

Increasing overall equipment effectiveness of drilling machines by means of data driven dashboards

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Preface

I want to thank you for taking the time to read this study. The study originated from my desire to improve the working environment in which I am situated while adding value to academia. For this reason, I chose to make use of Action Design Science Research as my primary research methodology. It proved to be very successful, as the research and inputs from the industry, as well as academics, proved insightful regarding the development of solutions throughout this study. It contains interesting views with a practical focus on the improved use of data within a company. Although focused within the South-African mining industry, it is my opinion that the findings and deliverables could be adapted easily to most industries.

One of the aims of this study was to develop myself within the field of industrial engineering, as well as in the field of research. For this reason, I chose to publish an article in the South-African Journal of Industrial Engineering (SAJIE), which I presented at the 29th Annual SAIE conference. It proved to be an exceptional learning experience, as it developed my professional writing skills, professional presentation skills and way of thinking throughout the process. The article formed an integral part of this study, as it set the foundation on which the rest of the research is then conducted.

The largest global drilling company is used as a case study to validate the findings and artefacts of this study. It produced artefacts such as the improvement of data-driven services, and the development of an operational dashboard to decrease the complexity of project management within the drilling operations environment. It proved insightful with experts in the field contributing their opinions and knowledge to the research conducted. Being situated within the drilling environment, it was not that challenging to understand the situation itself, as it consists of my daily responsibilities in a professional context. Conducting this study proved to be a joyful endeavour, as it succeeded in the main goals of developing myself, contributing to the mining industry as well as the field of academics.

Abstract

The decline in revenues, within the South-African mining sector, over the last decade is troublesome, considering a significant level of employment it creates. This study aims to create a link between improved operations and operational dashboards. Improvement in the effectiveness of drilling operations creates the potential for mining companies to expand quicker and generate returns on their investments. The value of dashboards within companies is rapidly increasing with the growth in computer and data science worldwide. This growth, accompanied by the wave of Industry 4.0 technologies, has the potential to provide substantial value to companies investing therein. The study focuses on the use of such technologies within the South-African mining sector. It provides an interesting view of the improvement of operational project management, using data-driven dashboards. It considers various elements surrounding the dashboard.

A hands-on approach is taken, using the perceptions and opinions of experts within the mining sector, as well as academia. Some of the understandings and views originate from experts within the world's largest specialised drilling company. An Action Design Research method is followed, focusing the research on a solution that adds value in a practical application.

The solutions and discussions on specific research questions within the study provide a unique perspective on the use of a company's strengths, to increase its maturity regarding the adoption of Industry 4.0 technologies. Further research into the development of an operational data-capturing system within a drilling company is conducted, including the development of an operational dashboard with which its contracts can be managed. The value of such a dashboard is effectively verified using a well-structured validation approach, including the consensus of professionals within the mining sector.

This study displays the value of a data-driven services focus, in increasing the maturity of a company, using a case study throughout. The increase in maturity to adopt new technologies is evident when a strong focus is placed on the accuracy of, attaining of, and intelligent visualisation of operational data.

Keywords: Industry 4.0, Data-Driven Dashboards, Mining, Overall Equipment Effectiveness, Maturity Improvement, Operational Project Management

Opsomming

Die afname in inkomste binne die Suid-Afrikaanse mynbedryf, oor die afgelope dekade is lastig, met inagneming van die groot hoeveelheid mense wat dit in diens neem. Hierdie studie het ten doel om 'n verband te skep tussen verbeterde operasies en operasionele paneelbord. Verbetering in die doeltreffendheid van boor bedrywighede skep die potensiaal vir mynmaatskappye om vinniger uit te brei en opbrengs op hul beleggings te genereer. Die waarde van data verslae binne maatskappye brei vinnig uit met die groei in die rekenaar- en data-wetenskap wêreldwyd. Dit, vergesel van die golf van Industrie 4.0 tegnologie, het die potensiaal om baie waarde te bied aan maatskappye wat daarin belê. Hierdie studie fokus op die gebruik van sulke tegnologieë in die Suid-Afrikaanse mynbou sektor. Dit bied 'n interessante siening oor die verbetering van verbeterde operasionele projekbestuur, deur middel van data-aangedrewe verslae. Dit beskou verskillende elemente rondom die data verslag, sowel as die verslag self.

'n Praktiese benadering word gedoen deur die persepsies en opinies van kundiges in die mynbou, sowel as akademie, waarvan sommige in die wêreld se grootste gespesialiseerde boor maatskappy gebaseer is. 'N Aksie Ontwerp Navorsingsmetode word gevolg, wat die navorsing fokus op 'n oplossing wat waarde toevoeg in 'n praktiese toepassing.

Die oplossings en besprekings oor sekere navorsing vrae binne die studie bied 'n perspektief op die gebruik van 'n maatskappy se sterk punte om sy volwassenheid te verhoog rakende die aanvaarding van Industrie 4.0 tegnologie. Verdere navorsing word gedoen in die ontwikkeling van 'n operasionele data-vaslegging stelsel binne 'n boor maatskappy, insluitend die ontwikkeling van 'n operasionele data verslag waarmee die kontrakte bestuur kan word. Die waarde van so 'n data verslag word effektief geverifieer met behulp van 'n goed gestruktureerde evaluasie metode, insluitende die konsensus van professionele individue in die mynbou sektor.

Die fokus op data-gedrewe dienste binne die boor omgewing en die volwassenheid verhoging wat dit behels wanneer dit korrek benader word, word met behulp van 'n gevallestudie regdeur hierdie hele studie getoon. Die toename in volwassenheid om nuwe tegnologie aan te neem, is duidelik, wanneer daar sterk klem gelê word op die akkuraatheid, bereiking en intelligente visualisering van operasionele data.

Sleutel Woorde: Industrie 4.0, Data-Gedrewe Verslae, Mynbou, Algehele Toerusting Effektiwiteit, Volwassenheid Verbetering, Operasionele Projek Bestuur

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Chapter 1: Research Overview

“Mining is the art of exploiting mineral deposits at a profit. An unprofitable mine is fit only for the sepulchre of a dead mule.” — T.A. Rickard

1.1. Introduction to Industry

In 2017 the South African mining sector contributed a sizable 5.1% to the country's Gross Domestic Product (GDP) (O'Callaghan *et al.*, 2017). The impact of the mining sector on the GDP, however, has decreased by 15% since the 1980s (Africa, 2017a). It contributed to about 27% of the country's exports, adding up to R307 billion for the year 2017 (Mines, 2017) year-on-year. The sector currently employs over 450 000 individuals throughout the country, making up about 2.5% of the country's entire workforce (Africa, 2017c). The mining sector supplies materials and services which sustain various industry sectors within South Africa, while also contributing significantly to the successful functioning of global economies (Mancini, 2017). The country exported over R320 trillion worth of metals into the global market, used in numerous industries. These metals include chrome, copper, iron ore, zinc and coal to name a few (Africa, 2018).

In 2017 this sector alone lost over R4.84 billion due to stoppages, which excludes the labour costs of workers during idle time (O'Callaghan *et al.*, 2017). South Africa has rich mineral ore deposits that constitute long term improvement initiatives to increase profitability within the sector. Such initiatives aim to improve the growth of the sector by saving money, increasing efficiencies within the mining operations, or better use of capital. Improvements such as these will add value to the long-term development of the sector, increasing the sector's value contribution and footprint within, and towards the South African economy.

Large technological advances have been made in the last few decades, considering industries are moving from mass production to more diverse and dynamic production methods (Vaidya *et al.*, 2018b). Due to global technological advancements, the evolution within all industries is labelled as Industry 4.0. It includes an improvement from the use of automation technologies, computers and electronics, Cyber-Physical Systems, Internet of Things, Big Data, Artificial Intelligence, Virtual Reality, Artificial Reality and Machine Learning, to name a few (Vaidya *et al.*, 2018b). These technologies create accelerated levels of innovation within companies, thus creating more significant opportunities for value creation (Hagel *et al.*, 2013). The capability arises for global macroevolution of industries, created by the adoption of disruptive new technologies.

These advancements are increasingly becoming more visible in the global mining sector. The use of Virtual Reality, Big Data, Artificial Intelligence, and Internet of Things is already being adopted in certain mining and mining support services. Examples of the technology include predictive maintenance (Dingo, 2018), Virtual Reality centres used for training (Solomons, 2015), use of automated machines (Moore, 2018c), to name a few. The question is no longer *if* these technologies should be adopted, but rather how quick one can adopt them to stay relevant and profitable.

1.2. Background on Drilling in the Mining Industry

For a mine to be profitable, the ore needs to be extracted from underground or surface ore bodies in an efficient manner at minimal costs, generating revenues able to cover the costs, as well as yield profits. These ore bodies, mostly situated underground, need to be explored and accessed for extraction to take place. To access these ore bodies, mines must expand to reach the ore-rich areas. Mines can expand or develop using different methods, such as blasting and drilling (Newman *et al.*, 2010). Drilling is not solely for ore extraction but is also necessary to enable various other underground processes, such as transferring ore from underground to surface, and provision for oxygen and water underground.

Underground drilling is conducted at various angles with various types of machines, each focusing on different goals, depending on the requirement of the mine and the drilling method used. One such method is referred to as raiseboring. Raiseboring consists of the drilling of a pilot hole, attaching a reamer to the end of the drill rods, and pulling the reamer towards the machine using mechanical power in order to produce a shaft. These shafts are primarily used in the mining environment for ventilation shafts, ore passes or access shafts. Other applications include tunnelling of rail networks and pressure shafts in hydro-electric plants. This study focuses primarily on the practice of raiseboring within the mining applications.

Raiseboring can be a very challenging task to conduct, as it is influenced by multiple different variables which a service provider doesn't necessarily have control over. The variables which it does, in fact, have control over generates a lot of data on various resources. This includes the machine, labour, expenses, production estimates, activity management, ground conditions, failure and safety information to name a few. This data can potentially be analysed and used to improve current operational drilling practices.

According to Dr Christopher Ganz, Group Service R&D Manager of ABB Technology Ltd, the analysis of data captured by a company, after which the knowledge it creates leads to new and improved service offerings within the company to further create value for the customer (Ganz, 2016), is referred to as Data-Driven services. Without DDS forming an integral part of a company, the adoption and improvement of new disruptive technologies may prove to be very difficult. Such technologies are becoming even more important in the present competitive global markets. An Industry 4.0 maturity assessment was done on the world's largest drilling company, Master Drilling, identifying the lack of maturity regarding data-driven services in 2018 (Maasz & Darwish, 2018). This study indicates a very definite emphasis required in the field of data driven services within the South African, and potentially the global, mining sector. The assessment results are displayed in Figure 1.

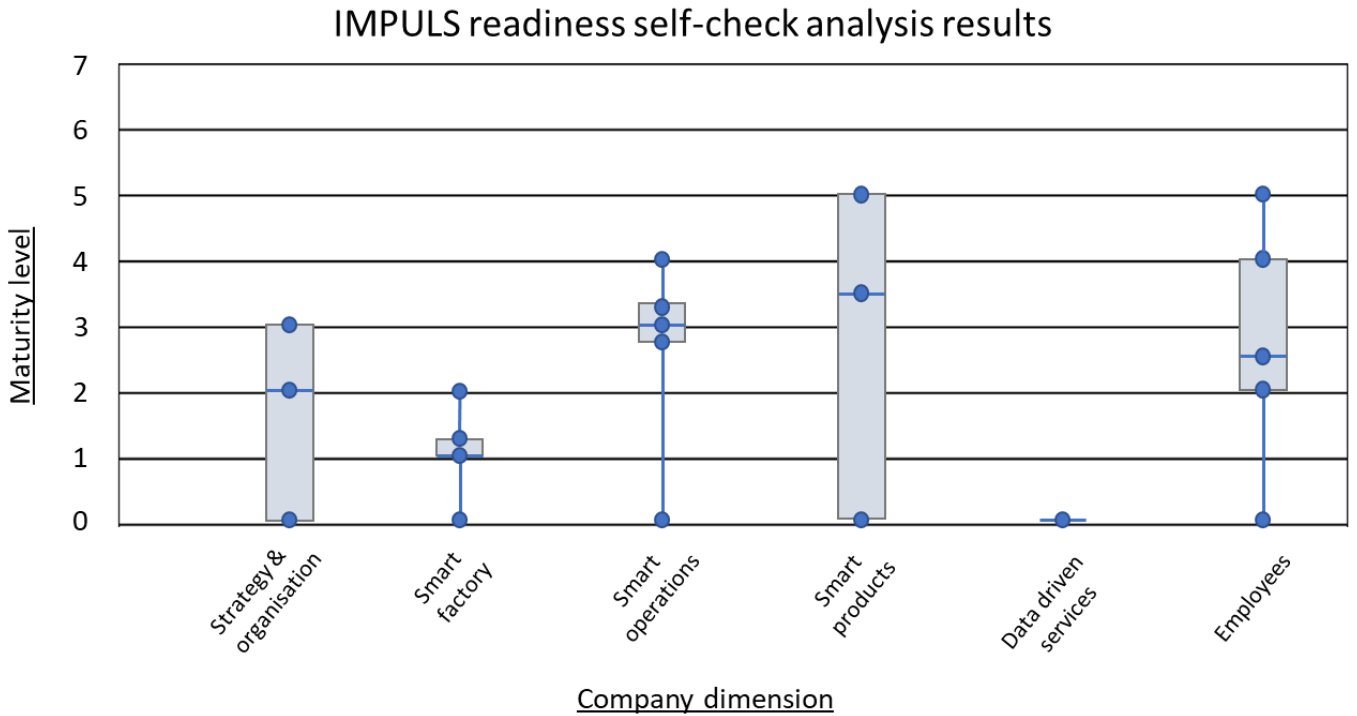


Figure 1: Drilling Company maturity assessment (Maasz & Darwish, 2018)

Among the six dimensions analysed within the company, Data-driven services presented to be non-existing at the time of the assessment. The article concluded with the development of an improvement process for different dimensions. This process, displayed in Figure 2, is valuable to use as a guideline on the improvement of data-driven services, which could potentially lead to better service offerings of drilling companies (Maasz & Darwish, 2018).

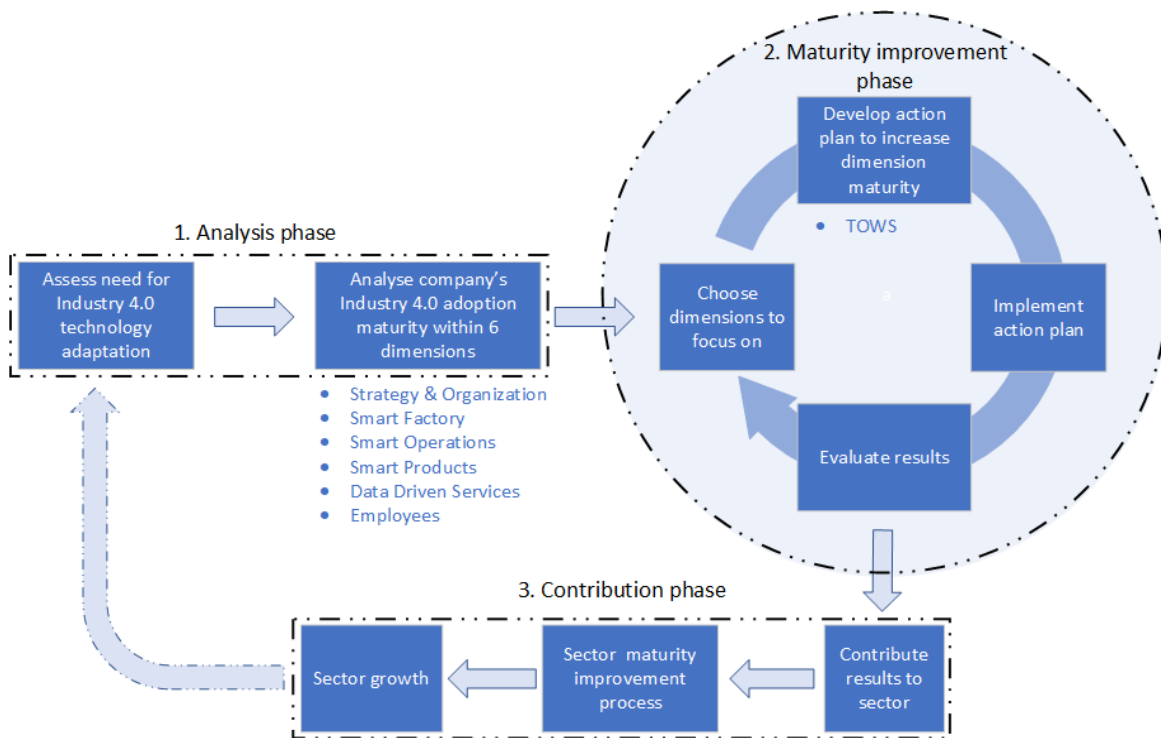


Figure 2: Maturity improvement process (Maasz & Darwish, 2018)

1.2.1. Context of a drilling company

To emphasize the validity of this study, a case study is conducted on a drilling company, to verify and validate the artefacts of this study.

Various drilling companies exist globally, focusing on exploration drilling, tunnelling, raise boring and shaft boring to name a few. Drilling companies in general have large amounts of data ranging from employee performance to machine voltage and vibration data. This data is used to provide insight into machine delays, contract and project health, customer delays, etc. The data is captured on various platforms over all drilling entities globally. The use of this data can potentially benefit drilling companies significantly. For this study, however, the focus will be scoped around the operations function within a South African based drilling company.

Due to challenging economic environments, a company should produce more significant revenues to stay as profitably successful as in the past, while not necessarily having more expenses. Accounting for large time losses on projects, due to delays within drilling contracts, the potential exists for process and procedural improvements.

In 2017, a drilling company recorded over 38.6% of the available time lost due to various delays. This excluded time which machines spent without contracts and included all machines within the company's drilling fleet. The daily time within this company's shift reports is currently grouped into the following activity categories which are discussed in more detail later in this document:

- Delays by the Company
- Delays by the Customer
- Neutral Delays
- Marketing Delay (Machine without contracts)
- Productive Time on Contracts

Machine availability on operational projects have a direct influence on the profitability of a project. If a drilling machine is unable to work due to any delay, the timeframe on which the project has been planned is more difficult to adhere to. Overall Equipment Effectiveness (OEE) is a suitable key performance indicator for improvements in manufacturing productivity. It is composed of three components:

1. Availability
2. Performance
3. Quality

Improving any of the three components, positively influences the OEE of a resource or process. Due to various delays in the operational raiseboring process, machine availability is low, thus decreasing the OEE of raisebore operations. Having a solution which drilling companies can use to make

quicker, more informed and better decisions will aid in better project management, with increased OEE. For this to be possible, accurate and timely data is required. The lack of machine availability cannot undeniably be attributed to a specific action or actions within the drilling process due to a lack of trustworthy data on the subject.

Data does not add value, if not transformed into information. One way of transforming data into information which can be used for decision-making is by displaying it on a dashboard. Dashboards are in essence a consolidated view of large amounts of data, aimed at empowering the users thereof to act or make decisions based on the information provided (Matheus *et al.*, 2018). The study conducted on a global drilling company maturity displayed a definite lack in the successful use of data within all its global entities (Maasz & Darwish, 2018). The detail of this study conducted by the author of this report is in Appendix O: SAIE article.

1.3. Examination of Core Problem

Overall equipment effectiveness is a standard used to measure manufacturing productivity, or in this case, that of a drilling machine. It uses a combination of availability, performance, and quality to calculate the productive time of a specific machine. Due to various delays, the productive operational drilling time on drilling contracts is reduced, increasing the time it takes to complete the contracts. The reason for this is low operational availability.

1.3.1. Problem Statement

There exists an analysis gap within drilling companies, primarily focused in the mining industry, between operational data captured and the management and improvement of on-site drilling operations that reduces overall equipment effectiveness of a company's drilling machines.

1.4. Research Questions

RQ1: How is operational data captured, and how can it be used to improve the management of drilling operations?

RQ2: What strategy can be used to simplify cumbersome operational data sets into useful operational information?

RQ3: How can the delay between operational issues and mitigation actions be decreased by increasing the visibility of project operations?

RQ4: Which Industry 4.0 technologies are best fitted to improve the use of operational data?

RQ5: What is the impact of a company's maturity on improving its data-driven services?

RQ6: How effective is the current process of capturing operational data?

1.5. Research Aims and Objectives

1.5.1. Research Aim

This study aims to demonstrate the value of data-driven dashboards in improving the overall equipment effectiveness of operational raise boring machines.

1.5.2. Limitations and Assumptions

The study focuses on the development of a dashboard; however, to contextualise the problem, a case study at a drilling company is conducted. Original company applications, as well as realistic operational data, are used to conduct research on, contextualize, test, and validate artefacts produced. Processes and methods designed throughout the study may be open to being used in any operational context. The concepts regarding the development of dashboards and the operational data capturing system can potentially form the basis of an effective operational management system if modified to the specific application.

1.5.3. Research Objectives

The following objectives have been formulated to answer the research questions stated in Section 1.4:

RO1: Prepare a list of common problems with the current data system issues within drilling companies.

RO2: Conduct a gap analysis of the current operational data capturing system within drilling companies.

RO3: Create a list of system requirements for data-driven dashboards.

RO4: Develop a classification matrix to group activities which occur in drilling operations.

RO5: Develop data-driven dashboards which create insight for management of drilling companies on contract states.

RO6: Redesign the current operational shift activity capturing process to be more productive.

1.6. Research Overview

A basic overview on the structure of the entire study displayed in Figure 3, presenting the different sections of the study. The research overview section applicable to each chapter will be discussed in the relevant chapters, further expanding on the applicable details.

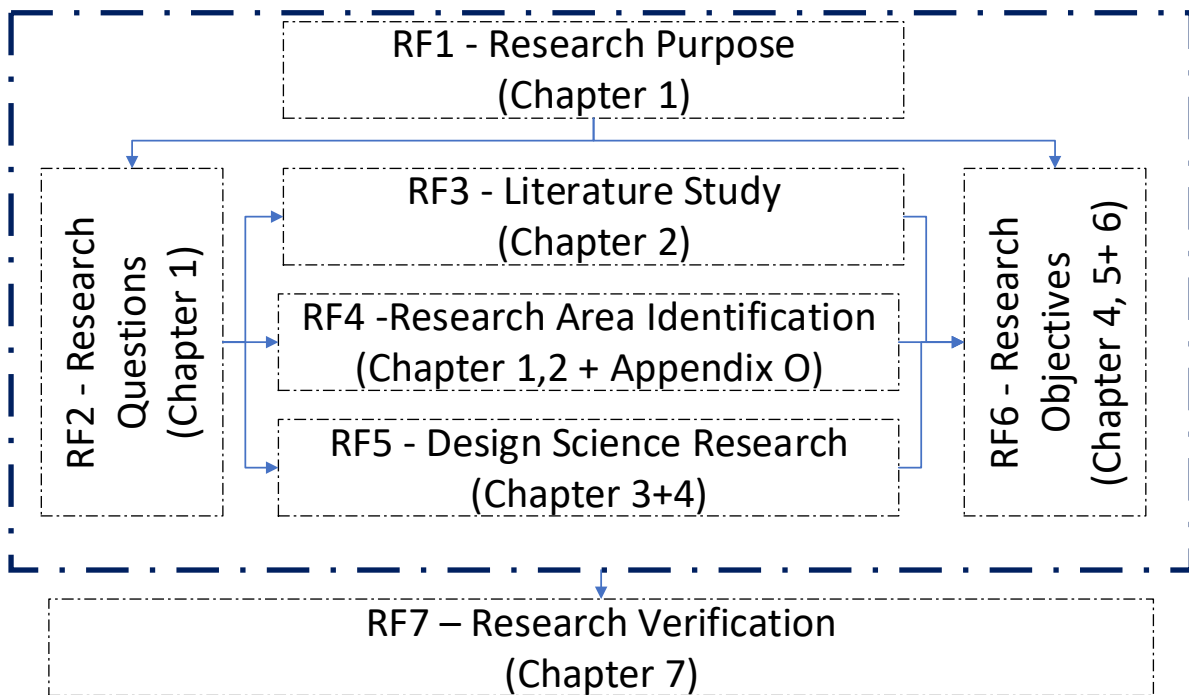


Figure 3: Research overview

The outline provides a high-level overview of the research conducted to deliver research-worthy artefacts. It includes the research method, research design, design science research cycles and the development of research questions into research objectives valid to the research topic.

1.7. Research Design and Method

1.7.1. Research Design

The research is approached with a qualitative philosophy, focusing on using the information and experiential knowledge of experts within a field, the results from this study, as well as knowledge found within literature, to formulate facts. It includes the use of a survey developed by the IMPULS Foundation of the German Engineering Federation (VDMA) to gather data to verify the problem, as well as assist in validating the developed artefacts. Data is then reported in a format which the end-user thereof can use and understand. An overview of the research design approached followed is displayed in Figure 4.

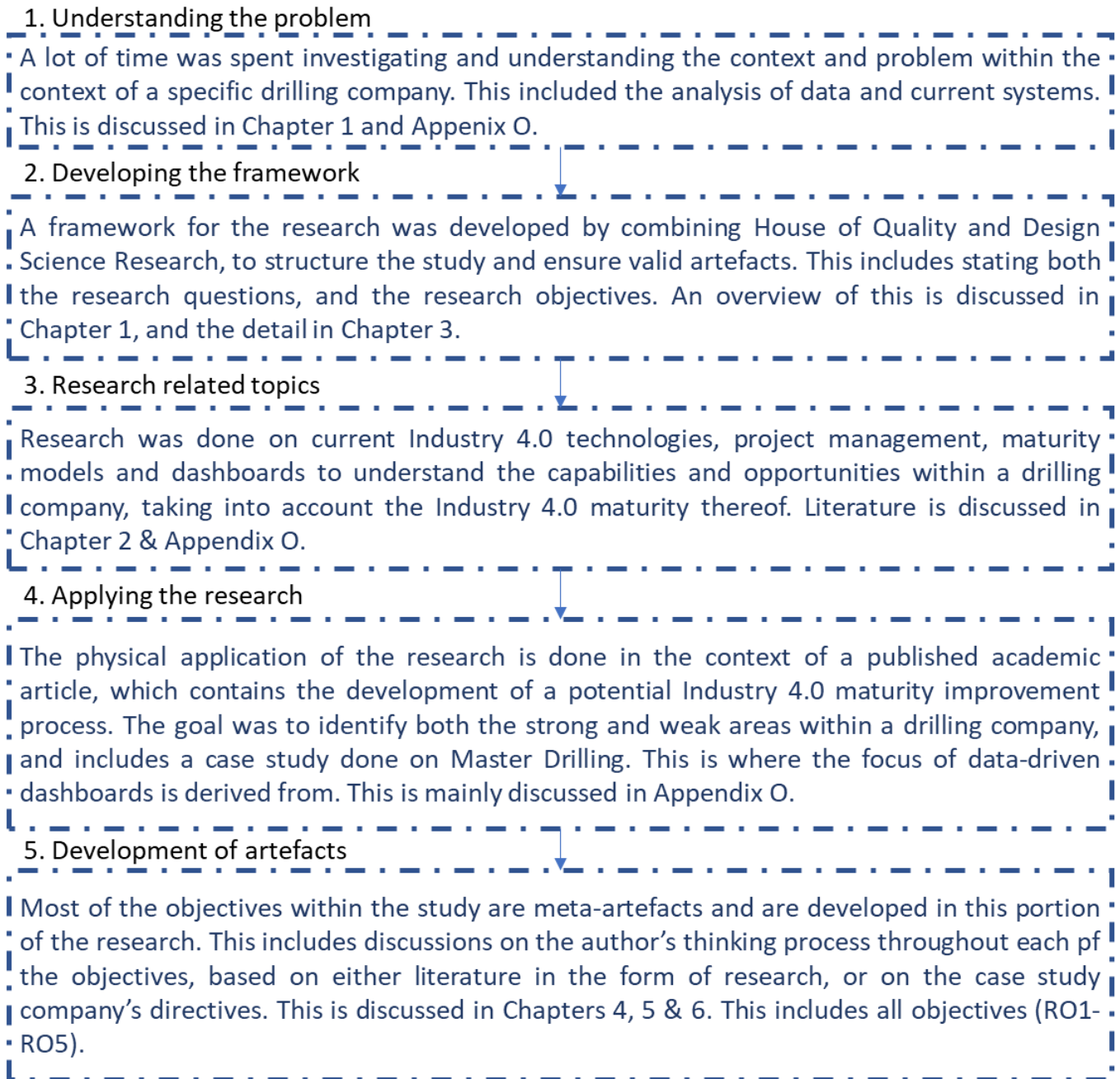


Figure 4: Research design overview

1.8. Chapter Outline: Research Purpose

The further expansion of the research purpose (RF1) and research questions (RF2) of the research outline is displayed in Figure 5, where the research gap identified is displayed. The research problem statement is further analysed to develop various research questions (RQ1-RQ5). This gap is the missing link between operational equipment effectiveness and tools which aid in the monitoring and management thereof. Such tools are not readily available within the South mining context. The problem and research questions form the foundation on which the rest of this study is built.

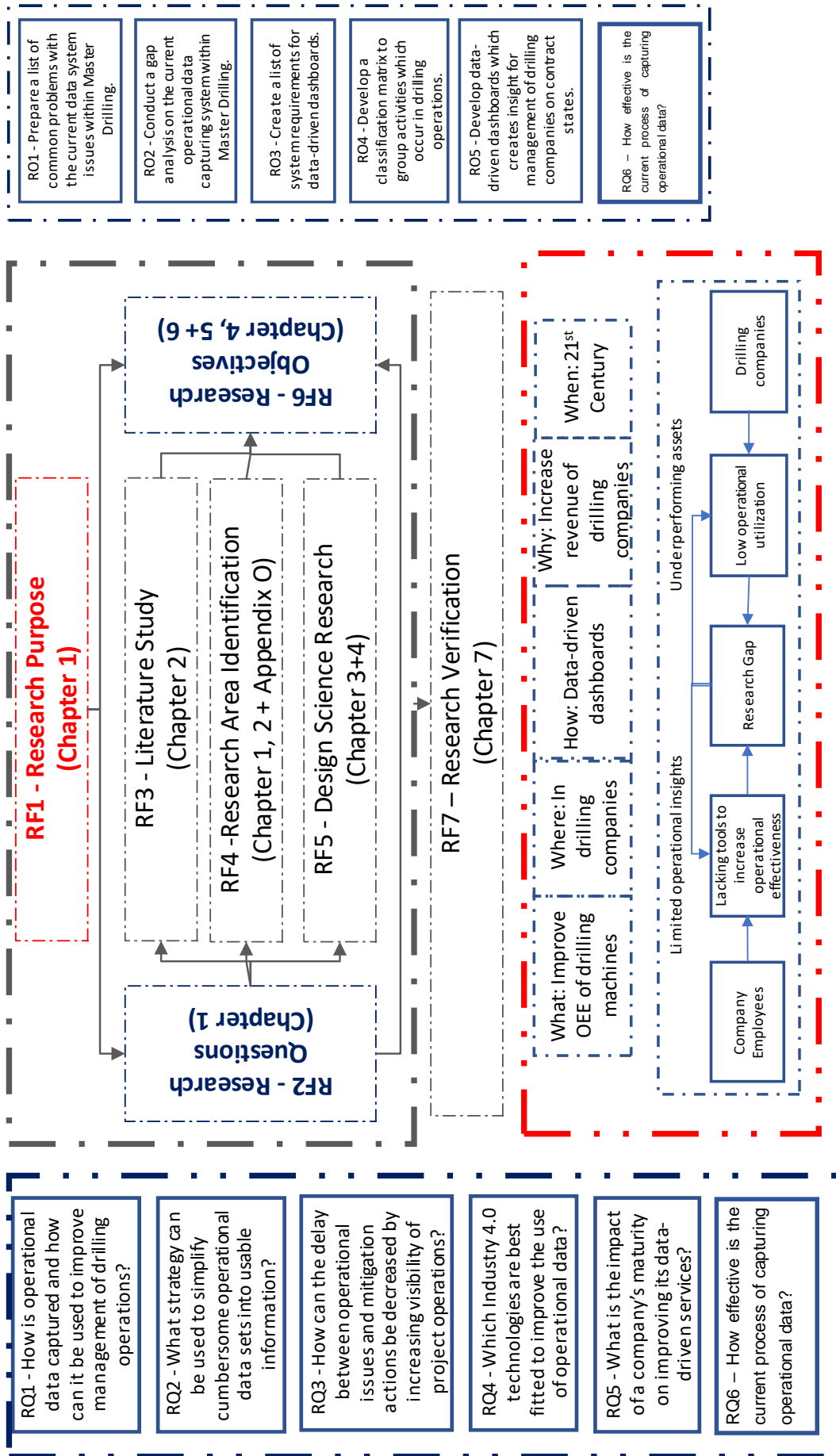


Figure 5: Research overview - research purpose

Chapter 2: Literature Review

2.1. Chapter Outline: Literature Study

To fully understand the value of this study, it is essential to understand the influence which increased drilling effectiveness has on the environment surrounding drilling companies. An overview of this is presented in Figure 6. Focusing on drilling operations with the goal of productivity increases has the potential to positively influence the South-African economy, as well as to help the national mining industry with various challenges currently faced.

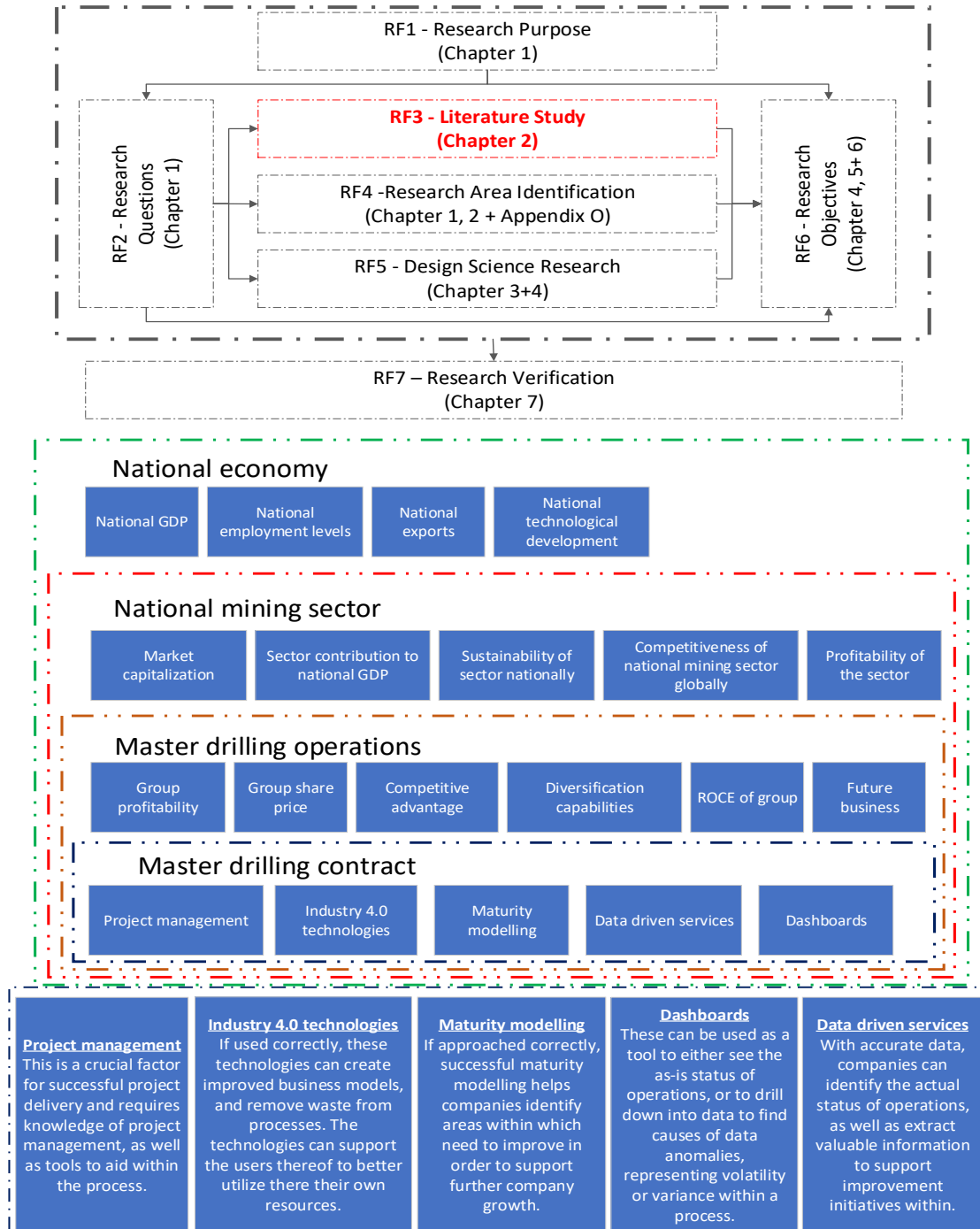


Figure 6: Research overview – literature study

Drilling companies create shafts required within deeper mine levels for underground expansion to take place. These shafts are used for ventilation, which is a necessity for further mine development. The company also performs horizontal drilling at speeds faster than that created using current conventional expansion methods. The company thus creates the ability for mines to develop at higher speeds, decreasing the return on capital days of the mining companies themselves.

Considering the decline in South-African mining sector revenues over the last decade, these methods can help turn the fall around. Quicker mine expansion means more rapid access to higher grade ore (Calvo *et al.*, 2016). The drilling methods expand mines without employees having to leave the undergrounds sites, due to explosives and toxic gasses usually associated with underground development.

The South African mining sector had a decline in its contribution to the national Gross Domestic Product (GDP) over the last two decades. It is primarily due to increasing expenses and difficulties in the extraction of higher-grade ores. These difficulties include increasing haul distances, increased time to the rock face, which directly influences time lost due to blasting and development. Improving capabilities to face these challenges and increase available mining time creates the potential for the mining sector to increase its contribution to the national GDP.

Correct utilization of methods and technologies discussed in this chapter can lead to possible utilisation increases within drilling operations. These methods and techniques will, however, yield higher utilisation improvements if combined, as they shift the focus to different areas within the management and improvement of operational drilling contracts.

2.2. Project Management

The Project Management Institute defines a project as a ‘temporary endeavour undertaken to create a unique product, service, or result (Anon, 2018). It further defines project management as the ‘application of skills, knowledge, tools, and techniques to project activities to meet the project requirements’ (Anon, 2018). The discipline of project management is thus required to ensure that the initial conditions or needs of the project customer are met on time, within budget and to the correct quality standards associated with it (Bjorvatn & Wald, 2018). Successful project management is a fundamental factor for a project, either succeeding or failing (Kivilä *et al.*, 2017).

A project lifecycle is split into five groups (Anon, 2018):

1. Initiating
2. Planning
3. Executing
4. Monitoring and Controlling
5. Closing

A project consists of each of these groups, each containing certain goals. Completing all the goals will result in a completed project. Achieving these goals, however, requires visibility and efficient project control (Kivilä *et al.*, 2017).

Additionally, effective project management aims to remove complexities from the project to increase project management performance as follows (Bjorvatn & Wald, 2018):

- Reduces risks of unscheduled delays
- Decreases the likelihood of cost overruns

Drilling projects are very similar to construction projects, as it is the construction of a shaft for a specific purpose. It contains the same project groups, as mentioned above, regarding the project lifecycle. Each of the groups must be managed effectively to reduce exposure to unnecessary and unexpected expenses. Compromising on quality, time or cost can have substantial effects, due to drilling projects being very expensive. When unplanned expenses are incurred, the service provider’s cash flow is influenced negatively. When compromising on quality, it leads to safety hazards for the customer. When compromising on time, either quality or cost may be compromised due to either a delay or drilling too fast, which may cause a decrease in the quality of the final product.

2.3. Industry 4.0 technology overview

The wave of technology developments referred to as Industry 4.0 has brought to light a significant change in available technologies, as well as the innovation on what all these technologies can be used for. Technology advancements have been occurring since the 1760s (Ashton, 1994). Revolutions within the industry are classified as different industrial revolutions, as presented in Table 1.

Table 1: History of industrial revolutions

Industrial Revolution	Year Started	Description
First Industrial Revolution	1700-1770 (Mantoux, 1961), (Nuvolari, 2019), (Trew, 2014)	Witnessed the emergence of mechanisation where industry replaced agriculture as the foundation of the economy. This included the mass extraction of coal and the invention of the steam engine.
Second Industrial Revolution	1870-1889 (Mokyr, 1998), (McLean &	The emergence of electricity, gas and oil lead to the development of the steel industry, which had major demand. Included the development of communication methods, the automobile and of the aeroplane. The production line era originated here.

	McGovern, 2017)	
Third Industrial Revolution	1969 (Davis, 2016)	The discovery of nuclear energy and electronics lead to space research and biotechnology. It included the use of data and personal computers.
Fourth Industrial Revolution	Current	Development of cyber-physical systems and digitisation, enabling the interaction of different systems via internet connection. Applications such as predictive maintenance, real-time improved decision making, improved inventory planning, to name a few.

Different technologies that have emerged globally include Big Data, Internet of Things, Machine Learning, Artificial Intelligence, Virtual Reality and Augmented Reality, to name a few. Each of the technologies has different applications and benefits to modern companies if applied and adopted successfully (Lu, 2017). The following technologies have the potential to either increase a company's ability to capture data or to analyse and display it, creating value for the user thereof.

2.3.1. Internet of Things (IoT)

This technology makes use of sensors and actuators embedded within physical objects and machines which work together by communicating via data transfers over either a wired or a wireless connection (Chui *et al.*, 2010b). It creates more significant opportunities for autonomous manufacturing services and increased data collection. McKinsey & Company summarises the different applications created by IoT in two different applications:

1. Information and Analysis
 - a. Tracking Behaviour – Monitoring behaviour of objects over time.
 - b. Enhanced Situational Awareness – Achieve real-time awareness of the physical environment.
 - c. Sensor-Driven Decision Analytics – Assist human decision making through in-depth analysis and data visualisation.
2. Automation and Control
 - a. Process Optimization – Automated control of closed systems.
 - b. Optimised Resource Consumption – This refers to the control of consumption to maximize resource use across the network.
 - c. Complex Autonomous Systems – Automated control in open environment containing considerable uncertainty.

IoT consists of different aspects such as the Internet of Service (IoS), Internet of Manufacturing Services (IoMs), Internet of People (IoP) and an embedded system and Integration of Information and Communication Technology (IICT) (Neugebauer *et al.*, 2016). It creates the potential for an intelligent value chain integrating physical objects throughout (Vaidya *et al.*, 2018b). It creates the ability for software and data to play an integral role in intelligent planning and control (Vaidya *et al.*, 2018b) within companies.

According to the Inmarsat Research Programme’s IIoT readiness survey, a South African drilling company is situated within the top 22% of the 125 respondents within the mining industry, which have completed the same study (Inmarsat, 2019). The survey ranks a company within one of 4 levels, namely (Laggard, Starter, Progressor, Leader) by scoring in it in the following areas:

Table 2: IIoT scoring criteria

1. Adoption	2. Skills
3. Data	4. Investment
5. Sensor deployments	6. Security
7. Connectivity	

Mining company, Newtrax, uses IIoT devices within mines to make substantial savings by focusing on minimising the effect of specific delays within the mining environment. Their focus is on the following (Technologies, 2019):

- Delays due to unknown equipment locations
- Short-term scheduling delays due to the lack of real-time information on mining operations
- Delays in hauling due to traffic congestion
- Delays in backfill due to the stoppage between shifts
- Delays in post-blast re-entry
- Delays due to unexpected breakdowns of mobile equipment

They mention the OEE increase of 4% for one of their customers, Glencore Matagami (Technologies, 2019), displaying the value of this technology within the industry.

Implementation of IoT technology can play a very important role within a drilling company to capture a lot of the data, currently captured manually, automatically. This can save both time and resources within the company, as well as increase the reliability of the data, due to human error being removed.

2.3.2. Machine Learning

Machine Learning refers to the automation of model construction using an analytical approach. It creates the ability for a system to learn, or adapt, based on the data it analyses (Ng, 2018). This includes the making of decisions and identification of patterns and correlations within the data using

minimal human interaction (SAS, 2018). A computer algorithm uses complex algorithms to detect patterns in a data set and uses these patterns to predict outcomes with other data sets. Applications for machine learning include:

- Financial industry – Fraud prevention and identification of essential insights in data
- Government – Public safety agencies mine data to prevent identity fraud
- Health care – Wearable devices and sensors can access patient data in real-time, also creating the potential to identify and diagnose certain illnesses
- Marketing and sales – Websites use customer buying history to recommend items they might be interested in buying.
- Oil and Gas – Finding and analysing new energy sources and predicting refinery sensor failures
- Transportation – Google’s self-driving car is a product of machine learning

Machine learning aims to understand the structure of data and fit statistical distributions from which it can then be analysed. Iterative methods are used to move through the data provided until it finds a robust pattern (SAS, 2018). Machine learning is the best way to approach human-level artificial intelligence (SAS, 2018). T.H. Davenport motivates the use of machine learning well in an article published in The Wall Street Journal where he stated the following:

Humans can typically create one or two good models a week; machine learning can create thousands of models a week (Davenport, 2013).

