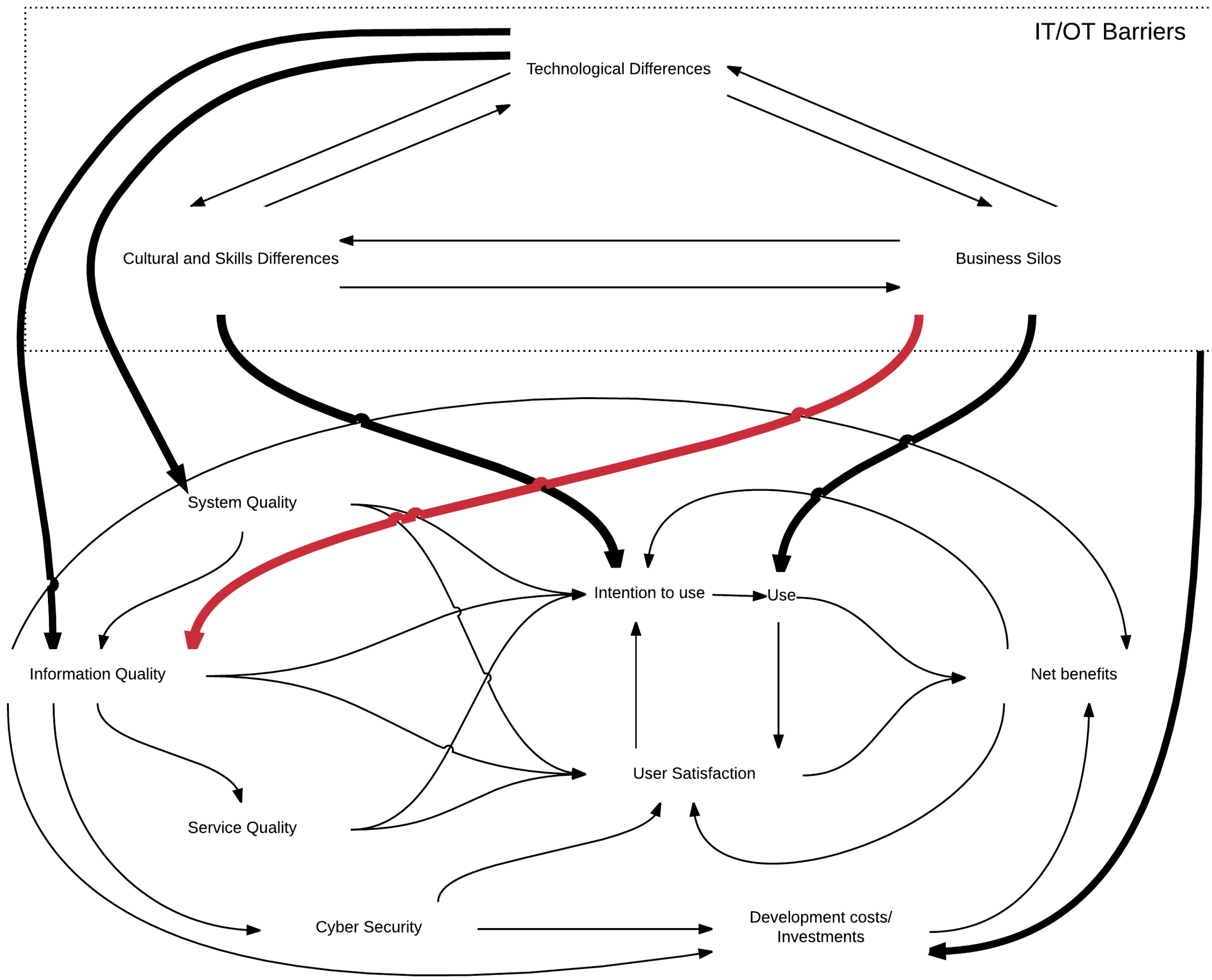

Figure 22: IT/OT Barriers implemented in Causal Diagram.

This diagram allows companies to discuss how to tackle implementation issues. It reveals all relations between the barriers, the properties of information systems and how these can be adjusted to achieve net benefits.

As said before, multidisciplinary teams are a perfect way to solve problems regarding IT/OT Convergence and Integration. The problem however of integrating IT and OT lies with current established, rigor and conservative companies in the Oil and Gas Sector.

5.8 Limitations Research

The different choices made by the researcher led to a number of limitations for the research. As discussed previously, the case selected was chosen well to study IT/OT convergence. The case, control systems of compressors, is however not representative for the whole Oil and Gas sector since IT/OT convergence has a greater impact on this piece of equipment than on others. This is however only a limitation from a business perspective since the impact (cost reduction) of IT/OT convergence is different for other equipment, the barriers, solutions and causal diagram will remain the same.

The researcher interviewed seven experts to gather data for the study. The number of interviewees itself is not a limitation since all these experts agreed on most topics. The variety of stakeholders interviewed is however a limitation, as mentioned before the actual users (operators, rotating equipment engineers) could have provided other insights for the research. All experts did have working experience in these positions but in future research all stakeholders should be represented.

Another limitation of the research is the funding of the relationships of the causal diagram. These relationships have been briefly described but not thoroughly tested. This could however lead to interesting future research but is a limitation of this study.

6 Conclusions

This research explored the concept of IT/OT convergence in the Oil and Gas sector and provides a valuable contribution by defining the categories of barriers and a set of solutions in the form of a roadmap for companies. The categories are a valuable contribution because even the experts had trouble pinpointing the origin of specific barriers and simply referred to them as ‘investment and implementation difficulties’. Furthermore, the Causal Diagram setup is a valuable tool that can be used to make decisions regarding investments in information systems. Concluding this report the sub-questions for this research are answered briefly while the elaborate answer can be found in previous chapters. Finally the main research question will be answered and recommendations for future research will be presented.

1. How do the current IT/OT systems perform, can IT/OT convergence add value to the Oil and Gas Sector?

The current systems perform according to requirements; the control systems are inexpensive compared to the hardware they control so they are often over-engineered to function 100% of the time. IT/OT convergence is however definitely an improvement. The concept of IT/OT convergence will, on the long-run, improve reliability, flexibility, uptime and overall performance due to the use of advanced analytics and predictive models.

2. What technological barriers prevent the integration and convergence of IT and OT?

With a different historical background, the exponential increase of Information Technology over the last 20 years and the different requirements for which IT and OT are designed causes a huge difference in characteristics between both technologies. The interviews proved that these Technological Differences together with two other ‘IT/OT barriers’ are the main contributors in preventing the worlds of IT and OT to converge. The other barriers are Business Silos and Cultural and Skills Differences. Business Silos represent the different departments that are in place in companies operating in the Oil and Gas Sector. Different goals, responsibilities, ownership, management and difficult communications between these departments all avert IT and OT into converging and integrating. Cultural and Skills Differences are complications caused by the different skills and cultural habits of people working in the IT and OT departments. These people often have different educational backgrounds, working habits, responsibilities and impact on their working environment. These differences also prevent the convergence and integration as described in chapter 4.4.

3. What social/organizational barriers prevent the integration and convergence of IT and OT?

Next to the technological barriers the experts confirmed the presence of social/organizational barriers as well. These barriers can be divided into two different categories; Business Silos, which refer to difficulties that are caused by the different IT and OT departments within organizations; The other category is Cultural and Skills differences which result from the different people working in IT and OT and educational background of these people. The complete description of these barriers can be found in chapter 4.4.3.

4. What are the requirements for successful integration and convergence of IT and OT in the future?

The integration and convergence of IT and OT is a complex matter due to the different barriers in place. The fact that convergence and integration cannot be implemented over night makes this more difficult. Companies in the sector often cannot afford any downtime so a convergence project must be carefully planned en executed.

Furthermore, the experts described the sector as ultra-conservative regarding new technologies so only thoroughly tested and proved concepts will be adopted. To aid these companies, a roadmap has been setup from the different solutions proposed by the experts, to guide companies into achieving IT/OT convergence. This can help companies in obtaining competitive advantage over their rivals and achieve IT/OT convergence and integration.

With the answers for the sub-questions, the main research question can be answered:

What blocks the convergence and integration of Information Technology and Operational Technology in the Oil and Gas sector and what are the requirements to integrate the technologies?

The convergence and integration of IT and OT is blocked by three categories of IT/OT barriers, Business Silos, Cultural and Skills Differences, and Technological Differences. The research proved that companies could benefit significantly from convergence and integration. However, the business case is quite difficult to rectify because the positive benefits take time to establish, while the investment is immediate. Providing solutions to deal with these barrier categories is not an option for Oil and Gas companies since they cannot afford any downtime. The technologies can therefore only converge in a well-planned implementation trajectory for which this research provides a roadmap. This roadmap has been developed in cooperation with industry consultants and solutions from the experts and consist of the following steps:

1. Check the maturity of the organization regarding IT/OT convergence, setup a well-planned project plan.
2. Convince the whole organization of the value of IT/OT convergence, from managers down to users, everybody must realize and believe in its value.
3. Find feasible (pilot) projects that quickly show tangible results as an example or best practice.
4. Integrate IT and OT departments and setup common governance model.
5. Stakeholder management and communication, to keep all involved parties informed of the progress, the value it creates and the opportunities it offers.

This roadmap will help companies in implementing IT/OT Convergence. The next paragraph will conclude this research by highlighting possible direction for future research.

6.1 Recommendations for Future Research

The research into IT/OT convergence is limited so there are a number of interesting directions for future research based on this research possible. Findings like the barriers, the causal diagram that has been setup, the roadmap and the suggested weighting of factors of the D&M model provide are of value as a basis for future research. Below a brief description and motivation which directions could be particularly interesting.

Investigate real IT/OT convergence implementation case

This research proved the benefits gained by converging IT and OT and provided a valuable roadmap for integration. The research however only investigated a fictive scenario instead of a real implementation trajectory. Researching a case from beginning to end where IT/OT convergence is actually being implemented is therefore an interesting research direction for future studies. The causal diagram, the D&M model with the suggested weights from this study could be used during this research.

Longitudinal study into the benefits of IT/OT convergence

Part of the benefits of IT/OT convergence take time before they can be noticed due to the required gathering of historic data that is used in advanced analytics and simulation tools. These simulations predict future states based on previous situations. Investigating the benefits over a longer period of time to see if the initial investment was worth it is a research option that can be explored. The causal diagram from this research and the suggested weighting of the factors proposed in this study could aid this research direction as well.

IT/OT convergence as an enabler for the Internet of Things

The Internet of Things (IoT) will be next disruptive technology that will change the world. While it is easy to connect and benefit from new equipment, this study proved that technological barriers prevent an immediate integration of older legacy equipment. Before companies can therefore jump on the IoT bandwagon they must achieve IT/OT convergence and integration. IT/OT convergence as an enabler for IoT is therefore an interesting topic to investigate.

Further investigation into the IT/OT barriers

The three categories of IT/OT barriers proposed simplify the complex misalignment between IT and OT. It is interesting to see and perhaps quantify which barriers contribute the most to the misalignment. The categories themselves could be divided into sub-categories to specifically find the origin of the barriers.

Investigate merging IT/OT departments

Merging both departments can present other benefits for organizations even if the final goal is not IT/OT convergence. The re-establishment of rules, procedures, business processes, responsibilities and physical merger of the departments is definitely a very complex problem that allows for future research.

Validate developed model

The factors/variables from the model developed with the D&M model as a basis are interesting to validate to see how strong these relationships are. The current relationships are based on the views from the experts but have not been thoroughly tested, the internal validity of this research could be improved if these relations are more thoroughly tested. Another research direction is to use the suggested weights in order to validate a real-life business case.

6.2 Personal Reflection on Research

In this reflection I would like to personally reflect on the research and the choices made during the research. I will review the research methods and execution, the literature and the results.

Regarding the research approach, for future projects I will ensure that all stakeholders involved in the research (the University, the company where I started my research: Accenture and myself) are aligned. After starting my research at Accenture I put to much focus on the results desired by Accenture. This complicated the start of the research since Accenture had more interest in the business aspects of the study instead of the academic contribution. I should have aligned all interests from the start and this would have aided me during the rest of my research.

Looking for candidates to interview for my research I learned that it was quite difficult to find the right person to make an appointment. When the interviews were finally planned I did not take time to adjust the interview setup or interpreted and reflect on the results. In retrospect I should have used the first interviews as preliminary research and adjusted the questions asked. These preliminary interviews would have aided the interpretation of the results as well. Certain results were not what I expected and I had to be creative in order to use these results instead of wasting them. In my opinion the number of interviews was correct since all experts agreed on most topics. More interviews could have provided more practical solutions and examples on how to implement IT/OT convergence but I believe most topics were discussed since all experts had quite some experience in the field.

The literature review I conducted was of great aid for the research; it gave me a descent understanding of the industry and the problem with the misalignment between IT and OT. The understanding of the industry was particularly important since the experts have their way of talking and abbreviations. The general know-how of the industry allowed me to discuss matters with them. The barriers found in the specialist journals and by research institutes were accurate descriptions of the problems the experts described. The categorization actually aided the experts in overseeing 'the whole problem' and all of them insisted that I would share my results with them personally. The solutions provided by literature however were often managerial 'top-down' solutions without taking into consideration the implementation difficulties. I think the roadmap I developed will be of much more aid for companies trying to integrate and converge IT and OT. What could have contributed to the research regarding literature was looking for barriers from other similar industries. I looked at industries where IT/OT convergence had been applied to predict the impact on the Oil and Gas Sector but I forgot to look at any barriers these industries encountered. Interviewing an IT or OT manager at a company from another sector could have provided me with interesting insights. Other industries might have faced similar barriers and their solutions could have been valuable as well.

Using the D&M model helped me see the mechanism of how an information system can impact organizations. The model is self-reinforcing when the input variables (System-, information- and service-quality) are improved; However, looking at a trade-off between input variables and quantifying the inputs could make the results more tangible. In other words, if I increase the 'Information Quality" by 10%, it will decrease the "System Quality" by 5% but the overall impact on the organization will be 12%.

The original D&M model was not able to capture the impact of a future scenario of integrated and converged IT/OT systems and the implications of implementation. The experts all mentioned that IT/OT convergence obviously has a positive impact on organizations; the problem is how to achieve it. Transforming the D&M model into a causal diagram and including different factors helped me see the trade-off that companies have to make. Using the model to test different scenarios helped me understand the mechanisms that led to the outcome. Experts often named certain outcomes as logical consequences but the causal diagram revealed what happened exactly when the input variables are adjusted.

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Appendix A Gas Processes

To get a feel for the different processes and equipment at Gas production sites, a typical production site has been visualized in Figure 23: Typical Gas production facility. Below the figure the different processes and equipment are explained.

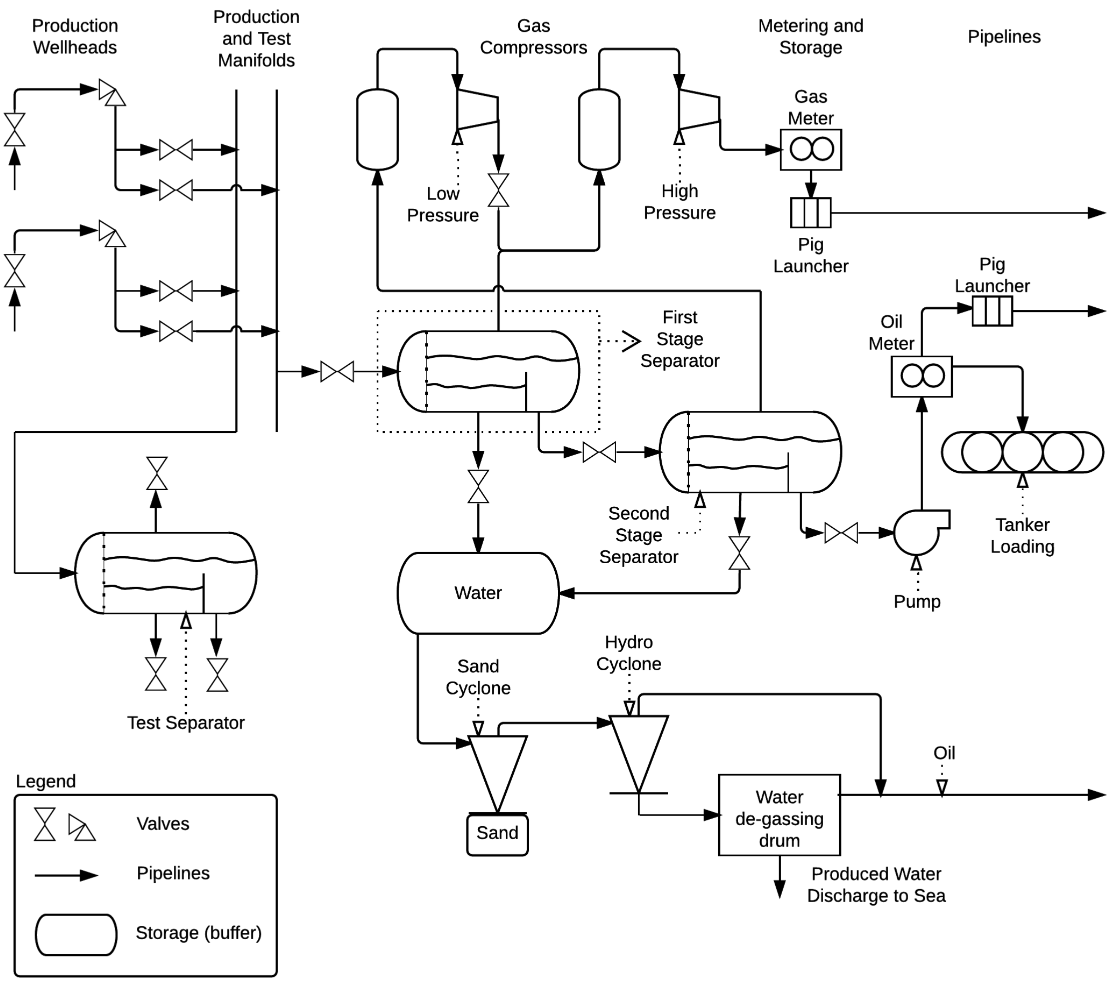

Figure 23: Typical Gas production facility.

Wellheads: Wellheads sit on top of the pipe leading to the reservoir. The wellheads can also be an injection well, where gas or water is injected into the reservoir to maintain well pressure and an efficient production rate. The wellhead structure, due to its shape is often named a Christmas tree and must allow for a number of operations relating to the production and well work-over. Well work-over refers to the process of maintenance as well as other techniques to improve the production capacity.

Manifolds: From the wellheads the stream goes to two different manifolds, a testing and a production manifold. The testing manifold is mixture of the stream at the start of the operation of a well and periodically to check the mixture and adjust the controlling set-points.

Separators: The streams from the reservoir can contain pure gas or oil but a mixture of both is more common. In the separator the core substances are separated into a water, an oil and a gas stream. This can be done in different stages in a horizontal separator. The stream is fed into the separator where the gas will bubble out, the oil will settle in the middle and the water below in roughly five minutes.

Metering, storage and export: Offshore facilities often rely on tankers to transport oil and gas to shore. Since these facilities have limited storage capacity, they have to know exactly how much oil and gas they have in storage. Some governments also tax the amount of oil produces so measuring the flow levels etc. is very important for production sites.

Utility systems: The different utility systems support the main processes on site but do not handle the hydrocarbon stream itself. These systems include safety measures for residents, power and water supply for remote installations and infrastructure.

Compression: Gas from pure natural gas wells may have enough pressure to feed directly into the pipeline. Gas from separators has lost so much pressure that is must be recompressed before it can be fed into the pipeline. The compression is driven by turbine compressors that use a small portion of natural gas or electricity to function. The electronic option does however require a reliable source of electricity to be nearby. The gas compression include a section of scrubbers to remove liquid droplets and heat exchangers to get the gas on the ideal temperature.

Meters and storage: Before entering the pipeline, the final product must be checked for consistency, volume, composition, etc. This happens at a metering station that includes an array of sensors, meters and analysers that analyse the flow. The metering is very important since all stakeholders rely on the output of a plant, the invoices are calculated on this number and the ownership and responsibility is transferred to a different partner/customer.

Pipelines and Pig launcher: The pipelines transport the end-products and can measure anywhere from 15 to 120 cm in diameter. To assure safe and efficient operation, intelligent robotic devices named ‘pigs’ can be launched to inspect the pipes for corrosion and defects. Pigs can detect pipe thickness, roundness, signs of corrosion, miniature leaks and any other defect that can obstruct the safety of flow.

At the end of the process, the various streams are transported through pipeline or tanker to the next destination. The water streams, when cleaned, are transported back to the ocean.

Appendix B Compressor Types in Oil and Gas Sector

In order to get acquainted with the compressors used in the Oil and Gas Sector, the different compressors used are listed below.

Reciprocating compressors

Reciprocating compressors use a piston and cylinder design and use around 30 MW at 500 – 1800 rpm to pressurize up to 5MPA (50 bar). The capacity is lower and the compressors are used for high-pressure reservoir injection.

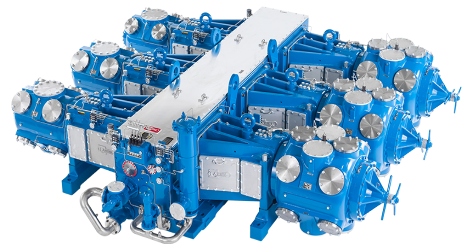

Figure 24: Reciprocating Compressor, Copyright Ariel Corp.

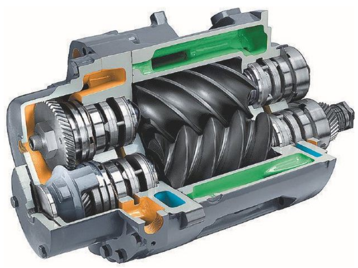

Figure 25: Screw Compressor

Screw Compressors

Manufactured to use several MW at synchronous speed, 3000 – 3600 rpm and pressures up to 2.5MPA (25 bar). Two counter-rotating screws with matching profiles provide positive displacement and a wide operating range. Typical use is natural gas gathering.

Axial blade and fin type compressors

Axial blade and fin type compressors ar designed for high volumes with low pressure differential (discharge pressure 3 – 5 times inlet pressure). Speeds of 5000 to 9000 rpm and inlet flows up to 900.000 m^3/hour.

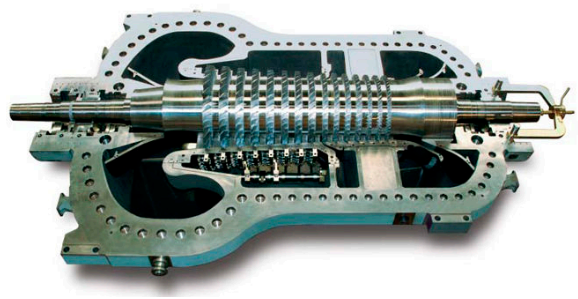

Figure 26: Axial blade Compressor, © General Electrics.

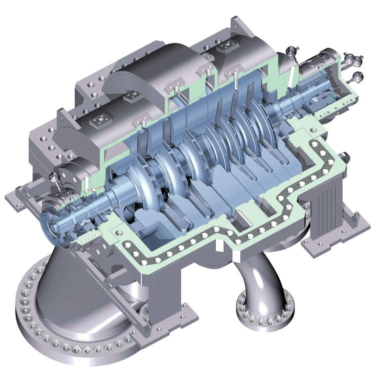

Figure 27: Centrifugal Compressor, © Siemens.

Centrifugal compressors

For the larger oil and gas installations, centrifugal compressors are used. These use up to 80 MW with speeds between 6000 – 20000 rpm to discharge of up to 50 bar. Centrifugal compressors can handle inlet volumes of up to 500.000 m^3/hour and a pressure differential of op to 10.

The different compressors all serve different goals and are suitable for different conditions. Due to the high power, speed, temperature and volumes however, all are very maintenance sensitive and expensive to fabricate.

Appendix C Interview script

Practical Information: Explanation of goal, structure (semi-structured) and length (1,5 hours) of the interview. Explain why the interview will be recorded and notify interviewer that interview becomes 'data' when he/she agrees with the summary of the interview. Check if everything is clear, confirm name, date, time, function and subject.

Part 1: Definition IT/OT and IT/OT Convergence

1. Can you give a definition of IT and OT?
2. Can you describe the difference between IT and OT?
3. What is your definition of the convergence of IT and OT?

Explain assumed definition of IT, OT and their convergence.

Part 2: Case study IT/OT Systems that control Compressors

Description of the compression process and the production plant in general.

4. Can you confirm the general purpose/outcome of the process?
5. Which steps are controlled by IT/OT systems?
6. What kind of data is collected? (Do you have an overview?)
7. Can the IT/OT systems that control the compressor be improved? How?
8. Why is the performance of the current systems at the level that it is at?

Explanation of D&M Model for IS Success

Explanation of "Information Quality"

9. Why is the quality of the information important for the process?
10. Can you give an example of a situation when information quality influenced the process?
11. Does a lower information quality result in an incident (failure, process stop, manual intervention)?
12. What possibilities would an increase in information quality present? (data availability!)
13. How often does this happen?
14. Can you estimate the costs resulting from inferior information quality?
15. How do you rate the information quality?

Explanation of "System Quality"

16. How important is the system quality?
17. Does the system require training/certificates to operate (how elaborate)?
18. Is the system intuitive to control?
19. How flexible is the system in responding to unforeseen inputs?
20. Can the system operate without human interference?
21. How does the system respond to (human) interferences?
22. Is it possible to control the system with man-power?
23. How reliable is the system? How many breakdowns do you have per year, which are not caused by a lack of information quality?
24. How can the system be improved?
25. How can the process be improved?
26. Which (sub)variable is most important for system quality?