Davenport further mentions a conservative estimate on the value of machine learning models developed for IBM saving around \$50 million in 2009 (Davenport, 2013), with systems creating up to 5000 models a year.

Machine learning is mainly categorised with two types of techniques, each having sub-categories and accompanying mathematical algorithms as displayed in Figure 8. A systematic workflow on how to tackle machine learning problems is shown in Figure 7.

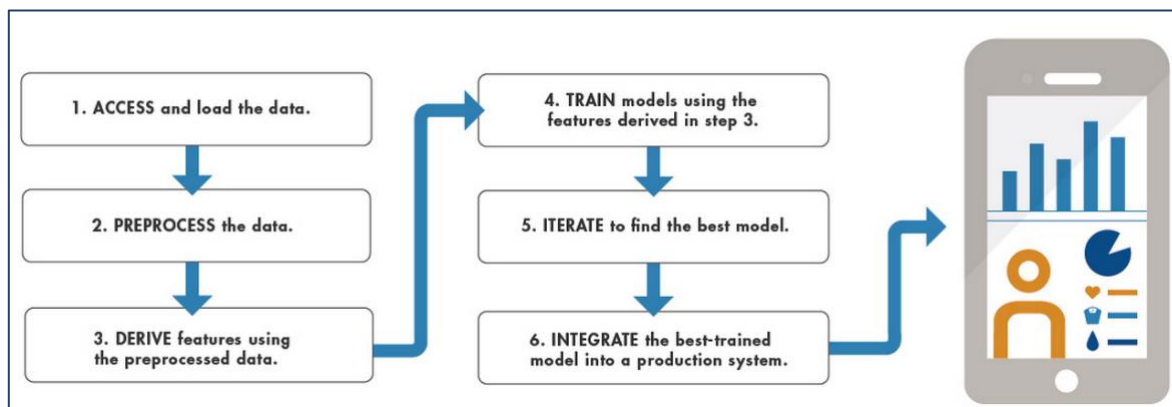


Figure 7: Systematic Machine Learning workflow (Mathworks, 2018)

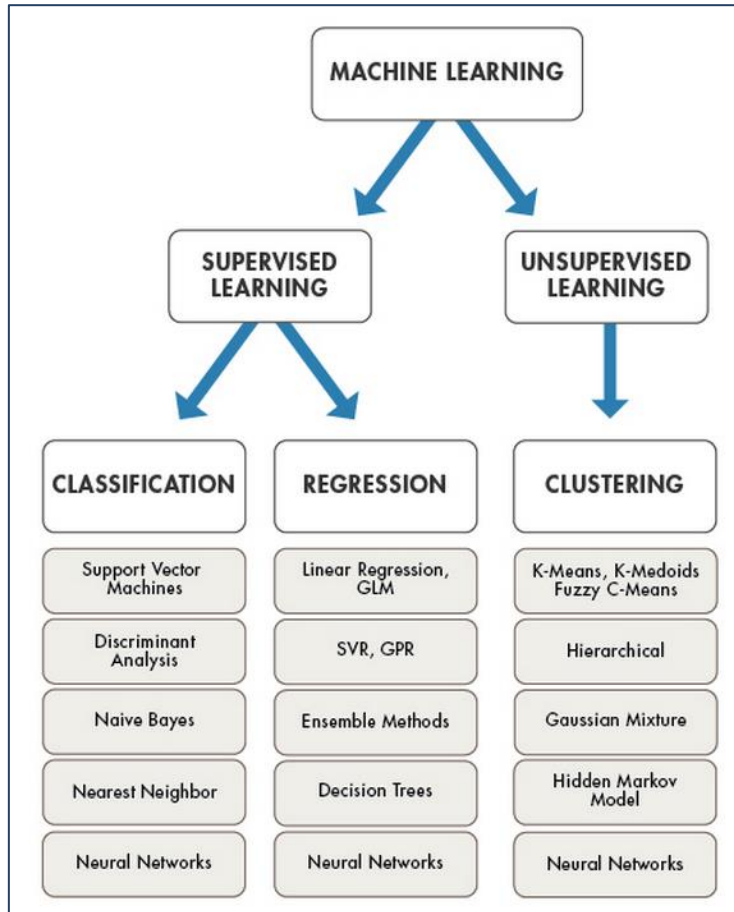


Figure 8: Machine Learning techniques and algorithms (Mathworks, 2018)

Supervised Machine Learning

Using a dataset, a computer is trained that specific inputs yield specific outputs. The output is approximated using a mapping function, created by the computer, using a specific supervised machine learning algorithm (Christiano & Zhao, 2016).

Unsupervised Machine Learning

These methods consist of an untrained computer algorithm using the data set provided to categorise items throughout the learning process using the structure of the data (Christiano & Zhao, 2016).

Both supervised and unsupervised machine learning techniques can significantly benefit companies in the analysis of large data sets, as well as aid in decision making of certain basic functions currently conducted by human personnel.

2.3.3. Artificial Intelligence (AI)

Some of the first applications of AI are attributed to a computer winning a professional player of the Chinese board game “Go” (Silver & Hassabis, 2016). The technology of AI imitates the evolution of the human mind to adapt and reason towards reaching a specific goal, without having any built-in knowledge (Gurkaynak *et al.*, 2016). AI is classified into three different categories:

1. Artificial Narrow Intelligence (ANI) – It consists of limited capabilities which focus only on a specific task or goal.
2. Artificial General Intelligence (AGI) – It is described as ‘human-level’ AI’s which can perform tasks and make decisions at the intellectual capacity of a human being.
3. Artificial Super Intelligence (ASI) – It is smarter than the best human minds, including scientific creativity, general wisdom and even social skills (Bostrom, 2006).

With the exponential growth of technology and computational power, as described by Moore’s Law (Gurkaynak *et al.*, 2016), the potential of AI is unfathomable. It has greater intellectual capacity and working speeds than human beings. If harnessed correctly, this technology can provide significant benefits to any company, primarily when used to work with complex big data.

Goldspot Discoveries Inc. is a company which leverages big data to use machine learning and artificial intelligence technologies to disrupt and create more resource-efficient ways to explore resource reserves in the mining industry (Inc., 2019b). The company uses AI to make intelligent investment decisions, optimise operations and identify drill targets. According to them, they have “outpaced the capabilities of traditional geologists” in analysing geology data. The data collected by the customers are used to predict gold spots by focusing on the following (Inc., 2019a):

- Ore deposits
- Prospects
- Occurrences

Input data includes the following:

- Mineral Occurrences
- Faults
- Geology
- Geochemistry
- Geophysics
- Satellite Imagery
- Topography
- Spatial Data

Combining this data, and educating machines and algorithms to analyse them, proves to be an asset within the mining industry. The company demonstrates the value of AI in developing new business models within an industry.

Having artificial intelligence technology can aid in the predictions of certain outcomes which negatively influence machine performance, such as predictive maintenance technologies, as well as aid in the decision-making process of current basic human interactions found within operational drilling processes.

2.3.4. Virtual Reality (VR)

VR digitally immerses the user thereof into specific predesigned environments. It is achieved by using special glasses, or similar devices, which cover the user's vision and so creates a digital environment. This environment can be anything from natural scenery to the interior of buildings. It is primarily used in military, educational, entertainment and sports applications. It creates a first-hand experience of a specific environment without having to enter the actual environment. It is used to communicate and re-enact training methods while keeping personnel safe during training exercises (Huang *et al.*, 2018).

A VR system exists at the University of Pretoria, which is used to educate and train students and mine staff on the safety within mines (Solomons, 2015). Prof Ronny Webber mentioned the following operational benefits at a Mining Indaba (Webber, 2018):

- Simulating different scenarios can increase the utilisation of resources applied to courses of action.
- Stakeholders can make better long-term decisions within the mine before decisions are followed through.
- Simulated operational risks provide a better understanding of the impact of certain circumstances without exposing people.
- Visualisation of decisions and scenarios within an immersive experience can lead to better research deliverables.

The value of VR technology within the mining sector is undeniable. It can lead to substantial cost savings and reduce the risks associated with various scenarios which can take place underground. These risks, if unmitigated, can lead to severe injuries, and even fatalities.

Virtual reality technology can benefit the users capturing the data within systems to train doing so in a controlled training environment, without negatively influencing the quality of the data.

2.3.5. Augmented Reality (AR)

AR refers to the use of a smart device, such as smart glasses or smartphones, to insert 3D objects into your current environment (Huang *et al.*, 2018). The objects are viewed digitally via a device. This enables an individual to analyse and display an object from different angles, sometimes even interacting with it. Many AR applications exist of which a few are listed:

- Advertising – Using your GPS location, a smart device augments your environment by displaying different services around you, such as restaurants, entertainment, etc.
- Military – A transparent display, Heads-Up-Display (HUD), is positioned in front of the user's vision, containing data such as altitude, airspeed, and the horizon line.
- Medical – Used to practice surgery without the risk of injuring somebody. It can be combined with MRI and X-ray scans for the surgeon to use as guidance within an operation.

- Navigation - Users can see the navigation view directly in front of the car via the smart device.
- Maintenance – Using a headset, the user can see visually represented data on a machine or asset in need of maintenance. The zone or parts in need of maintenance are highlighted or illuminated with specific colours.
- Commerce – Fashion and furniture companies sell products by creating the capability for their customers to view the products and see if it fits them or their current house-environments.

Although only a few are mentioned, the applications for AR are still increasing. The demand within the mining industry is currently minimal, leaving thoughts on the importance of this technology going forward.

Through augmented reality users can be aided in training and support of on-site operations. Navigation of smart devices to ensure the correct capturing of data during certain scenarios can benefit the quality of data captured by users.

2.3.6. Big Data analytics

Big data has the challenge of constructing intelligent data-driven applications which capture domain knowledge in analytical processes while using standardised formats (Barba-González *et al.*, 2019). Utilising this eases the use of third-party data sources, algorithms and business intelligence. Various systems exist to manage and analyse large data sets (Mahdi Fahmideh, 2018), all able to simplify and gather valuable information from large data sets. An example of a proposed approach to a big data analytics architecture is shown in Figure 9.

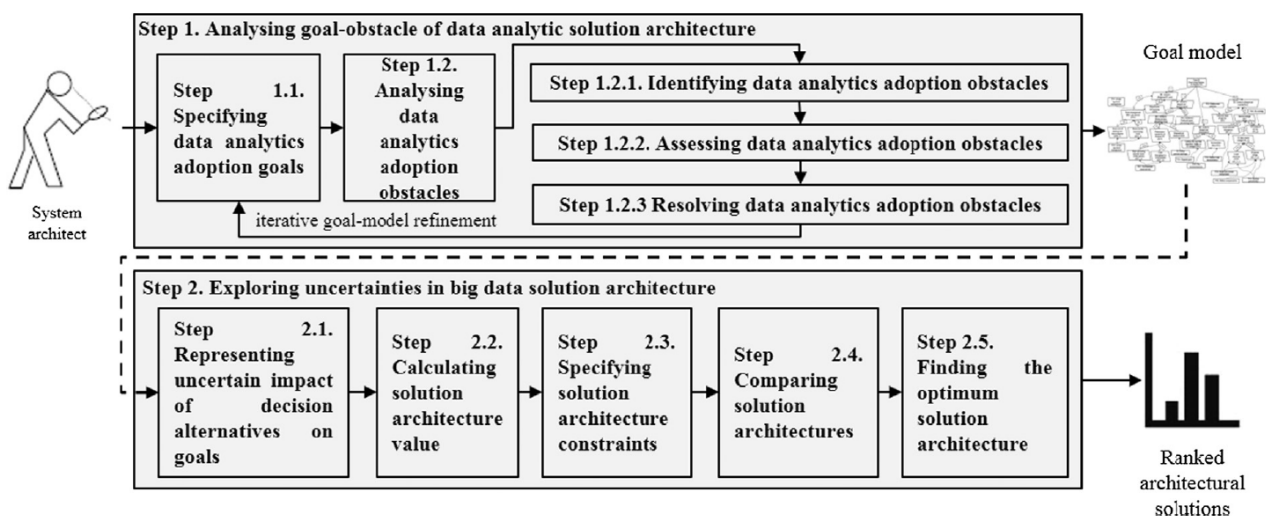


Figure 9: Proposed approach to big data analytics architecture (Mahdi Fahmideh, 2018)

Essential factors to consider when analysing large amounts of data consists of (Barba-González *et al.*, 2019):

- Data format

- Data source
- Volume of data
- Using the correct technology

Matillion, a company specialising in the development of cloud-based big data dashboard solutions, describe dashboards as a great way to make sense of data and “bring it to life” (Thelwell, 2015). Dashboards create a holistic view with which large amounts of data can be analysed. It increases the capability of decision makers within a company to make informed decisions.

With the vast amounts of data and different systems on which it is captured within a drilling company, big data analytics will add value in managing company drilling operations. It may lead to various improvements, such as:

- Quicker response times when delays or failures take place
- Predictive maintenance
- Increased production times
- Improved planning and estimation of operational projects

The improvements mentioned above could be reached by creating value through better displaying the data or using technology to interpret and analyse it. Achieving these goals will lead to better OEE achieved on drilling machines, as machine availability and performance is increased.

2.4.Maturity modelling

Both vertical and horizontal integrations of IT systems are required throughout a company’s entire value chain if the upgrade to modern technologies is to create value for it (Weber *et al.*, 2017). All functions within a supply chain are seldom on the same maturity levels, regarding technology adaptation (Weber *et al.*, 2017). It is necessary to approach each function within the value chain with a specific approach tailored to its respective maturity. It is therefore not optimal for a company with a high maturity to be approached with methods which are tailored to improve a company with very low maturity, as the current state of each differs. Maturity models involve the indexing of an object or organisation with regards to certain pre-defined maturity levels or stages (Wendler, 2012). It is described as a collection of different aspects collectively describing the maturity or development of various processes or functions of an entity (Wendler, 2012). It requires that different maturity stages be defined in which each function of an entity can then be ranked according to the rating system behind it.

The concept of maturity models, although not the same as today, originated in the 1930s with the work of W.A. Shewhart (Shewhart, 1931). The idea evolved within the software engineering field, becoming more important in the 21st century (Wendler, 2012). It is in some cases, also compared to Capability Maturity Modelling (CMM). The US Ministry of Defence commissioned CMM development to optimise software processes (Ahlemann *et al.*, 2015). It comprises the use of various maturity

models to assess different departments, making it challenging to use within organisations (Butzer *et al.*, 2017). It follows the method of dividing the maturity of functions or elements into five different levels:

- Initial
- Repeatable
- Defined
- Managed
- Optimised

An advancement of CMM, known as Capability Maturity Modelling Integration (CMMI), optimises the whole organisation's processes, instead of focusing on just one area. Four process categories are used to describe the company while further dividing them into 22 process categories. The CMMI Institute links the following results to CMMI adaptation within companies (Institute, 2018):

- Increased customer satisfaction
- Increased probability of capturing new and repeat business work
- Increased profits due to better quality processes
- Increased productivity
- Decreased risks.

2.5. Industry 4.0 Maturity Model

Different maturity modelling approaches exist which focus specifically on a company's ability to adapt to modern day technologies. Two of these, which have been developed by research entities and industry representatives are:

1. Acatech Study – Industry 4.0 Maturity Index
2. IMPULS Readiness Self-Check Analysis

Both models use approaches which group company functions into certain areas. After each area within the company is assigned a maturity level, quantified with a set of focused questions. The difference between the two methods is that the IMPULS Readiness Self-Check Analysis provides the maturity level of 6 different company dimensions, giving general approaches to improve the maturity of each (Foundation), whilst the Acatech Study focuses on improving the reaction time of companies with regards to incoming situations which disrupt the core business (Schuh *et al.*, 2017). The two models are summarised in Table 3. Maturity models are designed to index or rate the maturity of existing functions or dimensions within a company. The approach of developing plans to increase the maturity of functions or aspects within a specific company should, however, be tailored around the company's requirements.

Table 3: Maturity models summary

IMPULS Readiness Self-Check Analysis	Acatech – Industry 4.0 Maturity Index	
6 Readiness Dimensions:	4 Key Areas of Focus:	
Strategy & Organisation	Resources	Information Systems
Smart Factory	Culture	Organisational Structure
Smart Operations	6 Stages of the Model:	
Smart Products	Computerisation	Connectivity
Data-Driven Services	Visibility	Transparency
Employees	Predictive Capability	Adaptability

2.6. Data-Driven Services (DDS)

According to the IMPULS Foundation of the German Engineering Foundation, Data-Driven Services align future business models, while creating more value for customers (Foundation). Businesses should be better prepared for the competitive environment in which they are situated. They should use opportunities to create new business models. This does, however, require the ability of machinery and products to capture vast amounts of data, which can, at times, be challenging. Three criteria are used to evaluate the maturity of Data-Driven Services within a company when using the IMPULS Foundation's model:

1. Availability of DDS
2. Share of revenue derived from DDS
3. Services share of data used

Figure 10 presents the different types of data-driven services, as adopted by the IMPULS foundation, from *Strategisches Dienstleistungsmanagement*, a German textbook on the strategic orientation of service companies in the production environment.

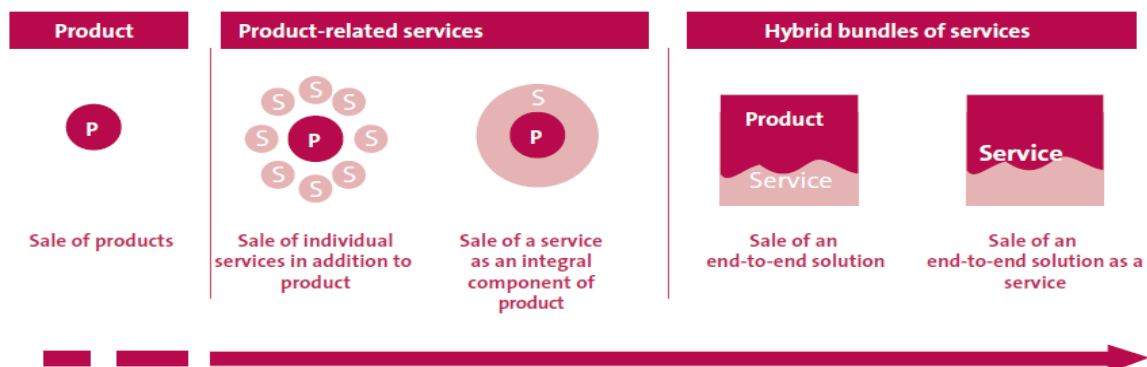


Figure 10: Different data-driven services categories(Lichtblau *et al.*, 2015b), (Hildenbrand *et al.*, 2006)

Drilling companies are within the group of ‘Hybrid bundles of services’, due to them selling an end-to-end solution to the customer. The data gathered aids the company in creating more customer-centric solutions by improving the services currently rendered.

2.7. Dashboards

Dashboards refer to single-screen displays presenting value-adding information on a particular subject or area within a specific company (Tokola *et al.*, 2016). A similar definition states that a dashboard is a graphical user interface improving decision-making capabilities within a company by displaying key performance indicators (Yigitbasioglu & Velcu, 2012). Current research on dashboards mainly focuses on Information Technology issues and systematic study of dashboard contents. Dashboards present information on different levels for different people on different hierarchy levels (Tokola *et al.*, 2016), thus creating a requirement for multiple dashboards, each satisfying the requirement of its end-user.

Dashboards represent high-level data which should then be drilled down further if deemed necessary. It highlights areas of focus where problems or successes occur, and not as such on the reason or cause of the success or problem (Yigitbasioglu & Velcu, 2012).

There are different reasons for building dashboards (Yigitbasioglu & Velcu, 2012):

1. Consistency – Creating consistent measures and measurement procedures throughout a company
2. Monitoring – Daily monitoring of specific KPI's or scorecards to see the current state of a project or business objective
3. Planning – Decisions can be made from dashboards to plan for specific business scenarios. A 'what-if' analysis is used for this purpose
4. Communication – Organizational values and operational performance are communicated to stakeholders using Dashboards

2.7.1. **Dashboard Designing Principles**

The following principles are mentioned in the literature regarding the way dashboards are to be designed:

- Should be on a single-screen display
- Should be a static display without distracting functionalities (Matheus *et al.*, 2018)
- The top left and centre should contain essential information (Tableau, 2019)
- KPI's should be relevant to the user (A., 2009)
- Should offer interaction support (Matheus *et al.*, 2018)
- Ensure real-time updating of data (Matheus *et al.*, 2018)
- Provide overview and details (Matheus *et al.*, 2018)

Dashboards have different functions on different hierarchy levels of an organisation. The reason for this being the different roles each of the organisational levels are assigned. Each level has different

outputs required from it, requiring different inputs. The top level within an organisation focuses more on the direction and strategy of the organisation, whereas the operational level more on day-to-day activities.

Dashboard Type	Users	Goal
Strategic Dashboard	Executives/ Board	Monitor
Tactical Dashboard	Managers/ Analysts	Analyse
Operational Dashboard	Operational Staff	Details

Figure 11: Information levels for different organisational hierarchy levels (Tokola et al., 2016)

Because of the nature of each user level, and the expectation of them within a company setup, a dashboard will add value in different ways.

Strategic – Strategic dashboards give executives an overview of what is happening within the company and can be used to highlight areas of concern. It should be viewed regularly within gatherings between managers and executives.

Tactical – Tactical dashboards are used to analyse specific areas within a company, whether it be department or function specific. The visuals in this dashboard should enable the user to drill down into details. It should be viewed whenever capacity in a company exists to attempt improvement projects, or when reporting to executives is required on the current state of operations within departments.

Operational – Operational dashboards are used daily for operational staff within departments to manage their KPI's and progress on specific tasks or activities. It provides managers within the departments an overview of staff activities and performance. It enables both the operational staff, as well as managers of their departments, to effectively manage their operations.

2.7.2. Dashboard applications

Applications of dashboards differ across industries and departments, based on the requirements the user has of the system. Various software packages exist to create dashboards and are chosen for use based on cost, availability and ease of use. The primary function of all these applications is to turn data into value-adding information for decision-makers. Some examples of the use of dashboards include (Kourtita & Nijkampa, 2018):

- Comparing data from different groups in the same application with one another
- Viewing data on a specific application over time
- Visualising a real-time performance metric to motivate increased performance
- Display further detail on a subject, such as showing the way data is split into different categories
- Shows the as-is state of a physical operation

Making use of dashboards can unlock a substantial amount of potential within operational data, which, without it, will potentially remain unknown to the management of the company. Below are some developed dashboard applications with a summary of the research findings for each:

1. **The Stockholm Experiment (Kourtit & Nijkamp, 2018)**- An experiment was conducted in Stockholm where dashboards were used to address 'strategic governance challenges' within smart cities, by visualising big data on dashboards. The study mentions the value of the dashboards in successfully achieving strategic goals for a city, as well as analysing current statuses and risks on current city initiatives. The dashboard is referred to as a 'strategic decision support tool'. The feasibility and usefulness of such a dashboard are also presented within the research.

The dashboard was developed as a solution within a 'complex and ever-changing' economic global geography containing 'non-linear' problems. The dashboard was built with a multidimensional model in mind focusing on the following:

1. Economic Capital – Entrepreneurship, Innovation, Wages, Jobs
2. Social Suprastructure – Labour Force, Participation, Human Capital, Relative Poverty
3. Ecological Resources – Environmental Pollution, Health, Social Cohesion
4. Geographical Infrastructure – Land Use, Public Transport, Mobility
5. Knowledge Capital – Science Parks, Universities, Accessibility to Digital Technology

The solution integrates collected data of heterogeneous forms from various sources. The solution showed feasibility and usefulness in the decision-making process of improvement initiatives.

- 2. The Traffic Problem (Matheus *et al.*, 2018)**– A combination of government and publicly generated data helps the city of Rio de Janeiro to monitor and control traffic, aid in the detection of accidents and improve road safety. This data displayed on dashboards for the people driving within the city presents drivers with alternative routes between destinations, reducing the impact of traffic jams within peak traffic times. This dashboard is also used for the purpose of planning future city improvements.

The complexities within this dashboard application include the following:

- Massive amounts of data from various resources (About 12GB per day)
- Integration from different data sets in different formats
- Millions of people having to interpret the same information and have the same conclusion
- Gaining participation from the public to generate data for the dashboards
- Low data accuracy
- Mistrust in the local government
- Data privacy

Successful benefits within the application of dashboards in this context include the following:

- Users can make better decisions faster due to the visualized nature of the available data.
- Different stakeholders can integrate data sets to share data, benefiting the service offerings of some businesses in the long run.
- It enables participation from the public because the public directly benefits from the information displayed.

- 3. SME Performance Improvement (Vilarinho *et al.*, 2019)**– This research displays the value of dashboards in productivity increases by using it for visual management purposes, and the identification of areas which can be targeted with continuous improvement initiatives, within SME companies. Research shows that dashboards are effective tools to combine information from different departments to assist in decision making of the user thereof. This is however only if the dashboard information itself is aimed at the person using it for the purpose it was created. Continuous improvement within this field is confronted with the challenge of creating a sustainable infrastructure to support the growth initiatives. One solution mentioned within literature is visual management, in the form of a dashboard.

One challenge with literature on dashboards within smaller companies is that the systems are too complex, and that information displayed is not necessarily always relevant to the main driving KPI's of the company. Research indicates a direct correlation between a structured problem-solving approach in an industrial context, and organizational performance. The identification of problems is however a lot simpler to do when relevant data is visually displayed with the applicable KPI's.

4. Strategic Brand Management (Erkollar & Oberer, 2016)– The brand management field contains significant amounts of data. This includes the requirements and interests of customers in a dynamically changing environment. Dashboards in this area are used to create visibility of current state information and can potentially aid in the development of improved service offerings of companies making use thereof. Brand performance could thus be benefited due to the visibility and potential improvement of processes and offerings found within the data.

5. Pulse Mining Systems (Short, 2017)- Mining systems company, Pulse, has faced various challenges up until 2017 where a production increase in the global mining industry lead to various challenges resulting from an ageing workforce negatively influencing the capability of mining companies. The company targeted specific mining challenges with the use of business intelligence dashboards, which gave its users a real-time view of operations, 'enabling clients to drive millions worth of additional production'. These dashboards had the following positive results once implemented:

- The accuracy of the data reported was greatly increased due to automated data capturing.
- Pulse's customers were enabled to run automated machines for longer, increasing production rates, since they had real-time visibility of operations.
- Data could be viewed in different formats, including visual graphs, which gives the client/user a better overview of what is going on within operations.

The implemented technology lead to a 3.2% increase in operating production rates, having a financial impact of \$0.5 million increase in revenue.

6. Neudesic in Mining Industry (Neudesic, 2013)– Technology company, Neudesic, parted with a gold mining company in creating a real-time dashboard displaying operational KPI's in the form of graphs, enabling the customer to analyse operational data. This improved operational decision making within the mining company, and lead to increased efficiencies in production. The system was also built in a scalable manner so that future expansion won't negatively affect the system's performance or usability. The sustainable expansion focused on here is a critical component for ay fast-growing company.

7. Atlas Copco Drilling (Hedblo, 2014)- Mining company, Atlas Copco, created a shift capturing system in 2014, which is manually updated on a daily basis, displaying the details of a shift on a specific day. This data is displayed is then available for crews to use on-site. This shows the as-is state of what is going on on-site data given time, and thus has limitations in the value it can add. Although similar to the shift capturing system touched on within this study, the output of the dashboard here focuses on the operational users, whereas the artefact of this study is focused on a more managerial audience.

Table 4: Dashboard application summary

Application Example	Benefit to End-User
1. The Stockholm Experiment	Aided in the achievement of strategic goals
2. The Traffic Problem	Aids in the planning of improvement projects; Aids in the improvement of traffic movement efficiencies
3. SME Performance Improvement	Aids in improvement of SME productivity through using dashboards as visual management tools; Improve interdepartmental decision-making processes; Identify problems within key performance areas
4. Strategic Brand Management	Improved visibility and decision making within brand management practices
5. Pulse Mining Systems	Improved visibility of operations; Increased production efficiencies
6. Neudesic in Mining Industry	Increased production efficiencies; Increased operational visibility
7. Atlas Copco Drilling	Increased visibility of operations

Table 4 displays the results from the different dashboard applications across different industries. The findings show a clear trend that in all cases dashboards lead to increased visibility of operations, better enabling the users thereof to make informed decisions. In the case of the applications used within mining environments, dashboards lead to improved production efficiencies. Although little to no specific research was found on the use of dashboards within drilling companies, the results in Table 4 is still a positive indication that the use of dashboards can lead to increased operational equipment efficiencies. The one case of a dashboard within a drilling company mentioned in an online source is not discussed or displayed, and the value thereof not clearly defined.

The different dashboard applications and uses within the different industries mentioned above highlight critical success factors for a dashboard as a research artefact. The data model design and integration between different data sets should be well thought through to ensure that data is displayed in a manner using the least possible resources to save costs. The data which should be

input manually by users should generate value for these users to ensure they input accurate information. The KPI's used on the dashboard should be well defined and applicable to the users of the dashboard itself. Trying to accommodate for too many levels of an organization on one dashboard can become cumbersome. The design and visuals of the dashboard should fit the type of data displayed (e.g. not showing time series data on a pie chart as it won't trend with dates). Dashboards should lead to better decision-making by the users thereof or influence the behaviour of the end-user in a positive manner. Within the correct environment dashboards can lead to substantial revenue increases and/or in substantial decreases in costs. Dashboards assist in the increased visibility of operations, creating an increased sense of security to management within organizations, as they have a clearer picture of operational performance.

The mining sector itself can benefit from all these opportunities seeing that it's contribution to the national economy within South Africa is decreasing. This sector does however have various challenges of its own which should be considered in the development of any system to be used underground. Connectivity and real-time gathering of data underground is a pressing issue within South African mines. If data can't be extracted from the sources generating it, it can't be displayed on any dashboard. Underground operations don't take place in 'standardized' environments, adding to the complexity of standardizing operations in order to generate more uniform data. Another challenge faced is the literacy of the employees working underground. The case in South Africa, and specifically in the drilling company used for the case study, is that the operators working in underground environments are rarely literate, thus posing a risk of inaccurate data being input by them.

The company used as the case study is a multinational global organization, having various hierarchical levels. Each of these levels can't necessarily be satisfied with one simple dashboard. Thus, another challenge is that the dashboard should cater for the correct audiences, or multiple dashboards be developed. Nonetheless literature indicates various uses for dashboards, including the use thereof within operational environments. The use thereof in a drilling company could potentially lead to improved service offerings, better brand awareness, increased visibility of operations and better decision making by the end-users of the dashboard, which in this case would be contract managers within a drilling company.

Chapter 3: Research Method

3.1. Disruptive technologies in drilling companies

It is essential to understand that not all disruptive technologies have a business case in the environment within a drilling company, considering the current maturity level of its Industry 4.0 dimensions. In Table 5, the different existing and emerging technologies within a drilling company are displayed.

Table 5: Disruptive technologies in drilling companies

Technology	Applicability in drilling companies
Internet of Things	Modernised drilling machines make use of sensor technology to monitor certain elements, as well as control certain behaviours on drilling machines. This technology is essential for automated drilling machines and is used to capture data which can be analysed for further business cases to be developed.
Machine Learning	The technology creates value for a drilling company by utilising its data to automate various manually intensive computing tasks.
Artificial Intelligence	As ML is only in the development stages in the drilling company used for the case study, the value of AI can't yet fully be understood. It is, however, estimated that AI would add value to the analysis of operational data, and business cases which can result from this.
Augmented Reality	Although this has been proven to add value in warehousing and training applications, it is not yet in the pipeline for company development.
Virtual Reality	VR can add value to the company's marketing department to help display the capability of operational machines. It might, however, be overkill, as the development is expensive, and animations of operational practices already exist.
Big Data Analytics	In combination with ML and AI, the analytics of the data within the company is seen as a priority, as well as how this can be transformed into valuable information to equip decision makers within the company better.

3.2. Chapter Outline: Research Method

The conceptual maturity improvement process developed in the previous chapter, in conjunction with the Industry 4.0 maturity analysis, highlights data-driven services as an area in need of focus.

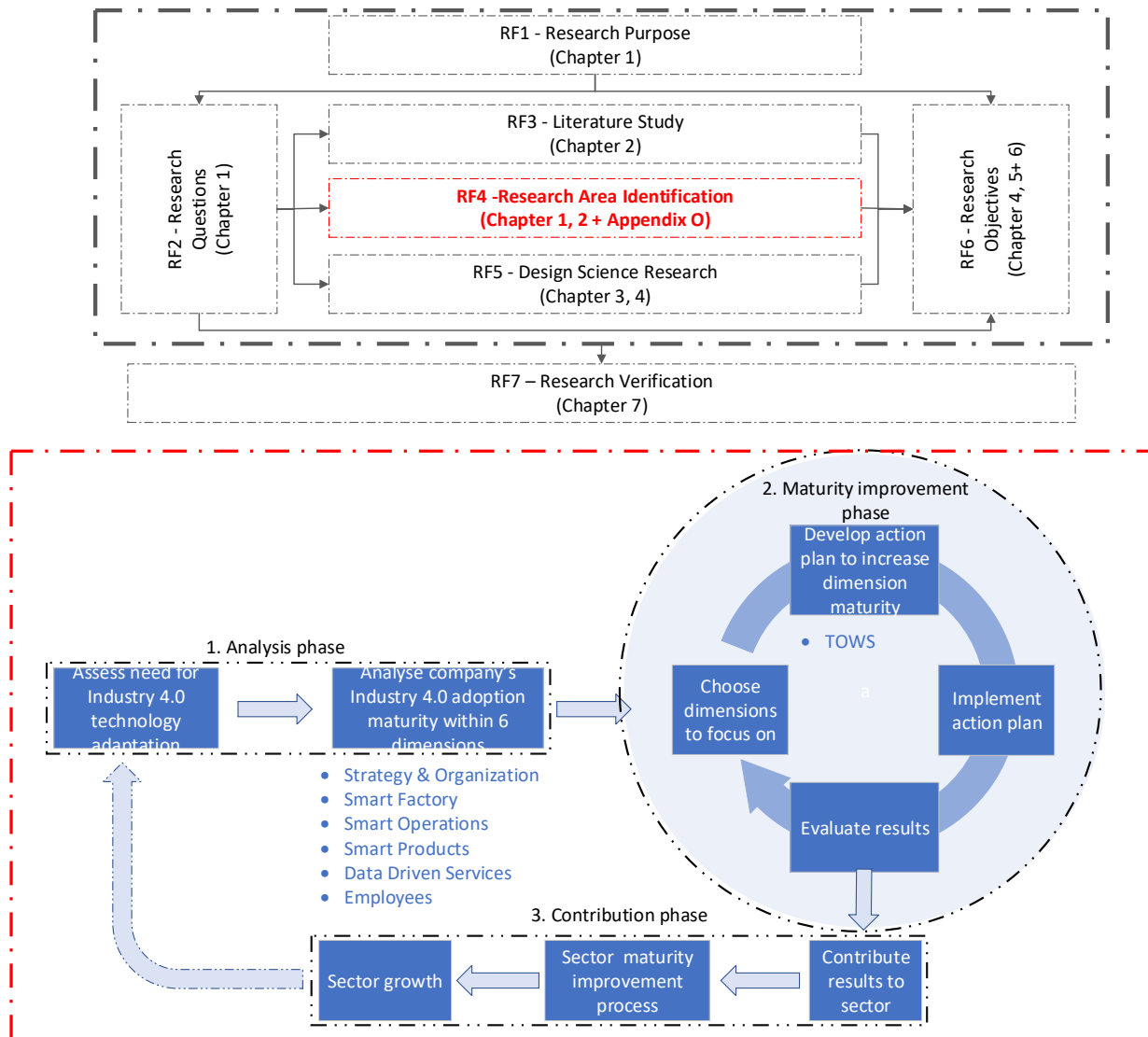


Figure 12: Research overview - research method

The author published an article ending towards developing a company maturity improvement process, which can potentially be used in maturing specific company dimensions. This article is discussed in detail in Appendix O: SAIIIE article, where the results indicated a lack of data-driven services within a specific drilling company, Master Drilling. The process starts with an Analysis phase wherein the problem area is identified. The second phase of this process, referred to as the Maturity improvement phase, recommends that a specific company dimension be chosen and improved, rather than various being attempted at the same time. This chapter focuses on the method followed in conducting this improvement.

After selecting a dimension for improvement (in this case, it is data-driven services), the process (Figure 69) states that action plans must be developed to increase dimension maturity. It led to time

spent within a drilling company to understand where data-driven services could potentially add the most value. The time spent within the company included various informal meetings with the company’s Chief Operations Officer, Chief Information Officer, Digital Innovation Officer, Chief Strategy Officer, as well as the operational staff, to understand the challenges they face within drilling operations, and the management thereof.

The outcome of these discussions verified the fact that the company has a lot of data, which was either not made visible in some manner, was cumbersome to make visible, or the integrity thereof questionable. This data, however, is what a lot of operational decisions are based on. Asset forecasting and resource planning are also conducted using this data, although little of it is in a ready-to-use real-time visualised state as valuable information. Action Design Science Research, as a methodology, aims to place focus on both the academic and operational environments.

3.2.1. Research Method

The philosophy of Design Science Research (DSR) is chosen to guide the study by presenting artefacts to solve a research problem. The methodology adopted is Action Design Science Research (ADSR) as it generates knowledge through the development and evaluation of artefacts (Sein *et al.*, 2011). It aims to use innovative and value-adding artefacts to impact and improve the environment (Simon, 1996). It breaks the context in which a problem, along with its theoretical and practical components exist in, into three research cycles (Hevner, 2007). The different cycles are displayed in Figure 13. Each adds value to a separate area, being either the company’s knowledge base or the academic environment. It is crucial for the research to move through all the cycles, to ensure that the solutions presented are based on theoretical knowledge, but also tailored to the specific environment in which it is to be implemented.

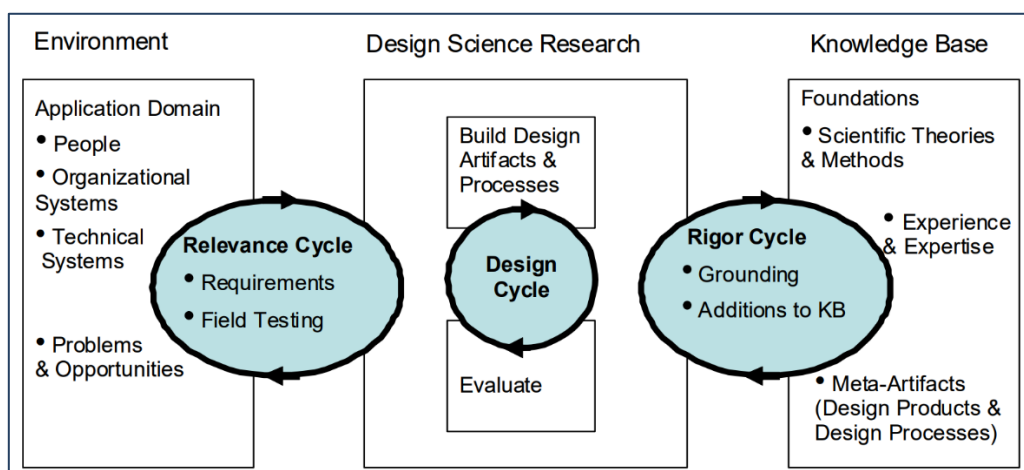


Figure 13: Design science research cycles (Hevner, 2007)

The methodology uses a concurrent research approach where both the practical and theoretical environments are sufficiently consulted to deliver an artefact as a deliverable, which solves the problem to the inherent challenges at which a study is aimed. The three cycles are summarised in

Table 6. This methodology is practical, having the potential to combine rigour and relevance to provide a valid research artefact (Hevner, 2007).

Table 6: Summary of the design science research cycle

Relevance Cycle	Bridges the research project’s environment and the design science activities.
Design Cycle	Continually cycles between the building of the artefact and its evaluation to ensure the artefact is delivered successfully.
Rigor Cycle	Connects the design science activities with literature, experience and expert knowledge to validate the approach of the research.

Further emphasis can be put on the relevance cycle, as explained in Table 6, which is referred to as Action Design Science Research. It focuses more on the actual application in the environment for which the project or solution is designed. By working through the respective cycles of DSR, the artefacts should achieve a goal. In the case of this study, that goal is to improve the OEE of a drilling companies’ drilling machines.

Action Design has four distinct phases, each consisting of different principles (See Figure 14). Each one is discussed below.

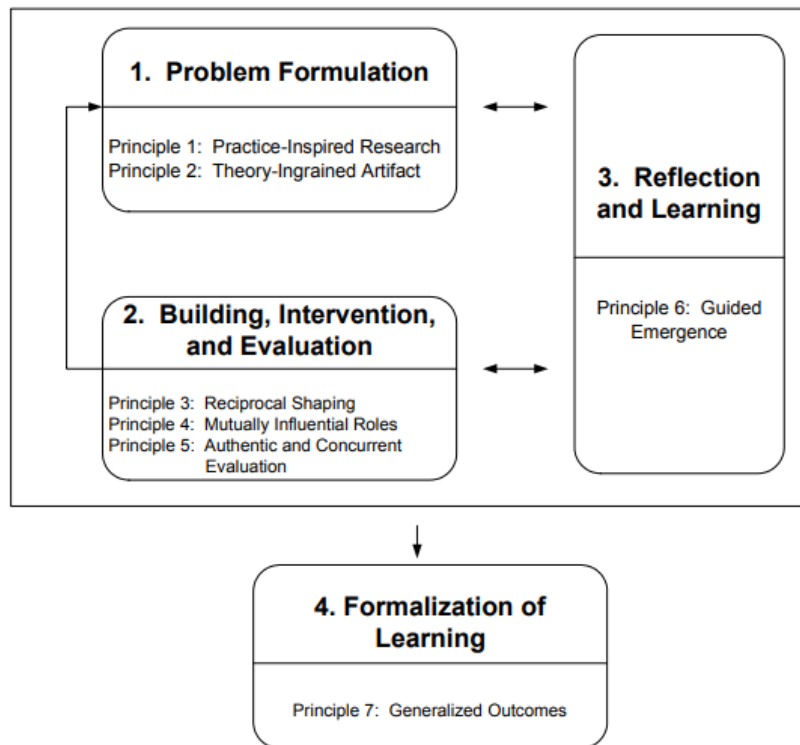


Figure 14: ADR stages and principles (Sein et al., 2011)

3.2.1.1. Stage 1 – Problem formulation

It includes the formal definition of a problem perceived in practice, or identified through research, and motivates the research to be conducted. It consists of two principles:

1. Practice-inspired research
2. Theory-ingrained artefact

3.2.1.2. Stage 2 – Building, intervention and evaluation

A setting is created in which the problem defined during Stage 1 is evaluated while the organisation intervenes. It includes the following three principles:

1. Reciprocal shaping
2. Mutually influential roles
3. Authentic and concurrent evaluation

3.2.1.3. Stage 3 – Reflection and learning

It refers to reflection on the lessons learnt during the review and construction of the problem solution. During this stage, continuous reflection improves on the quality of the research insuring its contribution to the knowledge field. It includes the following principle:

1. Guided emergence

3.2.1.4. Stage 4 – Formalization of Learning

The final stage consists of the formulation of organisational outcomes, and the outline of knowledge created, and accomplishments received. It contains the following principle:

1. Generalised outcomes

3.3. Chapter conclusion

The Appendix O: SAIE article yielded the finding that DDS is an area within a drilling company which requires improvement to adopt technologies. Using the ADSR methodology, the study utilises knowledge from academia, as well as the actual operational environment.

Other research conducted using DSR in the development of dashboards includes the development of emergency department crowding dashboards (Martin *et al.*, 2018). The research consists of the visualisation of a dashboard and the explanation on the design thereof. The study does, however, verify the philosophy of DSR to be successful in developing dashboards.

Chapter 4: Conceptual Design

4.1. Chapter Outline: Design Science Research

This chapter provides detail on how the research objectives are approached. It follows the DSR philosophy of consulting both the operational environment and the current knowledge base on the subject. It contextualises the problem and proposed solutions within a specific drilling company’s context, focusing on the system components which lead to accurate and value-adding data captured so that the value can be derived from a data-driven dashboard.