Explanation “Service Quality”

27. Who is responsible for the service of the system, are there different levels of responsibility?
28. How quick does the support department respond to irregularities?
29. Is the support department technically capable of solving all issues?
30. How emphatic is the support department when dealing with issues?
31. Are regular checks by the support department needed?

Review of D&M Model for IS Success

32. Which variable between Information Quality, System Quality and Service Quality is the most important in the Upstream Oil and Gas Sector? (Why?)
33. How will the System Quality change when IT/OT Convergence is achieved?
34. How will the Information Quality change when IT/OT Convergence is achieved?
35. How will the Service Quality change when IT/OT Convergence is achieved?

Part 3: IT/OT Convergence in general

Explain goal to find barriers, solution for these barriers and present a roadmap to achieve IT/OT Convergence. Sketch ideal scenario of successful integration/convergence of IT/OT. Use example of VW, online configurator is send directly to the factory (capital intensive, customer driven).

1. What core problem does the convergence/integration of IT/OT solve?
2. What are the (dis)advantages of IT/OT Convergence in your sector?
3. What complications may arise with (step by step) implementation?
4. Can these complications be eliminated?
5. What are further ‘barriers’ for implementation?
6. Are there further organizational requirements for the convergence of IT/OT?
7. Are there other requirements (knowledge? Skill?) for the convergence?

Explain barriers identified in literature leading to misalignment of IT and OT. Do you recognize these factors in your company?

8. Which factors have the biggest influence on the misalignment?
9. Could you name other ‘barriers’ that lead to the misalignment?
10. What (sub)processes are best suited for step by step implementation?
11. How advanced and convergent is your IT/OT compared to other companies?
12. What could be the value of integrated/convergent IT/OT? (for you, organization)
13. Are you working on IT/OT convergence projects?
14. Could you think of any other business models in the sector which can be enable by convergence?
15. Looking back at the D&M Model for IS Success, which variable will be the most important in the future?

Explain goal of roadmap

16. How would you solve this misalignment and implement IT/OT convergence (give examples!)?
17. What steps need to be taken to achieve IT/OT convergence in brownfield/greenfield projects?
18. How do you need to monitor this implementation?
19. How can you convince management the importance of convergence?

Concluding questions

1. Personal feeling about IT/OT convergence/integration?
2. Was everything clear?
3. Do you have any further remarks?

Appendix D Filtered and Categorized Barriers from Interviews

This appendix contains all the raw barriers filtered from the interviews and categorized according to the proposed categories in chapter 4.4.

Blocker #101: IT is bought by OT department from the IT department. IT is not asked for advice and is not included in decision making process although this is a goal in the future. Decision makers are still in the OT organisation. IT department provides the service.
Categor(y)(ies): Business Silos
Motivation: The different responsibilities is clearly a problem caused by the business silos that are in place. It could also be caused by cultural differences but in this case that is not specifically mentioned.

Blocker #102: OT departments distrust IT products and services. OT departments want to avoid 'IT problems' within their core business. This is being overcome by setting up local IT departments to support OT on site instead of through service centres in India. This to support each other, OT cannot function without IT and vice versa. That is correct at the moment. IT is mostly proving itself trustworthy towards the OT department.
Categor(y)(ies): Cultural Differences and Business Silos
Motivation: The distrust between the domains is caused by the cultural differences. The local or centrally organized departments is a sign of business silos, where IT is preferably organized centrally while OT is organized locally.

Blocker #103: A major difficulty is the huge variance in different systems.
Categor(y)(ies): Technological Differences
Motivation: This relates to the different systems used by IT and OT personnel and how they are incompatible with each other.

Blocker #104: There is not enough knowledge of IT within the OT environment. OT cannot capture IT's knowledge to use for their own best. Systems can be standardized, simplified with this knowledge, become cheaper, supplied quicker, safer, risks reduced, efficiency. OT looks pure at functionality, if I press this button, which valve opens? How this happens does not matter for OT.
Categor(y)(ies): Technological Differences, Cultural and Skills Differences and Business Silos.
Motivation: Standardization is something that is more common in the IT world than the OT world and together with the functionality aspect is a clear example of technological differences. Capturing and exchanging knowledge is something that is blocked by both the cultural differences and the business silos.

Blocker #105: Implementation is difficult, standardization as well due to different and multiple stakeholders (suppliers and users). Implementation is time-intensive and could be costly before all current systems are ready/compatible. Change will be slow. Also because of the different 'islands' within the organization. This is a target for asset managers, but they lack the IT knowledge named before. Offshore we want to go to unmanned sites, because it is difficult and expensive to supply. Certification of parts is difficult and costly as well. IT needs to enable this so this is where we are currently supporting the OT departments. Groningen is an asset which is completely monitored and controlled remotely and this is where offshore is going as well.
Categor(y)(ies): Technological Differences, Cultural and Skills differences, Business Silos, Investment and Implementation difficulties.
Motivation: The different islands in the organization refer to the business silos, while the lack of knowledge is an aspect of cultural and skills differences. The standardization and need for unmanned sites is a technological difference. Another barrier that is named is the implementation difficulties, this is therefore added as a barrier category: Investment and Implementation difficulties.

Blocker #106: Safety, costs, standardization, installed base and compatibility. Suppliers could provide converged systems but if the whole site needs to be replaced, this has no use. This decision is then cost-driven. Life-time of the rest of the plant has influence as well. We pitch our IT solution to the OT

department, who in their turn pitch their solution to the asset manager who makes the final decision.
Categor(y)(ies): Technological differences, Business Silos.
Motivation: The compatibility, safety and standardizations are all technological differences. The different responsibilities and departments refer to the business silos.

Blocker #201: Very complex challenge, in OT availability is key, security is important. Ideally you have no interference with the ‘outside world’. This drives completely against the goal of IT, who wants all data real-time available for everyone involved. This is one of the main differentiations between these worlds. This is something we encounter in practise on a daily basis. The worlds are completely different, the service levels are different, the people are different, the methods and ways of working are different. In the IT environment you can reboot something for instance, if the mail-server does not work, you just reset it, this is impossible in the OT environment. In the oil and gas world you want as few people on site as possible, in Groningen for instance, we have 2 desk-operators controlling over 300 wells. The environment is hazardous, the substances we work with, the equipment, basically humans on site is a hazard for us. Furthermore humans are not very cost-effective, this is why IT is getting more and more important. The more remote we get, the more information we require to manage these sites.
Categor(y)(ies): Technological differences, Cultural and Skills differences.
Motivation: The availability, security and interference aspect described are technological differences. The stated ‘different worlds’ and people clearly refer to the cultural and skills differences between IT and OT personnel.

Blocker #202: Yes the organization requires the uptime to be 100%, so you basically cannot turn any systems off. All systems in the office domain make use of the same data, all maintenance models, business models etc. are fed by one single system so a lot of people rely on this system.
Categor(y)(ies): Technological differences.
Motivation: The requirement for 100% uptime is a clear example of technological differences.

Blocker #301: IT is everything handled by the IT department. This is a different organisation than the process control organisation. OT is operational technology (Cisco), we name this process control. These are the primary customers of Honeywell process solutions. We do not deal with IT that much, recently with the employment of Wi-Fi, certain business intelligence systems on our process control network, this is the first time IT was ‘at the table’ during discussions. We notice at a lot of customers that these departments are strictly separated. This results in an unclear balance and clarity on topics of governance and ownership The departments are often out of sync as well. OT keeps IT out of the room in the process control area, while IT claims Wi-Fi is their speciality/business.
Categor(y)(ies): Business silos, cultural and skills differences.
Motivation: The strict separation of departments is a key aspect of business silos. OT keeping IT out of the room an IT claiming Wi-Fi is ‘their’ speciality is a cultural and skills aspect.

Blocker #302: We believe that in the future IT and OT must collaborate because all network systems will become more and more complex. OT will have to use IT skills for remote collaboration, control and monitoring. It is inevitable that these worlds will converge. Traditionally the OT department wants to keep everything local and certainly not sharing information globally due to safety risks, cyber security. IT in general prefers a scenario with 20 plants and only one control room that monitors and controls all plants real-time. With operational technology they want to keep that local and preferably locked out from the outside world through the Internet or whatever. OT prefers an island from a security perspective. This is not realistic anymore these days, most OT people realize this and you simply need IT personnel to achieve this safely, secure and in good order.
Categor(y)(ies): Cultural and skills differences, technological differences.
Motivation: The skills differences and how these should convergence is described thoroughly. The technological differences are made clear by the safety and cyber security risks.

Blocker #303: OT is in general controlled by old-school die-hard engineers who have been performing their tasks perfectly for years. These men speak another language than the young and bright IT people. OT prefer the least IT interference as possible.
Categor(y)(ies): Cultural and skills differences.

Motivation: The educational background and the 'different language' they speak refers to cultural and skill differences.

Blocker #304: The technological differences are very clear. Example when an OT department wanted to implement something but did not receive the funding, the IT department took over and they did receive the budget needed (also governance and ownership). The worlds don't completely work separately but collaboration could certainly improve. The department also have different competencies (cultural differences), if you come to my department you might take over some work which makes me irrelevant, they want to protect their own island. OT has to deal with requirements, compliancy and environmental restrictions. IT does not have to worry about this. If there is an OT failure it hits the newspapers, a server going down and having to be reset isn't even noticed by the own personal. The impact both organisations have is different. When designing new projects they both have to be involved and work together, this way you will lay a good foundation. This to ensure to maximize efficiency and cost control because IT is just better at their speciality and the OT people at theirs. This is also relevant because you prevent the departments from doing double work.

Categor(y)(ies): Technological differences, business silos, cultural and skills differences.

Motivation: The technological differences are literally named and funded with examples, the business silos are clearly described by the departments and their responsibility while the cultural and skills differences are explained by the different competencies.

Blocker #305: The difference in vision of the heads of departments. The security aspect, the fact that IT wants to globalize everything while OT wants to keep everything local. The impact of the worlds is different and this makes it complex. Look at an OT failure at the Deep Water Horizon. IT, although the uptime and requirements begin to come closer to OT standards, will never have that kind of impact. This is a hurdle to overcome. They completely speak another language which is difficult to overcome as well.

Categor(y)(ies): Business silos, technological differences, cultural and skills differences.

Motivation: The vision of the one in charge of the departments is an example of business silos. The security aspect refers to technological differences while the language is a cultural and skills difference.

Blocker #401: The sector however is very conservative and does not want to invest that much in these solutions.

Categor(y)(ies): Cultural and skills differences.

Motivation: This refers to the OT people being very conservative, only trusting proven concepts, a cultural aspect.

Blocker #402: Investment costs. Quality and safety are the most important factors so costs do not matter. Concerning efficiency, so looking at return on investment, this part is often more difficult to manage. Legacy equipment is also difficult. A huge problem is also the different suppliers and switching costs. Operators must be trained in new equipment etc. Overcoming installed base. Privacy is also a difficult topic. Cybersecurity and cybercrime is something the sector is afraid of. Responsibility, ownership and governance, operators do not want to and cannot be responsible for too much assets and equipment.

Categor(y)(ies): Cultural and skills differences, technological differences, business silos and investment and implementation costs.

Motivation: The training of operators is a skills difference, cyber-security and –crime is a technological difference, the business silos are represented by the ownership and governance and the investment costs are literally named.

Blocker #403: Money, investments, conservative sector, fear for change, the fact that people are getting older in the sector (cultural and skills), expertise flows away easier.

Categor(y)(ies): Investment and implementation difficulties, cultural and skills differences.

Motivation: Investment is stated, the conservative sector and fear for change is a cultural aspect.

Blocker #404: There is a strict separation between departments and their goals are often different. Solutions however must come from above (management), this will not be reached by the departments themselves because of their different interests. For greenfield projects this is easier. Brownfield projects

are near impossible. Maintenance department want this, asset manager wants lower costs.
Categor(y)(ies): Business silos, technological differences.
Motivation: The goals of different managers is complicated by the business silos, the difficulties with brownfield (old legacy projects) is the compatibility which is a technological difference.

Blocker #501: Convergence is letting the system talk to each other, making sure you gather the right data from both systems in order to make better decisions. This is different from the silos currently in place. IT and OT are part of different department, they are managed differently.
Categor(y)(ies): Business silos.
Motivation: The different management structures, departments and exact silos are named.

Blocker #502: Cybersecurity is a big risk and this will increase in the future. The OT world is currently physically locked-out of the IT world. When the systems are fully integrated data protection and data security will be very important and need to be something to focus on.
Categor(y)(ies): Technological differences
Motivation: The cyber-security aspect is a technological difference between the IT and OT world.

Blocker #503: Depends on the company, how mature a company is concerning their IT and OT management. One step for companies is to figure out where their focus needs to be, what are the most critical systems and processes and how are these currently managed and controlled (mapping current IT/OT structure). The risks of current systems must me mapped, which data is needed for all critical steps. Next the integration itself is difficult, to be able to let the machines and systems talk to each other. This again is a hurdle for lots of companies in the sector. A lot of companies are not ready yet for this step. This step is difficult because it incorporates not only the integration of software and hardware but also departments within organisations. The goals and mission of the different departments must be aligned. Since the systems must integrate and cooperate, the departments and silos within companies must do this as well.
Categor(y)(ies): Technological differences, business silos, investment and implementation difficulties.
Motivation: The risks and compatibility issues are technological differences, the goals of different departments refer to business silos, lastly the integration problem can be categorized in implementation difficulties.

Blocker #504: The organization must be ready, must believe in the convergence and integration and must support it. Goals must be formulated and communicated, otherwise the convergence will not work because everybody in the organization is involved in IT/OT convergence/integration. The transition is similar to companies transferring from reactive to condition based monitoring. The integration cannot be done by one person only, all involved departments and people must support it. The mind-set of an organisation must change.
Categor(y)(ies): Investment and implementation difficulties, business silos.
Motivation: These are clearly steps that need to be addressed during implementation. Involving all departments is breaking through original barriers caused by business silos.

Blocker #505: OT are usually more conservative compared to IT people. IT people can be obsessed with protecting and securing systems which may lead to a system which is very difficult to use or manage. OT on the other hand focuses on their field which may interfere with the interests of the IT people. Maintenance people have traditionally learned to monitor systems without being able to read all data which is available. They must learn how to use this, change from their traditional methods and rely on other technologies. In the past they could listen to the machine, check some valves and perform minor adjustments, now they have to use all sorts of high-tech sensors and equipment.
Categor(y)(ies): Cultural and skills differences.
Motivation: The difference between IT and OT people is a cultural aspect.

Blocker #601: Within our company we have separate departments who are responsible for IT and OT. IT and OT departments are separate silos in the company with their own people, own methods and ways of working and can be seen as different worlds. Both IT and OT departments could learn a lot from each other but unfortunately this rarely happens in practise. OT is more traditional, holds on to proven concepts and is less quick and eager to adopt new technologies while IT is the opposite. IT architecture

is very advanced these days. OT architecture is in general built to last, very robust and reliable. OT is built on commonly accepted blocks (platforms) using different standards, IT is more flexible and purpose built. User acceptance is difficult, resistance to change. People from both worlds speak a different language.
Categor(y)(ies): Business silos, cultural and skills differences, technological difference.
Motivation: The different departments refer to business silos, the cultural and skills differences are represented by the different worlds, languages and skills while the difference in architecture and standards is a component of technological differences.

Blocker #602: Having the historian in the OT network is difficult if people from the office domain want to access data. We are setting up a two-way authorization where the specific person and his laptop could get access from the central monitoring engineers. Data from the historian is accessible for the office domain but this needs an approval and takes a while before people can run their analysis. Ideally this would be available real-time, by placing the historians in the office space. A problem that comes with that case is the fact that the IT department is then responsible for the historian.
Categor(y)(ies): Technological differences, business silos.
Motivation: The two-way authorization is a difference that follows from the technological differences between IT and OT. The office and production domain is an example of business silos.

Blocker #603: Both worlds can learn a lot from each other. At the moment both worlds are separate islands and both domains can learn so much from each other that both will get to a higher level. One domain is more advanced in one area, while the other has expertise in another. The silos are definitely a problem in this sector. Cultural differences should therefore be overcome since this blocks the transfer of knowledge and expertise. From a technical perspective, there is a need to integrate and converge the data from the different domains in order to perform analysis. Ideally all available data should be available on 1 spot in order to improve decision making. This to drive efficiency, cost and risk reduction. I guess in 10 years engineers will walk around the plant with a smart glass, look at a machine and a manual pops up together with all data being measured but also data on when the machine was last checked. Bringing all data together will improve almost all decision making. It can improve quality as well and effectiveness. Maintenance induced failures could be prevented.
Categor(y)(ies): Cultural and skills differences, business silos.
Motivation: Blocking the transfer of skills and knowledge is due to cultural differences and the business silos.

Blocker #604: IT likes to protect their domain and let no one interfere with their tools, if OT adopts this we cannot switch and adjust fast enough to unforeseen inputs. I don’t think security is a risk or disadvantage because this is one area where both worlds are working together and sharing best practises.
Categor(y)(ies): Technological differences, business silos.
Motivation: The switching difficulties has to do with compatibility and technological differences while the protection of domains is an example of business silos.

Blocker #605: Political games within and governance and ownership, who is responsible, who will finance the project. The return on investment is quite long and may never arrive when the project is not managed well. The business case is therefore quite difficult. Making everything smart and gathering data is the first step, then you must do analysis and only in the end you can do something with the information you find. Companies really need to believe in the convergence and integration, otherwise it will not work. Pilot projects can definitely lead the way for other, bigger projects. Success must also be communicated clearly to convince people. There are no technical barriers anymore, it is scalable as well. The physical machines may be old, but the control systems are in a lot of cases state of the art systems.
Categor(y)(ies): Business silos, investment and implementation difficulties.
Motivation: The business silos are described by the governance and ownership example while the pilot projects propose a solution for investment and implementation difficulties.

Blocker #606: There is definitely a gap between the decision makers and the shop floor.
Categor(y)(ies): Business silos.
Motivation: The decision makers on top of business silos have different goals that the people on the shop floor which causes problems.

Blocker #701: Cyber threats, the availability mismatch of information between OT and IT systems. Literally 90% of the systems out there are not the latest version. It will take decades to remove those legacy systems and as a result they will always be exposed to new sorts of cyber threats. Two years ago I updated an MS-DOS systems, these are systems that are 30-40 years old. So for the next 30 to 40 years, unless we start doing something different, we will still be vulnerable to attacks. So what makes vendors today believe that their current systems are resilient enough to last for 30 to 40 years? They have no prove whatsoever. It also requires a different skill, the way you connect and or manage OT systems and the engineering methodologies there are not the actual methodologies used by IT. IT rarely takes into account the probability of failure, or the probability of any events, since they can usually just shut down and reboot the system. For OT this is impossible, the risks and dangers are to big.
Categor(y)(ies): Technological differences, cultural and skills differences, investment and implementation difficulties.
Motivation: The mismatch between the systems is due to technological differences, the skills difference is stated literally and the implementation difficulties are explained by the decades it will take to replace legacy systems.

Blocker #702: Governance is complex, it is a multi-discipline approach. In certain discipline approach, sometimes on a single computer. As a result, you are introducing new disciplines to the computer, so IT in engineering and engineering in IT. As a result, it confuses who should be making decisions.
Categor(y)(ies): Business silos, cultural and skills differences.
Motivation: The governance issue is an example of business silos, engineering in IT and IT in engineering refers to a difference in skills.

Blocker #703: A key issue like security, needs to be build from within so an IT individual must be on the team from the start, that way the security of the whole site is more rigor and safe. A problem with this is that you cannot create individuals that know both worlds. You have to have experience in both fields in order to work. By just having the educational background will not allow you to make decisions in this space.
Categor(y)(ies): Cultural and skills differences, business silos.
Motivation: The experience needed from both fields is a gap in what is required, the fact that the departments keep their people separate prevents them from learning from each other.

Blocker #704: Not really advanced, like I said you want and need the big data analytics machines to crunch through all available data before anything useful can be said. A problem we encounter at the moment is the fact that the systems are so complex that there is no ‘normal state’, the system is always in some sort of exceptional state. As a result, if you have no definition of normal, you cannot defend against abnormal. So you really systems to be smart enough to say if a certain state is dangerous. If you collect enough data, there will always be one parameter that will be abnormal. On the other hand, advanced analytics could always find a correlation between two data point while in practise they are not related. The intellectual capacity to update and maintain those model, if we use that to improve the systems we are trying to simulate, we get better results. Another thing of condition based monitoring, it is usually exception detection. This then triggers an alarm on which an operator responds. The problem with this is the fact that the human does not have the situational awareness to prevent it in the first place, he/she only fixes it and tend to make poor decisions.
Categor(y)(ies): Technological differences, investment and implementation difficulties.
Motivation: The different states refer to the complex environment the systems are in, a technological difference. Maintaining and updating the model is a difficulty that arises during implementation.

Appendix E Summaries of Interviews

Below the summaries of the seven interviews, names of companies and interviewees have been hidden.

Interview #1

Q1: Differences between IT/OT, what is your view?

A: Two different 'worlds', OT is an engineering discipline within COMPANY1, IT is a function, a service. Both are owned by completely different management structures. Decision makers do not speak with each other.

Q2: We have recognized different silos from the literature as well.

IT is bought by OT department from the IT department. IT is not asked for advice and is not included in decision making process although this is a goal in the future. Decision makers are still in the OT organisation. IT department provides the service.

Q3: What is your view on the convergence of IT/OT?

A: We have advanced a lot during the last 5 years. IT departments are being involved in the decision making process, but have no decision making power themselves. IT departments cannot block or empower a decision.

Q4: Is also caused by trust issues from the OT side regarding IT?

Definitely, this also has to do with 'off-shoring' IT, it becomes more vulnerable. OT departments want to avoid 'IT problems' within their core business. This is being overcome by setting up local IT departments to support OT on site instead of through service centres in India. This to support each other, OT cannot function without IT and vice versa.

Q5: What is your view on an integrated/converged IT/OT system?

Cannot be completely integrated, OT will always be the main part, with an advanced IT system attached. This is the highest form of integration/convergence possible at the moment. We are also working towards that. One department will always be responsible for the end-decision (OT) so the other (IT) will have to support their choice. OT departments accepting IT advice and functionalities more and more, all the more because of the low oil price, efficiency and cost pressure, these are very strong drivers to pick up more and better IT solutions.

Q6: You do see the advantages of this integration/convergence?

Yes definitely and the business as well, but this is very difficult to achieve due to the different management structures. I do not see these structures align or converge high up in the tree, on the shop floor they do because it is necessary but not on a higher management level.

Explanation assumed definition of IT/OT, different standards.

REMARK: The standards are interesting, IT is allowed to pressure vendors more and more to use 'standards' which allow for better compatibility and less dependence on specific vendors. We cannot handle five different standards from five vendors, this has to be compatible.

Explanation and confirmation gas production process.

Explanation System Quality

Q7: What is the most important variable of the D&M model for IS Success?

Reliability, availability and efficiency, these have a direct link with turnover of the company. The system should function without interference. Furthermore, I cannot say anything about the system quality because of the many different systems? Asset Groningen is more advanced in predictive maintenance because of the age of the site, the geographical position, the same equipment. Compared to offshore sites where some installation are installed in the 60's, 70's or the 80'. Perhaps some are upgraded in the meantime.

Q8: How is the system secured, physical, digital?

Differs per supplier, some suppliers update windows systems immediately, others must approve them. IT systems have a shorter life-cycle than the OT systems they support, this causes problems. The system have a maintenance contract for the OT part, but not often for the IT part. Physical security is often controlled but differs per supplier as well.

Q9: Control, ease of use?

Systems are custom built for every situation/asset, most operators are qualified.

Q10: How can the system be improved?

IT part can be improved drastically. Suppliers can improve their products, all suppliers have different security standards, which are difficult to implement, since COMPANY1 has security standards as well. If these are standardized, the information you can retrieve from all this data will improve as well. A trend you see these days is that compressor manufacturers collect all data themselves to analyse and provide service and maintenance contracts. This is already implemented in certain assets. Business wise this part can be improved as well, better maintenance contracts etc. The systems must be designed to be able to upgrade the IT components without interfering with its core functionality. Must come from suppliers, we are responsible as well as a buyer but decisions are cost driven.

Explanation Information Quality

Q11: How is the data displayed?

Differs per supplier. Most information is forwarded to PI. Is also different per asset.

Q12: Can you give an example of how a shortage or lack of data leads to problems?

No, operators mostly judge on experience whether the compressors can keep turning. Lack of information from one or more sensors do not influence the uptime. Operators have been using the systems before everything was monitored.

Q13: What possibilities could an increase in information quality present?

Better algorithms for predictive maintenance. We should use the sensors smarter, not only for monitoring, control and maintenance of current states. All this data can provide great insights into the different processes. You could use wireless technologies to place more sensors on a compressor to collect all sorts of different data and this is what we are currently doing. For control the security demands are way higher but the data could provide other possibilities, this is more costly. Security measures also affect the people working with the systems, it requires more and better authorization.

Q14: Do you see this implemented within the organisation?

Yes in the Groningen asset, where the demand was a very high uptime because this is the gas-buffer for the Netherlands. Therefore predictive maintenance is more important at this asset. Penalties are high for not delivering the amount of gas required. At the moment the business case is not yet there for other assets to implement these kind of systems. A major difficulty is the huge variance in different systems.