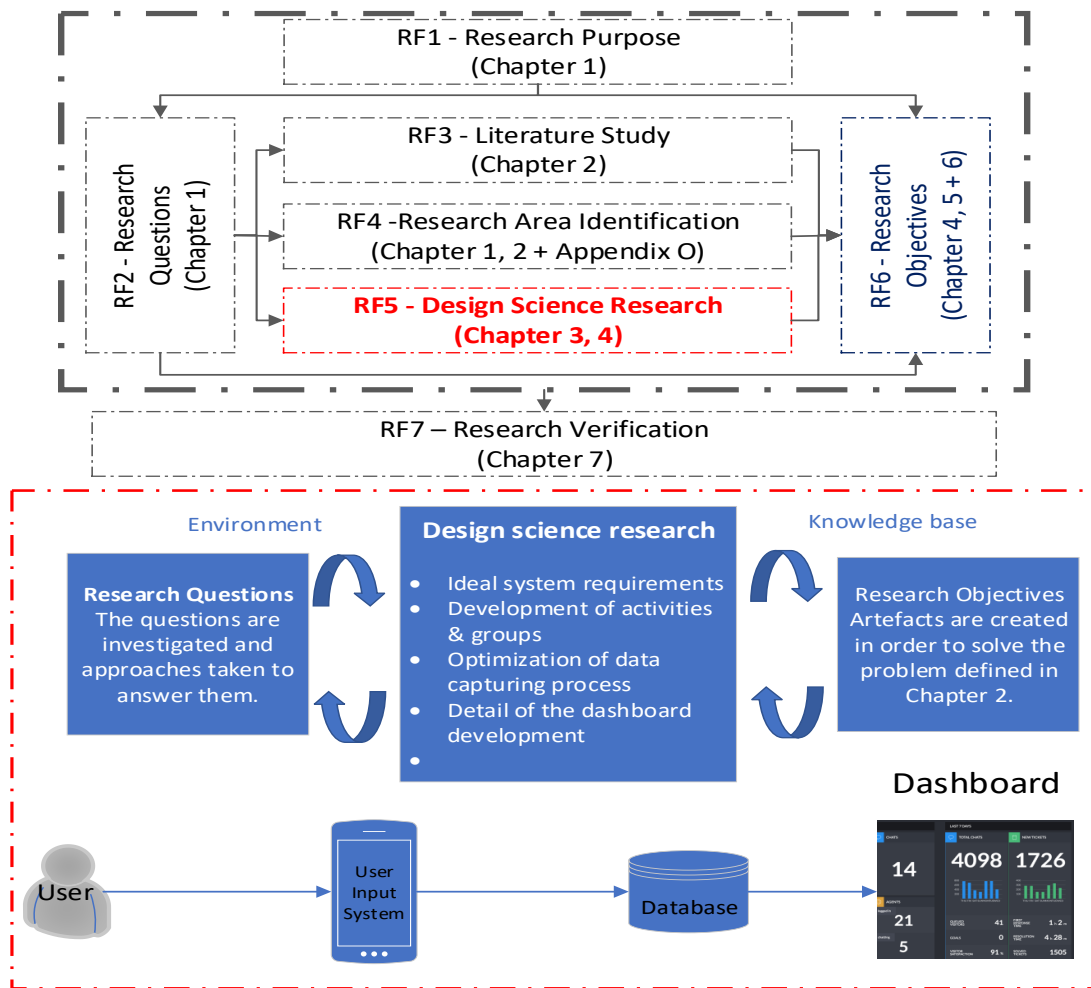


Figure 15: Research overview - conceptual design

4.2. Re-Examination of Problem

Drilling operations, in general, have large amounts of activities which affect operational productivity. The number of events is too large to manage without proper tools and project management methodologies. Variances exist within the data when different drill site types are not differentiated, and the activities on which data is captured not properly scoped and categorised. Understanding the set-up and process of drilling operations is essential to attempt any improvement within the drilling environment or the support services thereof.

4.2.1. Operational Context in a drilling company

The operations function within a drilling company is summarised in a diagram which the company refers to as the ‘Wagon Wheel’ of its operations. It summarises the different phases within a drilling project. The wagon wheel is displayed in Figure 16. Data on the projects are captured in all the phases, from site establishment to hole completion. Because most of the time on a contract is used in piloting and reaming, most of the delays are situated there. It is where the most focus will be put on for efficiency improvements within the company’s operations.

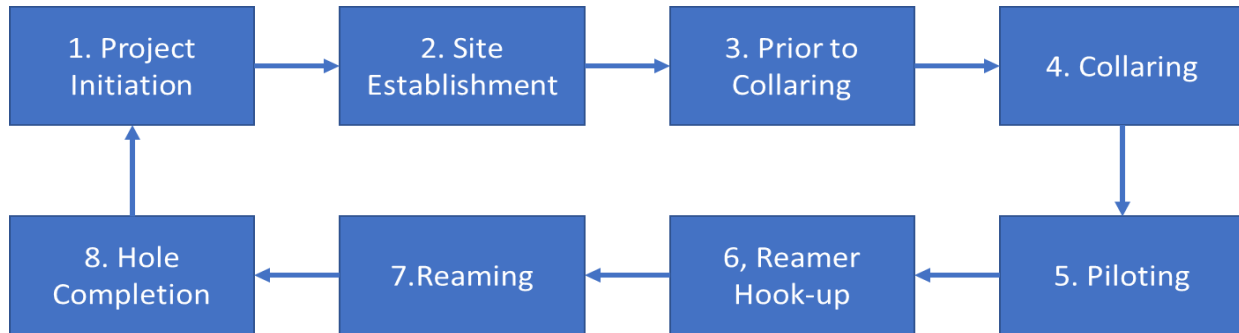


Figure 16: Operations wagon wheel

Each step of the Wagon Wheel consists of different safety and risk assessments and operational procedures which require the attainment of an authorisation number serving as permission to move on to the next phase of the Wagon Wheel. Simplifying the process, the 8 steps of the Wagon Wheel are combined into four phases, as displayed in Figure 17.

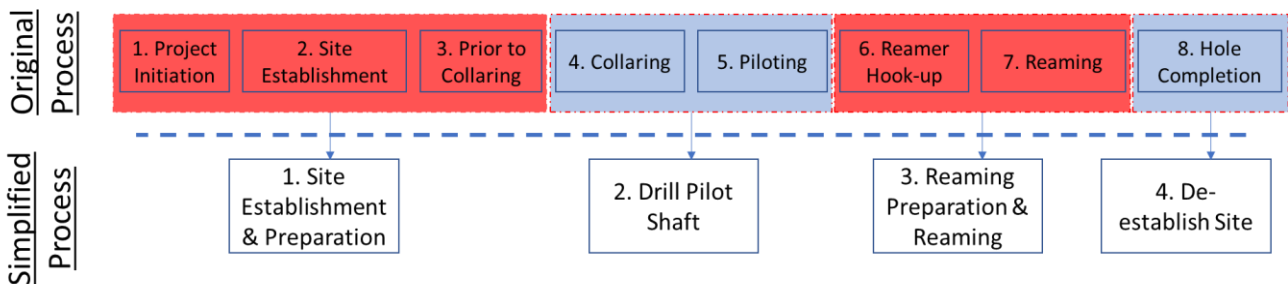


Figure 17: Summarized Raiseboring phases

The company tenders for contracts on the assumption of each phase within the wagon wheel takes a certain amount of time. When awarded, the contract follows the four summarised phases.

The total daily available time of a machine consists of productive and non-productive time. These are the two main categories against which time can be allocated on operational shifts. Every hour of the day on a contract is allocated to a predefined activity. The data is captured using computers and stored internally within an online data warehouse of the company. The availability of the data creates the potential for it to be analysed. A lot of variabilities exist within the data of global entities due to the following two main factors:

- Country laws and regulations leading to different levels of information being captured
- Contract types which use predominantly different types of activities
 - Surface
 - Underground

Due to these factors, the approach to the analysis of operational data is scoped within only one country, South-Africa, and focuses on one machine. The contract is then separated into the four different phases displayed in Figure 17.

Operational contracts are very elaborate projects to manage, consisting of operational project management, project budgeting and finance, legal requirements and commercial project management. Drilling companies have different ways to manage these contracts. In the case of the case study, the company has an individual, referred to as the 'Contract Manager', who manages various operational contracts simultaneously. With the complexity of these contracts, managing various can become a cumbersome task. Creating increased operational and contract visibility for contract managers will increase their ability to manage the projects for which they are responsible and increase effective drilling time on-site, leading to improved OEE of drilling machines.

4.3. Concepts

It is essential to understand all the main components leading up to a dashboard before a final design can be discussed on the artefacts this study aims to produce. The data needs to be categorised correctly for the dashboard to add value to the user thereof. The dashboard visualises the data that must be correct and reliable, and stored within a database. The basic anatomy of a system is visualised in Figure 18. The information required for the dashboard should be input by a user through an input system. The input system should be easy to use and guide the user to enter the correct information into the database. The data is fed to the dashboard software and visualised for management to make informed decisions on. The detail of the visuals is discussed in the Detailed Final Design chapter. A thorough analysis and ADSR approach is put into the user experience, as well as the user input method.

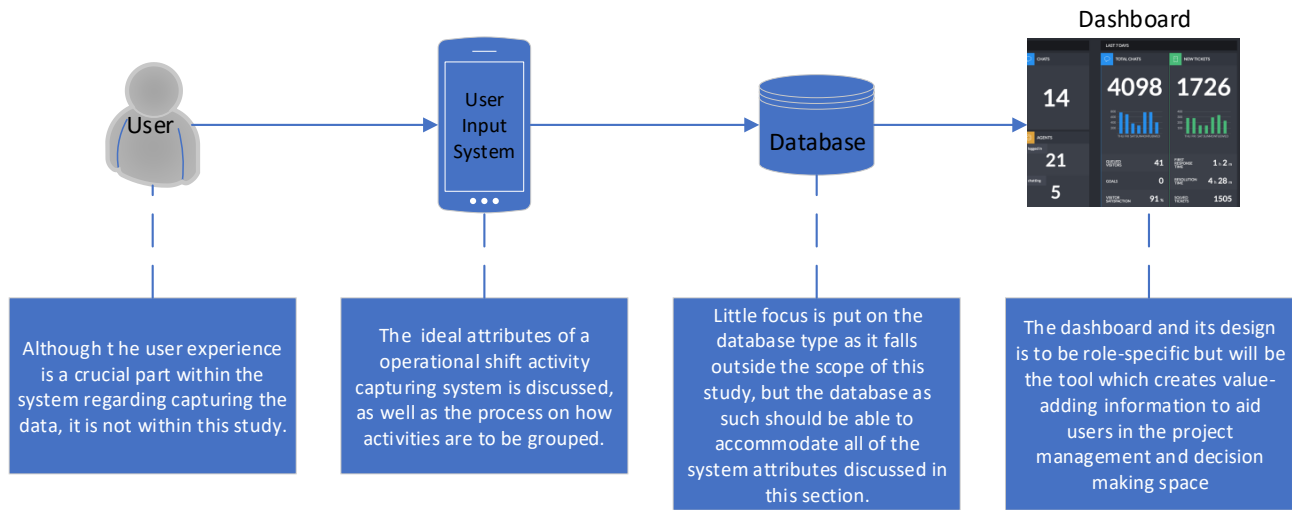


Figure 18: System anatomy

4.3.1. As-is operational project management

The as-is state, regarding operational project management and the use of data within the drilling company used for the case study, is consists of the rudimentary use of data within Excel spreadsheets. Within the case study company various Excel-based solutions exist for operational project management, although the South African entity, where this study is focused, does not currently have such a solution. This study focuses on developing a solution, not only improving the current state within South Africa but also improving on the solution of one of the international drilling entities within the group of companies. The dashboard currently used by an international drilling entity is displayed in Figure 19.

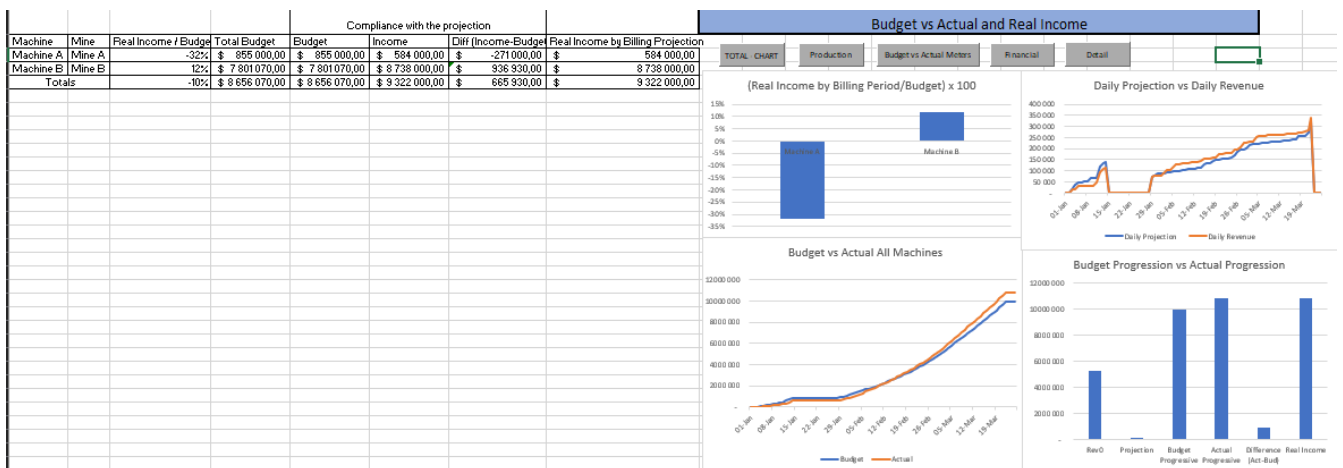


Figure 19: As-is dashboard within an international drilling entity

This dashboard consists of various pages, each being accessed with buttons on its home. The pages contain different information displayed in Figure 20 - Figure 24.

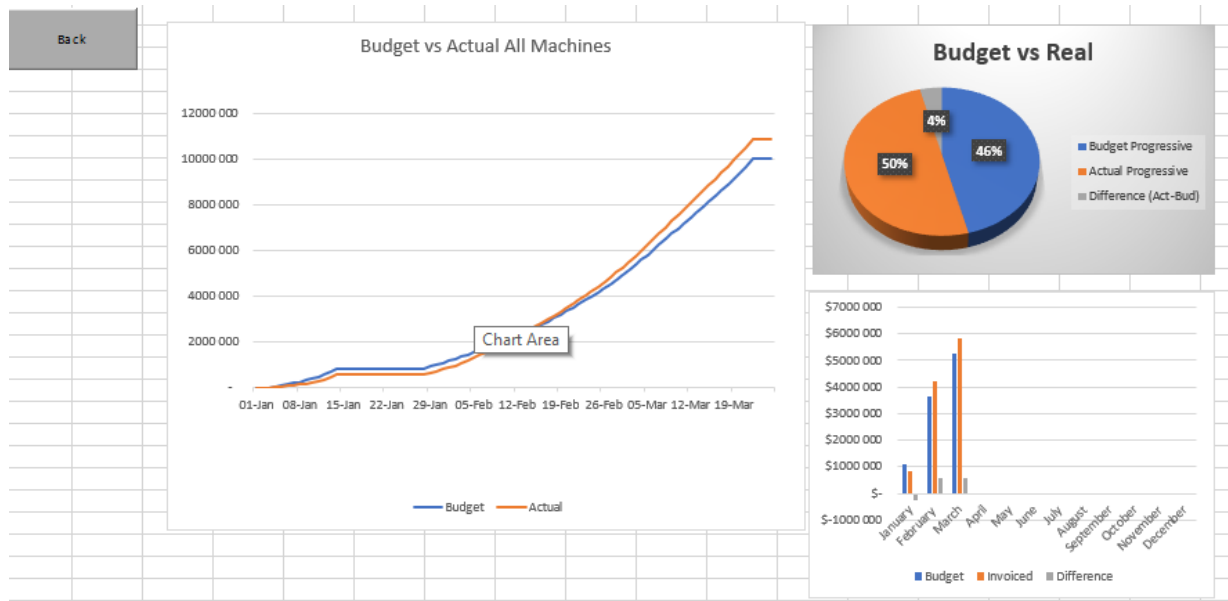


Figure 20: 'TOTAL CHART' page of the as-is dashboard

The details in Figure 20 provide an overview of the features within the dashboard. It displays budgeted vs invoiced revenue and budgeted vs actual expenses. This is an overview for all the machines, and cannot be filtered for specific machines, dates or mines.

Machine	Item	Budget month	Actual	Diff	Coments
Machine A	Ream 1.5m			0	Hole completed, no budgeted meters
Machine A	Pilot 0,7m			0	Hole completed, no budgeted meters
Machine B	Ream 1.5m			0	Hole completed, no budgeted meters
Machine B	Pilot 0,7m			0	Hole completed, no budgeted meters

Figure 21: 'Production' page of the as-is dashboard

The details in Figure 21 display the budget versus actual meters on each planned hole for each machine.

Machine	Mine		01-Jan-19	02-Jan-19	03-Jan-19	04-Jan-19	05-Jan-19	06-Jan-19	07-Jan-19	08-Jan-19	09-Jan-19	10-Jan-19	11-Jan-19	
Machine A	Mine A	Budgeted Daily Meters	0	0	4,25	4,25	4,25	0	0	0	0	2,8	2,8	
		Budgeted Progressive Meters	-	-	4,25	8,50	12,75	12,75	12,75	12,75	12,75	12,75	15,55	18,35
		Actual Daily Meters	0	0	3,75	4	5	0	0	0	0	0	2,5	3
		Actual Progressive Meters	-	-	3,75	7,75	12,75	12,75	12,75	12,75	12,75	12,75	15,25	18,25
Machine A	Mine A	Budgeted Daily Meters												
		Budgeted Progressive Meters												
		Actual Daily Meters												
		Actual Progressive Meters												

Figure 22: 'Budget vs Actual Meters' page of the as-is dashboard

Figure 22 displays the actual and budgeted progress of daily meters advanced for each operational project.

Machine		Mine		01-Jan	02-Jan	03-Jan	04-Jan	05-Jan	06-Jan	07-Jan	08-Jan	09-Jan	10-Jan	11-Jan	12-Jan	
Machine A	Mine A	Budget \$	Daily \$	-	-	22 000	37 000	49 000	50 000	51 000	52 000	67 000	68 000	69 000	119 000	
			Progressive \$	-	-	22 000	59 000	108 000	158 000	209 000	261 000	328 000	396 000	465 000	584 000	
		Actual \$	Daily \$	-	-	15 000	17 000	30 000	30 500	31 000	31 500	32 500	34 300	46 300	91 300	
			Progressive \$	-	-	15 000	32 000	62 000	92 500	123 500	155 000	187 500	221 800	268 100	359 400	
		Facturacion \$		Daily \$	-	-	15 000	17 000	30 000	30 500	31 000	31 500	32 500	34 300	46 300	91 300
				Progressive \$	-	-	15 000	32 000	62 000	92 500	123 500	155 000	187 500	221 800	268 100	359 400
Machine B	Mine B	Budget \$	Daily \$	-	-	-	-	-	-	-	-	-	-	-	-	
			Progressive \$	-	-	-	-	-	-	-	-	-	-	-	-	
		Actual \$	Daily \$	-	-	-	-	-	-	-	-	-	-	-	-	
			Progressive \$	-	-	-	-	-	-	-	-	-	-	-	-	
		Facturacion \$		Daily \$	-	-	-	-	-	-	-	-	-	-	-	
				Progressive \$	-	-	-	-	-	-	-	-	-	-	-	
Total Revenue	Country X	Budget \$	Daily \$	-	-	22 000	37 000	49 000	50 000	51 000	52 000	67 000	68 000	69 000	119 000	
			Progressive \$	-	-	22 000	59 000	108 000	158 000	209 000	261 000	328 000	396 000	465 000	584 000	
		Actual \$	Daily \$	-	-	15 000	17 000	30 000	30 500	31 000	31 500	32 500	34 300	46 300	91 300	
			Progressive \$	-	-	15 000	32 000	62 000	92 500	123 500	155 000	187 500	221 800	268 100	359 400	
		Real Income \$		Daily \$	-	-	15 000	17 000	30 000	30 500	31 000	31 500	32 500	34 300	46 300	91 300
				Progressive \$	-	-	15 000	32 000	62 000	92 500	123 500	155 000	187 500	221 800	268 100	359 400

Figure 23: 'Financial' page of the as-is dashboard

The financial details regarding revenue generated are displayed on this page of the dashboard (See Figure 23). Revenues generated are displayed on a daily timeframe for different projects.

Machine	Mine	Budget	Ingreso	Difference	(FACT.REAL/Budget)*100	Billing Period	ACT. REAL	TOTAL BUDGET
Machine A	Mine A	\$855 000	\$584 000	-\$271 000	-32%	Jan 1 - March 30	\$584 000	\$855 000
Machine B	Mine B	\$7 801 070	\$8 738 000	\$936 930	12%	Jan 1 - March 30	\$8 738 000	\$7 801 070
Rev0		5 252 660						
Projection		125000						
Budget Progressive		\$9 982 070	\$9 982 070	\$10 959 500	\$868 430	8,7%		
Actual Progressive		\$10 850 500						
Difference (Act-Bud)		\$868 430						
Real Income		\$10 850 500						

Budget Rev0 - 2019

Month	January	February	March	April	May
Budget	\$ 1 092 000	\$ 3 637 410	\$ 5 252 660		
Invoiced	\$ 812 000	\$ 4 227 600	\$ 5 810 900		
Difference	\$ -280 000	\$ 590 190	\$ 559 240	\$ -	\$ -

Figure 24: 'Detail' page of the as-is dashboard

Figure 24 contains the budget for each project per month, as well as the outstanding revenue per project.

The as-is dashboard is primarily focused on the revenues and meter advances on each project. The dashboard itself is not very user-friendly as it consists of various pages which are not very descriptive of the information displayed on it. There is however value within the method of using dashboards to present information, as it is currently used by project managers, as well as top management, within

drilling companies to review the status and progress of several drilling projects. The rest of this chapter focuses on the development of the improvement of the as-is solution currently used within the case study company.

4.3.2. System Gap Analysis (RO1, RO2 and RO3)

Having the necessary processes and systems in place to capture the data is essential. It leads to information which can be trusted, and on which decisions can be made. If this is not in place, there will be a 'lake' of data which won't add any value to the company for which it is captured.

An ideal system should have the following capabilities, as derived from informal discussions with developers and operational raise boring experts:

IA1: Store Data – A system should be able to store vast amounts of data over continuous periods so that the data can be utilised and analysed.

IA2: Easily Accessible – The user should be able to access the system easily, to input his/her data.

IA3: Reporting capabilities – The system must either have its own reporting functionalities or should connect with other reporting software.

IA4: Scalable – The system should be scalable to stay relevant over time when new drilling applications are added to a company's repertoire. The scalability should not increase system complexity.

IA5: Work offline – Users must be able to enter information as it happens, to remove the possibility of information being lost in the time passing in the as-is process. The system should then also be able to upload data to a database automatically when able to do so.

IA6: Accurate Data Verification – A verification step must be added to ensure the validity and accuracy of data captured. Ideally, this step should happen by the push of a button once the original activities have been reviewed.

IA7: 1 Point of data entry – Data shouldn't be communicated between individuals before being captured into a system. The 1st point of contact with the activity should input the data into the system to ensure accuracy.

IA8: Standardised activities – As information is reported on within an entire company, it is essential to have a standardised taxonomy of activities. It ensures that the data is accurate and easily understood when analysed and visualised.

IA9: Guide the user – The user should be guided to enter the correct data into the system. It is used to group data better or add metadata for better reporting and data analysis.

Current problems within the as-is process and system of capturing data within a drilling company have been identified through informal discussions with company executives and operational staff. They are as follows:

P1: No offline capabilities – Accessing the system requires a network connection, which is not always possible on operational sites. It creates a delay between activities taking place and the data being captured. It additionally creates possibilities for incorrect information being captured, as some time passes between the activities and capturing take place.

P2: Daily shift activities are not verified – Current practise consists of one individual entering the data which was given to him on a piece of paper, by the operator, at the end of shift. It creates the possibility of capturing the wrong information. Value can be created by inserting a verification step on the inputted data, as the accuracy of the data directly influences the value which can be created within the data-driven dashboards.

P3: Inputting data not done by the first point of contact – Having information transferred by individuals to each other before being input into the system creates the possibility of misinterpretation of activities or events. Having the individual who worked on the activity himself enter the activity would be ideal, as no misinterpretation can take place by transferring the information.

P4: Activities reported on are ill-defined – Activities are underdefined and can be interpreted in various ways. No formal activity creation process exists. Activities are added to the system without formal discussions or approvals. Activities are also not formally defined, and the scope of it agreed upon throughout the company.

P5: Duplicate activities exist in different languages – Activities are not added to a 'master activities list' but added in different languages without doing quality assurance for duplicates already existing in other languages.

P6: Excess activities – The individual capturing the data must search through all the available activities and isn't guided by the system to capture the correct one. Some activities can only take place in certain phases of the 'wagon wheel' and within certain drilling applications.

A gap analysis of the current system is displayed in Figure 25, where the attributes displayed in red are currently lacking within the company used for the case study.



Figure 25: System gap analysis

About 55% of the ideal attributes lack within current capabilities. Including these capabilities within the system will increase the accuracy of the data to be displayed on the dashboards. The data will enable the users to make better-informed decisions, further emphasising the importance of accurate data.

4.3.3. Activity Grouping (RO4)

Grouping activities is essential for easing the analysis process for the user. Data is grouped on the dashboard as it indicates a specific area of concern where the user could drill down for further details. It simplifies the use of the dashboard for the end-user.

There is data available within the current platform utilised for operational data capturing within the case study company. To understand the available data, the activities had to be grouped into easily understandable activity groups, as mentioned in Table 7. Currently, there are 457 individual activities which have various inconsistencies, as discussed in Section 4.3.

A significant contributing factor to the vast amount of activities is the lack of system requirements and various parties which want to make use of the system. The system wasn't initially designed with the specifications in mind but rather developed over time as the different parties recognised the value which the data holds. The following stakeholders currently use the system:

- Company engineers to identify improvement projects
- Company operational excellence forum to analyse information and reduce process variability
- Company commercial department for tender and financial recoveries

After various discussions on the system requirements with the different stakeholders involved, the number of operational activities is reduced to 48, excluding the different Hydraulic, Mechanical and Electrical (HME) and Down-Hole Equipment (DHE) failures. These activities are further grouped into the groups defined in Table 7. These individual groups will then also be drilled down when reported on, to extract more value from the system. The process of capturing shift information is presented in Figure 27. The list of designed drilling activities is displayed in Appendix A: Shift Activities.

Various activity categories are considered to create value for operational project managers. Benchmarks for specific periods within each contract phase are to be stated at the initialisation of a contract, which then serves as the acceptable limits for the specific activities within the period. Benchmarks will differ for each contract phase, as well as the different contract types. It can also happen that 2 contracts of the same type (i.e. both surface and both underground) will have different activity benchmarks. This is due to various operational conditions, commercial arrangements and equipment availability between these specific contracts.

Grouping activities into sensible categories eases the reporting and analysis of data when using a data-driven dashboard. As mentioned in Section 1.2.1, the current system groups activities into the following groups, where G1-G5 are all grouped as 'Non-productive time':

G1: Customer delays – Activities delaying productive time which is caused by the customer.

G2: Company delays – Activities delaying productive time which are caused by the drilling company. It includes equipment and component failures.

G3: Marketing delays – Activities consisting of the machine not working due to machines not having a contract.

G4: Neutral delays – Activities which delay productive time, which is not the customer's or drilling company's fault.

G5: Productive Time – Activities which create revenue for the company, including drilling, and machine installation/uninstallation.

Each of the groups consists of various activities, as explained above. The groups, however, don't all add value for the drilling company itself. Customer delays are split into multiple activities, but with the company not being able to influence these activities, it doesn't add any value for the company. The only information the drilling company needs to know is when the customer caused an operational delay. It is to satisfy the requirement of the company's commercial department, which needs to recover expenses from the customer if they delayed drilling operations. The customer must also sign-off these delays, as they will be held responsible for paying the duties associated it. Neutral delays are ill-defined activities which should be planned for when creating the tender. If intended for, it should be compared to a benchmark, and if unplanned, there should be a party responsible per definition of the tender. The reason for marketing delays is that the current system requires 24 hours recorder each day for all machines. When a machine is not busy on a contract, the time gets recorded within the marketing delays activity category.

The activity categories are redesigned for an ideal system where 24 hours doesn't have to be recorded on each drilling machine, and time is captured on a level of detail where it adds value to the drilling company which must make use of the data. Newly proposed activity groups are as follows:

Table 7: Operational activity categories

Activity Categories	Description
OAC1 - Planned unproductive activities	All activities which form part of the installation, commissioning and decommissioning of primary and support machinery and equipment. It also includes day-to-day activities which are tendered for such as the travelling of employees to the site, Sundays, vacation days etc.
AOC2 - Unplanned unproductive activities	All unforeseen activities that occur which delay operations. It is split into Company Delays, Mine Delays and HME Delays. It includes what Figure 26 refers to as 'Customer Delays'.
OAC3 - Productive time activities	All activities spent on creating actual value for the customer, referring specifically to piloting, reaming and collaring of the hole.

The process of developing the activity categories, as described in Table 7, is displayed in Figure 26. The link between the current activity categories (G1-G5) and the proposed activity categories (OAC1-OAC3) is that they are defined either as productive or non-productive activities. These two overarching categories are, however, not detailed enough for drilling companies to differentiate the activities which are required for value-adding activities to be conducted, from the actual value-adding activities themselves. The decision was thus made to further break down the 'Non-productive time' into OAC1 and OAC2. This break down satisfies the requirement to differentiate which activities are necessary but non-value-adding, from the actual value-adding activities.

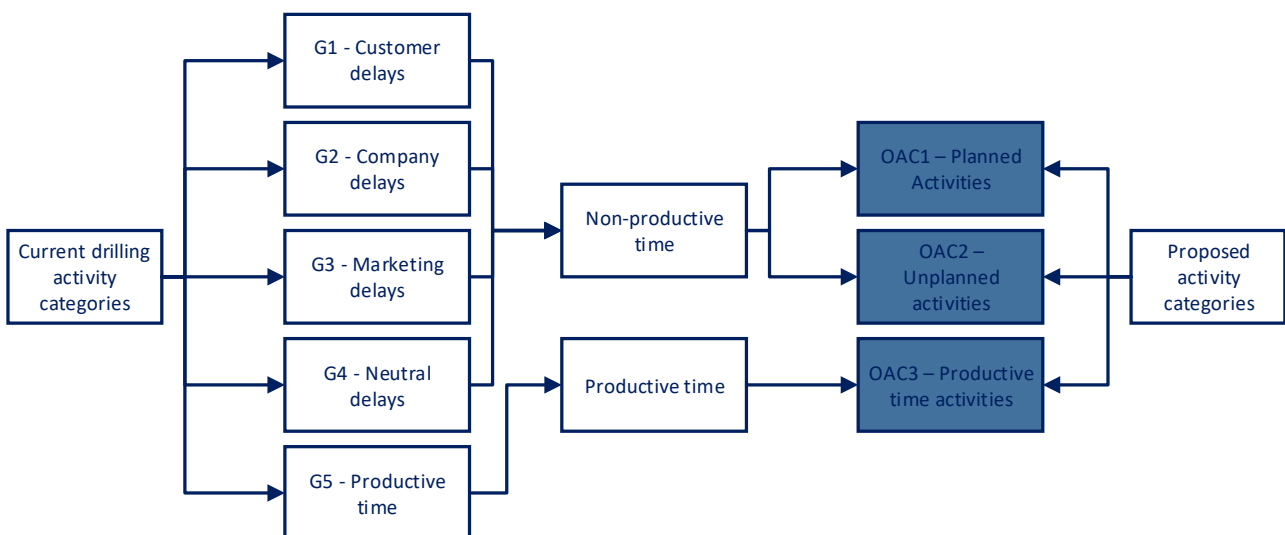


Figure 26: Activity category requirements tree

4.3.4. Daily Operational Project Management

Decreasing the time between events and mitigating actions is where effective daily reporting is critical to assist in operational project management. Current practices regarding daily reporting

consist of contract managers communicating problems on WhatsApp groups with the country’s operations managers. Together with the WhatsApp groups, operational information is captured on the current operating system database. Information obtained includes the penetration of drilling machines, daily shift activities and progress of the hole, to mention a few. To get valuable information from this data, it must be extracted from a SQL database into Excel spreadsheets. It must then be converted into pivot tables and in-turn into graphs containing slicers to filter the information required by management.

The exercise contains a lot of manual work, from the original data point of entry up until the extraction of data and displaying it on the dashboards, for management to make informed decisions. This process has a lot of room for error, being a very manual exercise. It unnecessarily delays the time to get value-adding information. A depiction of the newly proposed process for capturing shift activities is shown in Figure 27. It displays the process as completed by two specific individuals, namely the Contract Foreman and the Drilling Operator.

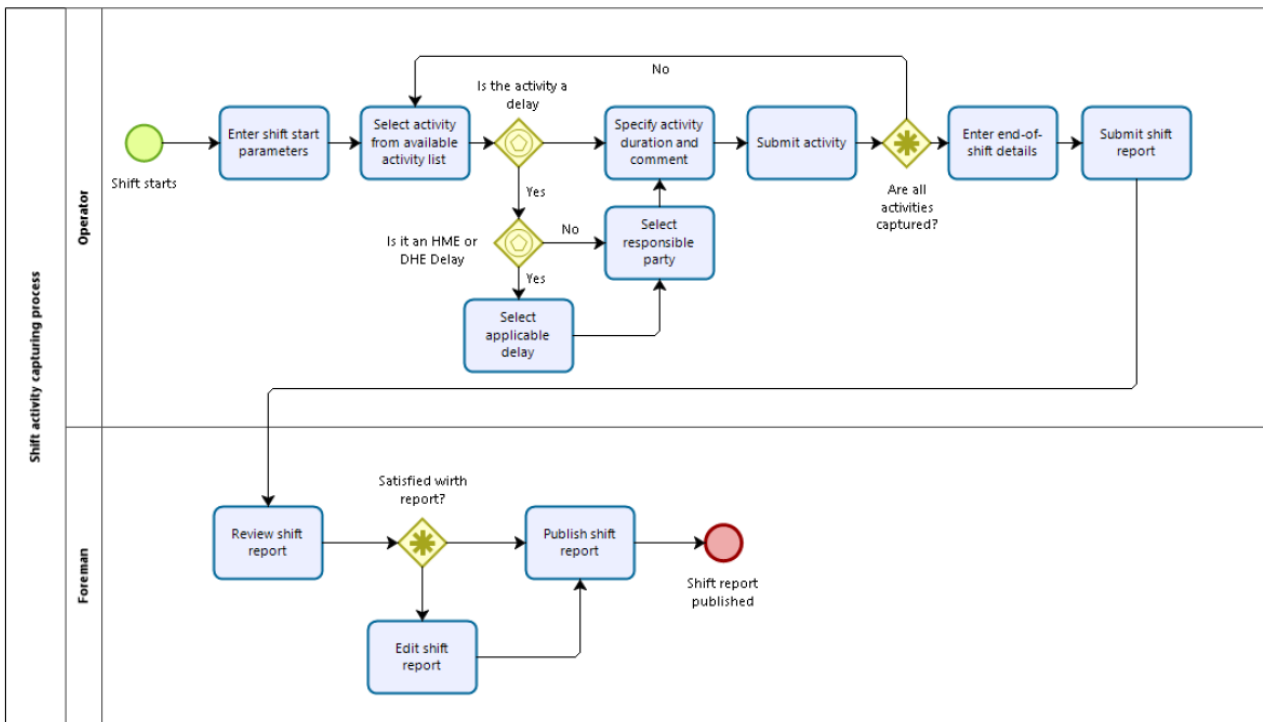


Figure 27: BPMN model of the to-be shift activity capturing process

The process is relatively simple, consisting of mainly one point of data entry, which is then verified for accuracy and relevancy. The first point of contact on-site is the same individual who enters the data into the system, removing the possibility of data getting lost when communicated to the clerk who would initially be responsible for entering the data into the system.

The value of dashboards comes into play at this very instance. Extracting data into the correct format, after assuring its validity, and displaying it in real time for the end-user. Importance of information

differs with different user-groups. The dashboard designed in the study is focused on the operational user groups.

Important operational details to be captured daily consists of the following:

1. Actual versus planned daily activities as tendered for
2. Actual daily penetration on the hole versus the planned penetration
3. Actual machine availability
4. Any delays holding up the critical path of the project

The benchmarks are set-up at the beginning of the project, and the actual performance will then be managed as Key Performance Indicators (KPI's) for the project. This information should be monitored daily in the author's opinion. It will form part of the category of Operational Dashboards, as displayed in Figure 11.

4.3.5. Weekly Operational Project Management

Current practises in any drilling company, which has data available captured over time, is to plot the data and trend specific data groups or activities. Historical data is used for this application. Having the data available can, however, lead to predictive approaches if combined with the correct expertise and algorithms.

4.3.6. Historical Data Analysis

Using historical data, trends can be visualised to detect declines in operational performance, or even to identify the HME areas which cause the most delays for company operations. It, in turn, helps management to react on current performance issues and allocate resources to the tasks which are directly impacting operational performance. The following two examples will illustrate this in the context of the case study company:

Example 1: The decline in lost-time injuries on-site

Using historical information over a year, divided into monthly intervals, the rise in lost-time injuries on operational sites within a specific region or country is derived. Proactively acquiring this information indicates to management the need for safety awareness campaigns, or the improvement of certain operational technologies, based on the root cause of the different safety incidents.

Example 2: Spread between HME Delays

Using statistical methods on the different HME delays captured on operational shifts, it is found that 80% of delays are due to mechanical failures on a specific gearbox component. Company and employee resources can now be shifted to this component and how it can be improved, rather than focusing on various other HME delays which don't contribute as much to machines being delayed during operations.

This method of data analysis accompanied by data-driven dashboards add tremendous value to operational improvements and efficiencies when utilised. Combined with minimal user interference or manual input, as well as the real-time data outputs, this method should improve current practices.

One method of comparing daily activities to the benchmarked values using statistical control charts. The deviation from a planned activity is indicated over a period, which can be specified as the specific contract phase, or over the whole period of the contract. It provides the viewer with a quick insight into the progress on the drilling site. The control chart is, however, limited in the sense that it is viewed per activity or at most per activity group.

Another method is by showing the actual daily hour-usage of all activity groups over a period, using area charts. The charts conclusively show variation in the process. It is essential for any drilling company to try and decrease the time and variability of operations in the future. The area chart creates value when compared to a benchmarked chart for the specific site and contract phase. There is a requirement for the project manager to set-up the benchmarks for the contract before drilling operations are initiated.

4.3.7. Potential for Improvement

An as-is drilling project is challenging to manage due to complexity (refer to 4.2.1), and the fact that various of them are managed by a single contract manager. A dashboard aids the contract manager in managing multiple projects by creating real-time visibility on the project's activities. It uses the data updated daily by site personnel to provide the contract manager with a digital twin of what is happening operationally. This data can be used to predict specific outcomes or display trends in both planned and unplanned activities. The dashboard includes the budgets, actuals and targets for different costs to aid the contract managers in improved project management.

Such a system adds value by enabling the user to make informed decisions and decreasing the reaction times on events occurring or preventing overspending of the project's budget. It must be aligned with the company's performance and KPI's, to emphasise the value that added OEE improvements have on the company's profitability. A drilling company's KPI tree is presented in Figure 28, displaying only the KPI's applicable to this study. The entire KPI tree is presented in Appendix B: Drilling Company KPI Tree. The effect of improved OEE leads to increased operational utilisation. It has the effect of revenue being generated at lower costs, due to contracts being completed at an increased pace, or within planned budgets.

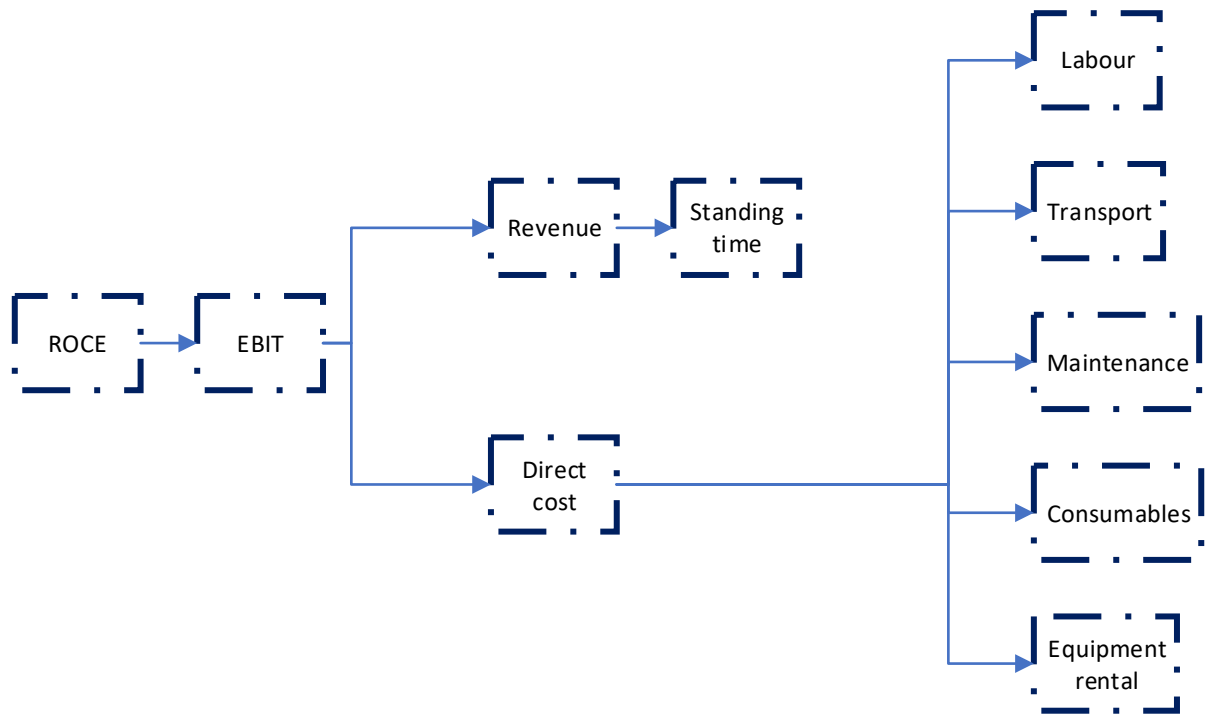


Figure 28: Drilling company's KPI tree

Standing time (as mentioned in Figure 28) refers to the unproductive time on a contract, which is attributed either to the customer or to the drilling company. The responsible party depends on the activity which took place, as well as the content of the contract between the legal parties. Decreasing standing time has the effect of increasing productive time, which means that the machine can drill for more hours per day. It leads to a contract potentially being completed quicker, and with decreased costs.

4.4. Final Concept Description

The meta-artefacts designed in this chapter all form part of the first three parts of a system, as presented in Figure 18. When implemented correctly, the system should have reliable data with a relatively high degree of accuracy. Value is created for the management of a drilling company with the data captured through this system. The primary artefact of this study will be the data-driven dashboard, which aids company management in making decisions and managing operations with greater ease.

This dashboard includes data which helps manage costs and operations on site. Each contract manager is responsible for making a target GP of 20% on a contract. To do this, managing operations and costs effectively are crucial. The primary artefact of this study aims to help this individual do precisely that.

Chapter 5: Detailed Final Design

The final artefact (See Figure 18) is an operational dashboard, where operational data will be transformed into valuable information for its user. Any dashboard should cater to the end-user thereof and contain only data on a level applicable to him/her. The dashboards to be designed should thus provide enough information and can drill down into enough details for management to make operational decisions. This dashboard should create visibility in such a manner so that expensive mistakes can be avoided, and better control conducted over the machines without having to add extra resources or employees.

5.1. Dashboard Elements

Based on current practices within a drilling company, as well as the KPI tree developed, a decision was made to add the following elements to the operational dashboard, and integrating the various platforms on which the current data is stored:

- **Operational shift activities** – Currently on a separate platform, having all the details of activities which took place on each operational shift since the platform was created. This data is valuable to contract managers on each site, as it indicates to them the responsible parties of each activity, as well as where the mine can reimburse them for expenses undergone due to mine delays.
- **Spread of productive and non-productive time spent in operations per machine** – This will serve as a first line indicator as to where machines are not performing according to the benchmarks and assumptions stated within the tender and planning phases in the creation of the contract.
- **Targets, budget and actual data of costs on different items per machine** – This assists the contract managers of specific contracts, as well as the GM's of the entity which the contract was awarded to, in managing the expenses per contract. If not managed well, the costs can negatively impact the profitability of the contract, and thus also negatively impact that of the entity itself.

5.2. Software Selection

The software chosen to develop the data-driven dashboard is Microsoft's data visualisation software, PowerBI. The reason for selecting the software is because it is currently the tool which the drilling company on which the case study is done is using, making the artefacts of this study more valuable to them, as well as the free access to the software provided by the company. The author also has extensive experience using PowerBI, which has all the functionalities required to develop the artefacts this study requires. A detailed matrix on the software selection is displayed in Table 8. The criteria for selection are discussed below. Each criterion is scored with a value between 1 and 5,

where one is the worst, and five the best. The score is based on the author’s experience with all three software packages, after downloading and using it to create the final artefact.

5.2.1. Visual interface

It mainly refers to the aesthetic look of the software product, namely the dashboards themselves. It includes the visual appeal of the visuals themselves, as well as the user experience when using it.

5.2.2. Ease of use

It refers specifically to the ease with which the software is adapted. It includes the time to learn to use the software, as well as the ease with which an inexperienced user will adapt to it.

5.2.3. Cost

This criterion is scored higher when the cost is less. Cost is calculated per user per month in US\$. The costs of the three software packages are as follows:

- PowerBI - \$10/user per month
- Tableau - \$12/user per month
- QlikView - \$15/user per month

5.2.4. Accessibility

It refers to the ease with which the software package is obtained and installed on a user’s personal computer, including the difficulty in searching for the software and navigating the installation process.

5.2.5. Sharing capabilities

It refers to the ability of the software to share dashboards and reports at minimal costs. For enterprise level sharing within any company, licences are required for all the reviewed products.

Table 8: Software selection criteria

Criteria	PowerBI	Tableau	QlikView
Visual interface	5	3	3
Ease of use	4	4	3
Cost	4	3	2
Accessibility	5	5	5
Sharing capabilities	3	3	4
Total	21 / 25	18 / 25	17 / 25

5.3. Dashboard Design

The dashboard itself is used to identify areas of concern on drilling contracts. When detected, it is essential for the user to be able to drill down into a specific area to try and identify a reason for the deviation in schedule or costs which has occurred. To make this possible, it is essential to not only display data within charts and visuals but to make some of the raw data itself visible on the dashboard. An example of this displayed in Figure 29, which uses fictional data to visualise this application.

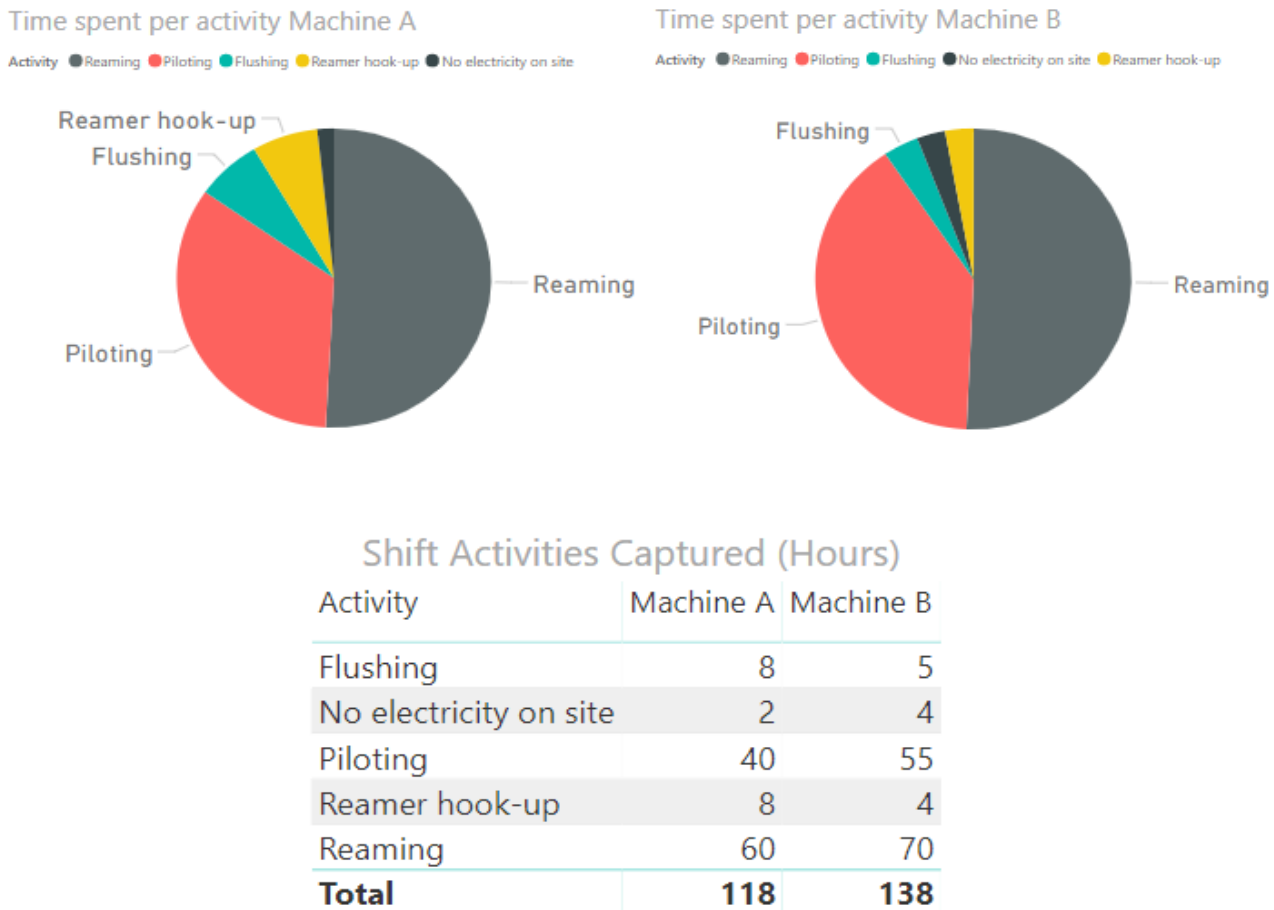
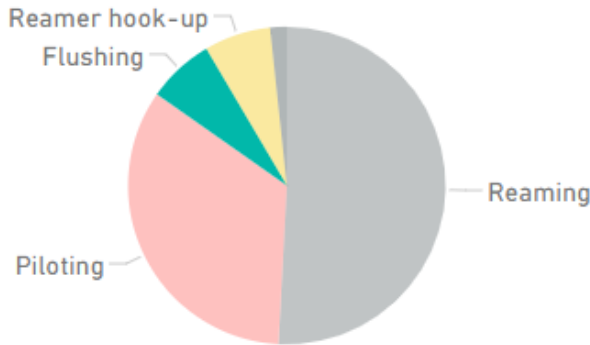


Figure 29: Fictional representation of dashboard visual including the data (Unfiltered)

When filtering the data by clicking on the pie chart, all the visuals linked to the visual clicked on will be filtered, including the data itself. It is displayed in Figure 30, where the data is filtered to view all details regarding the flushing time on both machines A and B.

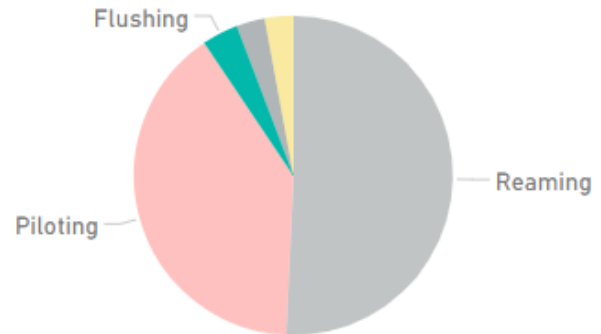
Time spent per activity Machine A

Activity ● Reaming ● Piloting ● Flushing ● Reamer hook-up ● No electricity on site



Time spent per activity Machine B

Activity ● Reaming ● Piloting ● Flushing ● No electricity on site ● Reamer hook-up



Shift Activities Captured (Hours)

Activity	Machine A	Machine B
Flushing	8	5
Total	8	5

Figure 30: Fictional representation of dashboard visual including the data (Filtered)

The application of filtering data in such a manner can add value to the user, mainly when the dashboard contains a vast amount of data, and various visuals consisting of data from different applications and sources. Multiple visual types exist but have different applications. Some visuals are better for specific applications than others, for example:

A line chart is better fitted to show data over a period on a continuous base in comparison with a pie chart. Whereas a pie chart is better suited to display a comparison of data fields in a specific category or department.

Association Analytics, a company specialising in working with data and dashboards, provides guidelines on the validity of specific chart visuals for certain applications. These guidelines are summarised in their own personal ‘cheat sheet’ as displayed in Appendix C: Dashboard Visuals (Analytics, 2018).

Considering the data to be displayed in the dashboard this study aims to provide, as well as the ‘Cheat Sheet’ of Association Analytics, the following visual types are chosen to be tested with the fictional data, which was benchmarked to data supplied by Master Drilling. The different visuals are discussed in Table 9.

Table 9: Applicable visuals for different dashboard elements

Dashboard element	Applicable visuals
Operational shift activities	<ul style="list-style-type: none"> • Pie chart – Comparing the activity groups with one-another • Doughnut chart – Comparing the activity groups with one-another • Treemap – Comparing the activities of different groups with those in the same group. • Waterfall chart – Hours spent on activities over time • Stacked column chart – Time spent per activity on a machine over time • Gantt chart – Time spent on activities throughout a specific period per machine • Table – Show the actual data of the activities per machine for a specific period
Spread of productive and non-productive time spent in operations per machine	<ul style="list-style-type: none"> • 100% Stacked area chart – Compare productive vs non-productive time daily over time • 100% stacked column chart – Compare productive vs non-productive time over a time period. • Pie chart – Compare productive vs. non-productive time
Targets, budget and actual data of costs on different items per machine	<ul style="list-style-type: none"> • Line chart – Compare the target, budget and actual data on expenses over time • Stacked area chart – Compare the target, budget and actual data on different costs over time • KPI visual – Display the current value of a cost-related KPI • Gauge – Display the present value of a cost-related KPI, including a benchmark on the visual • Table – Show the actual data of purchases per machine over time
Filters for machines, companies, dates etc.	<ul style="list-style-type: none"> • Dropdown filter – Select one or multiple elements to filter on the current dashboard • Checkbox filter – Select either one, or multiple elements to filter on the existing dashboard

Table 9 considers various visual elements, most of which are suitable for the requirements of an operational dashboard. The method of mapping the business requirements to the different dashboard visuals is displayed in Figure 31. It includes the explanation of the various visuals, as presented in Table 9. After testing the different visuals and reviewing them with company experts,

the visuals elements are selected. Each selected dashboard element is displayed in Table 10, including the reasons for why they are chosen.

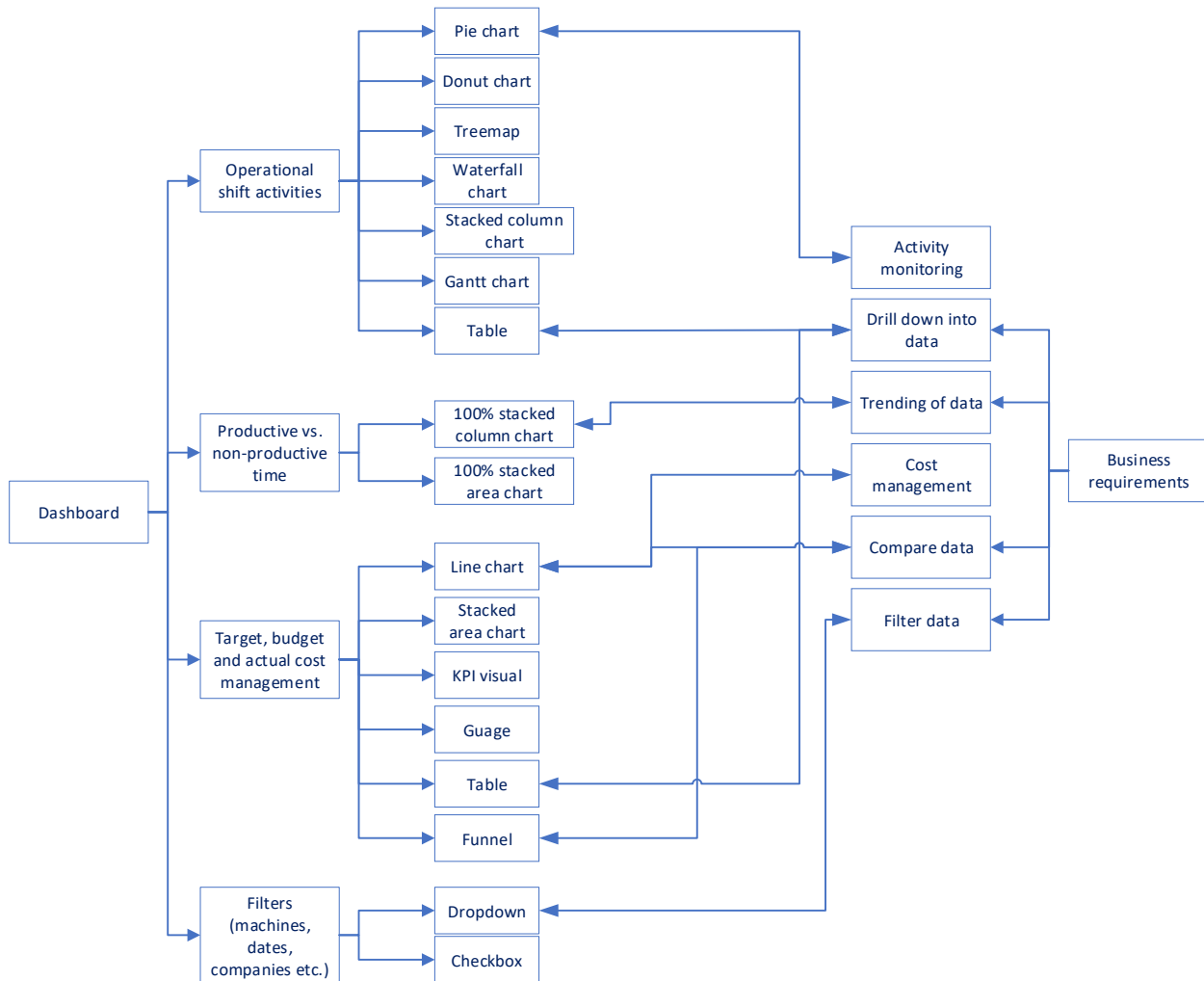


Figure 31: Dashboard visual selection requirements tree

Table 10: Chosen visuals for different dashboard elements

Dashboard element	Chosen visuals	Reason for choice
Operational shift activities	<ol style="list-style-type: none"> 1. Pie chart 2. Table 	<ol style="list-style-type: none"> 1. Compare the time spent on different activities throughout the group, with the ability of further filtering per machine 2. Easy-to-understand display of the data, which adapts to the filters on other visuals
Spread of productive and unproductive time spent in operations per machine	<ol style="list-style-type: none"> 1. 100% Stacked Area chart 	<ol style="list-style-type: none"> 1. Easier to read than the 100% stacked column chart over more extended periods and displays 24 hours on the y-axis which adds value on a group level if all machines are viewed, as well as on a specific machine level

Targets, budget and actual data of costs and revenues on different items per machine	<ol style="list-style-type: none"> 1. Line chart 2. Table 3. Funnel Chart 	<ol style="list-style-type: none"> 1. A consolidated view can be given for all costs incurred on a group level, which can then be filtered to an entity, cost bucket or machine level 2. Easy-to-understand display of the data, which adapts to the filters on other visuals 3. Easy-to-understand visual displaying the different cost categories compared to one another
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5.4. The sequence of Visuals on the Dashboard

As mentioned in section 0, the essential information should be positioned in the top left and middle sections of the dashboard. Having various sets of data and visuals to display on the dashboard, it is important to differentiate what will be ‘important’ to the end-user thereof. Some of the visuals are used to indicate the status or performance of an element, whilst others, such as the data, are used for further details when drilling down to find a root or specific cause of a problem. Visuals are thus divided into three types:

1. Indicating visuals – Visuals showing the status or performance of a contract or element.
2. Meta-indicating visuals – Visuals indicating the status or performance of a contract or specific element and are used to support the indicating visuals in identifying a problem.
3. Data visuals – Visuals are displaying the data, in a table format, required when drilling down into an area to find the root of a problem identified using either of the above visual types.

The importance of the visuals might vary to different users, but will be ordered in the same sequence as the different visual types, namely:

1. Indicating visuals – Most important
2. Meta-indicating visuals – Less important
3. Data visuals – Least important

The indicating visuals must be situated in the top left and middle positions, while the other two visual types will be located accordingly to group relevant information.

A more comprehensive overview of the complete dashboard is provided below. Considering the dashboard visual types selected, as well as the sequencing of the visuals as discussed in the previous chapter; the designed dashboard is created. This dashboard is presented in Figure 32.

Referring to Appendix B: Drilling Company KPI Tree, the different KPI’s which are measured within a drilling company, is displayed. Direct costs and revenues are the highest level KPI’s which need to be measured from an operational perspective. The higher-level KPI’s such as EBIT and ROCE will add value in the middle to executive level management range. As the costs and revenues are the most important KPI’s, the visuals indicating these measures are displayed to the top left and middle sections of the dashboard artefact.

5.5. Dashboard design overview

Considering all prior research of this study, the dashboard artefact is designed iteratively until its final version displayed in Figure 32.

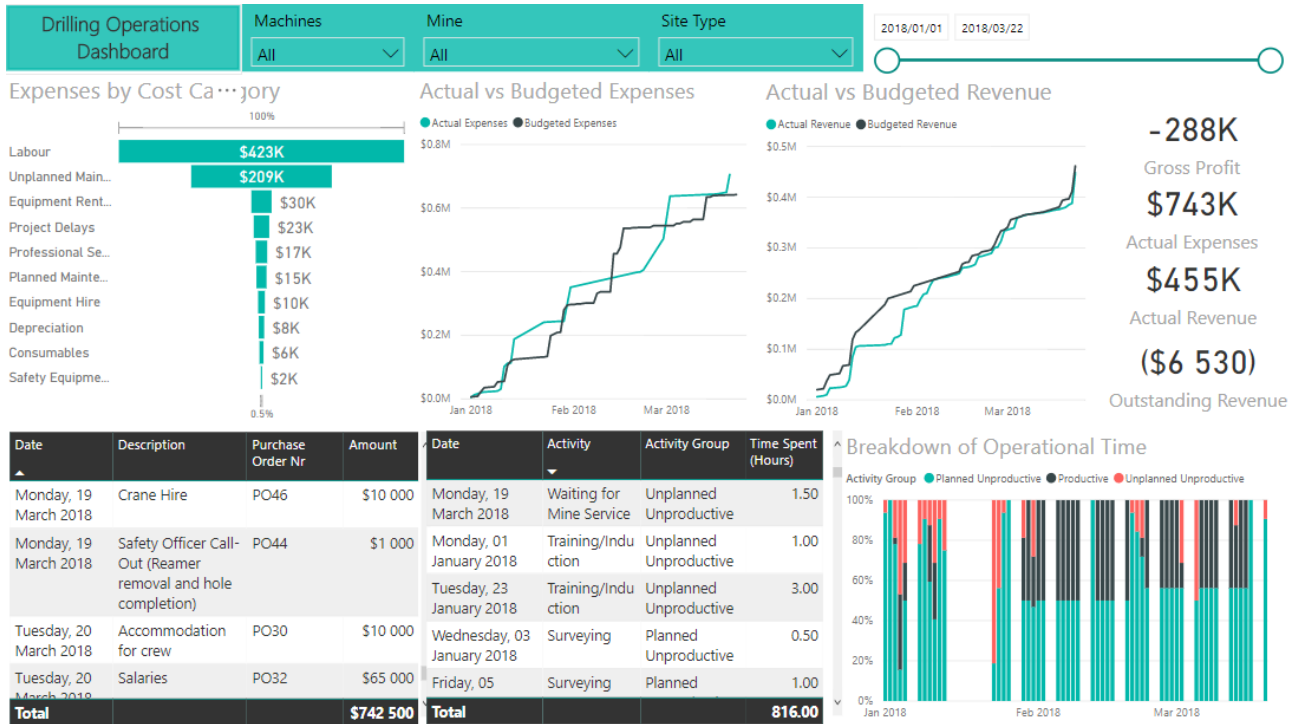

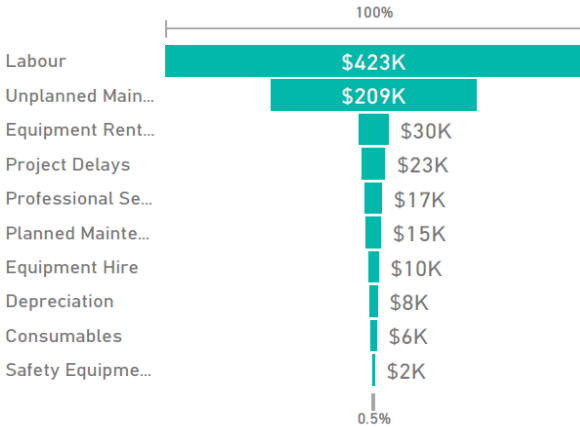
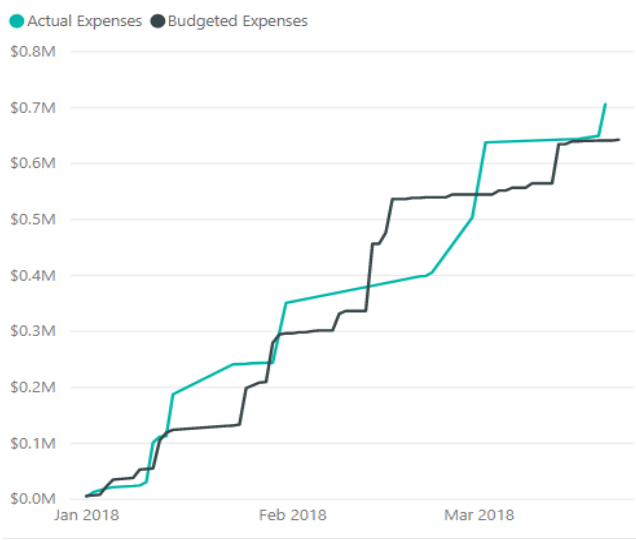


Figure 32: Designed operational dashboard

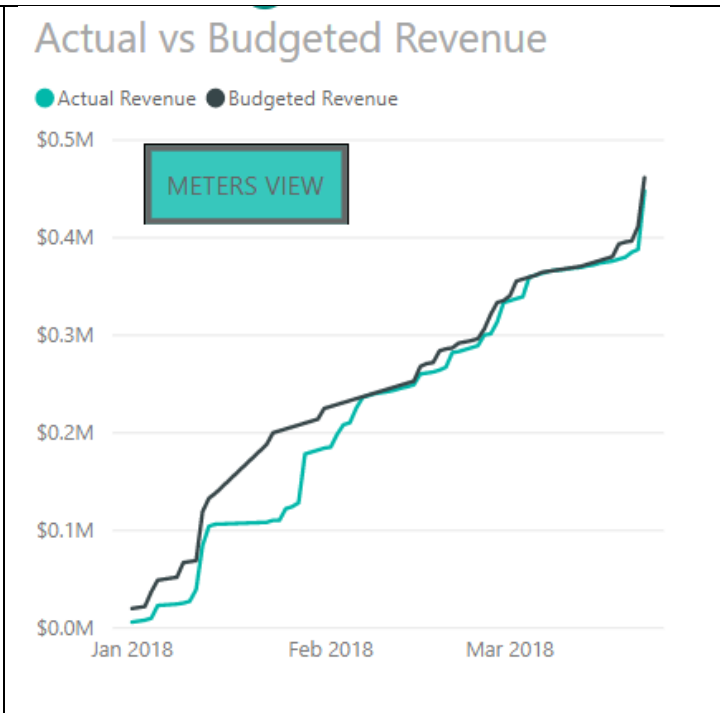
The dashboard consists of 14 different visuals, each having a specific reason for being included in the design. The visuals are codified in Table 11, after which each element is discussed. All data displayed on the dashboard throughout this study is 100% fictional, aimed only at conveying the intent and value of the research of this study.

Table 11: Dashboard visual element codification

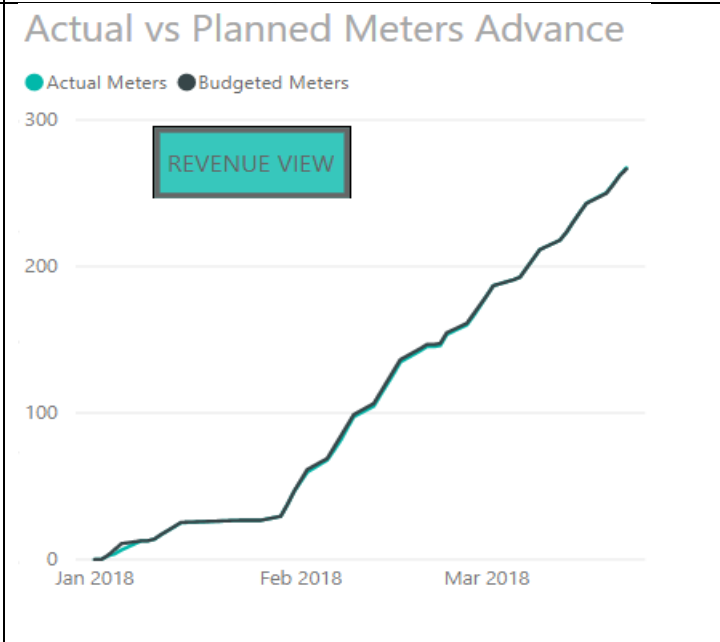
Codification	Element
DV1 – Machine Slicer	Machines All
DV2 – Mine Slicer	Mine All
DV3 – Site Type Slicer	Site Type All

<p>DV4 – Date Slicer</p>	<p>2018/01/01 2018/03/22</p> 																						
<p>DV5 – Expenses by Cost Category</p>	<p>Expenses by Cost Category</p>  <table border="1"> <thead> <tr> <th>Cost Category</th> <th>Expense Amount</th> </tr> </thead> <tbody> <tr> <td>Labour</td> <td>\$423K</td> </tr> <tr> <td>Unplanned Main...</td> <td>\$209K</td> </tr> <tr> <td>Equipment Rent...</td> <td>\$30K</td> </tr> <tr> <td>Project Delays</td> <td>\$23K</td> </tr> <tr> <td>Professional Se...</td> <td>\$17K</td> </tr> <tr> <td>Planned Mainte...</td> <td>\$15K</td> </tr> <tr> <td>Equipment Hire</td> <td>\$10K</td> </tr> <tr> <td>Depreciation</td> <td>\$8K</td> </tr> <tr> <td>Consumables</td> <td>\$6K</td> </tr> <tr> <td>Safety Equipme...</td> <td>\$2K</td> </tr> </tbody> </table>	Cost Category	Expense Amount	Labour	\$423K	Unplanned Main...	\$209K	Equipment Rent...	\$30K	Project Delays	\$23K	Professional Se...	\$17K	Planned Mainte...	\$15K	Equipment Hire	\$10K	Depreciation	\$8K	Consumables	\$6K	Safety Equipme...	\$2K
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Planned Mainte...	\$15K																						
Equipment Hire	\$10K																						
Depreciation	\$8K																						
Consumables	\$6K																						
Safety Equipme...	\$2K																						
<p>DV6 – Actual vs Budgeted Expenses</p>	<p>Actual vs Budgeted Expenses</p>  <p>Legend: ● Actual Expenses ● Budgeted Expenses</p> <p>Y-axis: \$0.0M to \$0.8M</p> <p>X-axis: Jan 2018, Feb 2018, Mar 2018</p>																						

DV7 – Actual vs Budgeted Revenue

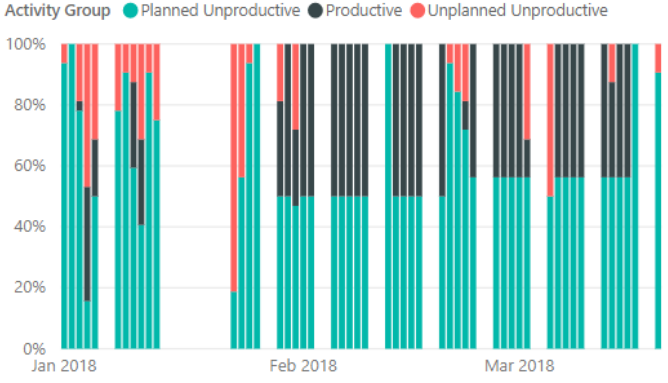


DV8 – Actual vs Planned Meters Advance



DV9 – Transactional Financial Data

Date	Description	Purchase Order Nr	Amount
Monday, 19 March 2018	Crane Hire	PO46	\$10 000
Monday, 19 March 2018	Safety Officer Call-Out (Reamer removal and hole	PO44	\$1 000
Tuesday, 20 March 2018	Accommodation for crew	PO30	\$10 000
Tuesday, 20 March 2018	Salaries	PO32	\$65 000
Total			\$742 500

<p>DV10 – Operational Data</p>	<table border="1"> <thead> <tr> <th>Date</th> <th>Activity</th> <th>Activity Group</th> <th>Time Spent (Hours)</th> </tr> </thead> <tbody> <tr> <td>March 2018</td> <td>Mine Service</td> <td>Unproductive</td> <td>1.50</td> </tr> <tr> <td>Monday, 19 March 2018</td> <td>Waiting for Mine Service</td> <td>Unplanned Unproductive</td> <td>1.00</td> </tr> <tr> <td>Monday, 01 January 2018</td> <td>Training/Induction</td> <td>Unplanned Unproductive</td> <td>3.00</td> </tr> <tr> <td>Tuesday, 23 January 2018</td> <td>Trainina/Induction</td> <td>Unplanned Unproductive</td> <td></td> </tr> <tr> <td>Wednesday, 03 January 2018</td> <td>Surveying</td> <td>Planned Unproductive</td> <td>0.50</td> </tr> <tr> <td>Friday, 05 January 2018</td> <td>Surveying</td> <td>Planned Unproductive</td> <td>1.00</td> </tr> <tr> <td>Total</td> <td></td> <td></td> <td>816.00</td> </tr> </tbody> </table>	Date	Activity	Activity Group	Time Spent (Hours)	March 2018	Mine Service	Unproductive	1.50	Monday, 19 March 2018	Waiting for Mine Service	Unplanned Unproductive	1.00	Monday, 01 January 2018	Training/Induction	Unplanned Unproductive	3.00	Tuesday, 23 January 2018	Trainina/Induction	Unplanned Unproductive		Wednesday, 03 January 2018	Surveying	Planned Unproductive	0.50	Friday, 05 January 2018	Surveying	Planned Unproductive	1.00	Total			816.00
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<p>DV11 – Breakdown of Operational Time</p>	<p>Breakdown of Operational Time</p>  <p>Activity Group ● Planned Unproductive ● Productive ● Unplanned Unproductive</p>																																
<p>DV12 – Gross Profit Measure</p>	<p>-288K Gross Profit</p>																																
<p>DV13 – Actual Expenses Measure</p>	<p>\$743K Actual Expenses</p>																																
<p>DV14 – Actual Revenue Measure</p>	<p>\$455K Actual Revenue</p>																																
<p>DV15 – Outstanding Revenue Measure</p>	<p>(\$6 530) Outstanding Revenue</p>																																

DV1 – Machine Slicer

This element enables the user to filter between specific machines, filtering the entire dashboard on the machine chosen. This aids in analysing data of machines, with the aim of either improving efficiencies, or determining causes of deviations in programmes or resource spend.

DV2 – Mine Slicer

This element enables the user to filter between mines on which projects are occurring. This aids management in to analyse data for specific customers.

DV3 – Site Type Slicer

This element enables the user to filter the dashboard to certain site types, surface or underground, and analyse the rest of the data to detect trends.

DV4 – Date Slicer

This element allows the user of the dashboard to filter all information between 2 specific dates to view detail of what happened on the projects, such as expenses and revenue generated.

DV5 – Expenses by Cost Category

This element displays the expenses split per cost category. Clicking on the specific cost category also filters the related visuals based on that category. This aids in determining the causes of overspending. It also aids the project manager to plan expenses per cost category.

DV6 – Actual vs Budgeted Expenses

This element displays the progress of actual costs vs the budget for the selected machines. It aids the project manager to plan for certain expenses better.

DV7 – Actual vs Budgeted Revenue

This element displays the revenue which has been received for the filtered projects, in comparison to the revenue which was planned on receiving with the original tender.

DV8 – Actual vs Planned Meters Advance

This element displays meters advanced up to the date filtered for, in comparison to the advance in meters which was planned for on that same date.

DV9 – Transactional Financial Data

This element is a table, which displays the related transactional data of the specific expenses. It provides detail such as the Purchase Order Nr for every transaction made, which is required if further root cause analysis is to be done outside of the system.

DV10 – Operational Data

This element is a table, which displays the operational shift details for specific dates and machines selected. It is an integral part of determining what happened on site in the case of incidents taking place or deviations from the budget occur.

DV11 – Breakdown of Operational Time

This element gives an overview of operational time spent on productive, planned unproductive and unplanned unproductive time. When selecting a day or specific filter, on the visual the operational data will be filtered accordingly to determine the shift activities which occurred on that day.

DV12 – Gross Profit Measure

It displays the gross profit generated for the filtered machine, site type or mines.

DV13 – Actual Expenses Measure

This element displays the expenses undergone on the filtered machine, site type or mines.

DV14 – Actual Revenue Measure

This measure displays the generated revenue on filtered machines, site types or mines.

DV15 – Outstanding Revenue Measure

This measure displays the revenue for filtered machines, site types or mines which has yet to be received from the respective customers.

Chapter 6: Research Results

The previous chapter provides detail on the development of the operational dashboard to aid project or contract managers within a drilling company in more effectively and efficiently managing operational drilling projects. This chapter displays how the dashboard effectively helps the project or contract manager. At the start of this study in 2018, no daily operational dashboard existed within Master Drilling South Africa, which provided the user thereof the ability to make better decisions. The closest to this was the raw data itself, which could occasionally be extracted into Excel pivot tables to answer the questions of top management, even though the data itself was in a rather unusable condition.

To explain the value added with the dashboard, a few scenarios are created with which the dashboard's value is discussed. The newly created dashboard's value is compared to that of the as-is solution within the case study company's South-African entity at the start of this study. This comparison within different scenarios verifies the design of the dashboard, and the data which it displays. This verification is further discussed in the next chapter of this study.

6.1. Scenario 1 – The project has gone over budget

It is an actual scenario which can easily take place within a drilling project, considering the size and value of the machines and operations taking place. In this scenario, a project has gone over budget, and the contract manager needs to find out why.

As-is Solution

The financial data would have to be extracted from local servers, entailing communication between the IT and Finance departments. A view on the actual and budgeted expenses could be provided with a bit of manual effort and the creation of Excel graphs and tables. It would take some time to develop and won't necessarily be used after it has been created to find this one problem. Relationships won't necessarily be seen between the cost categories, purchases made and specific dates on the project, as it will depend on the knowledge of the user to correctly set-up the tables and graphs to do so.

Developed Dashboard

Referring to the dashboard artefact, the contract manager can now use visuals DV5 and DV6, to see where the funds of the project had been spent. It can be viewed per day, as well as per cost bucket. When using visual DV9, the contract manager can see all the purchases by date and description for the period under review. The dashboard enables the contract manager to perform cost management on the project. The data can be viewed in real-time without further communication with other stakeholders.

Figure 33 displays the dashboard filtered to the two largest cost categories within the date of the project in question. DV5 shows that unplanned maintenance was a substantial contributor to the expenses on the project. DV6 displays when the expenditures took place. Additionally, DV9 can be used to see what some of the purchase order details were. In this case, there were cutters bought for \$60 000.

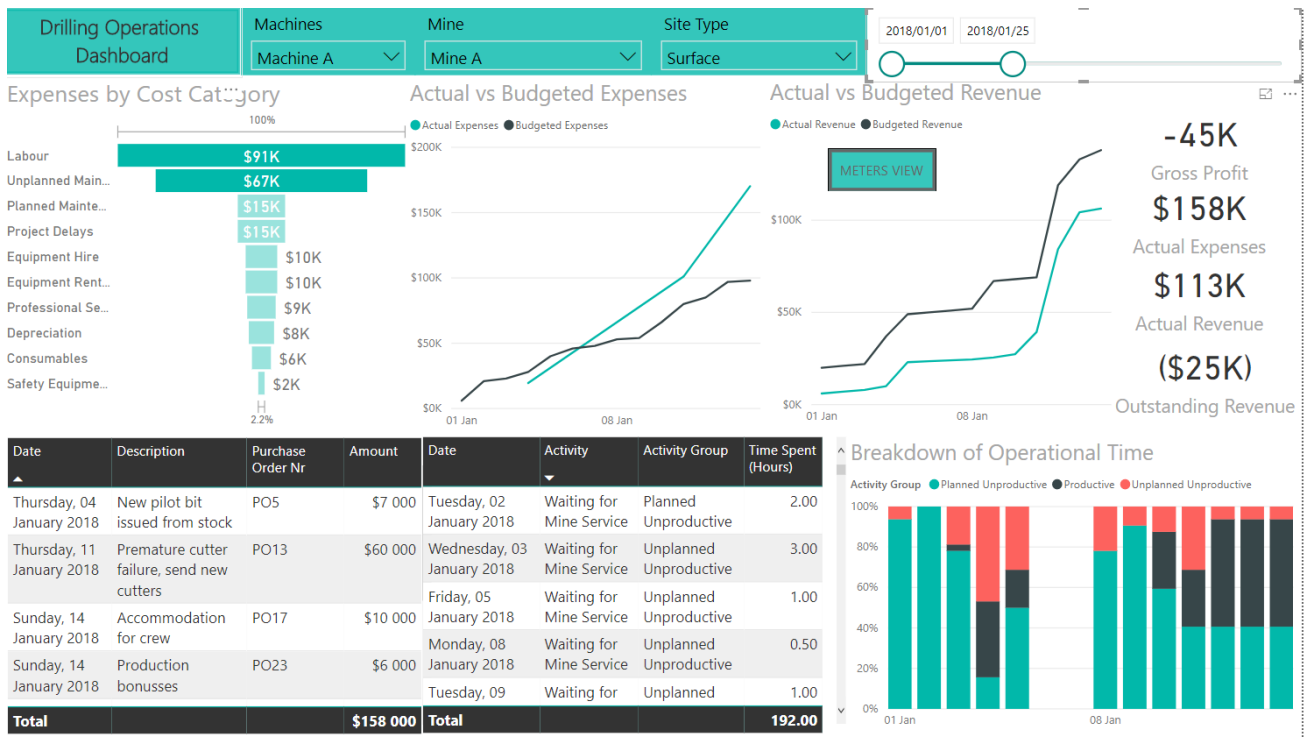


Figure 33: Results scenario one dashboard view

6.2. Scenario 2 – Drilling progress is behind schedule

Frequently it will happen that delays caused by the customer, delay production. The effect of this is not always immediately seen by the contract manager during a specific shift.

As-is Solution

There currently exists more than 450 different operational activities. These activities are duplicated, in different languages, and on different levels of detail. The choice on which activity to pick is subjective to the user, as no standard exists across all operational sites. The data will have to be extracted and then cleaned up, to extract value from it.

Developed Dashboard

Using the dashboard, the contract manager can now see on which activity time spent. Using DV8, actual vs planned meters advance can be viewed. Using DV11, the contract manager can see the days on which unplanned unproductive activities have occurred delaying the progress. When clicking on a specific day, visual DV10 can be used to identify the specific activities which took place during that day. It can be used to see whether the customer was at fault, or if the delay was due to unplanned

failures or incidents. This information can, in turn, be used to recover revenues from the customers, in the case of them being at fault for the occurring delay.

Figure 34 displays the dashboard filtered to specific dates for a project. Visual D11 is filtered by selecting all unplanned unproductive time, filtering D10 to display all the different times on those days in which unplanned unproductive time took place, as well as the activities which occurred, delaying the project. A tooltip is displayed over D8, revealing that the meters advance is behind schedule.

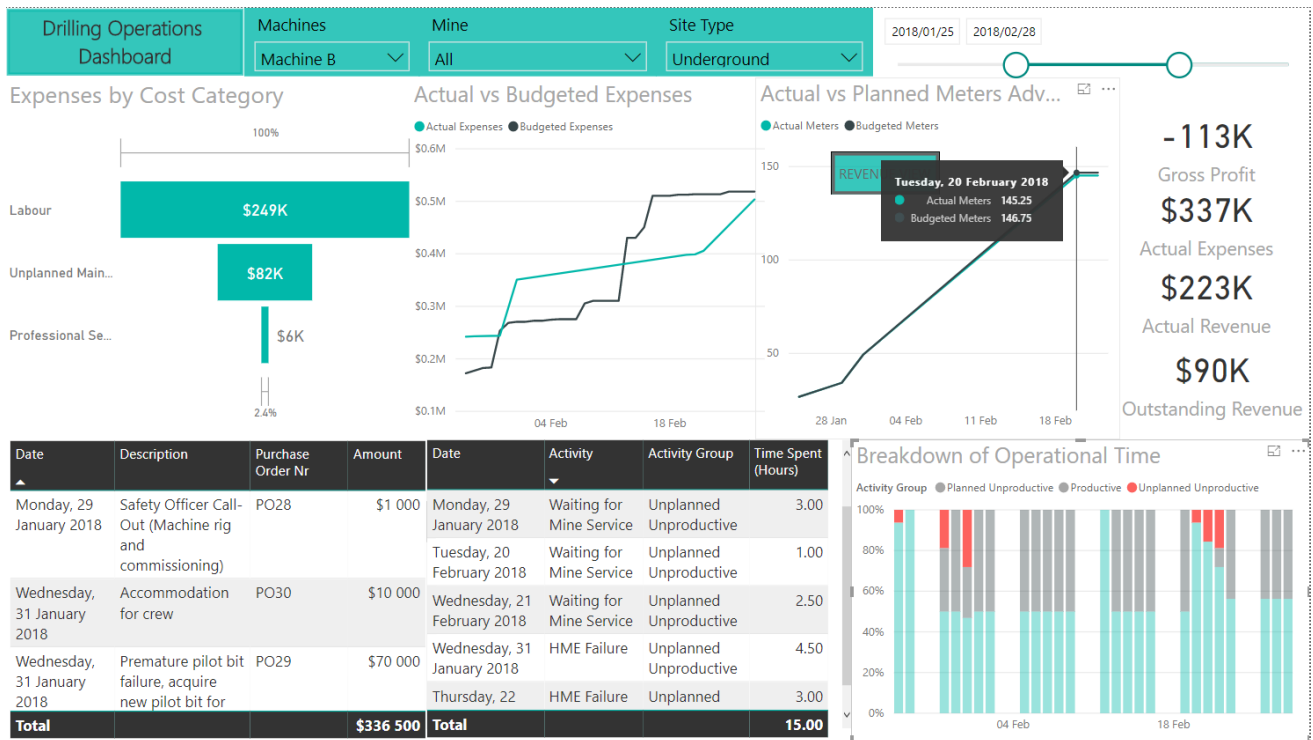


Figure 34: Results scenario two dashboard view

6.3. Scenario 3 – Estimation for new drilling contracts must be conducted

It regularly happens in operational contexts that estimation is done in a specific manner, and the assumptions made during this process is rarely revised due to a lack of data and information.

As-is Solution

Due to a lack of reliable operational data, and the lack of comparison thereof with the financial data, little can be done to improve the assumptions made when tendering and estimating for specific projects.

Developed Dashboard

Using the information generated by the operational data capturing system, with the newly developed dashboard, estimators can be assisted by contract managers to better plan for upcoming projects. It assures the drilling company that all expenses are accounted for during the estimation and planning phase of a potential contract.

Figure 35 displays the total expenses per category for underground sites, which the estimator can use to evaluate his costs planned on the original tender of the project. It will most-probably add value as the project went over budget as displayed in D6. The same exercise can be done with the time spent on activities. The time spent on planned unproductive activities should be evaluated against the planned durations during estimation of the project, as this directly impacts the profitability of a contract.