Explanation Service Quality

Q15: Who is responsible for the service of the systems?

Accountable will always be someone from COMPANY1, but he/she is always supported by the knowledge of the suppliers. They maintain the product.

Q16: During well workover, someone from the supplier comes by to check the equipment as well?

Yes

Q17: During normal production, how is the maintenance monitored?

By the supporting IT monitoring system provided by the supplier. When certain variables are not in the expected range, the situation is analysed to see whether it can be handled during the next workover or is immediate action required? This is a huge difference with systems that handle batch processes, we have a continuous production. Our system has to function continuously and are only maintained during planned maintenance.

Q18: How quick do the suppliers respond to unforeseen errors?

This differs per contract.

Introduction IT/OT Convergence, example automotive industry

Q19: What is the core problem, IT/OT convergence solves?

There is not enough knowledge of IT within the OT environment. OT cannot capture IT's knowledge to use for their own best. Systems can be standardized, simplified with this knowledge, become cheaper, supplied quicker, safer, risks reduced, efficiency. OT looks pure at functionality, if I press this button, which valve opens? How this happens does not matter for OT.

Q20: What are disadvantages of IT/OT convergence?

Implementation is difficult, standardization as well due to different and multiple stakeholders (suppliers and users). Implementation is time-intensive and could be costly before all current systems are ready/compatible. Change will be slow. Also because of the different 'islands' within the organization. This is a target for asset managers, but they lack the IT knowledge named before. Offshore we want to go to unmanned sites, because it is difficult and expensive to supply. Certification of parts is difficult and costly as well. IT needs to enable this so this is where we are currently supporting the OT departments. Groningen is an asset which is completely monitored and controlled remotely and this is where offshore is going as well.

Q21: OT does not trust IT, what is your view?

That is correct at the moment. IT is mostly proving itself trustworthy towards the OT department.

Q22: Are you currently working on IT/OT convergence projects?

We try to approach each other on a daily basis but this is not monitored from above or through a project. For new projects the convergence is also not a focus point. A way to achieve the convergence would be to expand OT's knowledge with IT skills and knowledge. This is happening within different organizational silos at the moment. Convergence does not happen yet because IT still is fundamentally different than OT. I do not know whether you should converge these silos.

Q23: What could be complications to achieve IT/OT convergence on a specific process?

Safety, costs, standardization, installed base and compatibility. Suppliers could provide converged systems but if the whole site needs to be replaced, this has no use. This decision is then cost-driven. Life-time of the rest of the plant has influence as well. We pitch our IT solution to the OT department, who in their turn pitch their solution to the asset manager who makes the final decision.

Q24: What are organizational barriers/demands/skills needed to achieve convergence?

Industry standards, internal training (COMPANY1 open university), increased knowledge and skills. COMPANY1 uses experienced people to train/educate other. Knowledge on different subjects, OT and IT is required for good decision making. Specialized functions will remain but COMPANY1 aims on broad knowledge domains for their employees.

Q25: What sub-processes are best suited for a pilot project IT/OT convergence?

We are working on this by looking at data and improving the process. Alarm management is an example, why are there so many alarms? Can we improve something that lowers the amount of alarms. This happens at all different assets on all type of processes. Up until now this was not necessary because of the oil price.

Q26: How advanced is your organization compared to others on the area of convergence?

Most are working on the same projects but since we are a big organisation, the implementation takes way longer. Therefore, other companies are further at the moment. Our installed base is also much more diverse which makes it more difficult as well. I think we started earlier but we are getting passed. Because of the low oil price and our cash position, we do have the means to continue investing where other companies cannot.

Q27: Can you imagine what other value IT/OT convergence could pose for your company?

A better grip on our assets by pro-active monitoring of our devices. We should be able to spot irregularities quicker. Status reporting could be improved as well.

Q28: Could IT/OT convergence enable other business models?

Suppliers could go from providing tools to services. Suppliers provide x uptime and handle all maintenance themselves.

Interview #2

Q1: Differences between IT/OT, what is your view?

IT is not part of the day-to-day control of for instance compressors. The DCS is what eventually controls the compressor and this has to be done as safe, quick, reliable and cost efficient as possible. The IT part of such a system is in place to provide the maintenance department, rotating equipment engineers and other third parties with data and information.

Q2: How do you see IT/OT convergence?

Very complex challenge, in OT availability is key, security is important. Ideally you have no interference with the 'outside world'. This drives completely against the goal of IT, who wants all data real-time available for everyone involved. This is one of the main differentiations between these worlds. This is something we encounter in practise on a daily basis. The worlds are completely different, the service levels are different, the people are different, the methods and ways of working are different. In the IT environment you can reboot something for instance, if the mail-server does not work, you just reset it, this is impossible in the OT environment. In the oil and gas world you want as few people on site as possible, in Groningen for instance, we have 2 desk-operators controlling over 300 wells. The environment is hazardous, the substances we work with, the equipment, basically humans on site is a hazard for us. Furthermore humans are not very cost-effective, this is why IT is getting more and more important. The more remote we get, the more information we require to manage these sites.

Introduction System Quality

Q3: Which of the sub-variables are the most important for a compressor control system?

Speed and reliability, anti-surge control must be able to respond to irregularities within milliseconds, otherwise the equipment breaks down. Availability therefore as well and reliability is crucial as well because you cannot afford to have a breakdown.

Q4: What is the most important variable that contributes to organizational impact?

System quality is the bottom line, the other two can fail completely, if the system quality is perfect, you don't need service or information.

Q5: Does the system require any training or certificates to operate?

No

Q6: How intuitive is the system?

The system is one complete package and works out of the box. All the parameters come from the compressor supplier.

Q7: How flexible is the system to respond to unforeseen inputs?

This is built in as well. You can determine and set how it should respond.

Q8: How are the systems secured, both physical and electronic security?

IT and process control security is according to guidelines from COMPANY1. Switching the compressor on and of is done from the control room. Adjusting anti-surge control however requires a key, since this can destroy the equipment. However there is always a backup system running to monitor and control the compressor when wrong parameters are put into the system.

Q9: Can the system operate without human interference?

Yes, the compressors have been running since 1950 so yes.

Q10: Reliability of the control system?

0,999999 repetitive. The goal is to have the highest uptime for the compressor so the control system must function 100% as well.

Q11: What value could an improve of service quality?

The system is near perfect. The challenge is not in the control system but in the compressor itself. The control system is redundant.

Introduction Information Quality

Q12: How is the information available?

All information that is available on the compressor itself is available in the control room as well. Real-time for all operators and semi-real-time for maintenance personnel. The control system is also linked to a data historian to store all operational data. This is mainly for maintenance purposes.

Q13: Why is the information quality important?

The complete maintenance and all service intervals are based on the information from the system. The operator could see the compressor running with no errors while the maintenance engineer sees a spike in power usage which could indicate friction or broken parts.

Q14: Could a lower information quality result in failure?

Yes this could be the case. Normally the operator tries to get some more data to verify when an alarm goes off. In the future however we will definitely rely more and more on this information. The goal is to be able to measure so much information that we can predict future scenario's (predictive maintenance).

Introduction Service Quality

Q15: Who is responsible for the service of the control systems?

The customer itself, but we provide all necessary service if needed.

Q16: How quick can the service department respond?

During office time immediately, otherwise within 4 hours.

Q17: How is the hierarchy concerning the service?

We can instruct the client and advice him but he is responsible.

Q18: How would you rate service quality compare to the other variables?

70% for System quality, 20% service quality and 10% information quality. Without a proper system, both other variables are useless.

Introduction IT/OT Convergence

Q19: Can you give an example of a perfectly executed IT/OT converged project?

Everything real-time, no firewalls, all software open. Advanced analytics to be able to predict future scenario's.

Q20: What is the core problem solved by IT/OT Convergence?

There is a lot of information available, but this is not accessible or used in a proper manner. Making the data accessible allows for better insights in processes, decision-making, reducing costs and risks, enhancing efficiency.

Q21: What are the disadvantages of IT/OT convergence?

Monitoring everything could be a liability, from a privacy perspective, but analytics could also find correlations which are not funded. Correcting operators or pointing out mistakes they make is a very delicate matter since they feel threatened or watched by big brother. From the IT world, there is a need to access all data, although some data may be rubbish. Filtering this data and turning it in information will be a challenge in the future. Making wrong decisions on faulty data should also be avoided. Also, not all legacy equipment is compatible with modern control systems. The investment costs to make all data available must be taken into account. Also, security issues and the investments to solve these need to be handled.

Q22: What complications do you encounter when you want to convergence IT and OT?

Load problems, old systems cannot handle all data requests required.

Q23: Can you name barriers for IT and OT alignment?

No

Q24: Can you name organizational barriers for IT/OT alignment?

Yes the organization requires the uptime to be 100%, so you basically cannot turn any systems off. All systems in the office domain make use of the same data, all maintenance models, business models etc. are fed by one single system so a lot of people rely on this system.

Introduction barriers

Q25: Which of these variables is the most difficult to overcome?

Differs per organization, but the governance and ownership and cultural differences cause a lot of problems.

Q26: How would you rate your expertise on the level of IT/OT convergence?

High

Q27: Do you foresee any new business models made possible by IT/OT convergence?

Yes, we try to manoeuvre customers in the direction where they rent compressors instead of buying.

Q28: Your view on the future of IT/OT convergence? How fast will it be achieved?

The golden years of oil and gas are behind us so efficiency, cost effectiveness and risk reduction will become more and more important since easy to access oil will become depleted. Security and service will be something we will focus on. Virtualization is really good opportunity where we are going to focus on.

Interview #3

Q29: What is your definition of IT and OT and the differences between them?

IT is everything handled by the IT department. This is a different organisation than the process control organisation. OT is operational technology (Cisco), we name this process control. These are the primary customers of COMPANY3 process solutions. We do not deal with IT that much, recently with the employment of Wi-Fi, certain business intelligence systems on our process control network, this is the first time IT was 'at the table' during discussions. We notice at a lot of customers that these departments are strictly separated. This results in an unclear balance and clarity on topics of governance and ownership (BARRIER!). The departments are often out of sync as well. OT keeps IT out of the room in the process control area, while IT claims Wi-Fi is their speciality/business.

Q30: How do you view the convergence of IT and OT?

We believe that in the future IT and OT must collaborate because all network systems will become more and more complex. OT will have to use IT skills for remote collaboration, control and monitoring. It is inevitable that these worlds will converge. Traditionally the OT department wants to keep everything local and certainly not sharing information globally due to safety risks, cyber security. IT in general prefers a scenario with 20 plants and only one control room that monitors and controls all plants real-time. With operational technology they want to keep that local and preferably locked out from the outside world through the Internet or whatever. OT prefers an island from a security perspective. This is not realistic anymore these days, most OT people realize this and you simply need IT personnel to achieve this safely, secure and in good order. On the area of business intelligence the worlds can and should work together more often to be able to do better analysis, optimize processes, methods etc. Ideally all data will be brought together into one system to be able to perform advanced analytics, trending and predicting through simulation. How this will go in practise, the process control domain is in general ultra-conservative. Nobody wants to ruin their reputation by experimenting with certain technologies. Everything needs to be thoroughly tested, proven concepts and OT people want references of these technologies before they will try it themselves. This will definitely take some time in the Oil and Gas sector, in general the smaller, more innovative companies will lead this. The big companies will take much longer to implement due to legacy equipment, politics, thorough testing and security issues. Furthermore, OT is in general controlled by old-school die-hard engineers who have been performing their tasks perfectly for years. These man speak another language than the young and bright IT people. OT prefer the least IT interference as possible. A global trend however is the fact that IT budgets outweigh OT budgets by a factor 100 so IT has, or will definitely catch up or even take over.

Q31: How important are the different variables of the D&M model?

System quality is definitely on top, however this can never be 100% so the information quality is important as well, otherwise you have no idea what is possibly wrong. Certainly not on remote and unmanned sites, normally you can inspect a machine on-site. With these remote or subsea locations, which is trending as well since all easy to access oil has been depleted, inspecting the machine is not always possible. Service quality is the least important, it is certainly important but you try to plan this according to the information quality. If your information quality is better, you can enhance your service quality. But system quality has direct impact on the turnover so this is definitely the most important.

Q32: Does the control system require training to operate?

The sites and compressors themselves require certain knowledge, next to that we have training software that simulates complete refineries. We also have training centres and we provide training on site. Furthermore, the systems are not that technical, so everybody will get the hang of it after a certain amount of time. The interface is pretty intuitive as well.

Q33: How fast does the system respond to unforeseen inputs? How direct is the DCS coupled to the compressor?

Depends on the site where it is used, from milliseconds to seconds.

Q34: How is the systems physically and digitally secured?

There is always an emergency shutdown system, that responds locally and independent to power-downs, unforeseen inputs, tampering with parameters. We also provide add-ons like remote collaboration systems and remote control rooms. Finally we have different advanced solution systems. All suites are updated regularly with the latest patches to prevent leaks etc.