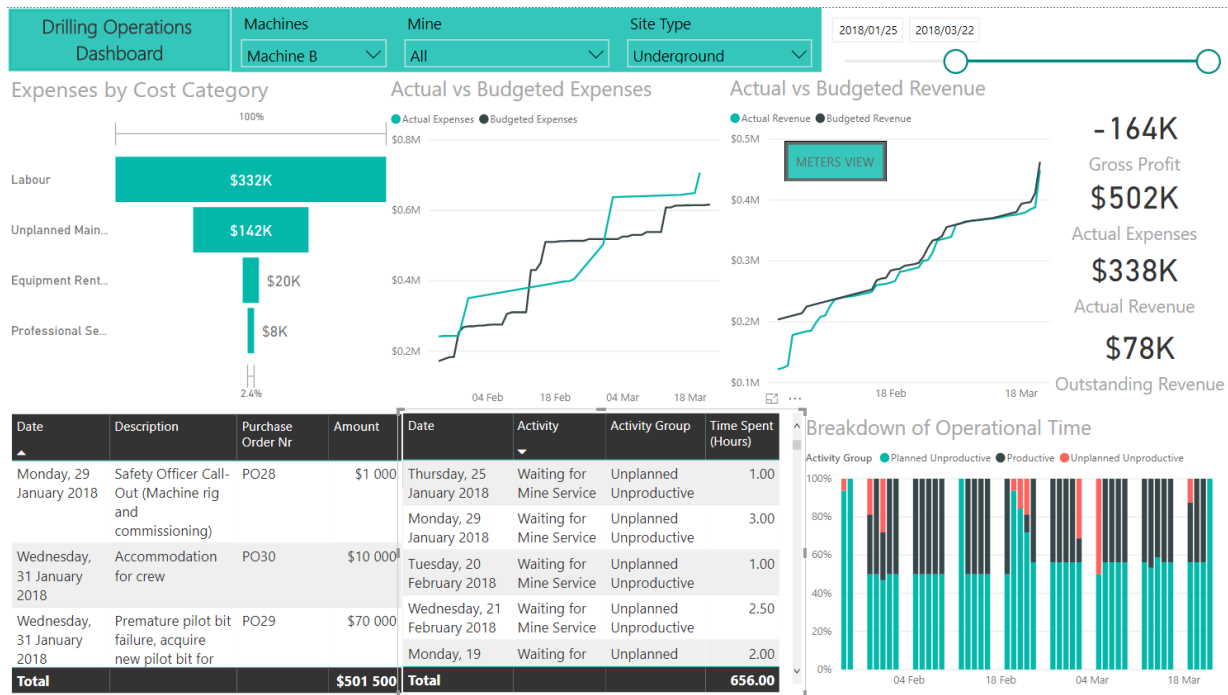


Figure 35: Results scenario three dashboard view

6.4. Scenario 4 – Top management wants constant updates on the progress

Due to the lack of visibility over operations, top management of companies continually run blind when discussing the efficiency and effectiveness of operations. It leads to overcommunication between them and operational staff, to ensure peace of mind and the profitability of the company.

As-is Solution

Currently, this process entails the vast amount of communication mentioned above. The information must be communicated repeatedly between all parties which desire to know the state of operations. It recurs as regularly as questions arise and must be answered.

Developed Dashboard

When provided to top management, the dashboard reduces recurring communication between head-office and operational sites. Although designed for operational use, the dashboard supplies management with a comprehensive overview of the progress on operational sites. The dashboard will give them the peace of mind they desire due to visibility on operations, as well as provide them with the information they usually would have to obtain from operational staff manually. It includes

information such as revenue generation, expenses being in-budget and progress of the shaft itself. All the visuals combined provide the user access to this information.

6.5. Scenario 5 – Profits are down on specific projects

Due to the commercial nature of drilling contracts, various amendments and special clauses are inserted into contracts as operations continue. With the operational delays taking place on-site, caused by the customer, revenue must be claimed from the customer by the drilling company for the operational time lost.

As-is Solution

The information required to reimburse from the customer is captured manually on a piece of paper. Bad handwriting reduces the quality of the data, as the same person writing the information down rarely captures the information on a system. It is done by another individual, which can potentially misinterpret the hand-written information. The information isn't linked to specific customers and entered within the over 450 operational activities existing to be used.

Developed Dashboard

Reduced revenues on contracts can be identified using DV7 on the developed dashboard. The contract manager can use the data captured during operations on-site and share it with the customer to be reimbursed for the financial loss due to the specific delays. This data is electronically stored and can be used to view certain trends for specific customers over a period. Using DV6 and DV11, this can be tracked daily. It can, in turn, be used to better estimate and tender for contracts on mines for the same customer in the future. The indicators D12-D15 play an integral role in displaying this. It provides the user with all measures regarding the profitability of the project.

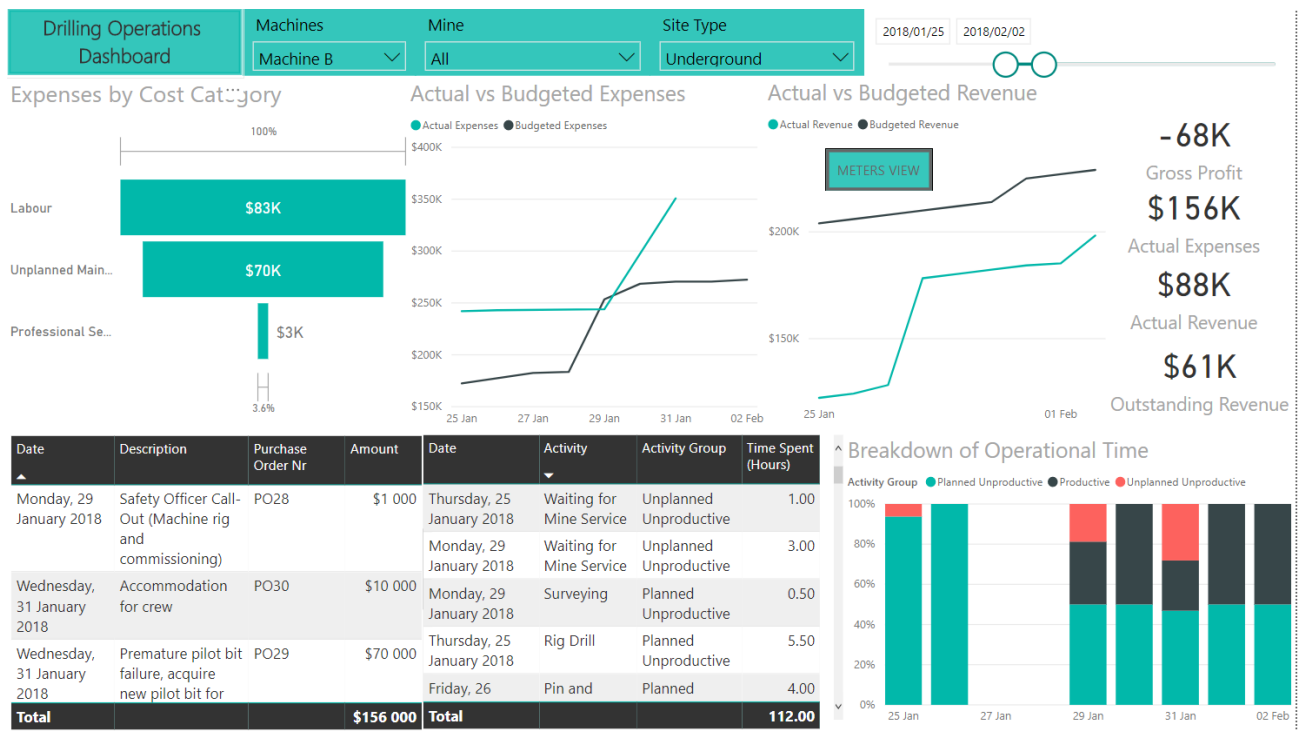


Figure 36: Results scenario five dashboard

Chapter 7: Evaluation of Results

7.1. Chapter Outline: Research Verification and validation

This chapter focuses on the verification of the research, as well as the different artefacts developed throughout. The research objectives and questions are validated using a combination between a house of quality matrix, and design science research, which is referred to as a research validation matrix. It is displayed in Figure 38 by using arrows which correspond with the relevant research questions, objectives and forms of literature where appropriate.

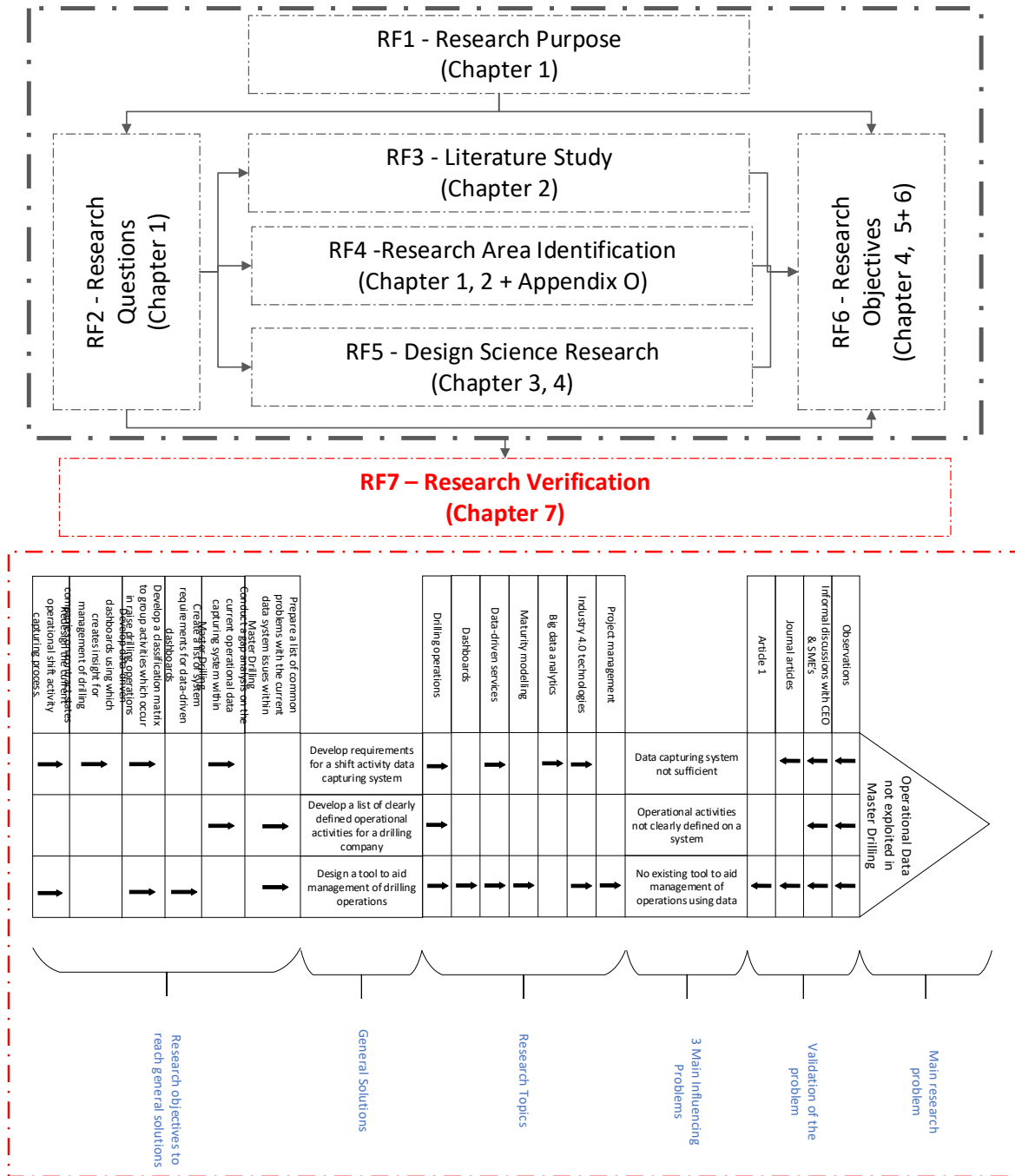


Figure 37: Research outline - research verification

7.2. Verification of the study

7.2.1. Research definition

The topic originated from research conducted on the maturity of drilling companies to adopt disruptive technologies (See Chapter 4). The research was published in the South African Journal of Industrial Engineering and presented at the 29th Annual conference for Industrial Engineering in South Africa. The background of the problem, as well as the problem itself, has been thoroughly researched and discussed in Chapter 1 and Appendix O: SAIIIE article. The problem is summarised as follows:

There exists an analysis gap within the mining industry between operational data captured and the management and improvement of on-site drilling operations that reduces overall equipment effectiveness of the company's drilling machines.

The scientific relevance of the research problem is within both academic and operational environments. The theoretical importance of the research is to display the value of dashboards within managing operations, specifically in the raise drilling environment. The applications within the study can be adapted to other operational and manufacturing environments if the correct changes and additions are made. Within the operational drilling environment, the study aims to add value in the form of better operational project management, as well as cost savings due to the better visibility on operational projects

7.2.2. Research methodology

The chosen methodology for this study is Design Science Research, which is suiting, taking into consideration the practical nature of this research. It consults the theoretical and functional environments in which the research takes place, ensuring that the solutions are feasible in the operational environment, and based on sound literature.

The study is situated within the South African mining environment, using a case study of a drilling company predominantly classified within the mechanical and mining engineering fields. The study itself takes an industrial engineering perspective on the defined problem, aiming to better aid operational project managers within the mining environment in better managing operational projects.

7.2.3. Technical composition

The research process started with the publishing of an article, which investigated the maturity of drilling companies within the South African mining sector. The research indicated a lack of data-driven services within a specific drilling company used for a case study. A maturity improvement process is developed and followed using Action Design Science Research to improve the maturity level of data driven services within the same drilling company.

The logical flow of this document follows the author's thinking process on the background discussion, problem definition, literature review, and application of literature, following the DSR methodology to develop artefacts and validate the research.

The research literature and findings are discussed and defended in the relevant chapters where the respective topics are discussed. The research is supported by operational data and conclusions within the operational drilling environment. It includes the responses for the Industry 4.0 maturity assessment completed by raise drilling experts at the beginning of the study, as well as while validating the research conducted.

Throughout the process of this study, the dissertation had been repeatedly improved, as it was sent between the author and the study supervisor for comments and restructuring. The grammatical and

technical proficiency of the author is verified using the Grammarly Premium software, as well as the objective opinion of the study supervisor.

7.2.4. Verification and validation

The study aims to equip operational project managers better to increase the OEE of the raise drilling machines for which they are responsible. The validation of the dashboard, as displayed in Chapter 7.5, indicates the successful improvement of a project management tool, aiding operational project managers in the raise drilling environment. This improvement is superior to the current solutions within the South-African environment being only the raw data itself. It also proved to be superior to the dashboard from another drilling entity which is situated internationally.

The validation chapter of this study contains two very distinct sections. Firstly, the validation of the improvement of data-driven services within a specific drilling company, due to the focus on data-driven services throughout the period in which the study takes place. The second part consists of the validation of the data-driven dashboard aiming to aid in better project management. It is done with the Delphi method, consulting experts within the drilling environment.

7.2.5. Study of sources

All literature sources used within this study are either journal articles, published dissertations, or the websites of registered companies. All the relevant topics within the research have been discussed with valid literature sources while using the NWU Harvard referencing style. The document is accompanied by the appropriate lists for tables, figures, sources, page numbers, appendices and table of contents.

7.3. Validation methodology

This section focuses on the validation of the following four elements of the study:

1. Validation of the research problem
2. Validation of the method followed
3. Validation of the improvement of data-driven services
4. Validation of the research output

The subsections of this chapter will discuss the detail on each of the elements' validation processes.

7.3.1. Validation of the research problem

The research problem identified and discussed throughout Chapter 1 and 2 is as follows:

There exists an analysis gap within the mining industry between operational data captured and the management and improvement of on-site drilling operations that reduces overall equipment effectiveness of the company’s drilling machines.

At the beginning of this study a research questionnaire, developed by the IMPULS foundation of the German Engineering Federation and the Cologne Institute for Economic Research, was distributed to the executives of a specific drilling company, which concluded the apparent lack of data-driven services within this company. These findings were further verified through informal discussions and literature, as discussed in Chapters 1-4. Chapter 4 contains a published article explaining the process of identifying the problem.

7.3.2. Validation of the research method

The validation of the research method followed is done using three different approaches to display that the research outputs satisfy each research question, as stated in Chapter 2. The three different methods are:

1. The design science research guidelines
2. The action design research principles
3. A research validation matrix

7.3.2.1. Design science research guidelines

Within the problem-solving process of DSR, there should exist the knowledge and understanding of both the issue in question, as well as the solution proposed to solve it (Hevner *et al.*, 2004). Seven guidelines have been developed to assist researchers and practitioners in using DSR effectively. The guidelines are displayed in Table 12. The authors of the guidelines mention within their research that each guideline should be addressed for effective DSR to be conducted. However, the extent to which, as well as quality with which the study complies to the guidelines is subject to the reviewers and editors of the study itself (Hevner *et al.*, 2004).

Table 12: DSR guidelines (Hevner *et al.*, 2004)

Guideline	Description	Confirmation	Chapter reference
1. Design as an artefact	DSR must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.	A dashboard is developed in this study to aid in the increase of OEE of drilling machines.	4-7

2. Problem relevance	The objective of DSR is to develop technology-based solutions for important and relevant business problems.	The artefact is for a business within the mining industry. A case study is conducted to display the value of the artefacts in this business.	1-7
3. Design evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated using well-executed evaluation methods.	The dashboard is evaluated using comparisons and a Delphi panel of professionals from different industries and management levels.	4-7
4. Research contributions	Effective DSR must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and design methodologies.	The method used is ADR, and the design process followed, and developed artefacts followed practices described in the literature. This ensures validity of the artefacts as well as rigour within the process followed.	3-7
5. Research rigour	DSR relies on the application of rigorous methods in both the construction and evaluation of the design artefact.	ADR methods were followed to gather the requirements from the working environment and test it with professionals. This ensured rigour within the design and research processes.	3-7
6. Design as a search process	The search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment.	Artefact requirements were gathered from the industry professionals and tested using a Delphi panel. The panel consisted of professionals from various industries and management levels.	3-7
7. Communication of research	DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.	The Delphi panel consisted of an audience ranging from operational users to management within the industry. The professionals included in the panel ranged from	7.5

		business to technology experts within their respective fields.	
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7.3.2.2. Action design research principles

In Chapter 5, the methodology of ADR is discussed. This discussion includes an overview of the ADR principles occurring in each of the four stages, which are required for successful ADR (Sein *et al.*, 2011). These seven principles displayed in Table 13: ADR principles are discussed to validate the effectiveness of the study’s method.

Table 13: ADR principles (Sein *et al.*, 2011)

Principle	Description	Confirmation	Chapter reference
1. Practice-inspired	Field problems should be viewed as knowledge-creating opportunities	Mining of ore is increasing in difficulty, and drilling companies can aid mining companies in generating quicker returns.	1.1, 2.1
2. Theory-ingrained	The artefacts created and evaluated should be informed by theories	Evaluation method for the primary artefact created is the recognised Delphi method.	3.2, 6, 7.2
3. Reciprocal shaping	The artefact and the organisational context should exert inseparable, equal forces	Academia and organisational context together were used to develop the artefacts.	1-7
4. Mutually influential roles	Mutual learning should take place among the different project participants	Multiple artefacts in this study contributed knowledge to the organisation used for the case study, and the author learned valuable skills within the research and development of artefacts.	4-6
5. Authentic and concurrent evaluation	Evaluation should form part of the build stage	Evaluation of artefacts was done with various artefacts, such as the data capturing system requirements and	4-7

		dashboard design and validation.	
6. Guided emergence	The collective artefact should reflect not only the primary design created by the researchers, but also its ongoing shaping by organisational use, perspectives and participants	The collective artefact of this study contains the process of thinking, as well as details on the artefacts themselves, which will continually be built on by the organisation used as the case study.	4-7
7. Generalise the outcomes	Outcomes of the research should be generalised by including the organisational change that took place along with the implementation of the artefact. In other words, it should move from the specific-and-unique to the generic-and-abstract.	The focus on data-driven services and the development of the artefacts led to an improvement in organisational maturity.	4-7

7.3.2.3. Research validation matrix

The goal of the research validation matrix is to display that all artefacts and objectives of the study have in fact, been reached. It also presents the contribution of each part of the study made to the main artefacts. The matrix has different sections (RV1-RV6), each contributing to another. An explanation follows in Table 14. The arrows within the matrix (Figure 38) indicate the area of the study which the corresponding item contributes. It serves as proof that each research question has been addressed. It suggests that the essential research areas have been addressed, to solve the research objectives, as stated in Chapter 2.

Table 14: Explanation of research validation matrix sections

Matrix Section	Description
RV1 – Main research problem	It displays the main research problem which this study contributes.
RV2 – Validation of the problem	It displays the different sources which lead to the three main influencing issues identified.
RV3 – 3 Main influencing problems	It displays the three main issues which lead to the main research problem.

RV4 – Research topics	It displays how each literature topic contributed to the different influencing problems being solved.
RV5 – General solutions	The general solutions are the main deliverables which the study must deliver to solve the three main influencing problems.
RV6 – Research objectives to reach general solutions	Each of these objectives is linked to one of the general solutions to have them completed successfully.

Figure 38 displays the value added by each different chapter and section within this study, to the overall research objective, which the study aims to address. It shows the validity of the problem, the literature reviewed, potential solutions developed, and the method of verification. It also displays that no work conducted throughout this study was mere information without relevance to the study itself. This method of verification spans over the entire study, adding immense value in a very simple-to-understand manner.

The research validation matrix assisted the author in aligning the research questions and research objectives of the study. In addition, it verifies that research was done on all the essential sections of this study. It assists in breaking down the main research problem into manageable sections, which are simpler to focus on. One advantage of the smaller research problems created using the research validation matrix is the fact that progress can be better tracked on the project in its entirety. One shortfall of the matrix is the fact that it doesn't capture the quality with which each section was completed.

The initial problem has been validated through discussing and defining it within Chapter 1:. This problem has been broken down into smaller problems, each solved by developing different artefacts throughout the study.

The literature researched throughout Chapter 2:, and Appendix O: SAIE article was focused on better understanding the research problem, and finding potential solutions with which to solve it. It guided the study to consider various technologies. However, after a maturity study was done on a specific drilling company, it was decided that the most value-adding solution would be to increase the maturity level of data-driven services.

The final part of the DSR methodology includes the verification of the design process, which is done in the rest of this chapter. It displays the value of the developed artefacts and how they solved the initial research problem. It is done through a research-based Industry 4.0 readiness survey, as well as with the use of a Delphi panel.

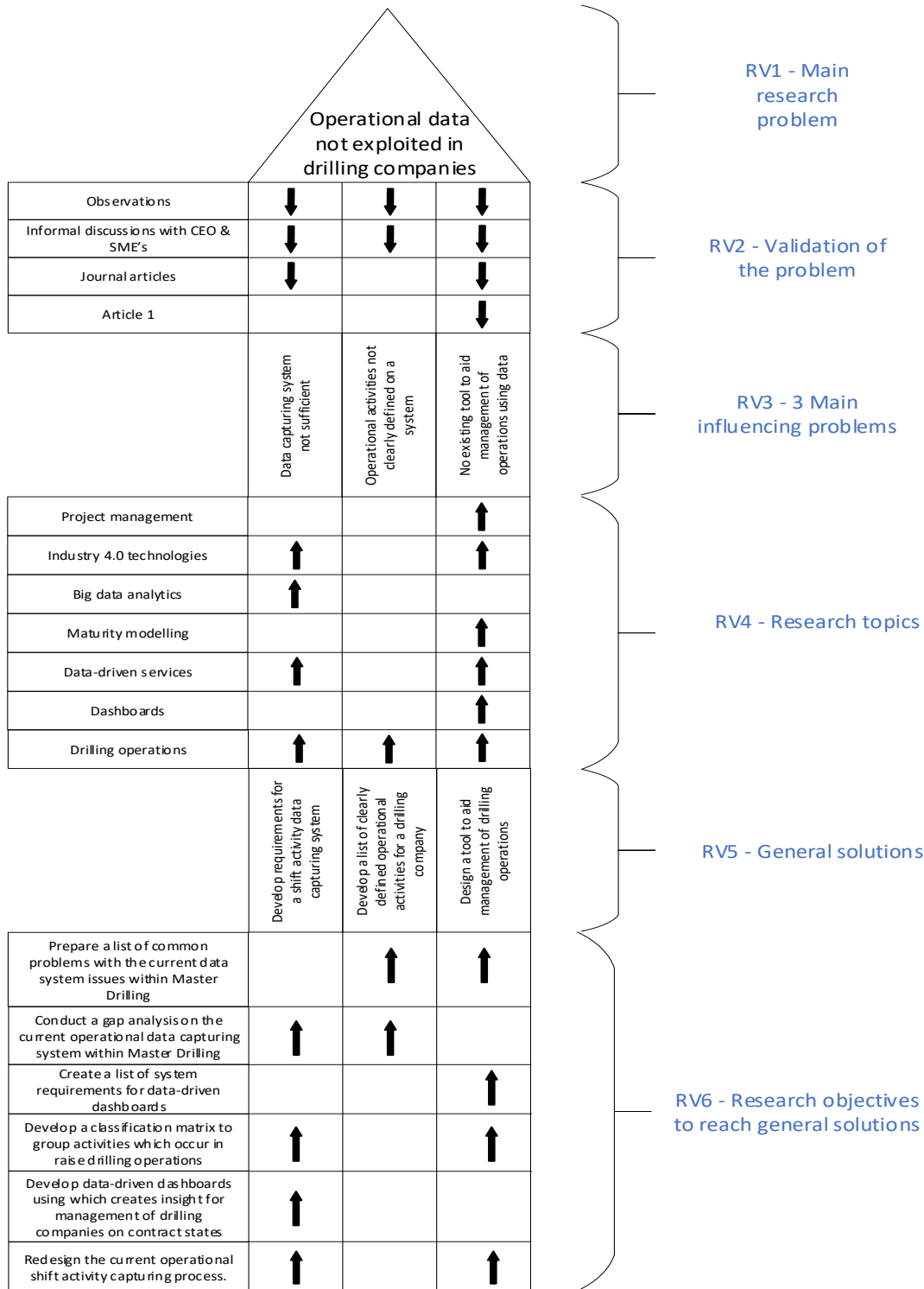


Figure 38: Research validation matrix

7.4. Validation of data-driven services improvement

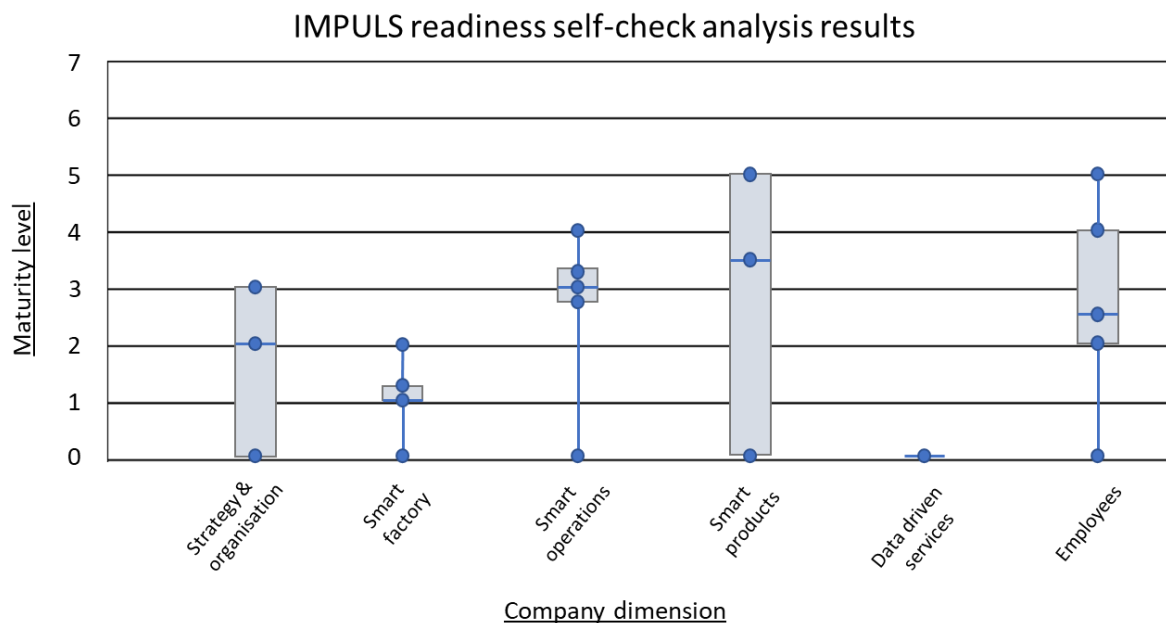
Over the last year (March 2018-March 2019), there has been a focus on the value of data and the better use thereof within Master Drilling, the drilling company used for the case study of this research. This study led to the initiatives within the business to increase the value generated by operational data captured, which in turn increases the visibility on projects, while potentially decreasing the notification time when projects are not on track. These improvements include the artefacts developed

and discussed in Chapters 4, 5 and Appendix O. The survey was distributed to the respondents via an email link, requiring only their responses to the best of their knowledge. The email is displayed below:

Good Day,

About a year ago a questionnaire was shared to all of you to complete, in order to evaluate the maturity of certain areas within the company, regarding the adoption of disruptive technologies. The idea was to identify areas of risk, as well as areas of opportunity within Master Drilling. Below you will see a snapshot of the consolidated results of the previous findings. We would like to conduct the same study, to see where maturity improvements has taken place.

Box and whisker plot of the results:



At a quick glance the of the above image, you can see that Data-driven services was at a level 0 a year ago, and the company has put a lot of focus and effort on the use of data in the past year. Will you please take some time to complete the survey on the link below and send me your results. At the end of the survey, a report is given which can be downloaded. Please send the report to myself for further analysis. Please send the results by the end of next week. It will not take up a lot of your time. We need your inputs to get accurate outputs for the study.

Link to survey:

<https://www.industrie40-readiness.de/?lang=en>

Your help is kindly appreciated.

To verify the improvement of data-driven services within the case study company, the exact survey used in Appendix O: SAIE article was redistributed to the company’s management, one year after the survey has been distributed and results summarised within a published journal article. The Industry 4.0 readiness survey results once again focused on the maturity of a drilling company, focusing on six dimensions:

1. Strategy and organisation
2. Smart factory
3. Smart operations
4. Smart products
5. Data-driven services
6. Employees

The survey was completed by nine respondents, with the knowledge of the projects and initiatives completed, and in progress, within the timeframe stated above. The results are presented in Figure 39.

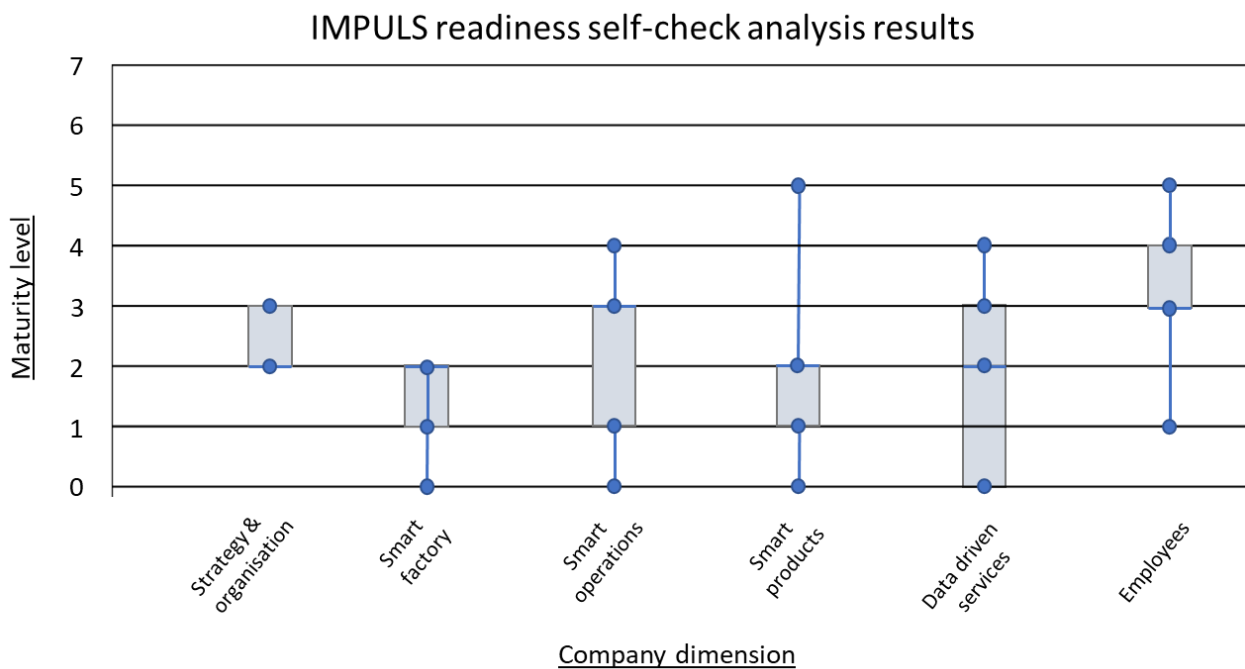


Figure 39: IMPULS readiness self-check analysis validation

When compared to the results of the survey, as discussed in Appendix O: SAIE article, differences can be identified. These differences indicate either an increase or decrease in the maturity of the specific dimension, since it either increased or decreased from 2018 to 2019. The differences of the average values are displayed in Figure 40, indicating the changes in the measured dimensions.

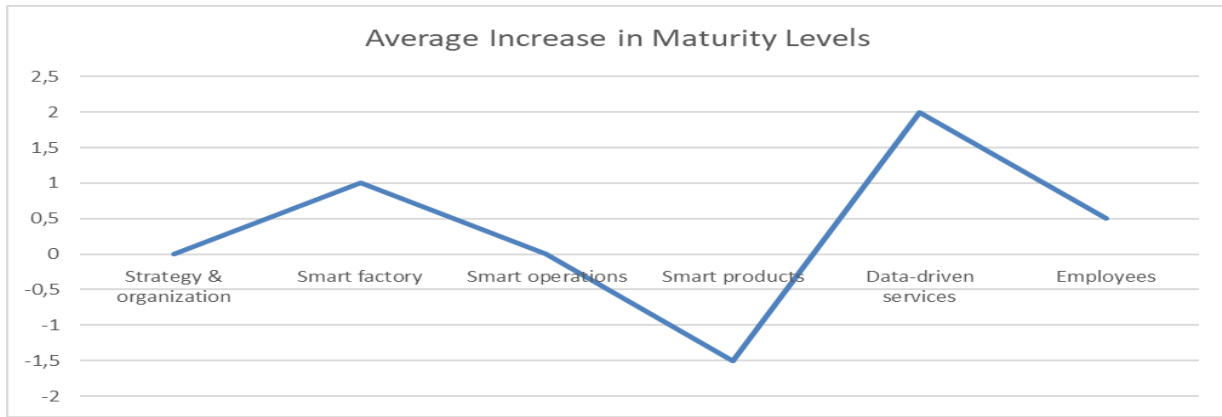


Figure 40: Average change in dimension maturity

Of the five dimensions evaluated, two of them remained the same from the previous survey. These two dimensions are the Strategy & organisation and Smart operations. The focus put on increased data-driven services didn't influence these two dimensions as the organisation still doesn't have a fully defined Industry 4.0 strategy. This is still being investigated internally. The smart operations haven't increased as the focus of the last year was to increase the accuracy and processes around the capturing of operational data, as well as the use thereof to increase machine effectiveness.

The smart factory dimension increased as the use of production-related data started adding value within the case study company. More of the captured data within this environment has been used, as the value thereof has been developed within internal business cases.

The reason why the smart products maturity level decreased can't accurately be indicated, as various external factors within the industry could have influenced this. Resources within the company are limited, and rapid growth and company expansion within new geographical regions could have negatively impacted the perception of this in the overall group.

The increase in the maturity level of company employees is due to a strategic focus of the case study company to equip itself with the skills required to implement strategic projects within various departments, to increase company profitability.

The data-driven services dimension has increased with two levels on average. It is the most substantial increase between all the included dimensions within survey. This research study put a strong focus on the improvement of data-driven services within a specific drilling company. The results indicate the value added by this study, as it led to an increase in data-driven services. The focus within the case study company included the development of an improved operational data capturing system, as well as the design of an operationally focussed data-driven dashboard to increase the ability of operational project managers to manage drilling projects.

7.5. Validation of the research output

The primary artefact of this study is the data-driven dashboard discussed in Chapter 5: & Chapter 6:. This dashboard aims to aid operational managers in the group to better manage operational projects. Verification of the dashboard is done using a Delphi panel method.

7.5.1. The Delphi method

The Delphi method is a widely used scientific research validation method to gain consensus on research outcomes. A series of research statements or questions are provided to a panel of professionals or experts within the field of study (Berman *et al.*, 2018). The method is subject to the anonymity of the respondents, to remove the possibility of influencing their results.

7.5.2. Stages of the Delphi process

The Delphi method consists of various stages which should be followed consequently to one another to complete the validation process. These stages are as follows (Humphrey-Murto & Wit, 2019):

- DS1 - Identify the research problem
- DS2 - Select the Delphi panel
- DS3 - Develop a questionnaire
- DS3 - Conduct anonymous rounds for feedback
- DS4 - Summarize the findings

Each of these stages is discussed in the subsections which follow.

7.5.3. DS1 – Identify the research problem

The research problem identified as that of the existing dashboard solutions within drilling companies being ineffective. The Delphi method for this study aims to evaluate a newly proposed solution to the problem by comparing it to a current dashboard solution within the industry.

7.5.4. DS2 – Select the Delphi panel

The panel is composed of 14 professionals, whose aliases are described in Table 15. These 14 individuals all received communication to participate in the validation of the data-driven dashboard. The requirements and the evaluation form were communicated using emails, while the evaluation form itself is an online survey. Participants on the panel are primarily situated within the mining industry, of which seven were in the case study company. The selection of participants is mainly within the mining industry because some knowledge of the mining environment would be beneficial to the validation of the dashboard. Various participants are situated within the field of operational efficiency improvements at top South African universities. A small description of each interviewee is provided in Table 15.

Table 15: Interviewee Details

Alias	Years of Experience	Description of Interviewee
Professional 1	10-20 years	The interviewee is an experienced mechanical engineer within the mining industry, working with operational drilling machines, or the data thereof, on a day-to-day basis.
Professional 2	10-20 years	The interviewee is an experienced mining engineer and currently functioning within a managing position of drilling operations.
Professional 3	10-20 years	The interviewee has extensive strategic experience, situated within operational management of drilling operations.
Professional 4	10-20 years	The interviewee is an experienced industrial engineer within the mining sector.
Professional 5	10-20 years	The interviewee is an experienced operations manager and the general manager of a drilling entity within the mining sector.
Professional 5	10-20 years	The interviewee is an experienced ICT engineer within the mining sector.
Professional 6	1-5 years	The interviewee is a consulting industrial engineer within the South African mining sector.
Professional 7	10-20 years	The interviewee is a senior lecturer at one of South Africa's leading universities, with over 10 years of experience as a rock engineering consultant.
Professional 8	5-10 years	The interviewee is an experienced researcher within the field of industrial engineering at one of South Africa's leading universities.
Professional 9	1-5 years	The interviewee is a mechanical engineer operationally situated within the mining sector, and currently conducting research in the field of underground resource optimization.
Professional 10	1-5 years	The interviewee is a mechanical engineer situated within an operational resource optimization consultation company within the mining sector.
Professional 11	10-20 years	The interviewee is a research engineer at one of South Africa's top universities with vast experience in the steel manufacturing industry.
Professional 12	5-10 years	The interviewee is an experienced network engineer with a focus on operational efficiency improvements based at one of South Africa's top universities.
Professional 13	5-10 years	The interviewee has a Masters degree in Engineering Management, with a focus of efficiency improvements within the rail industry.
Professional 14	5-10 years	The interviewee is a mechanical engineer specifically focused within the maintenance of drilling operations in the South African mining sector.

7.5.5. DS3 – Develop a questionnaire

A questionnaire is developed to capture the responses of the selected Delphi panel on the research problem mentioned above. The questionnaire consists of categorised statements, each accompanied by a Kaner Gradient (See Figure 41). The preferred gradient values can be selected by respondents, as well as open-ended feedback given if they would prefer to do so. The statement categories are listed as follows (adapted from (Vilarinho *et al.*, 2019)):

- DC1 – Layout: Aims is to validate the placement of the visuals (Tableau, 2019)
- DC2 – Intuitiveness: Aim is to validate the intuitive ‘feel’ of the entire dashboard (Aspin, 2016)
- DC3 – Analytics: Aim is to validate the type of data shown in the dashboard (Tableau, 2019)
- DC4 – Visualization: Aim is to validate the selected visual types (Analytics, 2018)
- DC5 – Application: Aim is to validate the solution as a whole

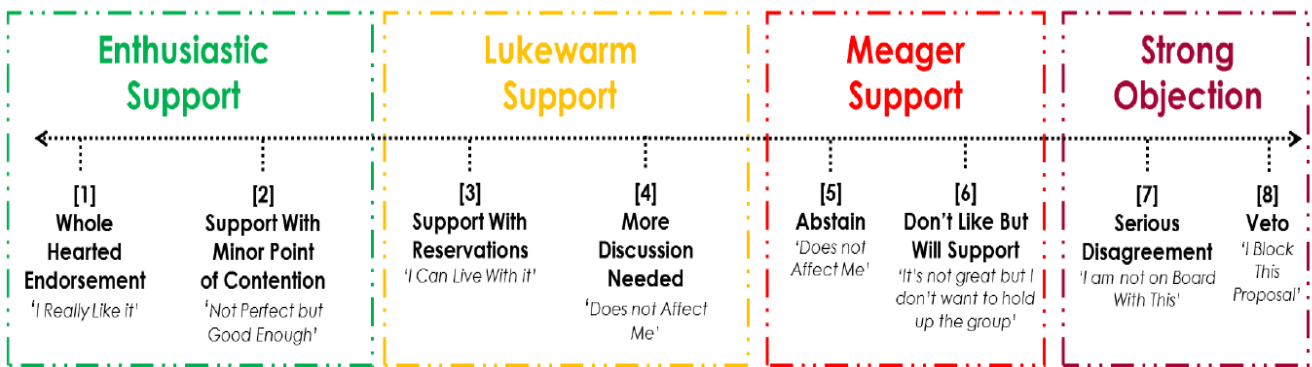


Figure 41: Kaner Gradient of Agreement (Hughes, 2017), (Darwish, 2018)

The questionnaire is sent to respondents as an evaluation form consisting of 21 statements (See Table 16), each focused on comparing the as-is dashboard, with the newly proposed solution. The as-is dashboard is referred to as D0, whereas the newly proposed dashboard is referred to as D1. The statements are focused on validating the problem, the dashboard artefacts and the survey itself. To validate the dashboard artefact, only DC2-DC6 are to follow the method of gathering consensus. DC1 and DC7 are only supplementary to the method used, and the problem validation.

Table 16: Evaluation statements

DC1 – Research problem context	
DC1.1	Data gathered within the South-African mining sector is not being used effectively to manage operational drilling projects better.
DC1.2	Drilling companies are not fully utilising operational data due to a lack of maturity in Data-Driven Services.
DC1.3	Designing more intuitive data-driven dashboards, which successfully filter through data and visualise data correctly can add value for companies within the mining sector.

DC2 – Layout	
DC2.1	The layout of D1 is simplified to that of D0, with extra information being visible on D1.
DC2.2	Relevant information of D1 is grouped and can be filtered per machine, whereas D0 does not have this functionality, which is beneficial to the user.
DC3 – Intuitiveness	
DC3.1	D1 is more intuitive to learn than D0.
DC3.2	D1 continually updates when filtered by clicking on visuals, whereas D0 does not have this functionality.
DC3.3	The colours and font size on D1 make the dashboard easy to read.
DC3.4	The type of filters on D1 make sense for the application it is used and is easy to interpret.
DC3.5	D1 is a 1-page dashboard while D0 consists of various, making D0 harder to understand intuitively.
DC4 – Analytics	
DC4.1	D1 displays the raw operational data to view what happened on a shift, and D0 does not.
DC4.2	D1 displays the transactional data for project expenses, and D0 does not.
DC4.3	D1 can filter all the data according to a machine, mine, site type and by date, whereas with D0, this is not possible.
DC4.4	The KPI's chosen for D1 make sense.
DC5 – Visualization	
DC5.1	The visual types selected for D1 is more suitable for the information displayed than the visuals used in D0.
DC5.2	D1's visuals can scale to the selected filters, whereas D0's visuals can't.
DC5.3	The title of each visual summarises the information displayed in the visual itself, specifically for D1.
DC6 – Application	
DC6.1	D1 is a better fit for operational project management of drilling machines on a day-to-day basis than D0.
DC6.2	D1 has the potential to better help project managers on drilling contracts plan and monitor costs as the project progresses than D0 does.
DC6.3	D1 has the potential to better help project managers on drilling contracts plan and monitor operational activities to stay on schedule than D0 does.
DC7 – Concluding evaluation	
DC7.1	How did you find the survey itself?
DC7.2	What is your overall impression of D1?

7.5.6. Conduct anonymous rounds

The goal of a Delphi method is to gain consensus on research statements or questions. It is done through repetitive rounds of evaluation by the selected panel until consensus is reached. The anonymity of the panel is essential to avoid influencing of results. In the case of this study, consensus on most of the statements was reached in the 1st round. The exception of 1 statement not having consensus is discussed in the applicable subsection of section 9.6.

7.5.7. Summarise the findings

Email communication was sent to everyone on the panel (see Appendix D: Validation Email), explaining the expectation of completing an evaluation form. The form itself was sent as an online survey, leaving space for any open-ended feedback per section. The evaluation results of all the respondents for each statement is summarised and discussed in the next section of this chapter.

7.6. Delphi Response Summary

Of the total panel of 14 professionals, a total of 10 people responded within the given timeframe of evaluating the artefact. Each of the statements within the evaluation form, specifically focusing on the developed artefact is discussed below. It includes all the statements from DC2 – DC6, as DC1 forms part of the problem validation, and DC7 part of the method evaluation. To reach consensus on a statement, an average of 2 or below is required for that respective statement. The values of the responses are linked back to the Kaner Gradient (See Figure 41).

7.6.1. Research problem validation

Firstly, the problem was again validated as part of the Delphi validation method discussed later in this Section. Three statements regarding the problem context are included in the Delphi survey (DC1.1-DC1.3). Each statement, as well as the summarised responses, are discussed below. The gradient used to discuss the survey responses is discussed in Section 9.5.

DC1.1 – Data gathered within the South-African mining sector is not being used effectively to manage operational drilling projects better.

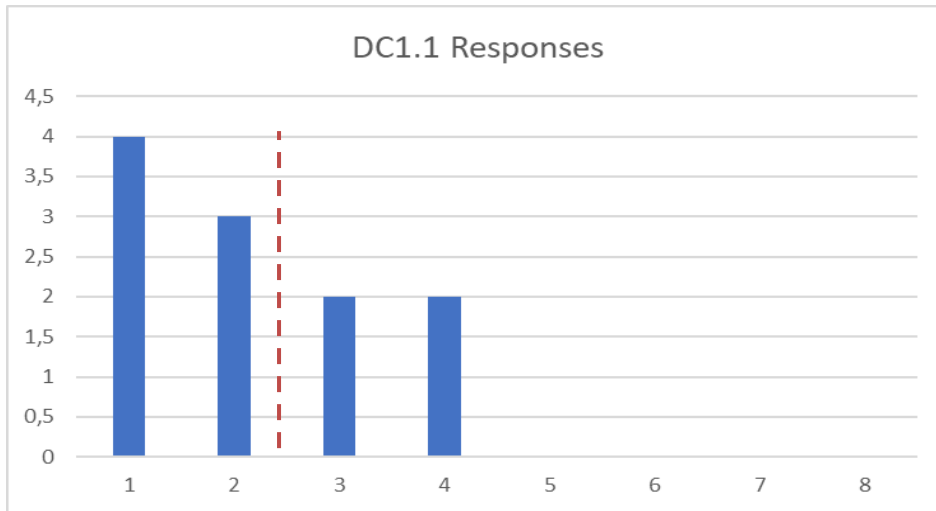


Figure 42: DC1.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The statement is not something consensus is required to be reached on, but with an average response of 2.3, from a population of individuals which had no prior knowledge of the research and background of this study, the validity of the problem is strengthened.

DC1.2 – Drilling companies are not fully utilising operational data due to a lack of maturity in Data-Driven Services.

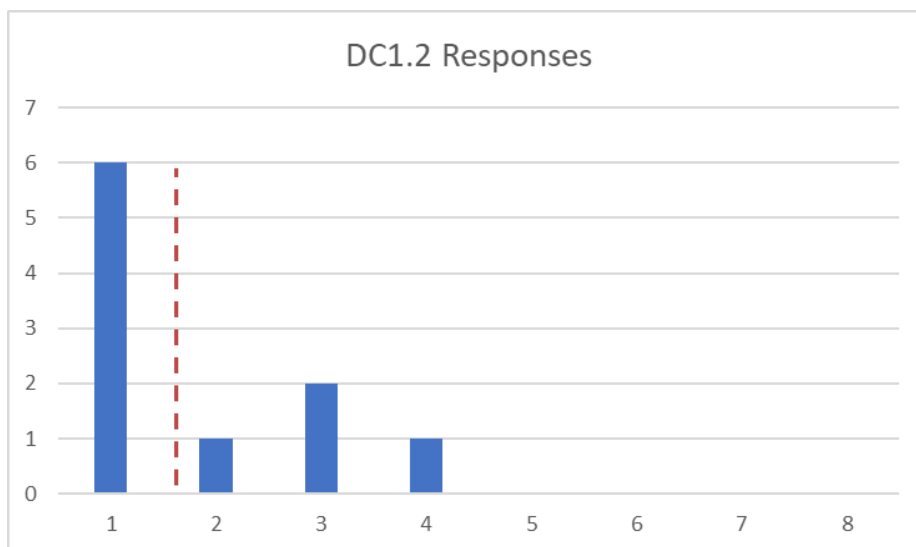


Figure 43: DC1.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The lack of data-driven services within drilling companies is validated again with an average response of 1.8. It emphasises the importance of drilling companies maturing in the use of data-driven services, to better utilise data in the improvement of operational project management.

DC1.3 – Designing more intuitive data-driven dashboards which successfully filter through data and visualise data correctly can be value adding for companies within the mining sector.

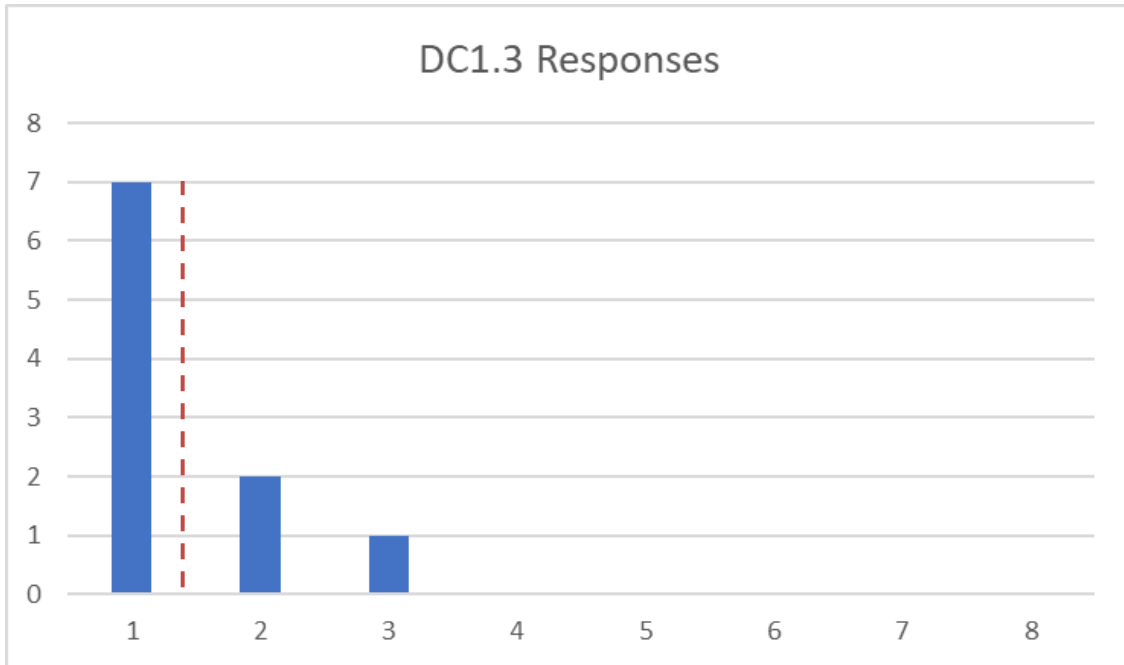


Figure 44: DC1.3 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The value of designing an operational dashboard is validated with an average response of 1.4, denoting consensus on the statement. The potential for data-driven dashboards within operational project management is a valid statement worth researching and improving on.

This concludes that the problem, as defined throughout this study, is relevant within the mining industry and will create value in solving. The approach of developing a data-driven dashboard as an artefact is also validated as the respondents indicated the potential value it might bring to the environment.

7.6.2. DC2 – Layout

DC2.1 – The layout of D1 is simplified to D0, with extra information being available on D1.

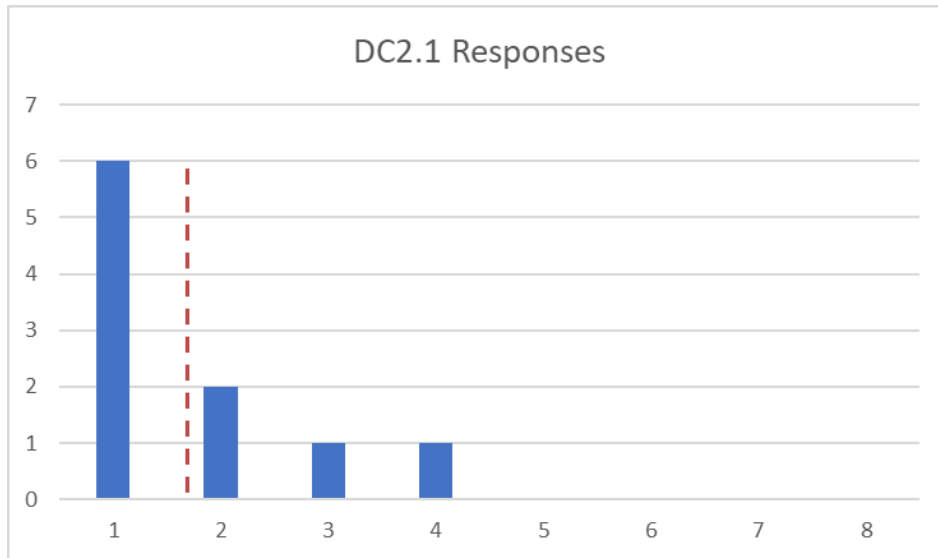


Figure 45: DC2.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The overall response to this statement is positive, as the average is 1.7. When visually looking at D1 versus D0, this is an obvious statement on which to gather consensus. It is due to D1 having a lot of extra operational and financial data which D0 does not have. The one response denoting more discussion being required can thus be attributed to the interviewee not fully understanding the value of all the data on the dashboard.

DC2.2 – Relevant information on D1 is grouped and can be filtered per machine, whereas D0 does not have this functionality.

The relevance of information is, to a certain extent, subject to the interviewee’s background and working environment. The overarching positive response, averaging at 1.5, denotes that consensus is reached on this statement.

Open-ended feedback

Feedback concluded that D1 is user-friendly, supports lean visual management principles, and having extra detail available which D0 did not, increased the value of D1. One comment was raised on the Kaner Grade itself, as the interviewee thought that some of the statements must either be true, or false. The gradient does, however, leave space for interpretation of the interviewee.

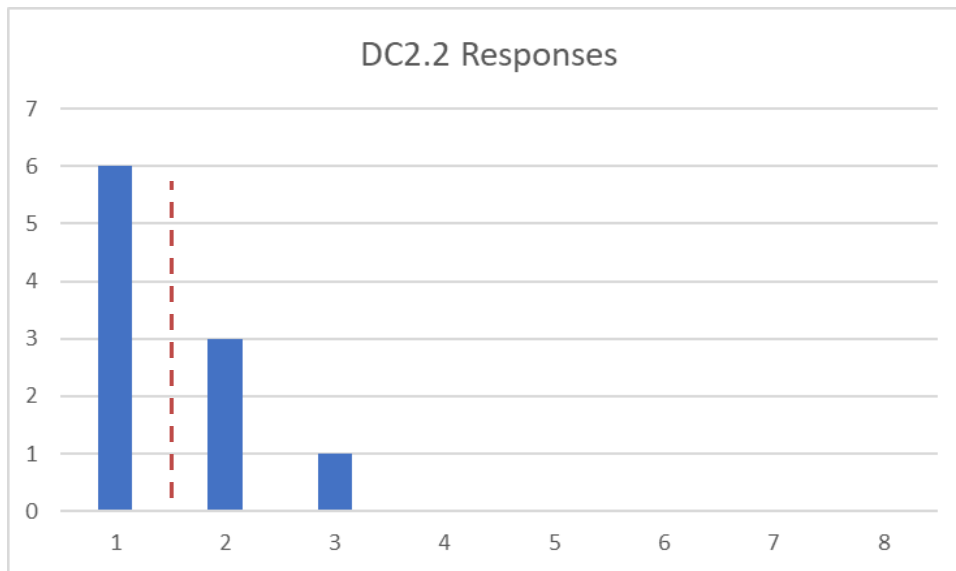


Figure 46: DC2.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

7.6.3. DC3 – Intuitiveness

DC3.1 – D1 is more intuitive to learn than D0.

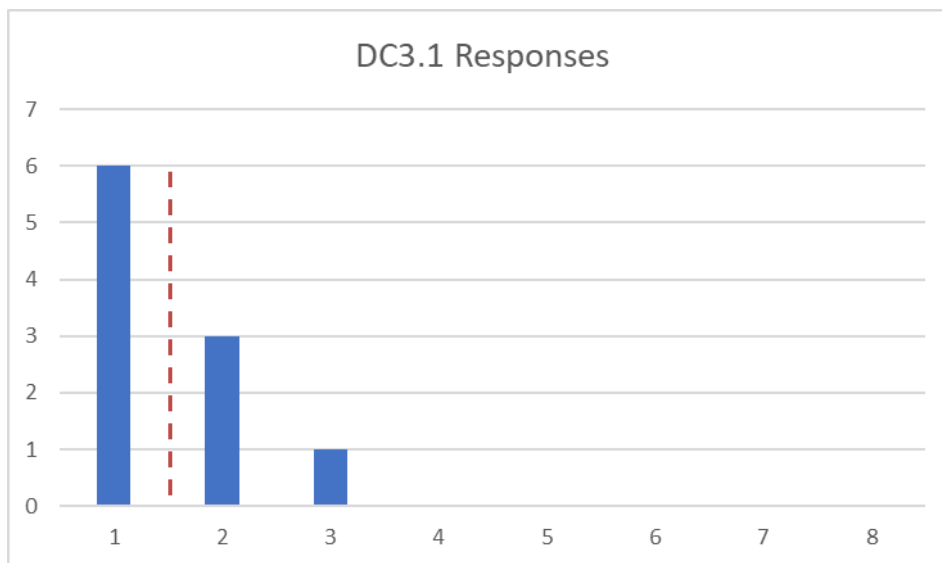


Figure 47: DC3.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

Intuitiveness being a subjective measure, the responses indicate a positive trend toward D1 being more comfortable to understand and use. The average response for this statement is 1.5, denoting that consensus is reached.

DC3.2 – D1 continually updates when clicking on visuals, whereas D0 does not have this functionality.

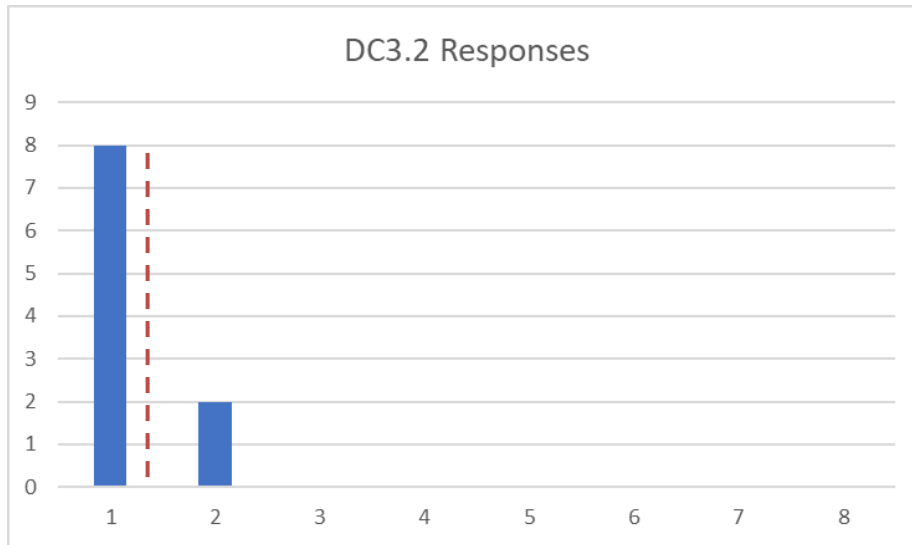


Figure 48: DC3.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response for this statement is 1.25, denoting definite consensus to the statement. It is due to the statement referring to specific functionality created within the PowerBI software, which Excel does not contain.

DC3.3 – The colours and font size on D1 makes sense and is easy to read.

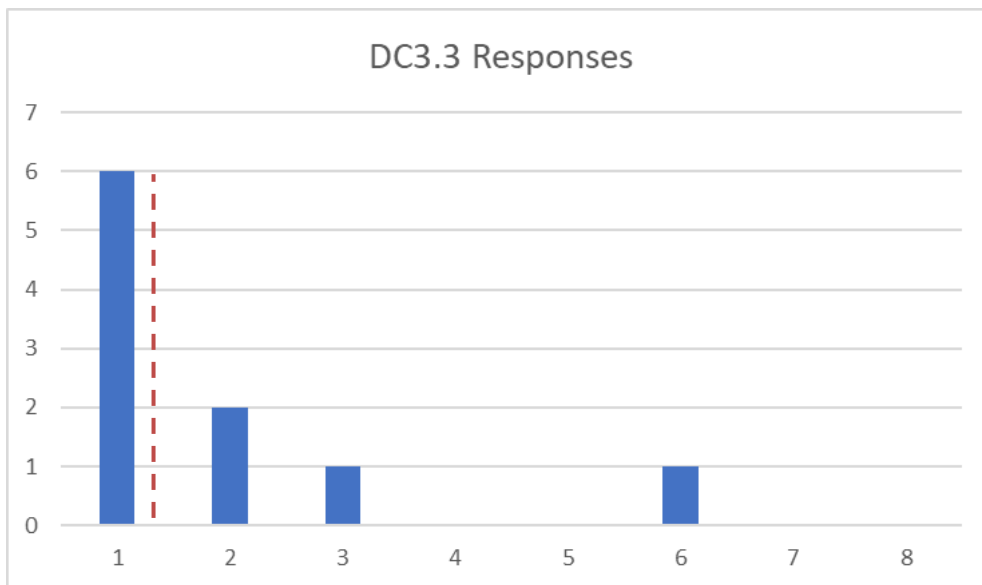


Figure 49: DC3.3 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

This statement had the largest average (2.2), due to one of the interviewees not supporting the colours used. The response mentioned that the colour should accompany the flow of information on the dashboard. The flow of information is linked to the importance of specific visuals in comparison to others. This derived importance of particular information is discussed in Section 5.4, which the interviewee did not have at his disposal. Thus, the response is an outlier when compared to the other nine responses to the statement. The current average is larger than the consensus value, stating that consensus has not been reached on the statement. However, when considering the former and removing the outlying response, the average response is 1.44, denoting consensus.

DC3.4 – The type of filters on D1 make sense for the application it is used and is easy to interpret.

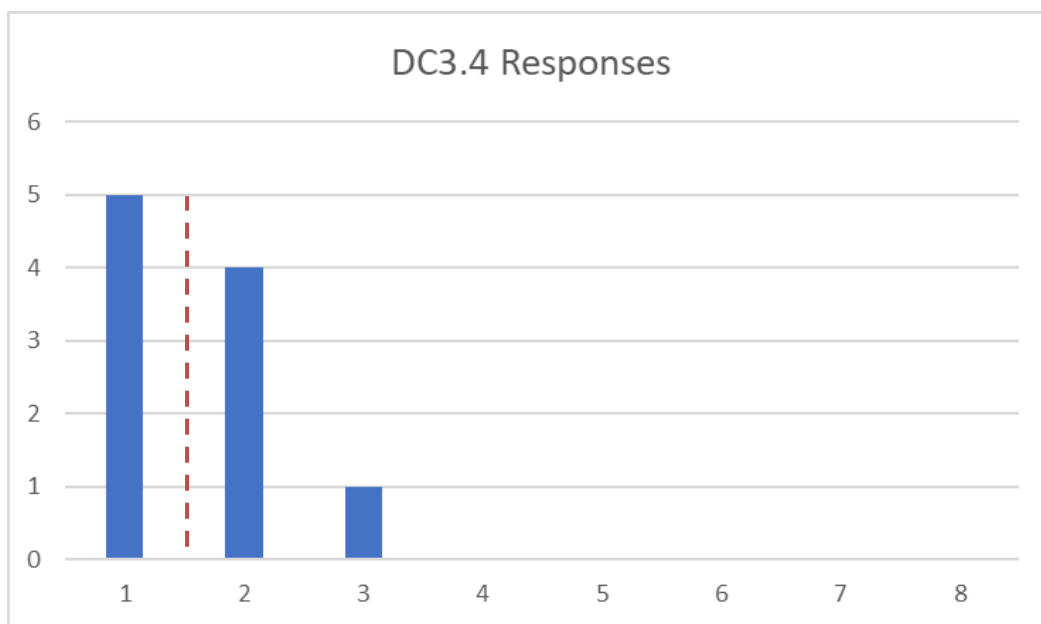


Figure 50: DC3.4 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response for the statement is 1.6, denoting consensus on the use of the filters on the dashboard. It is due to the filters being easily accessible and intuitive on the dashboard itself.

DC3.5 – D1 is a 1-page dashboard while D0 consists of various, making it harder to understand intuitively.

The statement reached consensus with an average response of 1.5, denoting consensus on the use of a 1-page dashboard. It supports literature which states that 1-page dashboards are more intuitively understood.

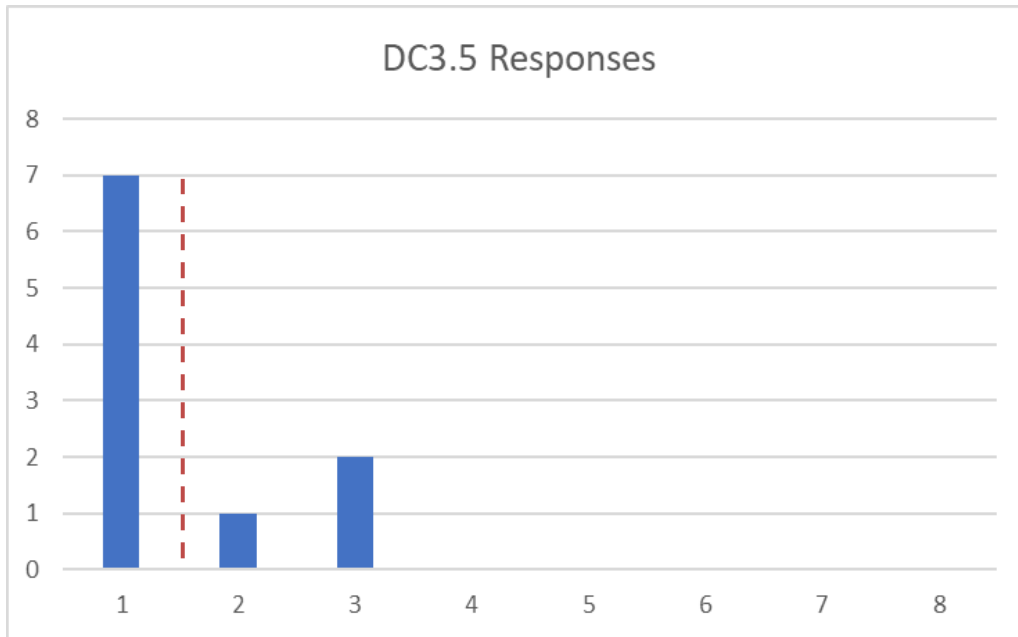


Figure 51: DC3.5 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

Open-ended feedback

Feedback on this section mentioned the value of a dashboard consisting of only 1 page, instead of having to drill down to various to retrieve all the information. A comment was, however, raised that too much information on one dashboard can become cumbersome. The last observation of information flow is discussed in the section of responses for DC3.3. It denotes the user seeing other information on the dashboard as more essential than that discussed in Section 5.4 of this study.

7.6.4. DC4 – Analytics

DC4.1 – D1 displays the raw operational data to view what happened on a shift, and D0 does not.

The average response for this statement is 1.3 denoting definite consensus on the statement. It is due to the extra data displayed on D1, which D0 does not contain. This was a rather obvious statement to gather consensus on as the answer can either be true, or false.

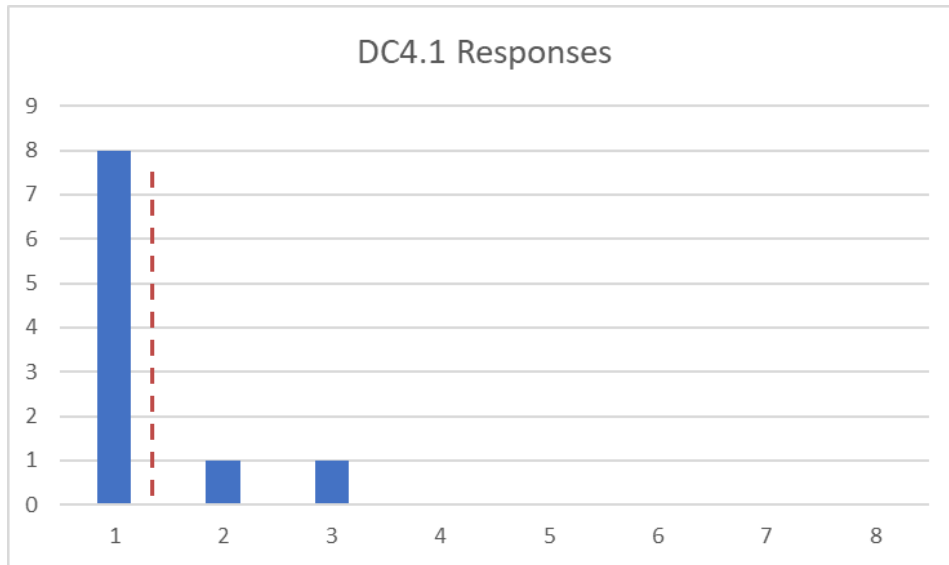


Figure 52: DC4.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

DC4.2 – D1 displays the transactional data for project expenses and D0 does not.

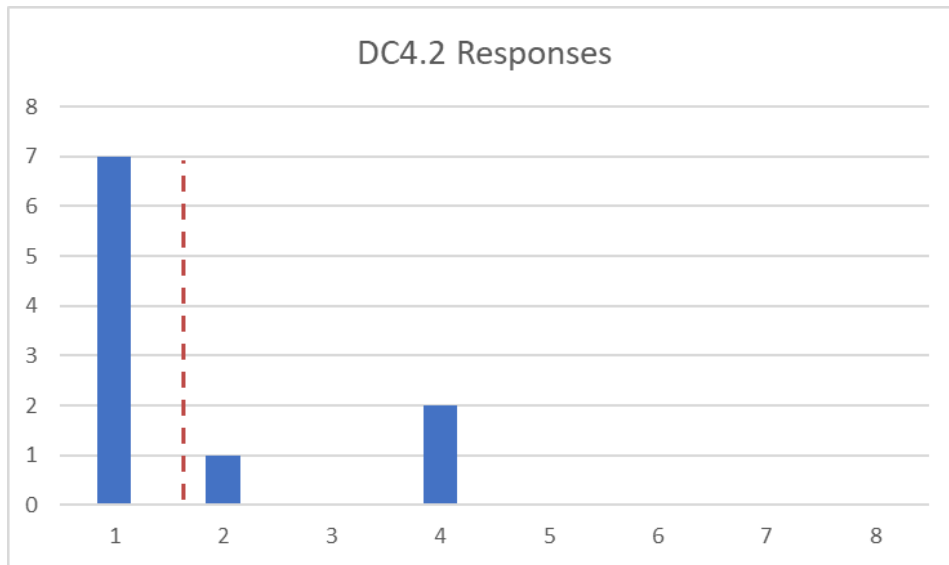


Figure 53: DC4.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response for this statement is 1.7, denoting consensus on the fact that transactional data is displayed on D1, and not on D0. The variance in the answers displays that the statement might have been confusing to some of the interviewees, as it is more a Boolean type of statement. It should either be true, or false.

DC4.3 – D1 can filter according to machine, mine, site type and by date, whereas with D0 this is not possible.

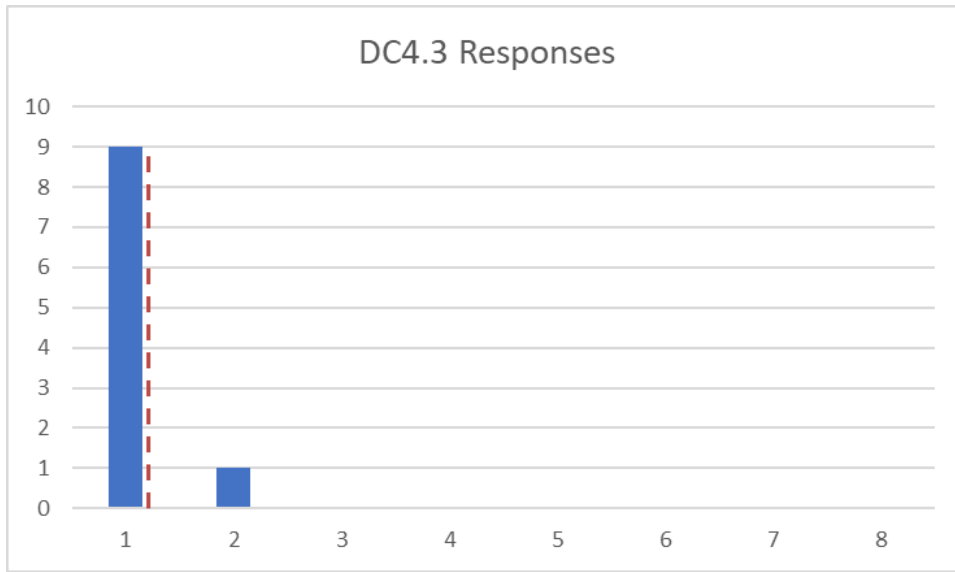


Figure 54: DC4.3 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The specified filters in D1 are all additional features to the improved dashboard which are not available in D0. The average response is 1.1, denoting consensus to the statement.

DC4.4 – The KPI's chosen for D1 makes sense.

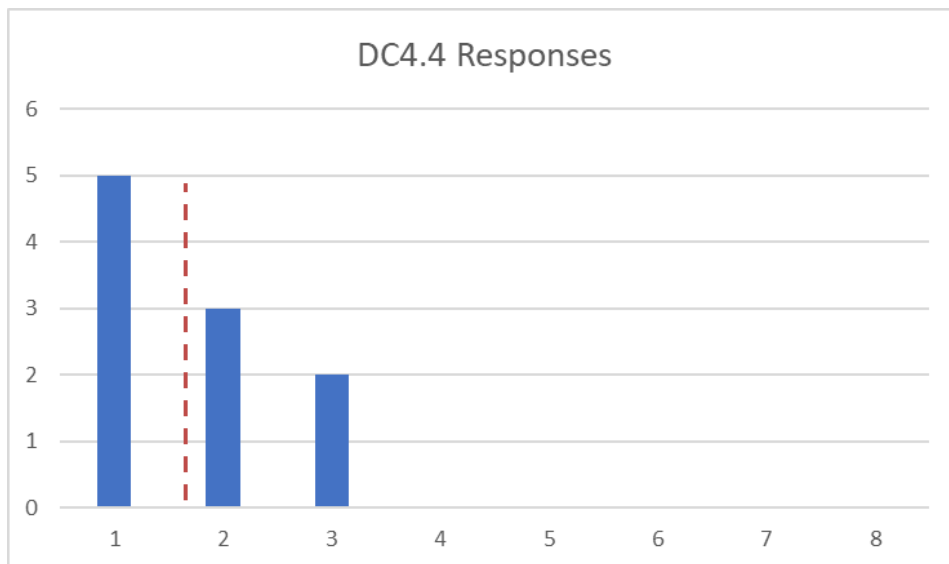


Figure 55: DC4.4 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response of this statement is 1.7, which is below the maximum consensus value, denoting consensus on the statement. It supports the KPI's chosen, as well as the method thereof, discussed in Chapter 6.

Open-ended feedback

Feedback on this section mentioned the attributes of D1 regarding analytics being satisfactory. A suggestion was made to incorporate human factors onto the dashboard, which, due to requirements and limited space is declined. One comment was raised mentioning the importance of the KPI's not shown on the dashboard. It is, however, taken into consideration with the layout of the dashboard.

7.6.5. DC5 – Visualization

DC5.1 – The visual types selected for D1 is more suitable for the information displayed than the visuals used in D0.

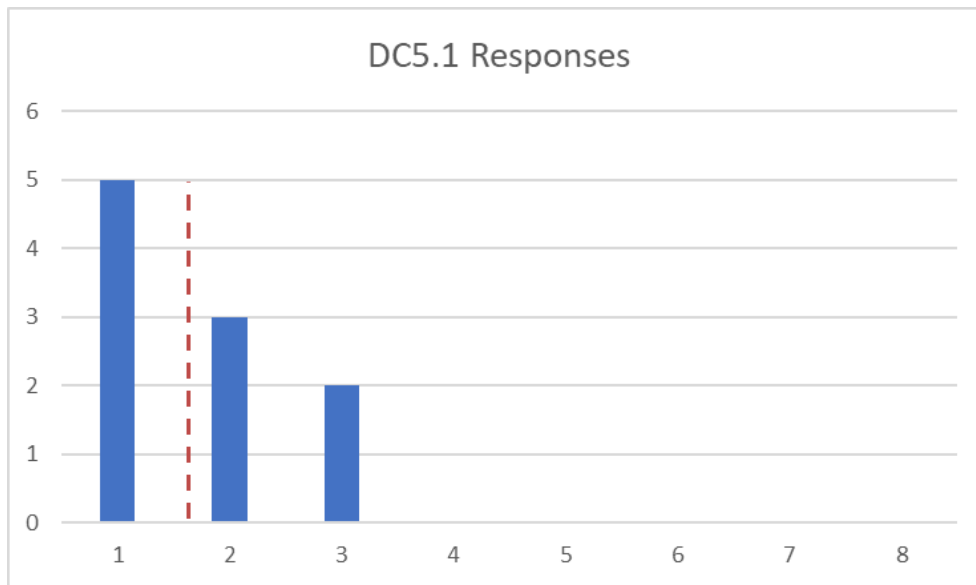


Figure 56: DC5.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response for this statement is 1.7, denoting consensus. This verifies the visuals chosen, as well as the method thereof, which is discussed in Chapter 7.

DC5.2 – D1's visuals can scale to the selected filters, whereas D0's visuals can't.

Due to this being a true or false statement, and D1 having the functionality whereas D0 does not, reaching consensus with an average response of 1.2 makes sense. This functionality proves to be useful with the analysis of information displayed on a dashboard, accompanied using filters.

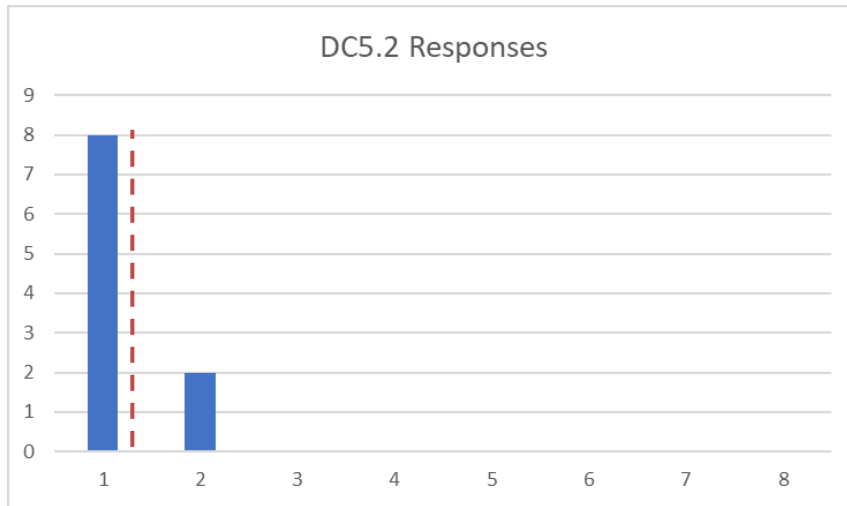


Figure 57: DC5.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

DC5.3 – The title of each visual clearly summarizes the information displayed in the visual itself, specifically for D1.

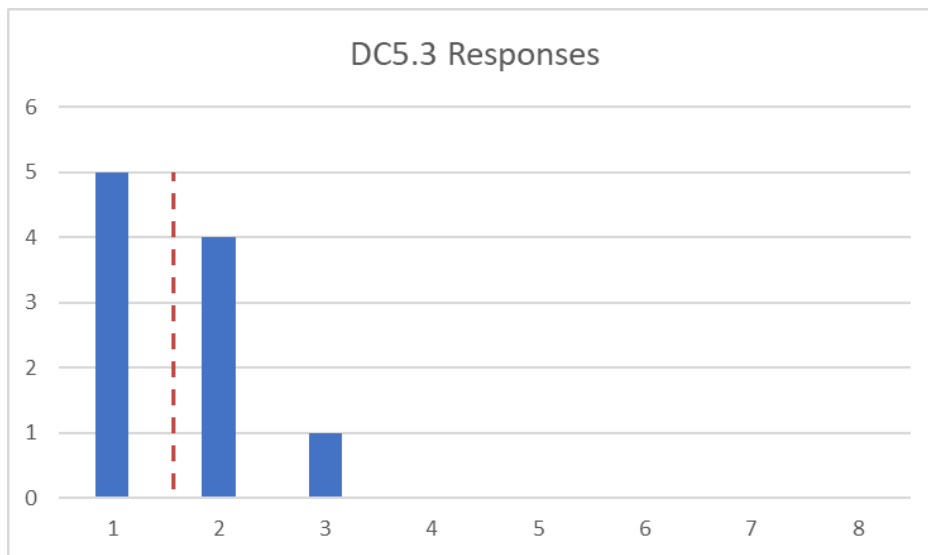


Figure 58: DC5.3 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

Consensus is reached on this statement with an average response of 1.6, further strengthening the argument on DC4.2, being a true or false statement, being misunderstood. The title of each visual is, however, clearly visible and descriptive. Thus, consensus is reached.

Open-ended feedback

Open-ended feedback concluded that the breakdown of operational time per day (DV11) was not that obvious to understand. The comment was aimed explicitly at the bars on the visual, and if each referred to a day. When hovering over the visual, the interviewee would have seen that it was referring to a calendar day. The title of the visual is, however, modified to describe better that each bar represents a day. Other feedback concluded that the D1 is visually very appealing and would work great in team discussions within the interviewee’s working environment. Due to different backgrounds and environments of the interviewees, one commented that the KPI’s might be displayed in another sequence, but did not specify which KPI’s he expressly referred to.

7.6.6. DC6 – Application

DC6.1 – D1 is better fit for operational project management on a day-to-day basis than D0.

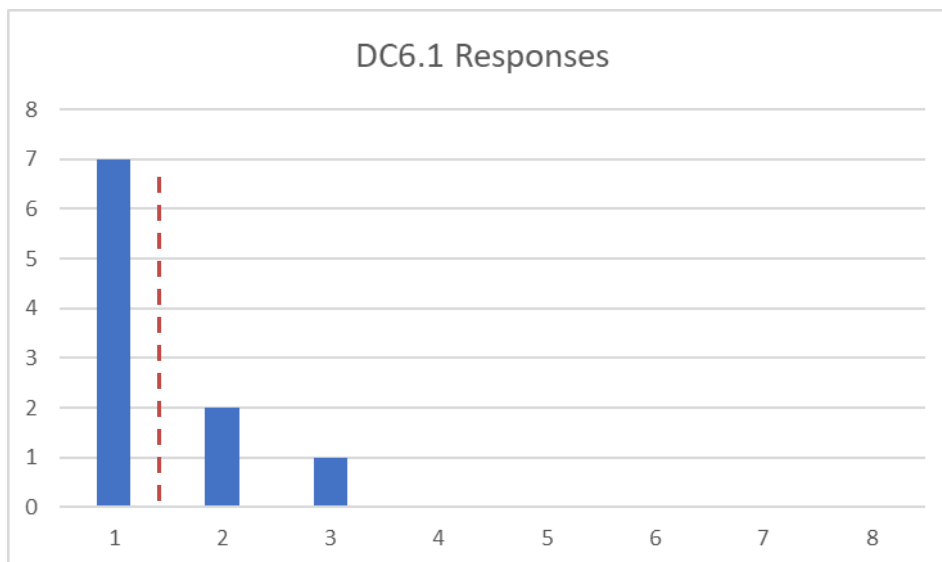


Figure 59: DC6.1 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response of 1.4 denotes consensus on this statement. D1 is thus a better overall tool than D0, regarding operational project management of drilling projects. It supports the information gathering methods throughout this study and the development of KPI’s and visual choices for operational information within the drilling project context.

DC6.2 – D1 has the potential to better help project managers on drilling contracts plan and monitor costs as the project progresses than D0 does.

An average response of 1.4 denotes clear consensus on the statement. The additional financial information contained in D1, which D0 does not include, is the transactional financial information (DV5), and the expenses undergone per cost category (DV9) on the operational project. D1 clearly

being stated as creating increased financial visibility due to only two visuals, further strengthens the argument of DC4.2 being misunderstood.

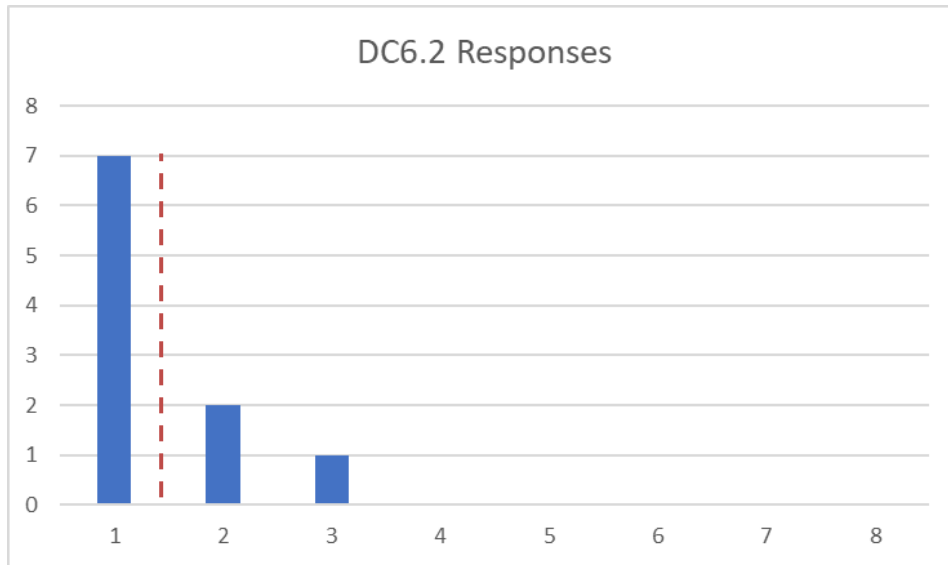


Figure 60: DC6.2 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

DC6.3 – D1 has the potential to better help project managers on drilling contracts plan and monitor operational activities to stay on schedule than D0 does.

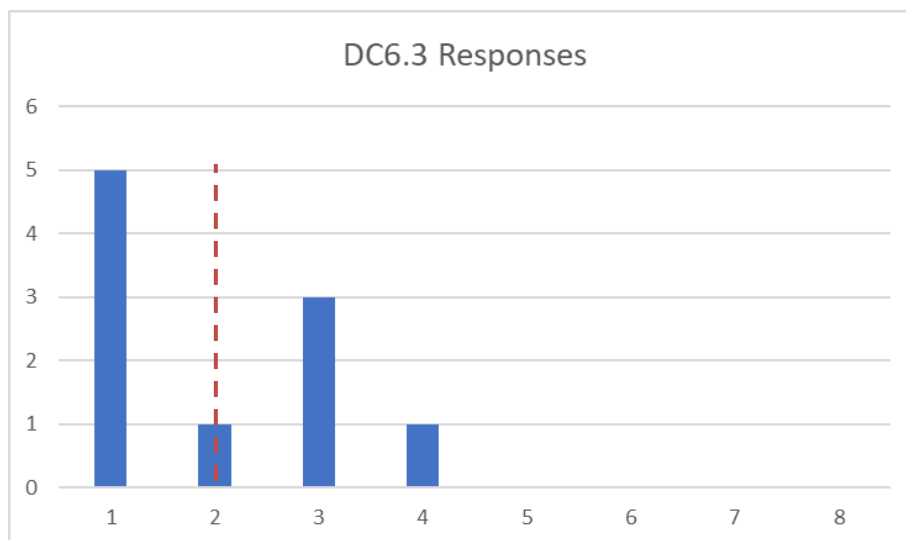


Figure 61: DC6.3 Delphi responses

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The average response for this statement is 2, just reaching the consensus value, further validating the effectiveness of D1 increasing effective operational project management.