Q35: How would you rate the reliability and availability of these systems?

Reliability is near 100%, this is a requirement of these systems. There are also a lot of redundant systems in place like power-generation. Our systems can also be upgraded on the go, real-time so we are not dependent on the well work-overs or shutdown.

Information quality

Q36: How is the information quality displayed? Who has access?

Differs per site, there are different levels. We have software which makes everything possible on the other side of the world but this is done according to the needs of clients.

Q37: Why is the information important now and in the future?

Example, alarm management is crucial. Different alarms are linked to each other and when one is triggered, 50 others are triggered as well but you want to suppress this since you only want to focus on and solve the first one. When even more data is measured, the amount of faults will grow as well so proper and well designed advanced solution systems must provide users only with the key information since the abundance of data will be impossible to process for humans. Data overflow. Furthermore, the data accuracy must be spot on, otherwise you cannot transform this data into information!

Introduction service quality

Q38: How are you involved in daily servicing?

Differs per site. On some sites we have engineers 24/7, other remote sites we have an engineer on call.

Q39: How is the hierarchy concerning the responsibility for service?

The end-user is always responsible. In the Oil and Gas industry they do work with contracters often.

Introduction IT/OT barriers

Q40: Can you give an example of the barriers?

The technological silos are very clear. Example when an OT department wanted to implement something but did not receive the funding, the IT department took over and they did receive the budget needed (also governance and ownership). The worlds don't completely work separately but collaboration could certainly improve. The department also have different competencies (cultural differences), if you come to my department you might take over some work which makes me irrelevant, they want to protect their own island. OT has to deal with requirements, compliancy and environmental restrictions. IT does not have to worry about this. If there is an OT failure it hits the newspapers, a server going down and having to be reset isn't even noticed by the own personal. The impact both organisations have is different. When designing new projects they both have to be involved and work together, this way you will lay a good foundation. This to ensure to maximize efficiency and cost control because IT is just better at their speciality and the OT people at theirs. This is also relevant because you prevent the departments from doing double work.

Q41: Could you name any other barriers for IT/OT convergence?

The difference in vision of the heads of departments. The security aspect, the fact that IT wants to globalize everything while OT wants to keep everything local. The impact of the worlds is different and this makes it complex. Look at an OT failure at the Deep Water Horizon. IT, although the uptime and requirements begin to come closer to OT standards, will never have that kind of impact. This is a hurdle to overcome. They completely speak another language which is difficult to overcome as well.

Q42: What new business models can IT/OT convergence provide?

The value is definitely in the remote control and monitoring. The Oil and Gas industry therefore is a perfect opportunity for converging both worlds. Being able to control and monitor everything will provide great value for these companies. Businesses want to avoid incidents and unplanned downtime, both are very costly for the reputation, revenue, human lives, equipment etc. Downtime runs in the millions for single sites.

Leasing equipment is also possible where the responsibility of service, data streams etc is managed by the supplier and the customer only pays for a certain amount of uptime. There are two possibilities, where the customer does buy the equipment but we do everything else, others prefer to lease the machines.

Q43: Which variable will be the most important in the future?

Information quality will become more important. Sites will become more and more unmanned and in combination with the remoteness it will be impossible to send someone for inspection. Information from these big and complex systems will be very important, otherwise a system can go out-of-bounds without anyone noticing.

Interview #4

Q44: Which variable of the DeLone & McLean model is most important?

A: System quality. Reliability and availability are the most important factors for such a crucial process. A site managers job is to maximise output, the uptime must therefore be as close to 100% as possible.

Q45: Which variable will be most important in the future?

A: Information will become more and more important. Analytics could provide trends for predictive maintenance etc.

Q46: How is the flexibility and response time of the system?

A: Systems measure and respond in milliseconds, this is needed for anti-surge control. The systems are directly linked to the control. The system must operate within a certain window and the system is smart enough to recognize when it will cross the borders of this window.

Q47: Who is responsible for the input variables of the operating window?

A: This varies, original input comes from compressor supplier. Afterwards the window shifts and this is measured and maintained by the system itself.

Q48: What are the levels of physical and digital security?

Sites are prohibited, compressors are in an enclosed space as well (often). Control room can over-rule everything, control room is closed.

Q49: Is all data accessible by business analysts?

This does not happen often, we are developing these kind of services at the moment but there was no need up till now from the client side. The services are KPI driven, so the systems only measure and forward data which have been specified beforehand. We do see this as a current demand, Internet of things, data-mining, analytics, COMPANY2 wants to catch this train of course since this is a core speciality of our company, it improves insights in current processes but allows companies to run simulations as well. This can drastically improve the maintenance for the companies and the service we provide. The industry however is very conservative and does not want to invest that much in these solutions.

Q50: How would you rate the reliability?

100%, the compressor needs to have the highest uptime possible so the control system must have the highest uptime as well.

Q51: Are updates installed real-time?

Depends, customers often prefer only during workover.

Q52: How is the information displayed?

Through a Human Machine Interface (HMI), real-time. This is displayed in easy to understand diagrams which displays the operating window, trends etc.

Q53: Can this information be accessed on another level?

A specific Unit Control Panel can send this information to the business level. This is a separate system next to the control. We want to visualize the data all data, process data as well to find links between phenomena and different variables. If you can monitor this you are better able to look into the future. Accessing this data does however present security risks and it is therefore limited.

Q54: Why is the information quality important?

Predictive maintenance, these systems cannot be controlled by humans because the response times needed are too fast for human interference. Visualizing is important because pictures are easier to interpreted. The graphic display can display trends and lines which can be analysed as well.

Q55: What could happen if the information quality goes down?

The system could shut-down.

Q56: What possibilities could an improvement in information quality pose?

We believe efficiency can be improved if efficiencies, results and variables are measured. We already have an algorithm which can choose the most efficient compressor in a parallel compressor setup. You must however keep an eye for the data accuracy as well, otherwise the information you extract from this data is worth nothing.

Q57: Which information is accessible by you as a supplier?

Almost all information is owned by the customer.

Q58: Who is responsible for the service of the systems?

Depends on service contract. Mostly the supplier. Upgrading and patching is all in our control.

Q59: What are the response times of service departments?

Direct, depends on asset.

Q60: Are regular checks performed?

No, this is managed by the customer. We would like to improve this but it seems difficult.

Q61: Do you provide training in the service and usage of your product?

Yes

Q62: What is the core problem which is solved by IT/OT Convergence?

Efficiency, cost- and risk reduction, availability higher.

Q63: Disadvantages of IT/OT Convergence?

Investment costs. Quality and safety are the most important factors so costs do not matter. Concerning efficiency, so looking at return on investment, this part is often more difficult to manage. Legacy equipment is also difficult. A huge problem is also the different suppliers and switching costs. Operators must be trained in new equipment etc. Overcoming installed base. Privacy is also a difficult topic. Cybersecurity and cybercrime is something the industry is afraid of and solving this comes at a price. Responsibility, ownership and governance, operators do not want to and cannot be responsible for too much assets and equipment. Increased security enhances this dissatisfaction since it will probably require more and better authorization etc.

Q64: What kind of variables would push IT/OT Convergence?

Safety hazards, difficult to reach (remote) areas, high/low temperatures, dangerous gasses, subsea, high pressures. Greenfield operations are more open to new solutions, brownfield is still difficult because of ownership and governance as well.

Q65: How would you advice clients to reach IT/OT Convergence?

Draw a current state and see what would be possible, always budget limited.

Q66: Can you imagine other/new business models using IT/OT Convergence?

Information is not easily shared by companies but this could provide opportunities. Remote sensors are interesting but the industry is still conservative.

Q67: What are barriers for IT/OT Convergence?

Money, investments, conservative sector, fear for change, the fact that people are getting older in the industry (cultural and skills), expertise flows away easier.

Q68: Which factor contributes to misalignment between IT/OT the most?

Governance and ownership, IT is mostly a service to the OT department. The goals are not aligned, so different departments have different goals.

Q69: Alignment could be a solution, how do you look at this?

Yes, common goals would help a lot. There is a strict separation between departments and their goals are often different. Solutions however must come from above (management), this will not be reached by the departments themselves because of their different interests. For greenfield projects this is easier. Brownfield projects are near impossible. Maintenance department want this, asset manager wants lower costs.

Q70: How do you help clients with step by step implementation?

By forming consortia with end- to-end solutions for the clients.

Q71: How do you see yourself within the industry?

Concerning automation we have the biggest installed base which says something. In the Benelux within the oil and gas industry we are smaller but worldwide bigger.

Q72: New business models, can you think of any?

We try to provide solutions for customers but the sector is to conservative. We believe augmented reality solutions could be very interesting for operators. To send them into the field with a backup engineer, display data on a wearable device and perform maintenance on the spot, using navigation as well.

Q73: D&M Model, what will change in the future?

The information will be more important. Society is data and information driven so this will be more and more important.

Interview #5

Q74: What is your definition of IT and OT and the differences between them?

These days, in most manufacturing companies, IT covers everything regarding users and software, finance, planning of personal, planning of production. OT is the process control domain, to make processes more efficient. A main difference is the fact that almost all OT equipment is 'hardwired' where IT makes use of new (wireless) technologies. IT is the business domain and OT the process side.

Q75: What is your definition of IT/OT convergence?

I would rather speak of a goal of IT/OT convergence. The goal of bringing these worlds together is to get better insights in how production facilities functions on all levels. An example: the state and condition of certain machines, what is the current output of my facilities, what is the state of current financial resources, how many order do we have. Convergence is letting the system talk to each other, making sure you gather the right data from both systems to get better insights in processes in order to make better decisions. This is different from the silos currently in place. IT and OT are part of different department, they are managed differently.

Q76: Can you give an example or a best practise from the Oil and Gas sector where IT/OT convergence has been reached?

Not specifically in the upstream Oil and Gas sector, for downstream I do have one concerning compressors. When companies decide to install systems that on one side have to protect the compressor. When there is a threat of a breakdown or failure, the system safely shuts down the compressor. On the other hand, the data gather from the compressor is being used to enhance the decision-making concerning maintenance, or to monitor controls. These systems require a strong OT basis but definitely need IT technologies to cope with the data and make the system work. Quite some big players in the Oil and Gas sector have recently or are currently implementing these systems.

Q77: What are the disadvantages of IT/OT convergence and integration?

Picking a certain system itself is crucial, not all systems are compatible with each other and this may cause safety and security issues. Companies also need to take into account which outputs they desire. On the IT perspective, if a system is not equipped with certain algorithms it may not function as desired.

Q78: What is your view on security?

Security is a critical factor and the systems are more exposed due to IT/OT convergence but should not be considered a disadvantage. There are enough systems available that provide perfect security on all different levels. The selection of systems therefore is crucial for companies! People from the OT department underestimate the possibilities and security solutions that are available at the moment.

Explanation DeLoan & McLean, System Quality

Q79: What are the most important sub-variables for system quality?

Reliability, availability, data accuracy and possibly intuitiveness. The system must function autonomously so reliability, availability and data accuracy are the most important. When interference is required, intuitiveness comes into play.

Q80: Which variable of the D&M model is the most important?

System quality is definitely the most important. The system quality is the ‘backbone’, if this lacks, the information quality and service quality are useless. When selecting systems, you first look at the quality of the system, then the information quality and finally you make arrangements on the service. The system quality directly impacts your revenue.

Q81: Could you give an example of system failure due to system quality?

This definitely happens. Some systems are upgraded or add-ons are installed making the system instable.

Q82: How flexible are the systems to respond to unforeseen inputs?

The systems must respond within milliseconds to prevent catastrophic failure. When a compressor goes out of its operating window, chances of anti-surge or mechanical failure become very high.

Q83: How are the systems secured, on a physical and digital level?

When you have access to the plant itself, most of the times, the machines are accessible. Tampering with the machines on the other hand is quite difficult since you need a lot of knowledge of the machinery to really mess with it. Control of the systems often happens from a control room which provides an extra level of security.

Q84: How can the system quality improved?

Process self is more and more controlled on capacity instead of uptime, systems must be able to cope with this. The systems themselves must be able to measure enough data, accurately, and make this available for the end users. This will enable users to improve decision making, especially considering maintenance. These could also be decisions on processes since these could also be improved when enough data is available.

Explanation Information Quality

Q85: How is the information displayed in general?

Different streams of data are available to different stakeholders. For example, process engineers need different kind of data than reliability or maintenance engineers. Data is usually scattered on different systems. Basic variables are always available but since the data streams are huge when everything is stored, these are not managed centrally (note: virtual systems could be a solution!). Ideally this would be managed by one system but then the data will be abundant for operators. This is definitely a hurdle to overcome for companies.

Q86: Why is the information quality important?

You buy a system with certain expectations and goals. In practise these are almost all of the time different from how we use them. The system must therefore have a certain flexibility to cope with this. The information quality itself: Process, maintenance and reliability engineers all make decisions based on the information provided so therefore it is very important.