Open-ended feedback

Feedback on this section mentions that D1 is a move in the right direction regarding the improvement of operational project management, although it is not the only attribute of project management. Another response mentions that D1 can be a powerful project management tool after the user spends some time familiarising himself/herself with the tool. One interviewee mentioned the value of D1 for frontline supervisors to stay on track with the project schedule and assist with continuous improvement within the environment.

7.6.7. Concluding evaluation

Two final statements are included within the Delphi evaluation focusing on the survey, and the dashboard artefact (DC7.1-DC7.2). The statements are summarised below.

DC7.1 – How did you find the survey itself?

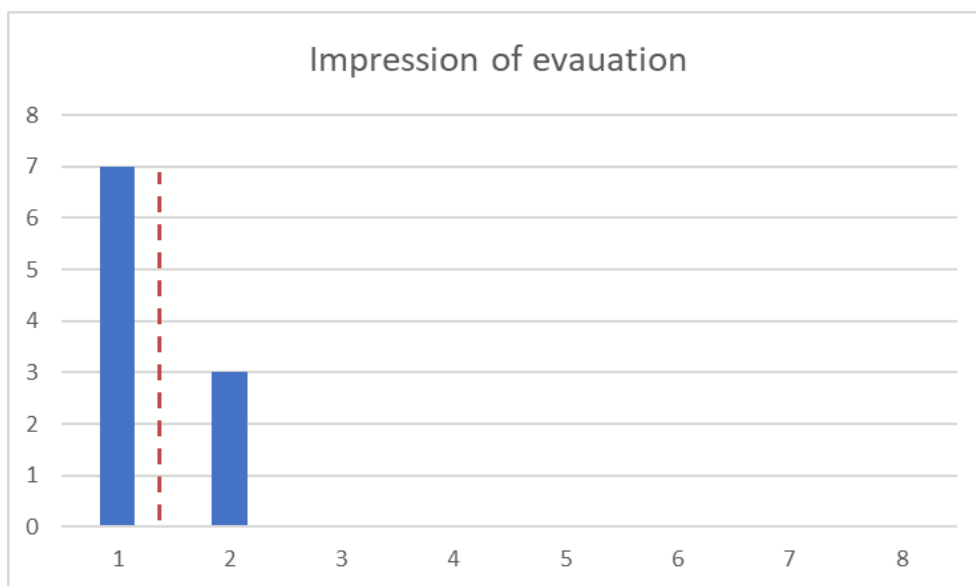


Figure 62: Impression of evaluation

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

The overall impression of the survey on the interviewees was very positive, indicating that the method successfully communicates the necessary information. The average response for this question is 1.3, denoting a positive response.

DC7.2 – What is your overall impression of D1?

The overall impression of the dashboard artefact is endorsed by all the interviewees who responded to the evaluation. The average response for this statement is 1.3.

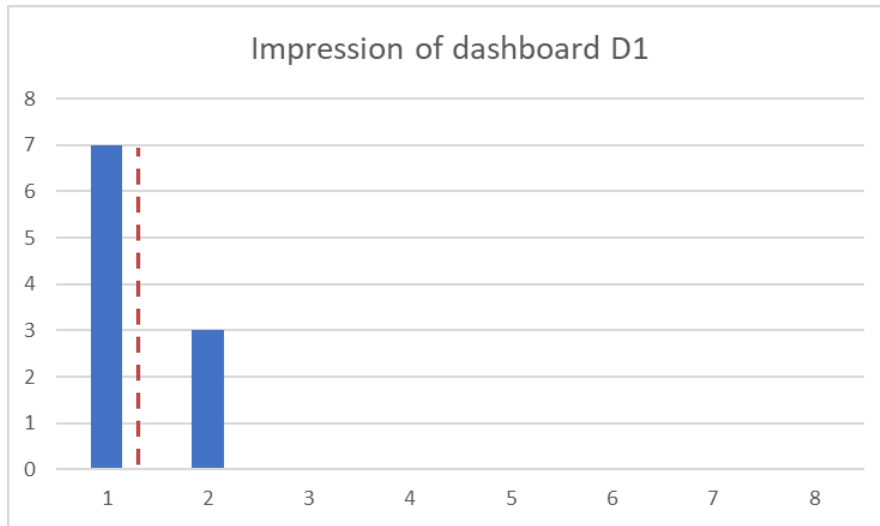


Figure 63: Impression of D1

[1] Whole Hearted Endorsement [2] Agree With Minor Point of Contention [3] Support With Reservations [4] More Discussion Needed [5] Abstain (Does not Affect Me) [6] Don't Like But Will Support [7] Serious Disagreement [8] Veto (I Block this Proposal)

7.7. Delphi method conclusion

The experience with the Delphi method as a means of artefact validation proved insightful and valuable to this study. Including both academics and working professionals within the validation process resulted in the attainment of useful insights on the final dashboard artefact, and comments regarding the study in general. The interviewees of the Delphi panel are, in a sense, the ‘customers’ of the artefact developed within this study. The method can thus otherwise be described as a customer satisfaction evaluation, whereby all of the customers had to agree on the designed elements to a certain extent, for the study to be a success.

Evaluating the defined problem, designed elements and the solution in its entirety validates the success of this study. Positive results indicate the success in the method used, as well as the value of the artefact itself.

Chapter 8: Conclusions and Recommendations

The improvement and increase of operational project management within the drilling environment proved to have various factors influencing it. It included the accuracy of data, the categorising thereof and the method of attaining the data itself. Developing artefacts to focus on each of the factors above, using a rigorous design methodology, delivered a successful artefact which could potentially improve the organisational environment.

8.1. Conclusions

The focus on maturity improvement regarding disruptive technologies proved to be a worthwhile endeavour considering the discussions and artefacts throughout this study. The analysis of company maturity leads to the sizable growth of data-driven services within a leading drilling company in the South-African mining sector. The action design science methodology leads to the effective use of academic knowledge, as well as practical drilling experience, being combined into a feasible artefact.

Data-driven dashboards in the operational drilling context provide the users thereof with valuable information to ease project management, thus increasing the user's capacity and ability to handle various demanding situations. The user can more rapidly react to underlying problems which arise, as greater visibility is provided with the existence of a data-driven dashboard.

The Delphi method used for the dashboard validation concluded that the dashboard artefact developed in the study would successfully aid operational project managers of drilling projects to manage operational drilling projects better.

The focus of data-driven dashboards thus has a positive effect on the project management capabilities within the operational drilling environment in the South-African mining sector. This focus also leads to the improvement of data-driven services maturity within the world's largest specialised drilling company, in-turn better preparing them for technology adoption.

8.2. Future Research

Having the availability of vast amounts of data creates the opportunity for machine learning technologies to be used to make predictions on machine operations. Predictions can include the failing of HME parts on a machine, when maintenance should be done on the machine, the speed at which contracts will be completed and to a lesser manner the different delays which can take place in a specific timeframe.

This study forms an integral part of such research, as it sets the scene for accurate data to be collected efficiently. It also provides a data-driven dashboard which can be used to analyse operational data better. Study into the algorithms and visualisation of predictive methodologies will add value within the context this study took place.

Other research endeavours can be focused on the use of dashboards in different environments supporting drilling operations. Improving supporting functions within the drilling environment can further increase the operational equipment effectiveness of drilling machines. It is potentially due to increased responsiveness of logistics operations, or a decrease in mechanical repair times.

8.3. Recommendations to Master Drilling

The use and value of dashboards in the operational environment have been displayed successfully within this study. As a tool, dashboards can further increase productivity in various departments, if the correct KPI's are made visible in doing so. One important thing to note is that KPI's drive behaviour and should be aligned with a company's strategy. It is recommended that the company's strategy and KPI's be revisited to ensure that it is aligned with the adoption of disruptive technologies aimed at making the company more profitable and competitive.

The company focuses on the improvement and development of the global mining industry in which it is situated. The focus on the development of disruptive technologies within its industry is leading to constant growth in the maturity of the company regarding the adoption of new technologies and adaptive solutions to sector-specific challenges.

Considering the research of this study, it is recommended that the company keeps investing in research within the field of technology innovation. Focusing on the maturity improvement of dimensions within the company, relevant to its industry, will prove to support the growth brought on by future endeavours sustainably. The current focus on the capturing of accurate and useful data has led to various improvements in the company over the last year. In the author's opinion, this growth has not yet plateaued, and a continued focus on the better use of data could lead to more growth within the company.

The author further recommends that after this sizable increase in DDS maturity within a company, the next dimension be targeted to further increase the ability of the company to adopt Industry 4.0 technologies. The surveys conducted within the study suggests that one of the following 2 dimensions be focused on namely, Smart Factory, and Smart Products.

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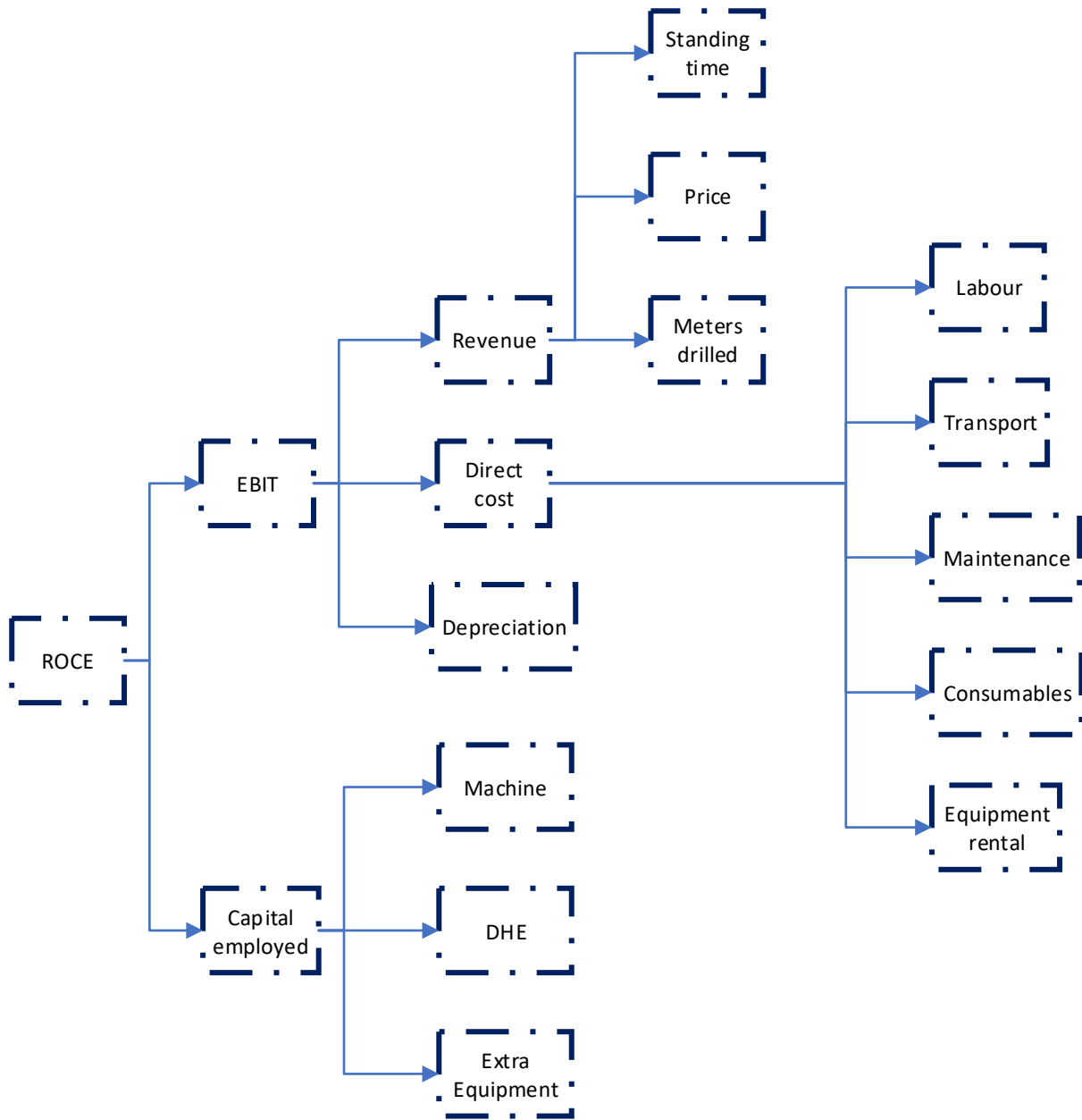
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Appendix A: Shift Activities

Activity Nr	Activity
1	Strike
2	Environmental Delay
3	Medical Assessment
4	Training/Induction
5	Blasting
6	Waiting for Mine Service
7	DHE Transport Underground
8	Waiting for MD Support Service
9	Lost Time Injury
10	HME Failure
11	Piloting Deflection
12	NDT/UT of Rods
13	DHE Failure
14	Adverse Ground Conditions
15	Reaming Cubby Preparation
16	Safety Compliance
17	Machine Cubby Preparation
18	Move Machine
19	Rest & Recovery
20	Meeting
21	Personnel Travel (On-Site)
22	Remove Reamer
23	Machine Decommissioning
24	Site Clearance
25	Surveying
26	Pilot Collaring
27	Grouting
28	Planned DHE Maintenance
29	Planned HME Maintenance
30	Inspections
31	Dress reamer
32	Reamer Hook-up
33	Mucking / Chippings Handling
34	Ream Collaring
35	Shotcreting
36	Establish Dams
37	Establish Concrete Pad
38	Machine Commissioning/Installation
39	Lash and Torque Reamer
40	Assemble Reamer
41	Pilot Decommissioning
42	Install Eyebolts
43	Re-pilot Drilling
44	Pilot Drilling
45	Reaming
46	Auto-Reaming

Appendix B: Drilling Company KPI Tree



Appendix C: Dashboard Visuals

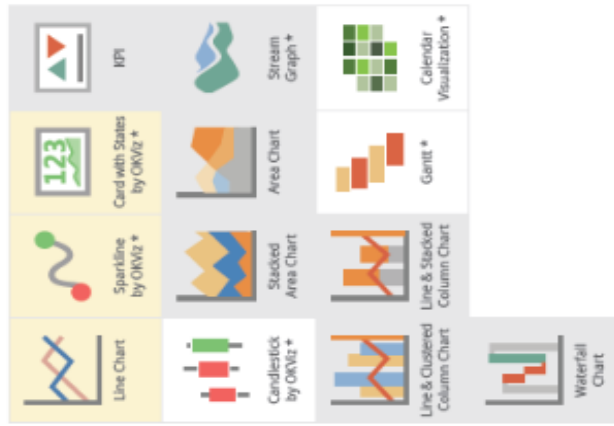
COMPARISON

Use these visuals when you want to display measures compared by its magnitude.



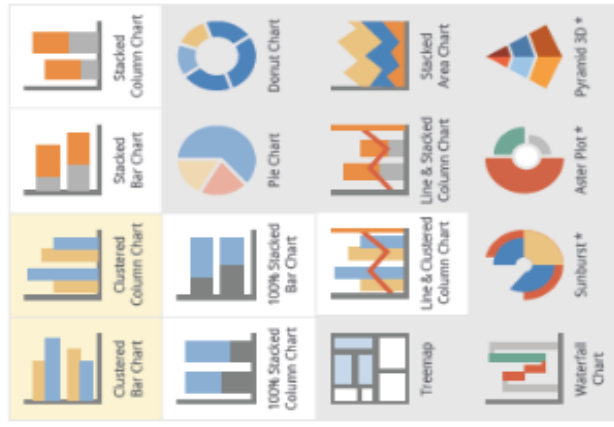
CHANGE OVER TIME

Use these visuals when you want to display the changing trend of measures.



PART-TO-WHOLE

Use these visuals when you want to display parts that compose measures.



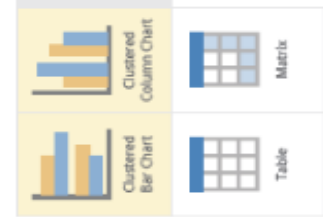
FLOW

Use these visuals when you want to display a flow or dynamic relations between measures.



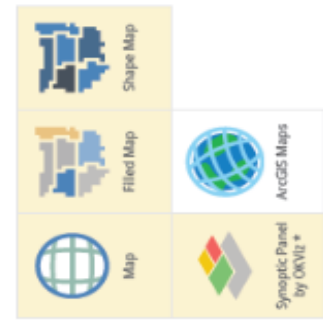
RANKING

Use these visuals when you want to display measures by its rank order.



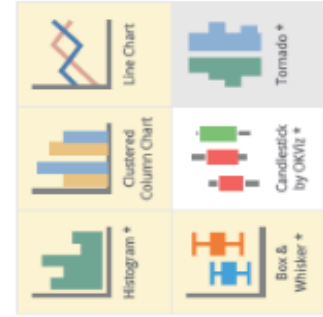
SPATIAL

Use these visuals when you want to display measures over spatial maps.



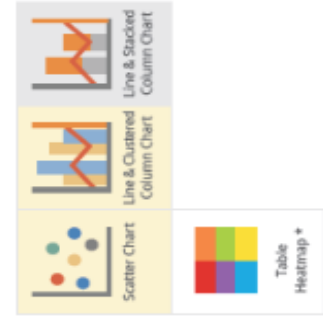
DISTRIBUTION

Use these visuals when you want to display the distribution of a measure.



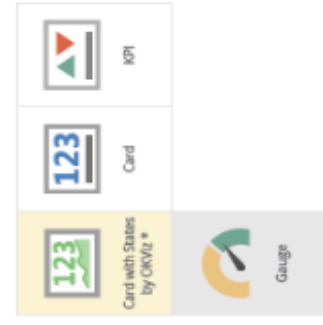
CORRELATION

Use these visuals when you want to display relations between measures.



SINGLE

Use these visuals when you want to display a single value.



Appendix D: Validation Email Communication

Dear XXXX

I trust you are well.

My name is Gideon Maasz, an Industrial Engineer in the South African mining industry, and current M.Eng student at the North-West University, Potchefstroom campus. My Masters degree is titled: **Increasing overall equipment effectiveness of drilling machines by means of data-driven dashboards**

The research focuses on the improvement of data-driven services within a global specialised drilling company situated in South-Africa. I have chosen to follow the recognized Delphi method to validate my research. As part of validating the study, I am sending an evaluation form to a few selected individuals. The aim of the form is to get your insights on an improvement presented, rating each of the provided statements of improvement to the best of your abilities.

All information regarding you and your answers will be handled anonymously, and your cooperation in the questionnaire will also be codified. None of your personal information will be shared in any way within the report. Your insights and feedback will however be included anonymously.

Below you will find the link to the evaluation form, which can be filled in electronically. If you choose to participate, please send your highly valued feedback to me before the 25th of April. You will also find 2 dashboard files, as well as a screenshot thereof, attached. They are named respectively Dashboard_D0 and Dashboard_D1.

Dashboard_D0 is an excel file which you can just open to answer the questionnaire. To open Dashboard_D1 and play around with it you will need the free version of Microsoft's PowerBI. A download link is provided below. The download takes about 10-15 minutes, depending on your bandwidth speed, and completing the evaluation form will take about 7 minutes. If you can for some reason not download the software, you are welcome to use the screenshot of the dashboard to answer the questions to the best of your ability.

Link to PowerBI download:

<https://powerbi.microsoft.com/en-us/get-started/>

Link to evaluation form:

<https://www.surveygizmo.eu/s3/90135095/Dashboard-Evaluation>

Feel free to contact me in the case of you having any questions. As mentioned, please send your feedback to me by 25th of April 2019.

Your participation is greatly valued. Thank you in advance.

Sincerely,

Mr. Gideon Maasz

Industrial Engineer

Master Drilling Group

Appendix E: Title registration form

Title Registration

Section A (page 1 to 4)

To be completed by student, signed by supervisor / promoter, and uploaded by student to eFundI before commencement of the Title Registration colloquium, together with:

- the Research Proposal per PowerPoint template of the Faculty of Engineering
- the signed Code of Conduct for researchers and
- the [Invention Disclosure Form](#) (if applicable)

Student Information

NWU Number	2 5 0 6 1 3 7 2	Initials & Surname	GJ Maasz
Qualification	M.Eng in Industrial Engineering		
! Compulsory	Research Group <small>[confirm with study leader]</small>	Industrial Engineering	
Provisional Title <small>[Pre-colloquium]</small>	Increasing overall equipment effectiveness of drilling machines by means of data driven dashboards		
Colloquium Date	2018/03/22	Is this an article-based dissertation/thesis	Yes

 Handwritten titles are not accepted.

Are there any confidentiality issues related the proposed research YES NO

IF YES:

1. Did you consult the rules for the [Classification of Thesis and Dissertations?](#)
http://www.nwu.ac.za/content/oa/cv_rules YES NO

2. Did you complete the [Invention Disclosure Form](#)
<http://www.nwu.ac.za/i-fts/invention-process> YES NO

This form must be uploaded together with your research proposal

Supervision

Indicate ALL supervisors

Main Study Leader

Name	Hasan Darwish
Tel	018 298 4026
Email	Hasan.Darwish@nwu.ac.za

Co-or Assistant Study Leader/s

Name		Name	
Tel		Tel	
Email		Email	
Type		Type	
Name		Name	
Tel		Tel	
Email		Email	
Type		Type	

Appendix F: Ethics Form

Student Statement on Research Ethics

(to be completed before the Proposal colloquium)

NWU Number	2	5	0	6	1	3	7	2	Initials & Surname	GJ Maasz
------------	---	---	---	---	---	---	---	---	--------------------	----------

Please answer each question by ticking the appropriate box:

		Y	N
1.	Does your research involve humans or animals? If so, please answer questions 2, 3, 4, 5, 6	<input checked="" type="radio"/>	<input type="radio"/>
2.	Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g. children, students, unemployed or otherwise compromised in responding to your questions)	<input type="radio"/>	<input checked="" type="radio"/>
3.	Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g. covert observation of people)	<input type="radio"/>	<input checked="" type="radio"/>
4.	Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind or any physical, psychological or socio-economic intervention?	<input type="radio"/>	<input checked="" type="radio"/>
5.	Will the study require the personal identification of individuals for follow-up evaluation? (i.e. through names and surnames, identification or staff numbers)	<input type="radio"/>	<input checked="" type="radio"/>
6.	Are you planning on making use of NWU students and/or direct and/or secondary/contracted staff members as research subjects in this research?	<input type="radio"/>	<input checked="" type="radio"/>
7.	Can your research activities potentially bring physical harm to yourself and other people (such as civilians, laboratory personnel, assistants and students)	<input type="radio"/>	<input checked="" type="radio"/>
8.	Did you/will you execute a formal risk assessment? Please indicate which type of risk assessment (e.g. HYRA/FMECA) in Section 8.a	<input type="radio"/>	<input checked="" type="radio"/>
8.a			
9.	Can your research activities potentially bring physical harm to the environment (such as a radioactive spill or pollution) more than normally faced by these people / environment? If so, state the scenario and estimate the magnitude of this potential harm and the chance of this taking place. Describe any preventative action planned in your proposal.	<input type="radio"/>	<input checked="" type="radio"/>
10.	Would the interests (financial or otherwise) of any of the involved parties (researcher, supervisor, research sponsor) be served or damaged by the outcome of this research? If so, do you consider this a threat to objectivity? Please elaborate in your research proposal and explain how you will maintain obje.	<input type="radio"/>	<input checked="" type="radio"/>

1 - Strongly Agree 2 - Agree 3 - Disagree 4 - Strongly Disagree

	1	2	3	4
Research Topic				
Does the topic fall within the scope of the Research Group?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Does the topic represent an important/key problem area that warrants research?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Research Title				
Does the title reflect the content and full scope of the research proposal?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the title concise (around 10 words) while at the same time being descriptive of the research?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Background and Rationale				
Does the Introduction lead the reader into the context and scope of the research topic?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is sufficient information provided to contextualise the research topic and the research problem?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the rationale and/or justification clearly illustrated?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is sufficient motivation for doing the research provided?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Literature Review				
Is the literature review relevant to the research topic, the problem statement and the overall purpose of the study?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the literature review adequate and comprehensive enough to justify the proposed research?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Does the literature review attend to relevant theories pertinent to the proposed study?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the literature review properly integrated and synthesized, including a justification of an own point of view?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are terminology and concepts clearly defined and clarified?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Purpose and Problem Statement				
Does the problem statement flow naturally from the Introduction?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the problem of practical and/or scientific significance which could lead to the creation of knowledge?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the problem statement congruent to the research title?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the problem statement congruent to the overall purpose of the research?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the theory(ies), practical problems and/or prior research upon which the proposed study is built, clearly described?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Research Objectives				
Do the research objective(s) flow naturally from the problem statement?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the research objective(s) clearly and unambiguously formulated?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the research objective(s) limited to the issues at stake in respect of the research?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Research Method/Design				
Does the research design provide sufficient evidence of an understanding of research paradigms and philosophical approaches to research?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the proposed research method appropriate for the proposed research problem?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the specified research method(s) adequately justified?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the research population and sampling procedures adequately described?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the data collecting techniques and administering briefly described?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the analysis techniques (quantitative and qualitative) briefly explained?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

Editing				
Are all the references in the text listed in the reference list?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are all the references in the reference list used in the text?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the referencing technique throughout the text and the reference list?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Are the references used adequately relevant and reliable for post-graduate research purposes?	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the language and grammar acceptable and without spelling errors?	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>

If you answered *yes* to *any* of the questions on page 2, you will need to describe more fully how you plan to deal with the ethical issues raised by your proposal. A slide is available for this purpose, in the research proposal PowerPoint template which can be found on eFundi. *This does not mean that you cannot do the research, only that your proposal will need to be approved by the Faculty Research Ethics Committee. Attach a full description of the specific issues to this declaration, for discussion by the panel at the Proposal Colloquium.*

Please note that it is your responsibility to follow NWU's *Guidelines for Ethical Research* as set out in the [Manual for Postgraduate studies](#) and any other relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring the confidentiality in the storage and use of data, and anonymity of participants. Any significant change in the question, design or conduct over the course of the research should be notified to the supervisor / promoter and may require a new application for ethics approval.

I have read the NWU's Manual for Postgraduate Studies and am familiar with the Guidelines for Research Ethics contained therein.	Y	N
	<input checked="" type="radio"/>	<input type="radio"/>
I have familiarised myself with the NWU Policy on Plagiarism and Academic Misconduct , and submit myself thereto.	Y	N
	<input checked="" type="radio"/>	<input type="radio"/>

Gideon Maasz

 Digitally signed by Gideon Maasz
 DN: cn=Gideon Maasz, o=NWU

 Student

17 Apr 2019
 Date

Section B

Declaration by Supervisor / Promoter

I am familiar with the content of the research proposal and I agree that the student present it to the scientific committee by means of a colloquium. I also agree with the ethics checklist, as well as the Supervisor/s (p. 1), as completed by the student.

I grant permission that the student upload the research proposal to eFundi.	Y	N
	<input checked="" type="radio"/>	<input type="radio"/>

Dr Hassan Darwish

 Digitally signed by Dr Hassan Darwish
 DN: cn=Dr Hassan Darwish, o=NWU

 Supervisor / Promoter

23 Apr 2019
 Date

Section C

Report by Scientific Committee

Research Topic	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Research Title	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Background and Rationale	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Literature Review	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Purpose and Problem Statement	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Research Method/Design	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent
Editing and Referencing	<input type="radio"/> Absent/Wrong	<input type="radio"/> Inadequate	<input checked="" type="radio"/> Adequate	<input type="radio"/> Excellent

Formative Feedback

Did the scientific committee make a voice recording to capture formative feedback, whilst completing the checklists above? Are all members of the scientific committee clearly identified and will you upload this voice recording, together with this form?

YES NO

If feedback is not provided by voice recording, please provide formative feedback on the issues indicated in the checklist

Recommendation

Please complete page in full:

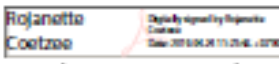
Final Recommendation by Scientific Committee

1.	The research proposal is accepted by the scientific committee, without further changes.	<input type="radio"/>
2.	The research proposal is accepted, provided that the formative feedback of the scientific committee is addressed under supervision of the supervisor/ promoter	<input checked="" type="radio"/>
3.	The student should rework the proposal, resubmit it and present it at another colloquium.	<input type="radio"/>
4.	The student should prepare a new proposal on a new topic.	<input type="radio"/>

Assessment of Ethical Risk:

1.	No Risk: There is no possible risk that the research may lead to any undesirable effects or unexpected negative consequence.	<input type="radio"/>
2.	Minimal, Low or Negligible Risk: The probability, magnitude or seriousness of unexpected negative consequences, harm or discomfort anticipated in the research is negligible and not greater than that ordinarily encountered in daily life ("Daily life" as a benchmark should be that of daily life experienced by the average person living in a safe "first world" country). Research in which the only foreseeable risk is one of minimal unexpected negative consequences, discomfort or inconvenience.	<input checked="" type="radio"/>
3.	Medium Risk: Research in which there is a potential risk of unexpected negative consequences, harm or discomfort, but where appropriate steps can be taken to mitigate or reduce overall risk. Remedial interventions can be undertaken should harm occur.	<input type="radio"/>
4.	High Risk: Research in which there is a real and foreseeable risk of unexpected negative consequences, harm and discomfort, and which may lead to serious adverse consequences if not managed in a responsible manner.	<input type="radio"/>

Title as approved by the scientific committee	Increasing overall equipment effectiveness of drilling machines by means of data driven dashboards
------------------------------------------------------	----------------------------------------------------------------------------------------------------

21 Jun 2018	Rojanetta Coetzee	 <small>Digitally signed by Rojanetta Coetzee Date: 2018.06.21 11:25:42 +0200</small>
Date	Name: Chair of Scientific Committee	Signature: Chair of Scientific Committee

*Name and signature:
First Additional Member
of Scientific Committee
(excluding supervisor)*

	
Name:	Signature

*Name and signature:
Second Additional
Member of Scientific
Committee (excluding
supervisor)*

	
Name:	Signature

Appendix G: Approved Ethics Form



Private Bag X1290, Potchefstroom
South Africa 2520

North-West University Engineering Research
Ethics Committee (NWU-ENG-REC)

Tel: 018 269-2645
Email: ENG-REC@nwu.ac.za

9/4/2019

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the North-West University Engineering Research Ethics Committee (NWU-ENG-REC) on 5/15/2019, the NWU-ENG-REC hereby approves your study as indicated below. This implies that the NWU-ENG-REC grants its permission that, provided the general and specific conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title:	
Increasing overall equipment effectiveness of drilling machines by means of data driven dashboards	
Principal Investigator/Study Supervisor/Researcher: H Darwish	
Student: Gideon Jacobus Maasz (gmaasz@maslendrilling.com)	
Ethics number:	NWU-00265-19-A1
<small>Institution-Study Number-Year-Status</small>	
<small>Status: S - Submission; R - Re-Submission; P - Provisional Authorisation; A - Authorisation</small>	
Application Type: Single	Risk: low
Approval date: 5/15/2019	
Expiry date: 8/23/2020	
Approval of the study is provided for a year, after which continuation of the study is dependent on receipt and review of annual monitoring report and the concomitant issuing of a letter of continuation.	

<p>General conditions:</p> <p>While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:</p> <ul style="list-style-type: none"> • The principal investigator/study supervisor/researcher must report in the prescribed format to the NWU-ENG-REC: <ul style="list-style-type: none"> - Annually on the monitoring of the study, whereby a letter of continuation will be provided annually, and upon completion of the study; and - without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study. • The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the principal investigator/study supervisor/researcher must apply for approval of these amendments at the NWU-ENG-REC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited. • Annually a number of studies may be randomly selected for active monitoring. • The date of approval indicates the first date that the study may be started. • In the interest of ethical responsibility, the NWU-ENG-REC reserves the right to:

- request access to any information or data at any time during the course or after completion of the study;
- to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;
- withdraw or postpone approval if:
 - any unethical principles or practices of the study are revealed or suspected;
 - it becomes apparent that any relevant information was withheld from the NWU-ENG-REC or that information has been false or misrepresented;
 - submission of the annual monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and/or
 - new institutional rules, national legislation or international conventions deem it necessary.
- NWU-ENG-REC can be contacted for further information via ENG-REC@nwu.ac.za or 018 200 2645

Special conditions of the research approval (if applicable): NA

Special in process conditions of the research for approval (if applicable): NA

The NWU-ENG-REC would like to remain at your service and wishes you well with your study. Please do not hesitate to contact the NWU-ENG-REC for any further enquiries or requests for assistance.

Yours sincerely,



Dr Rojanette Coetzee
Chairperson NWU-ENG-REC

Current details: (S270766) \NWU\RecCloud\ENG-REC\letters\eml\Date\& 1.5.4.3_NWU-ENG-REC_REC_GAL_{student surname_name}

File Reference: & 1.5.4.3

Appendix H: Solemn Declaration and Permission to Submit



Higher Degrees Administration

SOLEMN DECLARATION AND PERMISSION TO SUBMIT

1. Solemn declaration by student

I,

declare herewith that the thesis/dissertation/mini-dissertation/article entitled (exactly as registered/approved title),

which I herewith submit to the North-West University is in compliance/partial compliance with the requirements set for the degree:

is my own work, has been text-edited in accordance with the requirements and has not already been submitted to any other university.

LATE SUBMISSION: If a thesis/dissertation/mini-dissertation/article of a student is submitted after the deadline for submission, the period available for examination is limited. No guarantee can therefore be given that (should the examiner reports be positive) the degree will be conferred at the next applicable graduation ceremony. It may also imply that the student would have to re-register for the following academic year.

Signature of Student Digitally signed by Gideon Maasz Date: 2019.05.12 21:11:48 +02'00' University Number

Signed on this day of of 20

2. Permission to submit and solemn declaration by supervisor/promoter

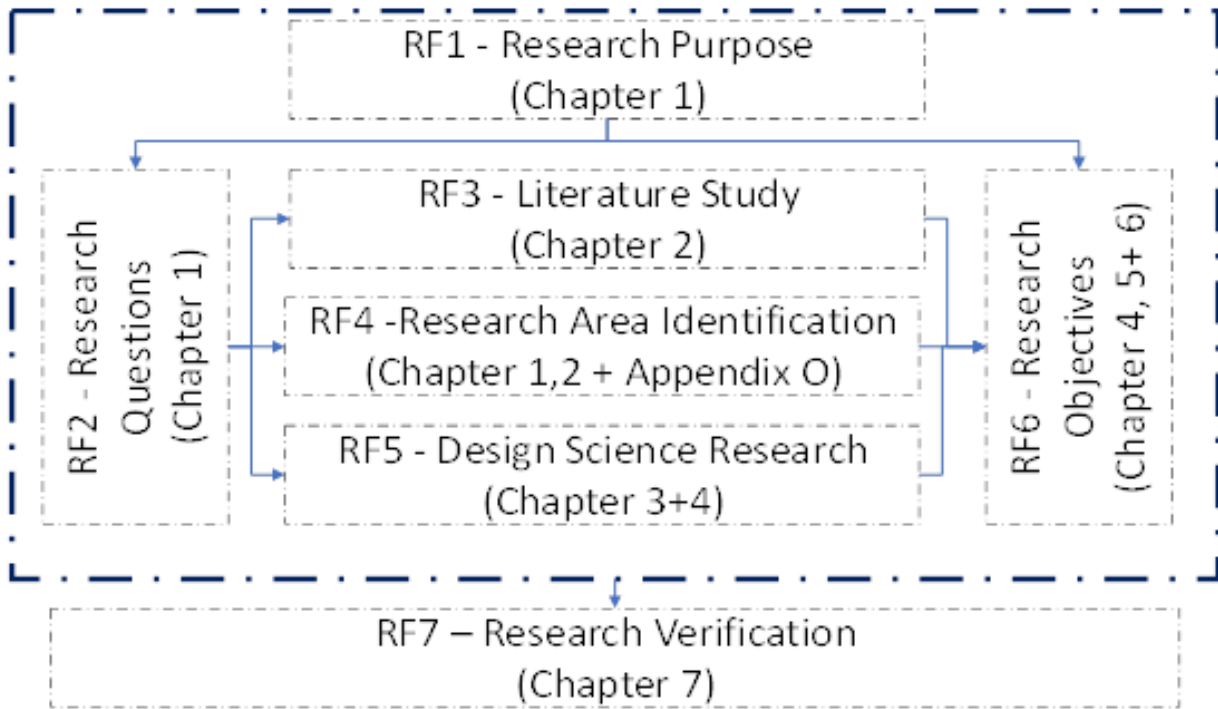
The undersigned declares that the thesis/dissertation/mini-dissertation complies with the specifications set out by the NWU and that:

- the student is hereby granted permission to submit his/her mini-dissertation/ dissertation/thesis:
 - Yes
 - No
- that the student's work has been checked by me for plagiarism (by making use of Turnitin software for example) and a satisfactory report has been obtained:
 - Yes
 - No

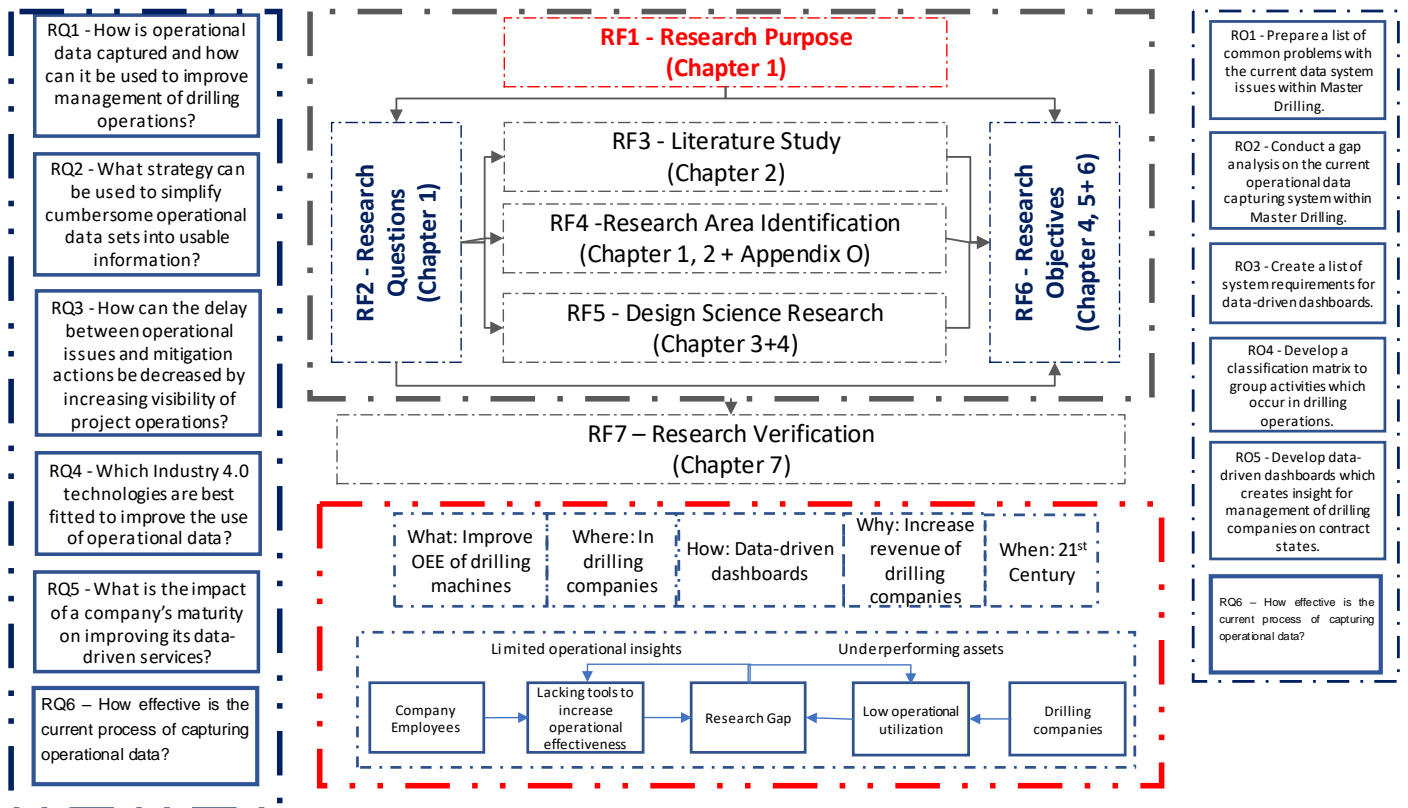
Signature of Supervisor/Promoter Digitally signed by Dr. Hasan Darwish Date: 2019.05.28 09:40:18 +02'00' Date

Original docid: 164464-Admin/10571877-1088support.docx/SOLEMN DECLARATION AND PERMISSION TO SUBMIT.docx 28 July 2017
File reference: 7.1.11.3.20

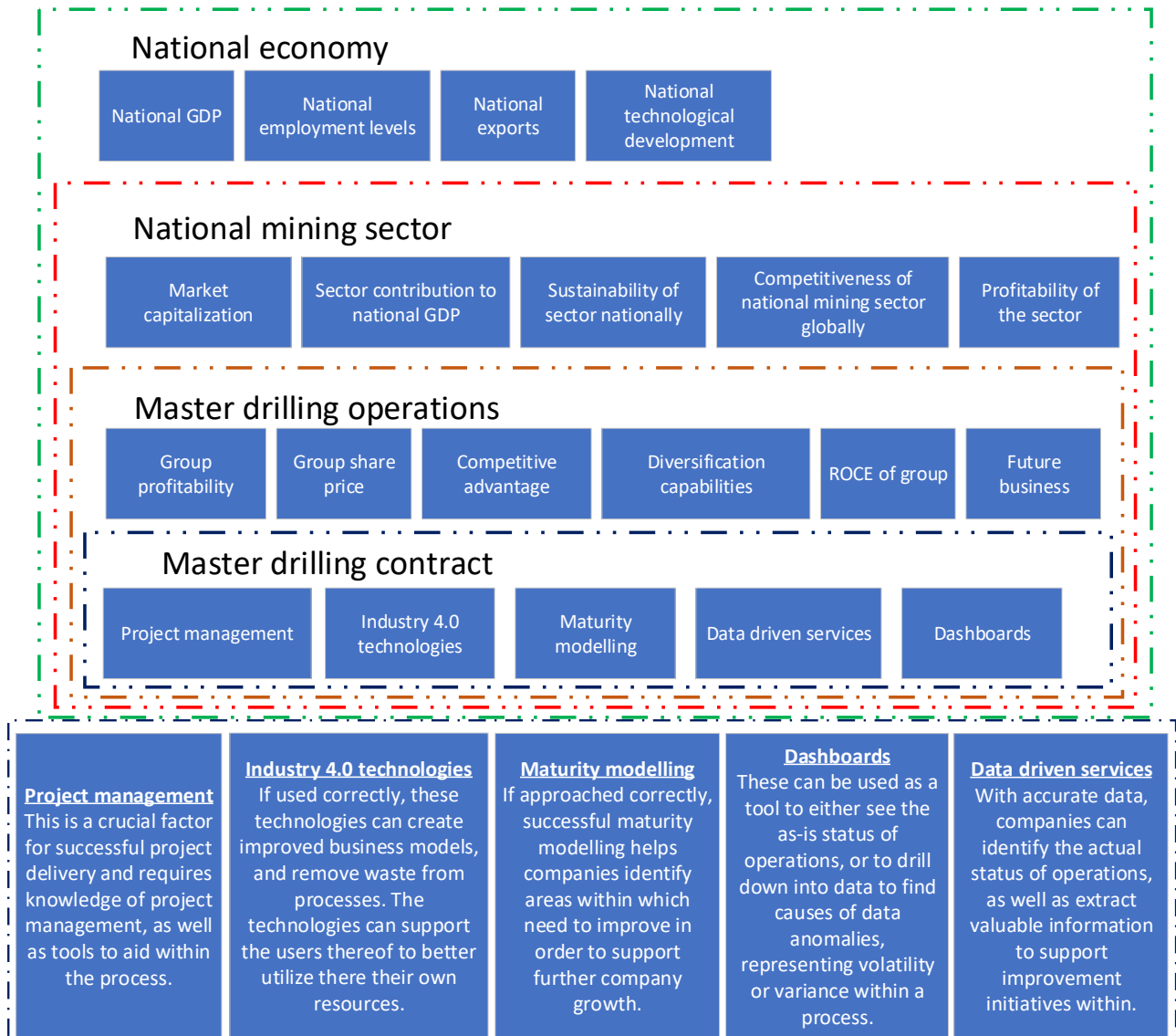
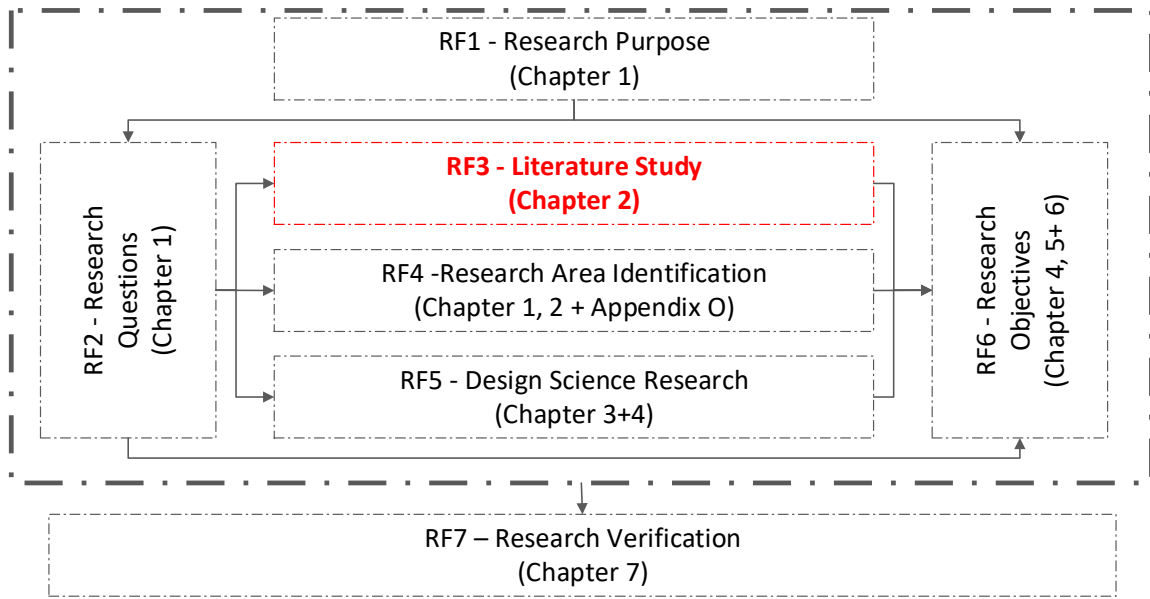
Appendix I: Research overview