Q87: Could the display of information cause problems?

Yes, this definitely happens.

Introduction Service Quality

Q88: Who is responsible for the service of the systems?

End responsibility is always at the user. Who they consult differs but the original equipment manufacturer is usually available. In general, when buying a system, a service contract is included.

Q89: Are regular checks performed, is the system updated remotely?

Updates are performed during well workovers. The industry is shifting to more regular updates and OEM's want more and more access to data to predict maintenance. In the past back-up systems where in place but the reliability has increased to such a level that this almost never happens anymore.

Separate note: In the future whole plants should be monitored conditionally, with prioritization between machines/processes. Data will enable this and even simulations could be possible to estimate a risk at a certain moment.

Q90: How is the hierarchy between stakeholders with access to data?

You have an IT department, a maintenance department and an operations department (IT OT BARRIER!). These have different responsibilities and goals, maintenance has to ensure reliability and well functioning machines while operations must maximize output. These goals are often conflicting and hierarchy is also complex.

Introduction IT/OT Convergence

Q91: What is the core problem that is solved by IT/OT Convergence, what is its goal?

Improving decision making throughout a company because all data is available. In the future IT/OT convergence will enable predicting and simulating scenario's by analysing historic data. This will only be possible when all data is available.

Q92: Can you elaborate on the opportunities of better decision making, what is achieved?

Efficiency, costs reduction, cost optimization, risk reduction and control. These are the most important drivers for IT/OT convergence.

Q93: What are the disadvantages of IT/OT Convergence in the Oil and Gas sector?

If IT/OT convergence is perfectly implemented and executed, there are no disadvantages. In an ultimate scenario unemployment could be a disadvantage, but think this only brings new opportunities. It does require investments however.

Q94: What are the risks of IT/OT convergence in the Oil and Gas sector?

Cybersecurity is a big risk and this will increase in the future. The OT world is currently physically locked-out of the IT world. When the systems are fully integrated data protection and data security will be very important and need to be something to focus on.

Q95: How would you advice companies to implement or start IT/OT convergence projects (step by step)?

Depends on the company, how mature a company is concerning their IT and OT management. One step for companies is to figure out where their focus needs to be, what are the most critical systems and processes and how are these currently managed and controlled (mapping current IT/OT structure). The risks of current systems must me mapped, which data is needed for all critical steps. Next the integration itself is difficult, to be able to let the machines and systems talk to each other. This again is a hurdle for lots of companies in the sector. A lot of companies are not ready yet for this step. This step is difficult because it incorporates not only the integration of software and hardware but also departments within organisations. The goals and mission of the different departments must be aligned. Since the systems must integrate and cooperate, the departments and silos within companies must do this as well.

Q96: You just named the different department as a barrier for IT/OT integration, are there any other barriers?

The technology is there, so this is definitely not a barrier anymore. Especially if you look at the current hype of the internet of things. There are lots of methods and technologies to gather data wireless without having to invest in cables and equipment. Lots of these wireless systems are also ready and compatible with all other systems in place allowing for a smoother integration/convergence. The industry is clearly lagging behind the technology that is available, in the consumer business the sector is way more advanced. The fear of security issues is ungrounded since the solutions are already there.

Q97: Does the Oil and Gas sector have problems with the legacy equipment?

This is a non-issue these day, all old equipment can be upgraded with sensors and made ‘smart’.

Q98: What are other organizational barriers to overcome?

The organization must be ready, must believe in the convergence and integration and must support it. Goals must be formulated and communicated, otherwise the convergence will not work because everybody in the organization is involved in IT/OT convergence/integration. The transition is similar to companies transferring from reactive to condition based monitoring. The integration cannot be done by one person only, all involved departments and people must support it. The mind-set of an organisation must change.

Introduction barriers

Q99: Do you recognize cultural differences in organisations as well?

Yes, as mentioned, the mind-set of the people must change. OT are usually more conservative compared to IT people. IT people can be obsessed with protecting and securing systems which may lead to a system which is very difficult to use or manage. OT on the other hand focuses on their field which may interfere with the interests of the IT people. Maintenance people have traditionally learned to monitor systems without being able to read all data which is available. They must learn how to use this, change from their traditional methods and rely on other technologies. Furthermore, the data accuracy must be accurate in order to transform it into worthy information. In the past they could listen to the machine, check some valves and perform minor adjustments, now they have to use all sorts of high-tech sensors and equipment.

Q100: How can these cultural differences be overcome?

A big problem is that the guidance, training and education lacks when implementing new technologies. New technologies are often implemented without consult or even notification and the people just have to work with it. This is an area which should improve drastically for the adoption of almost everything new. When the convergence/integration is complete this is even more important because then the alarms will be triggered by simulations and possible calamities instead of real errors so the operators do not have to respond immediately but think about a possible solution in the future for a possible error.

Q101: Which of the variables that cause misalignment between IT and OT is the most important?

In general all three are equally important but this differs between organisations. Some are more traditional and less mature than others. Others may have the latest technology and integrated departments but poor management. The maturity level of the organization is very important to assess before implementing these IT/OT projects.

Q102: How do you see yourself within the industry?

We are early adopters, we help implement these systems at different companies so we have a good view on where the industry stands, which is in a very early stage. A lot of companies are not yet ready for the integration. Checking the maturity of a company is very important.

Q103: New business models, can you think of any?

Predictive maintenance is one. In the consumer business this is already in an advanced stage. BMW for example can predict their maintenance intervals better by measuring and monitoring the data the vehicle gathers. Companies in the Oil and Gas sector can copy this for complete assets but that is a futuristic scenario. Most maintenance is time-based but analysing and gathering data is still difficult for these companies but this could be improved by IT/OT convergence.

Q104: When will the industry adopt the integration?

Most companies are working on it but before it will take effect at least 5 to 10 years.

Q105: Also example from consumer industry (airbnb) is renting out compressors instead of selling them, do you have other examples?

In the power industry, the plants are not sold completely anymore but leased, so the original owner keeps control of the maintenance and state of their equipment.

Q106: Looking back at the D&M model, will any parameter become more dominant?

Yes, information quality (Coolblue example).

Interview #6

Q107: What is your definition of IT and OT and the differences between them?

IT is automation in the office domain. OT is automation in the process control environment. OT is developed, managed and controlled by engineers. Within our company we have separate departments who are responsible for IT and OT. IT and OT departments are separate silos in the company with their own people, own methods and ways of working and can be seen as different worlds. Both IT and OT departments could learn a lot from each other but unfortunately this rarely happens in practise. OT is more traditional, holds on to proven concepts and is less quick and eager to adopt new technologies while IT is the opposite. IT architecture is very advanced these days. OT architecture is in general built to last, very robust and reliable. OT is built on commonly accepted blocks (platforms) using different standards, IT is more flexible and purpose built. User acceptance is difficult, resistance to change. People from both worlds speak a different language (cultural differences).

At the moment the worlds are being brought together by bringing all data together and allowing the business domain to analyse it for their purposes and the process control domain as well. This brings all data together and insights prove to be valuable.

Q108: What is currently being monitored, what data is gathered?

System-one from GE, everything what you can imagine is being gathered and monitored. During our regular 4000 hour checks we send all the data to GE and ask what parts must be overhauled. We compare this with our findings from the real overhaul to see whether the predictions are correct. At the moment the predictions are very well in line with what we find during the overhaul. Unfortunately, not everything can be predicted but we are working on fine-tuning the analysis and the reports to be able to let the site run autonomously. The end goal is to prevent the whole machine to receive an overhaul when only specific parts would need maintenance.

We have developed our own data historian that stores all data generated by the DCS for future analysis. We have no idea what data may be useful but when something proves to be useful, we can access it. We did struggle with the frequency of the measurements, storing everything is nearly impossible. At the moment we are analysing this data, discovering trends and trying to predict future states. For the compressors we are actually improving the reliability. Reports which we develop include efficiency reports, reports with total statistics (starts, stops, downtime, volumes, pressures). Conditional monitoring is the next step, being able to predict the future. We develop this on our own as a pilot project for the rest of the organisation. We may experiment with project R, a statistical analysis tool where you input all data and it will figure out the correlations between input variables.

Introduction System Quality

Q109: Which variable of the D&M model is the most important?

The control system itself has the function to run but also protect the compressor. Reliability, availability and data accuracy are therefore the most important factors and thus system quality is the most important variable in the model. Other variables as flexibility, intuitiveness etc. do not matter that much if the system performs how it should. Moreover, the operators are trained to use the machines so intuitiveness and ease of use are less important. Interference is only needed during malfunction, but during these times the system is and should be intuitive enough but no more (the Unit Control Panel). To conclude, the machine must be available, reliable and the data must be correct, this allows the machine to run, and the uptime is directly linked to the revenue. If an operator cannot fix the problem, he calls the service department and if they cannot provide a solution he will turn to the Original Equipment Manufacturer. The system definitely does not need to be self-explaining since not everyone should and can use it.

Information quality is obviously important but the data accuracy, what is used to make decisions and to keep the compressor running is most crucial.

Q110: How is the system secured, both digital and physical?

The terrain itself is secured by fences and an access system. The control room is secured again and only accessible for authorized personnel. The compressor itself could be sabotaged when you go in and cut some wires. Emergency hand valves can always be turn. The UCP can be controlled from the control room. Data from the DCS goes to the historian which is on a separate network from the business environment. Remotely accessing the compressor is not possible at the moment but we are trying to implement this. We want to provide access to rotating maintenance engineers who are on duty during the night to have access when alarms are triggered.

Q111: What are disadvantages of an integrated IT/OT system?

Having the historian in the OT network is difficult if people from the office domain want to access data. We are setting up a two-way authorization where the specific person and his laptop could get access from the central monitoring engineers. Data from the historian is accessible for the office domain but this needs an approval and takes a while before people can run their analysis. Ideally this would be available real-time, by placing the historians in the office space. A problem that comes with that case is the fact that the IT department is then responsible for the historian.

Introduction Information Quality

Q112: How is the information displayed currently?

Asset manager receives reports when needed, all data and reports are available. Reports are automatically generated, if new analysis is done, a model is immediately generated. Stakeholders can built there own reports from the abundance of data.

Q113: What can be the added value if the data is available for all stakeholders?

If the data is available, everyone can do their own analysis, the threshold for doing analysis becomes lower which means that more people can be involved and help think about better decisions. The end-goal is to make the data available for the whole organisation so everyone can learn from each other gain insights into, and optimize and tune maintenance and processes. Technically this is not a challenge.

Introduction Service Quality

Q114: Who is responsible for maintenance?

We prefer to do everything in-house, only if nobody can figure it out we go to the OEM. There are enough rotating equipment engineers available. The first line is always on-site, the second line is available through the headquarters and the third line is the OEM. We try to limit the contact with the OEM since we learn more and more the longer we use it. Next to that we have an extra system in place.

Q115: Are regular checks performed?

Since we have extra, redundant, systems in place we can perform maintenance around the clock. We do close down the site for 10 days a year.

Introduction IT/OT Convergence.

Q116: What is the core problem that is solved by IT/OT Convergence, what is its goal?

Both worlds can learn a lot from each other. At the moment both worlds are separate islands (IT/OT barrier: silos) and both domains can learn so much from each other that both will get to a higher level. One domain is more advanced in one area, while the other has expertise in another. The silos are definitely a problem in this sector. Cultural differences should therefore be overcome since this blocks the transfer of knowledge and expertise. From a technical perspective, there is a need to integrate and converge the data from the different domains in order to perform analysis. Ideally all available data should be available on 1 spot in order to improve decision making. This to drive efficiency, cost and risk reduction. I guess in 10 years engineers will walk around the plant with a smart glass, look at a machine and a manual pops up together with all data being measured but also data on when the machine was last checked. Bringing all data together will improve almost all decision making. It can improve quality as well and effectiveness. Maintenance induced failures could be prevented.

Q117: What are the disadvantages of IT/OT Convergence in the Oil and Gas sector?

IT likes to protect their domain and let no one interfere with their tools, if OT adopts this we cannot switch and adjust fast enough to unforeseen inputs. I don't think security is a risk or disadvantage because this is one area where both worlds are working together and sharing best practises. It does however require investments to eliminate these security threats.

Q118: How would you advice companies to implement or start IT/OT convergence projects (step by step)?

Companies must first setup goals what they want to achieve. Gathering data and bringing it together has no use. Furthermore people must believe and be educated in the possibilities of the integration, then they will become enthusiastic and will take full benefit of convergence. I do think people realise how much both worlds can learn from each other in general but perhaps cannot see the full potential of integration. Then gathering data, see what benefits are gained and then start including more and more data and involving more analysis and people. With our pilot projects we already see the benefits but we face our problems as well.

Q119: You just named the different department as a barrier for IT/OT integration, are there any other barriers?

Political games within and governance and ownership, who is responsible, who will finance the project. The return on investment is quite long and may never arrive when the project is not managed well. The business case is therefore quite difficult. Making everything smart and gathering data is the first step that requires quite some investments, then you must do analysis and only in the end you can do something with the information you find. Companies really need to believe in the convergence and integration, otherwise it will not work. Pilot projects can definitely lead the way for other, bigger projects. Success must also be communicated clearly to convince people. There are no technical barriers anymore, it is scalable as well. The physical machines may be old, but the control systems are in a lot of cases state of the art systems.

Q120: What are other organizational barriers to overcome?

There is definitely a gap between the decision makers and the shop floor.

Introduction barriers

Q121: Can you give an example of how to overcome this misalignment?

First the management must be convinced. The departments must overcome their pride and differences. They must be shown how much they can learn from each other, they must be forced into a conversation and collaboration. Ideally the departments should be fused, forcing them to follow one direction and goal. How it is currently run it is a complete waste of talent and knowledge. Their attitude is completely different as well, IT is higher educated, follow procedures and tend to overdo things. They speak another language as well, it looks like they want to graduate/promote on every project they take on. OT personal on the other hand is way more practical, it should work, quick, fast and reliable and nothing fancy, while sometimes taking shortcuts. IT personal tend to take to long to prepare a project.

Q122: How did you achieve this at your site?

I have a background in both worlds and this is sort of a hobby project. I know the skills from both sides and try to combine these. I believe in innovation and technological advancement. I receive no budget or anything, this is just a side project. I use people's own enthusiasm.

Q123: New business models, can you think of any?

The whole industry wants to make the step to the future, to conditional monitoring and preventive maintenance. The whole industry is looking how to achieve this, how we can work together? In the end however, the business case should be valuable as well.

Q124: Looking back at the D&M model, will any parameter become more dominant?

Information quality will definitely become more important. Data accuracy and availability first but when this is achieved, the data becomes open and people can turn it into information then we will be ready to take next steps. Improving processes, analysing data, pattern recognition and predictive maintenance.

Interview #7

Q125: Differences between IT/OT, what is your view?

OT are the computer systems which have the ability to affect the physical world. IT is the manipulation of information in order to make decisions. OT can often be found in the production environment while IT is the office domain.

Q126: What is the definition of IT/OT convergence?

Where the systems that can impact and/or measure the physical environment are closely merged with the information systems in order to make (better) decisions. IT is more about the manipulation of data and information in order to make decisions. If you can merge these you can make decisions on the 'real' physical world, using data from the OT systems.

Q127: What are the most important sub-variables that influence System Quality?

Integrity, data-accuracy, availability will control whether or not we make oil. Data-accuracy and integrity makes sure that we do it safely. If my data does not have integrity I do not know whether we should run the compressor at all. Reliability is definitely second, but as a company, our highest priority is definitely to make sure we do it safe. If our safety points are not validated, we could have multiple fatalities associated with using mechanical equipment. So our top priority is integrity. We control this by controlling the data-accuracy.

Q128: Which variable of the DeLone & McLean model is most important?

As said, the data-accuracy is definitely key so that automatically comes to system quality. The other sub-variables like availability are important but not as crucial as data accuracy. The data-accuracy enhances the information quality so System quality is definitely the most important. In the end, it is all about revenue, to achieve revenue, you need your equipment to be running 100% of the time.

Q129: How important is the response time and flexibility of the control system?

The response time needs to be able to respond within milliseconds to unforeseen inputs.

Q130: What are the physical and digital security measures for the system?

The sites where compressors are hosted are secured, inside they are often behind fences as well and the control systems in a rack with a lock. All data stays behind the firewalls. The only access point is from a control room and sometimes from another site, which uses encrypted tunnels to communicate.

Q131: How will the data and security be handled in the future?

At the moment we are bringing the control to the beach (land versus the offshore control rooms) in a secure and controlled manner. There is a method to access this data through a tunnel but this is not yet real-time or completely available to people in the office domain. In that way, a rotating equipment engineer can have direct access to the equipment and controls.

Introduction Information Quality

Q132: How is all information displayed?

In the control room. The low fidelity data is replicated to the DCS, it is then further compressed to the beach. So it is available for the business domain but it does not have the same fidelity as the raw data. In the form it is currently available, the decision making process cannot be enhanced.

Q133: How important are the reports available from the system?

The ability to report, to graph and to perform trend analysis is way better than it was. We discovered that the available data was insufficient to give operators situational awareness and to transfer this to other operators. The current display allows new operators in a rotational shift to see in one eyesight how the system has been performing, trends etc.

Introduction Service Quality

Q134: Who is responsible for the service of these systems?

System availability is managed by the engineering department. These individuals are located on a central 'control room' so they are not in the position to reach the system itself. So usually an authorized electrician is doing the physical repairs needed. The OEM is not often involved, COMPANY1 tries to solve everything in house.

Introduction IT/OT convergence

Q135: What core problem does the convergence and integration of IT and OT solve?

It allows for the information to flow to the limited number of individuals who know how to interpret the information in real-time so that problems can either be avoided altogether or they can be rectified in a certain amount of time. It inevitably enhances the insights into all processes, decision-making and production efficiency.

Q136: What are the disadvantages of IT/OT convergence?

Cyber threats, the availability mismatch of information between OT and IT systems. Literally 90% of the systems out there are not the latest version. It will take decades to remove those legacy systems and as a result they will always be exposed to new sorts of cyber threats. Two years ago I updated an MS-DOS systems, these are systems that are 30-40 years old. So for the next 30 to 40 years, unless we start doing something different, we will still be vulnerable to attacks. So what makes vendors today believe that their current systems are resilient enough to last for 30 to 40 years? They have no prove whatsoever. It also requires a different skill, the way you connect and or manage OT systems and the engineering methodologies there are not the actual methodologies used by IT. IT rarely takes into account the probability of failure, or the probability of any events, since they can usually just shut down and reboot the system. For OT this is impossible, the risks and dangers are to big.

Q137: How will the greenfield projects be managed in the future?

Well we already have the goal to only place a person on a platform if we really have to. We always want to automate and remove people from these environments since human errors are still the most dangerous, costly and most risk-full. Another problem is the fact that all the easy accessible sites have been deployed and we have to go to remote areas to find oil. Although we want to have as few people there as possible, the infrastructure for data transfer is often not in place. Therefore we either have to invest millions in providing secure data transfer with the required safety and bandwidth or place someone on-site.

Q138: How do you solve the cyber-security problem?

You should make sure that you have all updates in place. You should not assume that your current approach is undefeatable. Normally you have been hacked between 12 to 18 months before you notice it. So as a result to that, the question should not be, if we are hacked but where we are hacked. As far as mitigating the risks: the best you can do is upfront evaluation of the requirements of the software you will use. But after that it is a continuous battle to eliminate risks by updating, patching, staying up-to-date. Personel itself must stay up-to-date regarding threats as well and must comply to safety standards and measures which sometimes proves to be difficult in practise.

Q139: Are there any organizational barriers for IT/OT convergence?

Governance is complex, it is a multi-discipline approach. In certain discipline approach, sometimes on a single computer. As a result, you are introducing new disciplines to the computer, so IT in engineering and engineering in IT. As a result, it confuses who should be making decisions. (Barrier: Governance and ownership!)

Introduction barriers

Q140: How would you overcome the barrier Technological Silos?

In a practical way you should literally take people from one discipline and put them in the other. So IT people working in controls and automation teams and vice versa. As a result the people need to be credible and engage in the conversation in the other teams. That's the first, practical solution to this problem. However, there needs to be this idea though that in the future, controls and automation individuals should possess these skills.Usually there is more to learn for IT people in engineering than the other way around because in electrical engineering there already is an IT aspect, while there is not a lot of electrical engineering in IT. The way to control this is on an educational basis, from the assumption that IT will need a strong electrical engineering basis and OT needs a strong IT component in it. To the point where networking, how networks and telecommunication networks work and information management is a part of automation and control. The departments should eventually be hybrids or better, one merged department.

Q141: IT in big companies are often sort of consultant teams for OT teams who make the decisions and design a new site. They often 'buy' IT intelligence instead of involving them in the designing process.

A key issue like security, needs to be build from within so an IT individual must be on the team from the start, that way the security of the whole site is more rigor and safe. A problem with this is that you cannot create individuals that know both worlds. You have to have experience in both fields in order to work. By just having the educational background will not allow you to make decisions in this space.

Q142: How can you overcome the barrier cultural differences?

Part of this problem has to do with the legacy of IT. IT in the past, when things did not work, information would not flow, but peoples were not dependent on the information. Nowadays when 911 goes down, people will die so the evolution of how we as a society rely on IT has transformed to the point where the consequences are similar to the impacts of engineers. That is not really appreciated by the IT professionals as they come through 'our' level (OT world). They do not want to think there systems have these kind of impacts.

Q143: Which of these barriers will be the most difficult to overcome?

Governance and ownership

Q144: How can you overcome the barrier governance and ownership?

You literally have two disciplines and they have a good argument on why they are separated and responsible for certain decisions. However in practise, a solution is often a mix of both departments and when you leave it to the IT department they forget typical engineering methods and if you allow the engineering department to make the final call they do not put enough attention in a solid IT basis. You really need to align the decision makers who can force the two worlds to work together. If you cannot start at that point, there is no point in trying at all cause this needs to be implemented top-down.

The relationship between the different departments is and should be symbiotic. So as far of ideas on how to address it, you need to have hybrids, people who have enough experience and acceptance in both departments in senior leading positions. These people however are hard to find but it is crucial that they speak the language of both disciplines so they can broker this dispute.

Most of these organisations where originally created as one. In the past the IT component was so small that the engineers where in fact responsible for this part. But then IT evolved and eventually they split but now where figuring out that perhaps that was a mistake.

Q145: What could be the value of converged and integrated IT and OT?

Some of the emerging technologies on both sides will enable organisations to work more flexible and allow for a distributed control model. The ability for us to leverage that high-fidelity instrumentation data with some of the emerging capabilities like big-data analytics. This will enable the analysis of this data in real-time and allow for the data come to the shore so the big brains in the organisations can figure out what decisions to make. With the right analytics we can actually do that in the systems itself so there won't be any need for the data to come to shore, only the information that follows from the data. There is a huge potential as it relates to not just our industry, perhaps all industries. But it also allows us to make better use of our (scarce qualified personnel since the systems itself can do most of the analysis normally done by engineers.

Q146: Do you see any new business models emerging from IT/OT convergence?

There are at the moment companies that rent out control systems in the cloud. You can even rent a control system network. I don't see why that's a fundamental differentiator for a big player like COMPANY1. For small players however, it reduces the barrier to entry to this industry, which makes the whole industry more competitive. The big thing for big oil, if we are able to free up engineering capacity that allows us to focus those individuals as oppose to keeping systems online and available to engineer the new products and new ways of working so it speeds up our innovative cycle. This does create more and more risks for all parties.

Q147: How far are you with condition based or predictive maintenance?

Not really advanced, like I said you want and need the big data analytics machines to crunch through all available data before anything useful can be said. A problem we encounter at the moment is the fact that the systems are so complex that there is no 'normal state', the system is always in some sort of exceptional state. As a result, if you have no definition of normal, you cannot defend against abnormal. So you really systems to be smart enough to say if a certain state is dangerous. If you collect enough data, there will always be one parameter that will be abnormal. On the other hand, advanced analytics could always find a correlation between two data point while in practise they are not related. The intellectual capacity to update and maintain those model, if we use that to improve the systems we are trying to simulate, we get better results. Another thing of condition based monitoring, it is usually exception detection. This then triggers an alarm on which an operator responds. The problem with this is the fact that the human does not have the situational awareness to prevent it in the first place, he/she only fixes it and tend to make poor decisions.

Q148: What variable will be more important in the future (D&M model)?

Any system that you thrust more, you become more dependent on. So I can see all variables becoming more important but actually reporting could become less important since a lot of steps in manufacturing and production environments will be automated. So perhaps the future systems will only display output and a percentage of efficiency since all other errors will be automatically solved.

Q149: How would you advice other companies to achieve IT/OT convergence?

One of the things you could do on the technological silos is standardization of the silos themselves. Part of the difficulty when one discipline tries to approach the other is because of the different standards that are used in both worlds. Process-, communication- and methodological standards would greatly simplify working in any of these disciplines so learning will be simplified as well. On a typical site you have around 150 different control systems in place so for an IT person to understand 150 applications, this is impossible. This is because IT generally thinks more of global, centralized scale, while OT focuses on specific, decentralized processes and machinery.

Q150: What processes or systems would be suitable for IT/OT convergence?

In this space, you are more focussed on the operational risks than on any other risks. So if you follow those risks, you will find the systems that are best suitable.

Virtualization, hosting different control systems on the same, standardized platforms has been proven to work. Reducing costs, bringing data together, updating.

Point of View for Business Implementation

The following pages contain a summary of the findings of this research with a focus on the developed roadmap. This document is send to all participating companies as a tool in order to achieve IT/OT convergence.