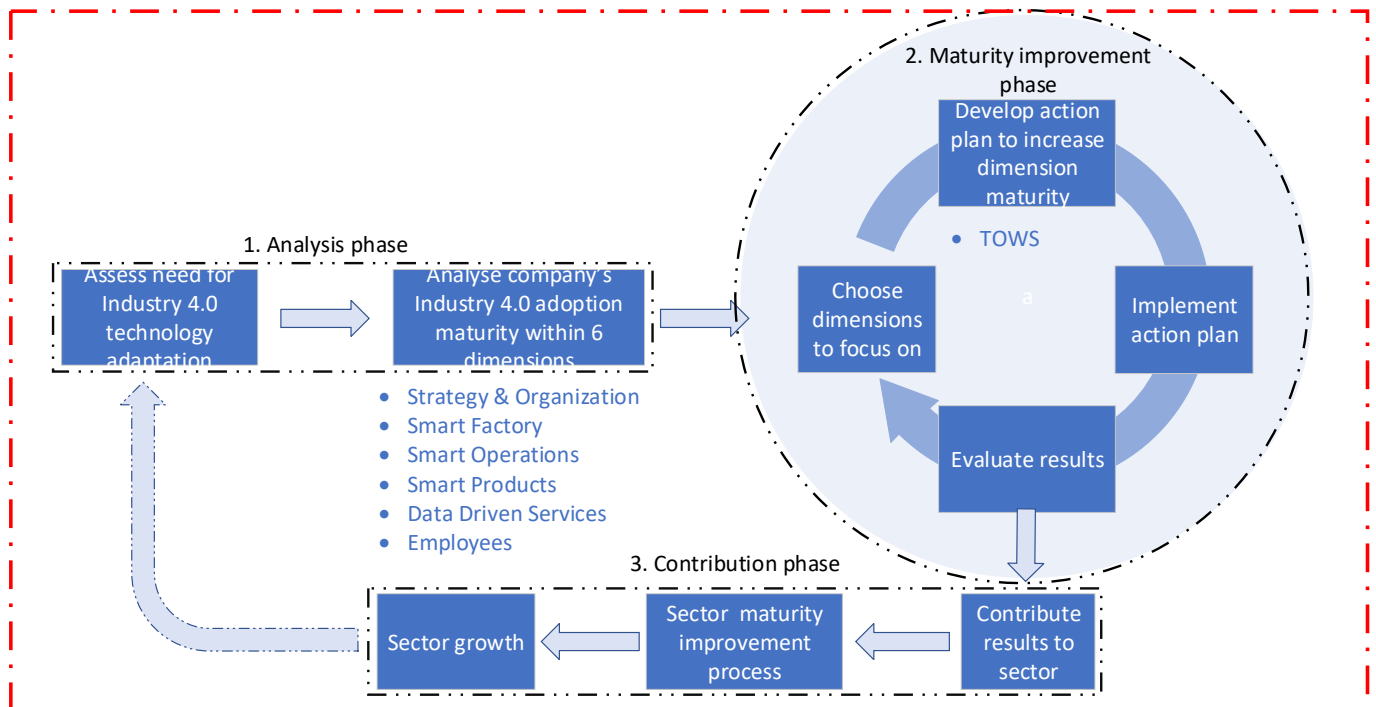
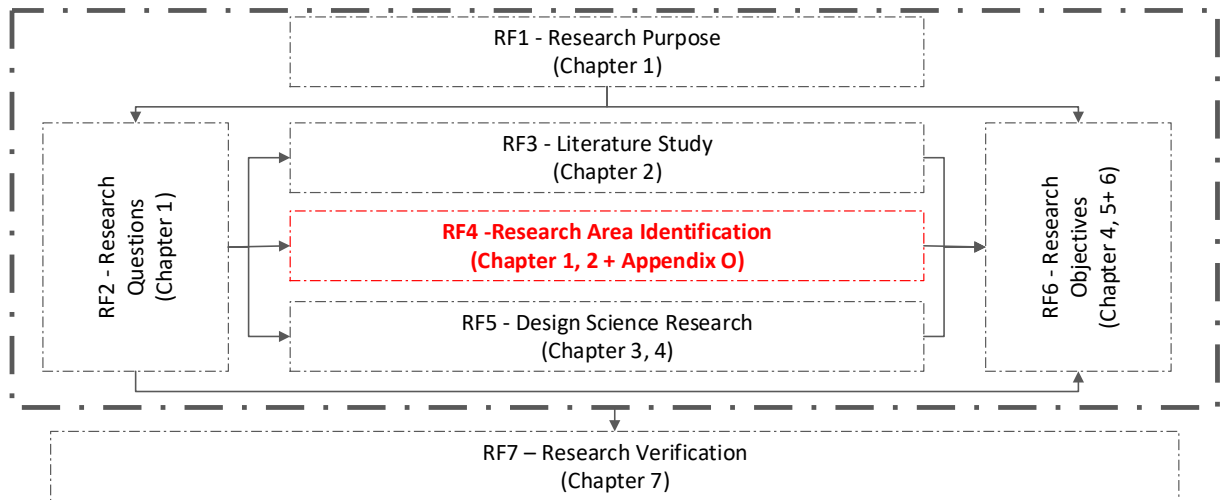
Appendix J: Research overview – research purpose



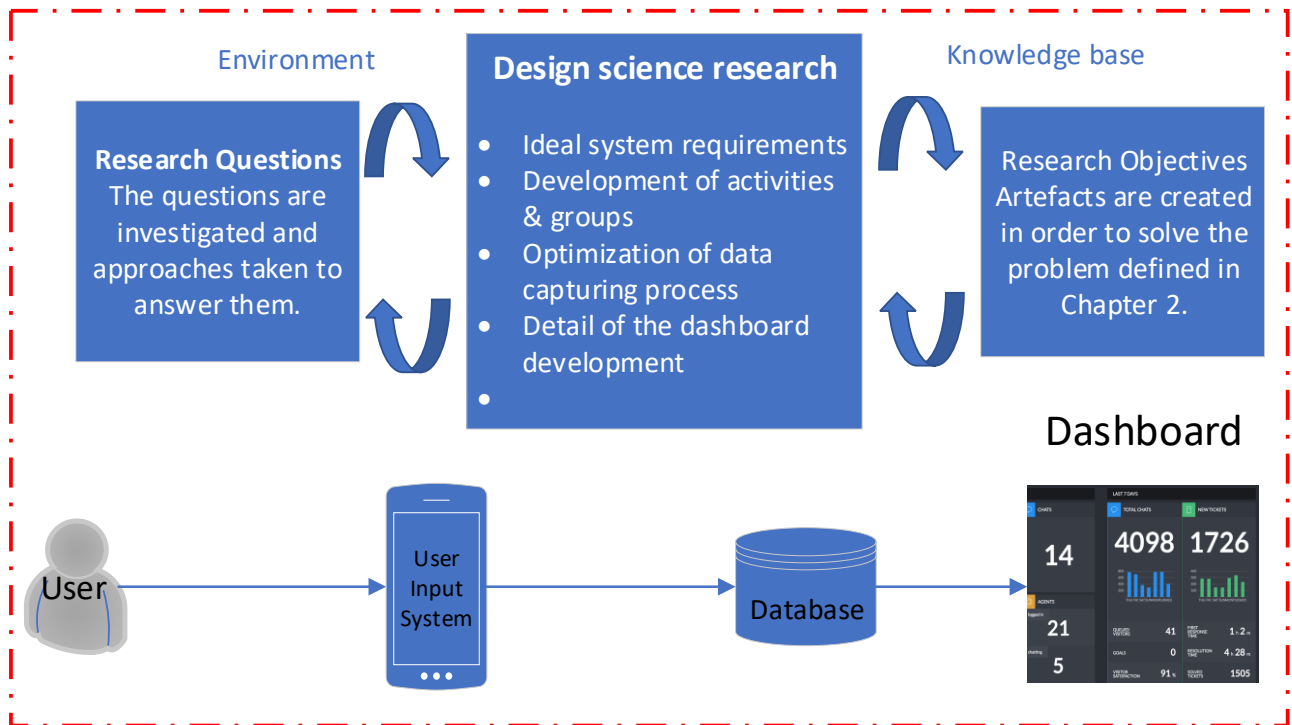
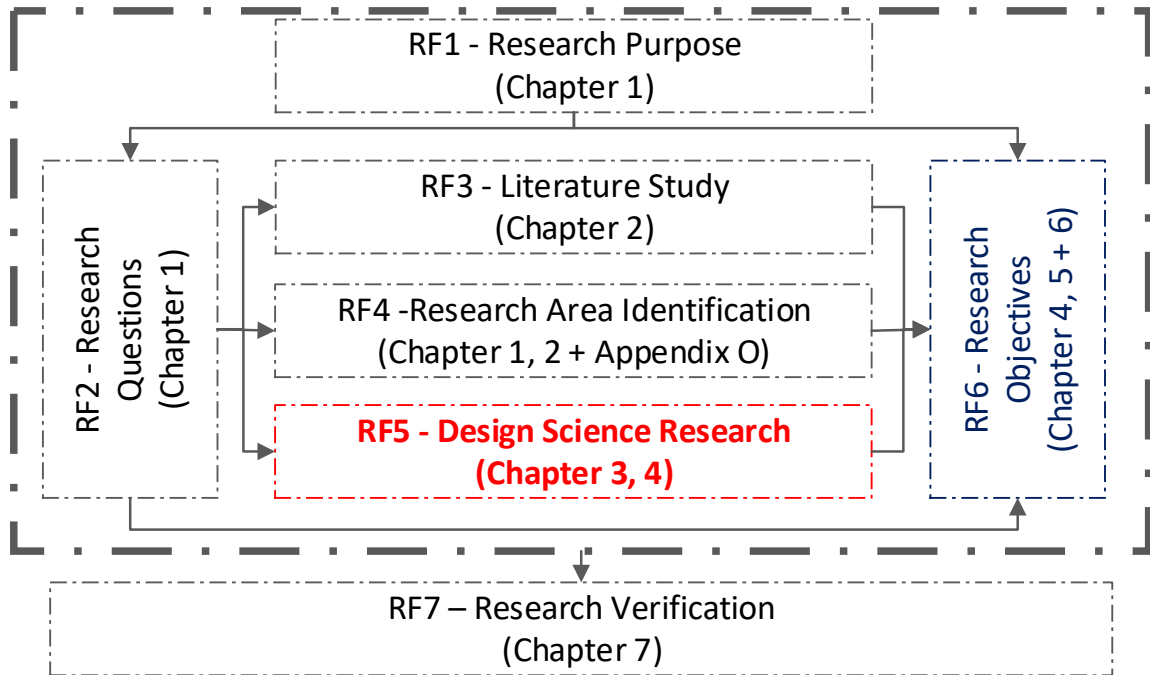
Appendix K: Research overview – literature study



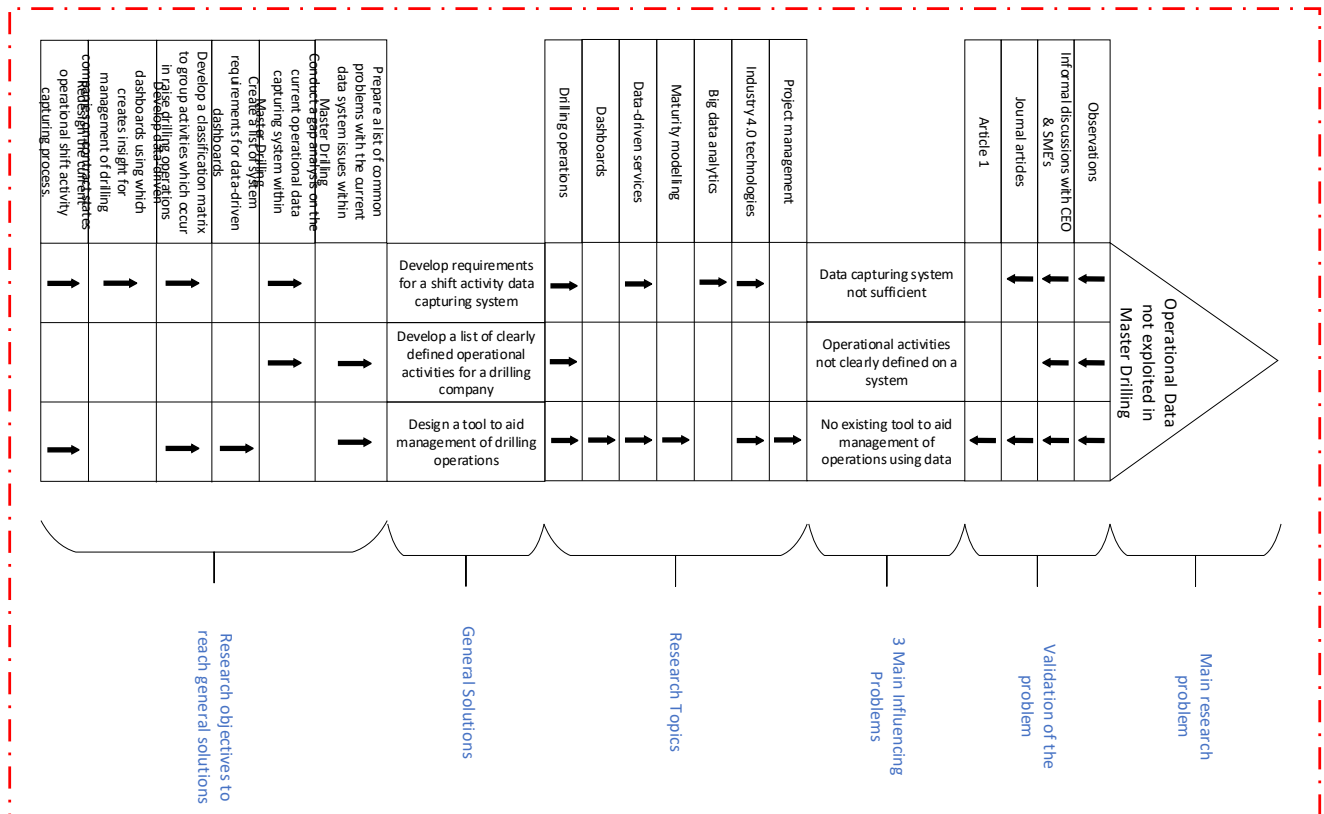
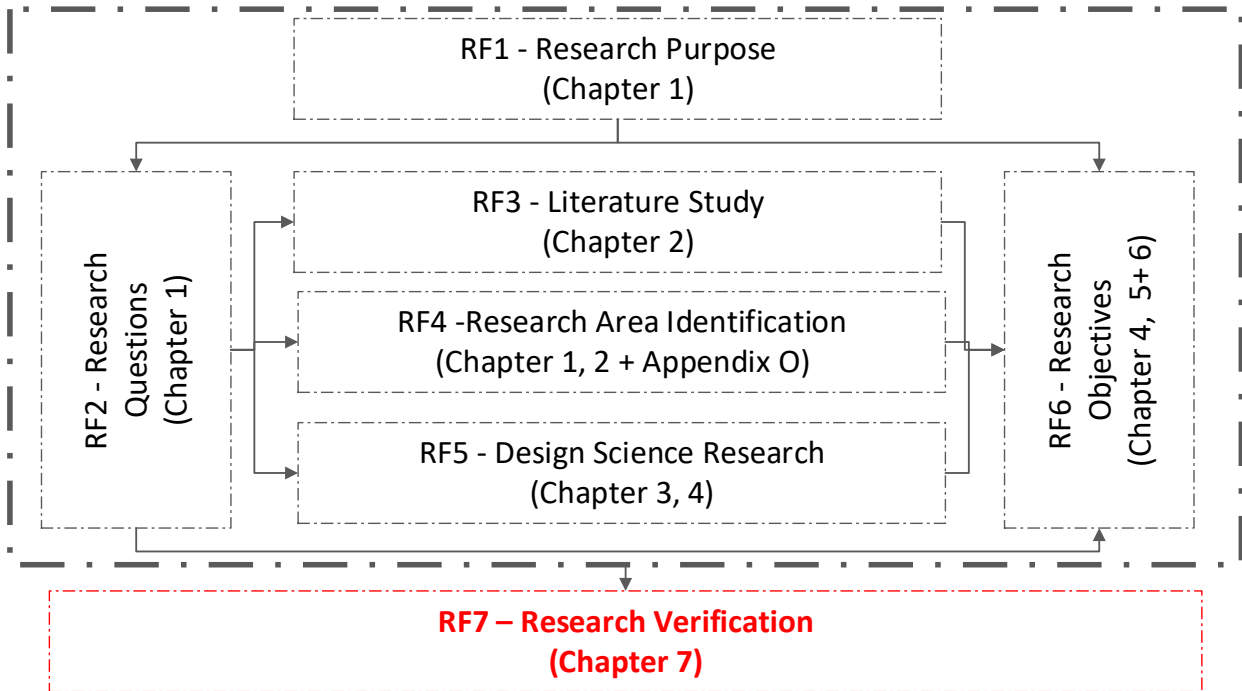
Appendix L: Research overview – research method



Appendix M: Research overview– conceptual design



Appendix N: Research overview– research verification



Appendix O: SAIE article

TOWARDS AN INITIATIVE-BASED INDUSTRY 4.0 MATURITY IMPROVEMENT PROCESS: MASTER DRILLING AS A CASE STUDY

G.J. Maasz^{1*#} & H. Darwish¹

ARTICLE INFO

Article details

Presented at the 29th annual conference of the Southern African Institute for Industrial Engineering (SAIE), held from 24-26 October 2018 in Stellenbosch, South Africa

Available online XX

Contact details

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The author was enrolled for an MEng (Industrial) degree in the School for Industrial Engineering at the North West University.

DOI

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ABSTRACT

Industry 4.0 is an unavoidable global revolution with disruptive effects. Many sectors in South Africa are currently underprepared for the transformation that is necessary to stay competitive. An ever-present need therefore exists for the country to stay relevant in the global industry. The mining sector consists of different companies that contribute to the sector in its entirety. There is major potential if this Industry 4.0 wave is properly leveraged, and its technologies are integrated into the operations of this sector. To use emerging opportunities fully, areas of weakness in the sector should be identified and appropriately addressed. This article takes a different approach to understanding mining sector readiness by analysing a company in the sector. A case study is done at Master Drilling to identify possible areas of weakness and potential, focusing on Industry 4.0 initiatives. This is further enforced, for Industry 4.0, by using a Threats, Opportunities, Weaknesses, Strengths (TOWS) analysis on the company. An Industry 4.0 maturity analysis is conducted to identify the areas needing further investigation. A process is created to enable any entity to analyse its maturity, providing an approach that leads to area-focused technology innovations in that company.

OPSOMMING

Industrie 4.0 is 'n onvermydelike globale rewolusie met ontwrigtende effekte. Baie sektore in Suid-Afrika is tans onvoorbereid vir die nodige transformasie om mededingend te bly. Daar bestaan 'n ewigduende behoefte vir die land om relevant te bly binne die globale industrie. Die mynbou sektor bestaan uit verskillende maatskappye wat tot die sektor in sy geheel bydra. Daar is groot potensiaal mits hierdie Industrie 4.0 golf behoorlik geïntegreer en aangewend word binne hierdie sektor. Om Industrie 4.0 geleenthede ten volle te benut, moet areas van swakheid binne die sektor geïdentifiseer en aangespreek word. Hierdie artikel neem 'n unieke stap in die begrip van mynbou sektor gereedheid deur 'n maatskappy binne die sektor te analiseer. 'n Gevallestudie word gedoen by Master Drilling. Dit identifiseer moontlike areas van swakheid en potensiële fokus op Industrie 4.0-inisiatiewe. Dit word verder aangevul deur 'n "Threats, Opportunities, Weaknesses, Strengths" (TOWS) analise op die besigheid, aangaande Industrie 4.0. 'n Industrie 4.0-volwassenheidsanalise word uitgevoer om die gebiede van verdere ondersoek te identifiseer. 'n Proses is ontwerp om enige entiteit in staat te stel om sy volwassenheid te analiseer, wat area-gefokusde tegnologie innovering tot gevolg kan hê.

Introduction & background

Introduction to context

Global industry has been advancing in technologies and innovation since the 1760s (Ashton, 1994). Industries are moving beyond the mass production periods and are entering a customised production era. Industry 4.0 aims to enhance the capability of a company to cater to the different needs of its customers by using various disruptive technologies (Vaidya *et al.*, 2018a). These technologies include the Internet of Things, smart manufacturing, artificial intelligence, big data, and machine learning, among others. A central requirement underpinning Industry 4.0 is autonomous machinery that can interact with objects and people through its digital twin (Vaidya *et al.*, 2018a).

The increasing complexity brought by the wave of Industry 4.0 creates uncertainty about the capacity and capabilities necessary for companies and sectors to adapt (Schumacher *et al.*, 2016). South Africa's industry has been slower to adopt new technologies [4]. Yet the potential is there to adapt and, possibly, even to leapfrog global competitors. The South African automotive industry has shown more improved adoption to Industry 4.0 technologies than any other sector in the country (Pillay, 2017). There is, however, a lack of successful technology adoption in the mining sector, which is mainly due to the lack of internet connectivity, communication technology, and accessibility to these technologies on site (Pillay, 2017).

Background on the mining industry

Mining in South Africa is a very labour-intensive, time-consuming, and expensive exercise due to the low optimisation levels of current practices. Global technologies, such as large tunnel bores, drone surveying, and other automated machinery, have not been a priority for local mining companies, and are increasingly more difficult to obtain due to decreases in profits over the years — in turn, the result of the capital required to acquire and adapt to these technologies.

The mining industry in South Africa contributes roughly 5.4 per cent of the country's gross domestic product (GDP), having decreased by about 15 per cent since the 1980s (when it constituted 21 per cent of the GDP) (Africa, 2017b). The industry employs over 450 000 individuals, or 2.7 per cent of the South African working population (Kotze' & Russouw, 2017). Market capitalisation decreased by 25 per cent from 2017, and investors in this sector are receiving decreasing dividends (Kotze' & Russouw, 2017). The potential for improvement and expansion is present, as the technologies are becoming more readily available. Yet it is often thought that the South African mining industry has little to no use for Industry 4.0 because of the remoteness of the operations and the strict regulations being enforced that limit the use of technology underground. This is further influenced by financial limitations, such as the decreasing market capitalisation and currency value in the country.

Examination of the Master Drilling case study

Master Drilling, a world leader in specialised drilling solutions (Drilling, 2017), functions not just in the South African mining industry, but globally. About 25 per cent of the company's revenue is generated in South Africa, where its head office is located. The company was founded in South Africa and has increased its global footprint over the years.

Being at the forefront of the raiseboring industry, it is imperative for Master Drilling to innovate and implement the best possible practices and technologies to increase its global performance. Using technology for strategic advantage is one of the foundational blocks of Kobayashi's 20 keys to workplace improvement (Kobayashi, 1990). This creates potential for the use of Industry 4.0 technologies, referred to in Literature survey. Master Drilling has recently finished developing a mobile tunnel bore that aims to increase the speed at which excavation can be done by 300 per cent. This could remove the need to blast tunnels with explosives. The tunnels thus created are circular, producing a more stable structure than that of the current square-shaped ones created by explosives. This is one of the many ways in which Master Drilling is contributing to the sector, changing it for the better.

Research method

Innovation and disruptive technologies have a major role to play in the South African mining context. The focus throughout the article is kept on recognising the gaps in the mining industry by investigating Master Drilling's Industry 4.0 readiness. Various technologies and different maturity models are discussed that unpack the readiness of Master Drilling to adopt Industry 4.0. The research framework is summarised in Fig. 1, and the research problem and questions are formalised. The objectives that are derived from the research questions are also listed. Everything in the article sets the groundwork for developing an initiative-based Industry 4.0 improvement process that will initially be applied at Master Drilling, but with the potential to be broadened to the sector.

Methodology

Locating the strengths and challenges in a company in the industry itself can lead to better area-focused technology innovations, not only in a company, but also in the industry. To determine the areas to which the focus should be switched in the industry, a case study is done on Master Drilling. Using the IMPULS readiness self-check analysis(Federation), the organisational maturity of Master Drilling regarding Industry 4.0 readiness is determined for six different dimensions. Seven high-ranking individuals in the organisation completed the analysis to reveal the company's as-is maturity and identify its areas of weakness and its areas of potential. A further focus is then placed on two of the areas that could lead to optimised operations in the business. It is worth noting that successful technological improvements in the company can lead to a quicker adoption of Industry 4.0 initiatives

for the entire industry. The study leads to the creation of a maturity improvement process for Master Drilling that aims to mature it regarding Industry 4.0 initiatives and technologies.

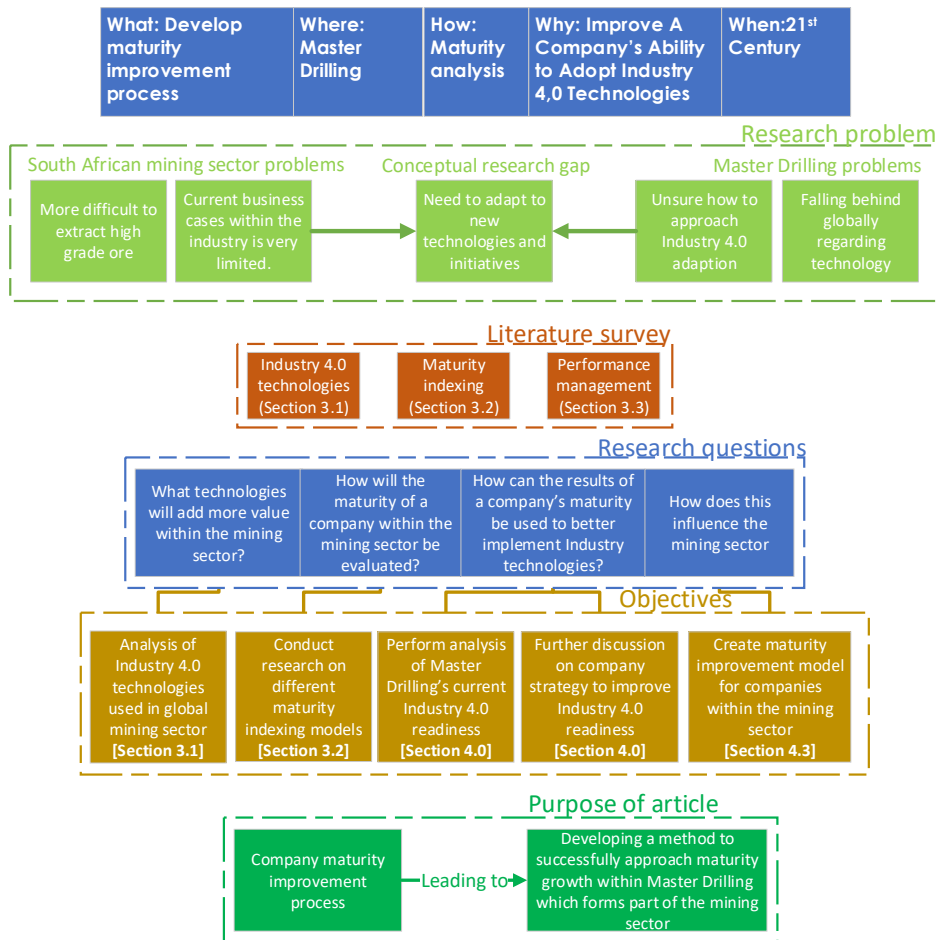


Figure 64: Research framework

Literature survey

Technology

“Through a virtuous cycle—technological improvement enabling innovation, which in turn serves as a platform for further technological improvement and innovation—exponentially advancing technologies lead to exponentially accelerating innovation. For companies, this accumulation of technological advances, and the consequent layering of innovation upon innovation, can pose the threat of disruption—but can also open the door to great opportunity. And the technologies show no sign of stabilizing.” (Hagel et al., 2013)

This lays a foundation for the global macro-evolution of industries due to technological innovations and improvements. Technologies such as the Internet of Things, machine automation, big data, virtual reality, and augmented reality open a new world to the automation of processes and the improved collaboration of man and machine. The automation of machinery in any sector creates an environment of sustainable constant outputs with extremely high accuracies that are not dependent on emotions, physical capabilities, or even academic background. These disruptive technologies can

be useful in any business sector if implemented correctly, but require a set of skills for, and knowledge of, the subject. Technology advancements in any company are dependent on the company's maturity to accept the improvements and implementations.

Internet of Things (IoT)

The Internet of Things is where sensors and actuators embedded in physical objects communicate via data transfer over a wireless and wired network connected to the Internet (Chui *et al.*, 2010a). Enormous amounts of data can be sent through these physical devices, creating opportunities for intensive data analytics and reporting. McKinsey & Company identified six types of applications, in two broad categories, that are emerging from this trend of the Internet of Things (Chui *et al.*, 2010a). The two broad categories are:

3. Information and analysis
 - a. Tracking behaviour: monitoring behaviour of objects over time.
 - b. Enhanced situational awareness: achieving real-time awareness of the physical environment.
 - c. Sensor-driven decision analytics: assisting human decision-making through deep analysis and data visualisation.
4. Automation and Control
 - a. Process optimisation: automated control of closed systems.
 - b. Optimised resource consumption: control of consumption to optimise resource use across network.
 - c. Complex autonomous systems: automated control in open environment containing great uncertainty.

A successful example from the mining industry can be seen in a company called Hard-Line, which remotely controls heavy machinery in mining and other industries (Hard-Line, 2018). This creates a safe and healthy environment for the operator, which leads to higher employee satisfaction and better operational utilisation. According to Eric Croeser, Partnerships Director of IoT.nxt, the use of IoT can protect jobs in the sector, as well as the lifespan of mining operations (Hills, 2018). The use of IoT creates increased capabilities for new business models and automated processes.

Machine automation

The use of automated machinery could replace 45 per cent of work activities using technology that had been developed by the year 2015 (Chui *et al.*, 2016). This includes all wage classes in the economy, resulting in a significant improvement in routine hard-labour activities. Even though this did not happen, the above fact stresses the opportunity of technology advancements that could have been made three years ago — not to mention the potential of current available technologies. McKinsey Quarterly states that about 20 per cent of a CEO's working time could be saved by automating certain functions (Chui *et al.*, 2015). This creates the capacity for individuals to spend time on more value-adding activities rather than on repetitive day-to-day activities. This leads to the

redefinition of jobs, and the transformation and increased optimisation of business processes (Chui *et al.*, 2015). This does not, however, mean the substitution of employees; rather, it creates value without associating it with labour-based activities. Workers must work alongside machines but will also need to transform (Manyika *et al.*, 2017) with regard to their knowledge, independent learning skills, and ability to stay up to date with global technology trends.

Labour-dependent activities, such as those in the mining industry, create various uncertainties and decreased productivity throughout the working day. They contain large risks, as people's lives and health are at risk. German mining machine manufacturer GHH Fahrzuege recently developed an autonomous underground loader on which research is being done in a mine in Chile (Moore, 2018c). The currently available automating technology is creating new horizons in the industry. Automation practices in industry are a threat to labour-intensive operations, as machinery has the potential to replace the jobs of some individuals. It is, however, an opportunity to improve operations in all industries.

Big data

Most activities in life create some form of data that, if used correctly, can be valuable in certain situations. Data creates the ability for people to make more informed decisions, using evidence, instead of relying on intuition (Torrecilla & Romo, 2018). Big data refers to the concept of a large administration-orientated database that is used to add value to an entity (Dhawan *et al.*, 2018). Big data only creates value when the massive amounts of data that are stored are used in some way or another to add value to those for whom it is captured.

To capture and store huge amounts of data is costly in most situations, which also creates the difficulty of analysing such vast amounts of data to extract useful information. When used correctly, data can lead to countless improvements, such as:

- Improved preventative maintenance
- Product and customer trends
- Product lifecycle analysis
- Population generalisations

These are only a few of the improvements that can be made by using big data technology. Outcomes, described as increased overall financial performance and optimised business prioritisation (Davenport, 2014), can be produced using big data.

Big data is used by the predictive maintenance company Dingo on equipment from all sectors. They have generated over US\$450 million in cost savings using their solutions in real-life applications (Dingo, 2018). Data and software initiatives hold major potential for optimisation in the industry. The benefit of big data in the mining industry is debatable; but while it currently offers only financial value, opportunities must still emerge where it increases the effectiveness with which mining operations

take place. Big data databases can store massive amounts of data, which poses a security threat to confidential data, as databases can be breached.

Virtual reality (VR)

VR is different from augmented reality in the sense that it digitally immerses the user in a virtual environment, instead of digitally inserting an object into the user's physical environment. This is done by using special glasses, or similar devices, that cover the user's vision, creating the 3D environment in which the user is then placed. Widely used applications in which this technology is effective are:

- The military
- Education
- Entertainment
- Sport

Users have first-hand experiences without entering the field, assisting with planning and various other tasks. Data is produced with this technology, which in turn is used to develop training methods, communication, and interaction methods (Huang *et al.*, 2018). The technology is, however, limited by the environments that are created and displayed via the hardware.

At the University of Pretoria, a VR system is used to train and educate both students and mine staff on mine safety and similar topics (Solomons, 2015). This is done by immersing the user in a simulated mining environment. The use of VR in training has countless applications because of the exposure it creates for the user while removing all safety risks from the exercise. Mining operations can become a lot safer and more satisfactory for miners if combined with the use of VR and IoT. This technology is an opportunity for training practices in Master Drilling.

Augmented reality (AR)

This refers to the practice of taking 3D virtual objects and inserting them into the user's immediate environment (Huang *et al.*, 2018) by using digital smart devices, such as smartphones or smart glasses. The smart image or 3D object is visualised in the user's current environment. It creates the opportunity for the user to view the object from different angles, and potentially to see the effect of the object in the real environment before it is physically placed in the environment.

Although countless more exist, current AR business applications are found in the following environments:

- Advertising: using your GPS location, a smart device augments your environment by displaying different services around you, such as restaurants, entertainment, etc.
- Military: a transparent heads-up display (HUD), is positioned in front of the user's vision, containing data such as altitude, airspeed, and horizon line.
- Medical: used to practise surgery without the risk of injuring somebody. It can be combined with MRI and X-ray scans for the surgeon to use as guidance in an operation.
- Navigation: users can see the navigation view directly in front of a car via the smart device.

- Maintenance: using a headset, the user can see visually represented data on a machine or asset in need of maintenance. The zone or parts in need of maintenance are highlighted or illuminated with specific colours.

All applications of this specific technology, in these environments, improve how the user will perform, be it for personal or corporate use. It is also necessary for the AR smart device to be linked with some sort of database via IoT.

NORCAT, a global leader in the development of skilled labour training, recently unveiled multiple VR learning technologies aimed at training in the mining industry (Moore, 2018a). This creates a vast potential for how training can both be approached and successfully delivered to individuals. The use of AR in mines is minimal, which brings into question the value of its improving operations efficiency and effectiveness. It is, however, a good supporting tool to be used for marketing and training purposes.

Maturity indexing

Industry 4.0 entails the vertical and horizontal integrations of IT systems in all stages of a company's value chain. For this to be achieved, the maturity of current technology and information architecture must be evaluated (Weber *et al.*, 2017), accompanied by the level of maturity that the company desires to achieve. This can be done using various tools and maturity index models, all of which constitute the analysis of a company's ability to integrate Industry 4.0 technologies effectively into its current business structure.

Acatech STUDY: Industrie 4.0 Maturity Index (Schuh *et al.*, 2017)

This maturity model gives guidance to companies for transformation to Industry 4.0, using a six-stage model focusing on four different key areas. These stages are:

1. Computerisation
2. Connectivity
3. Visibility
4. Transparency
5. Predictive capability
6. Adaptability

The four areas in which each of these stages are focused are:

1. Resources
2. Information systems
3. Culture
4. Organisational structure

The study analyses each specific area, after which action plans are designed and implemented to produce growth in each. The output of a company that is mature in all these fields regarding Industry 4.0 has a massive reduction in the time it takes to react to any event affecting the company. This

study thus improves the reaction time of companies to incoming situations that could disrupt their business.

IMPULS readiness self-check analysis (Federation)

This readiness measurement model, commissioned by the IMPULS Foundation of German Engineering Federation, focuses on six different dimensions to evaluate the readiness of an entity to adopt Industry 4.0 initiatives. These dimensions are:

1. Strategy and organisation
2. Smart factory
3. Smart operations
4. Smart products
5. Data-driven services
6. Employees

Questions are asked via an online questionnaire, and readiness levels are assigned as the answer to each question. These levels range as follows:

- Level 0, Outsiders: companies that have no plan to implement Industry 4.0 initiatives
- Level 1, Beginner: companies with introductory plans to implement Industry 4.0 initiatives
- Level 2, Intermediate: companies that have Industry 4.0 initiatives in place and have structures in place to facilitate further adoption
- Level 3, Experienced: organisations actively pursuing Industry 4.0 adoption and initiatives
- Level 4, Expert: organisations that have Industry 4.0 initiatives in place and are contributing to, and implementing, new technologies to improve their business models
- Level 5, Top Performers: leading the industry in Industry 4.0 innovation and implementation, while pursuing new technologies and actively contributing to the Industry 4.0 community

The results include an overview of the potential to adapt to Industry 4.0 initiatives in each of the above-mentioned dimensions on which the analysis focuses.

Performance management

Performance management helps organisations to achieve their goals (Zandin, 2001) through managing the people and skills currently found in them correctly. Better use of, or improvement in, the current human factor in an organisation leads to the following:

- Company knowledge and experience not being lost
- Upskilling of individuals, creating higher job satisfaction (Zandin, 2001)
- Ability better to accommodate changes in an environment

The role of the performance management of individuals in a company is aimed at achieving the company's strategic goals. When these goals are achieved, the company has a higher probability of

success. Various models exist on the successful management of employee performance, but an alternative approach is feasible.

In-depth management of employee performance identifies skill gaps, if done correctly. Analysis of the performance areas where employees fall short reveals where the skills deficiency is located. Aligning employees' performance goals with the company's strategic goals ensures that expectations are met. These are summarised in Fig. 2. The company, in turn, must thrive financially in the sector in which it is located.



Figure 65: Alignment of employee goals with company goals [self-designed]

Performance management is a key factor in identifying skills gaps in any area of an organisation or individual. It is best approached through a top-down methodology, starting with the company's performance with regard to the set goals, and working downwards to find the resulting issue that led to the underperformance of a certain party. It is thus of great importance to link the goals of the company, all the way to those of the employee, to the company's Industry 4.0 strategy.

Improvement models

Previous work has been done on improvement models for the mining industry. A specific example, shown below in Fig. 3, is a methodology geared to modernising the mining industry by managing the introduction of technologies and initiatives (Preis & Webber-Youngman, 2017). This formed part of a Masters study that emphasises the importance of innovative initiatives and technologies in the South African mining sector. The study focused on analysing an innovation stage-gate model. Further research was done on the different key gate criteria, stage activities, and critical success factors (Preis & Webber-Youngman, 2017).

The specific model shown in Fig. 3 uses best-practice stages and gates to focus further literature into each stage and gate (Preis & Webber-Youngman, 2017). This model is recommended for research and development work focused on the mining industry and was evaluated in a case study where a missing person locator system was designed. This approach has been proved successful, but still has potential for refinement, as stated by the author's suggestions for further work, including holding workshops and applying experiential learning (Preis & Webber-Youngman, 2017). It is thus a valuable approach to consider when creating a cyclical model for continuous improvement in the mining sector of South Africa.

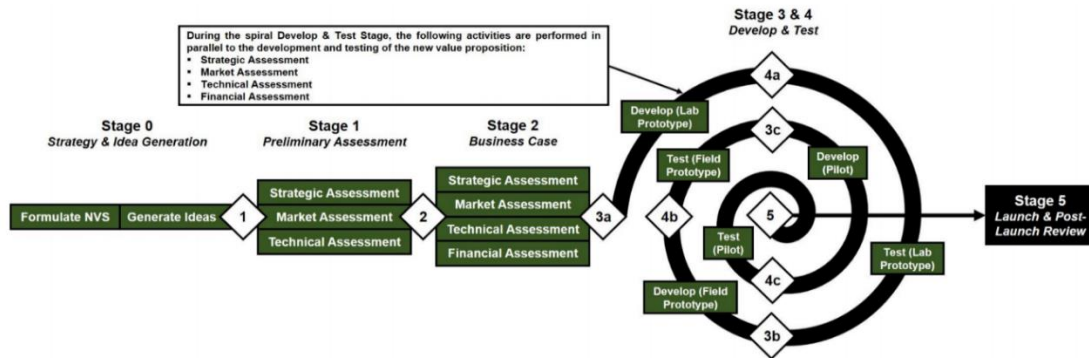


Figure 66: Stage-gate model for activities and development testing (Preis & Webber-Youngman, 2017)

The model above can be especially helpful in forming the internal process in Master Drilling. However, the process being developed in this study requires a more cyclical approach, closing the loop between company improvements and those in the affected sector. It highlights the potential of more improvement opportunities arising as the different technologies of Industry 4.0 are implemented over time. This process is discussed in Section 4.3, which describes the approach of identifying areas of weakness and areas of potential. It further describes the use of the areas of potential to improve the areas of weakness.

Master Drilling case study

Master Drilling is a company in the global mining sector, with a focus on technology, that serves clients with a specialised drilling solution to fit their specific needs. The company’s strategy focuses on their four strategic pillars (Drilling, 2017):

1. Sustainable growth
2. Optimisation and increased profitability
3. Technology optimisation and development
4. People capacity and development

All four of these pillars focus on the development of the company and all its assets, both tangible and intangible. Having such a strong technology and development focus while situated in the mining sector, it is a prime company to use as a case study on the topic of the Industry 4.0 maturity of the sector itself. Although the company currently works on new and developing mines, their goal is to be the first point of contact for any customer looking to expand their current, or start new, mining operations. The next section focuses on how maturity indexing is used to identify the strengths and weaknesses in Master Drilling.

Maturity indexing

The IMPULS readiness self-check analysis was completed by seven high-ranking individuals in Master Drilling. This specific maturity indexing technique was selected, based on the quality of the research on which the questionnaire is built (Lichtblau *et al.*, 2015a). The quality and academic

nature of the IMPULS readiness analysis was the reason it was selected as a suitable method for this study. The resulting data was consolidated and is reported on in the rest of Section 4. The questions were forced-choice based, requiring the user to choose an answer between provided options. This was subject to the user's knowledge of the specific business area. This data reveals areas of potential in Master Drilling that are highly mature in Industry 4.0 readiness, as well as less mature areas. This creates the potential in the company to strengthen and improve the areas of weakness by using the company's areas of potential.

The two most mature dimensions found are the 'employees' and 'smart operations' dimensions, based on their having the highest maturity levels with the least deviation in their answers (see Fig. 4). This shows that both 'employees' and 'smart operations' in Master Drilling are competent enough to adapt to new improvement and disruptive technologies. By exploiting these, the weaker dimensions can be improved. The costly nature and current financial state of the mining industry requires all improvements to make financial sense over the long term, while still moving in the direction in which the company's strategy and vision are aimed. This turns the focus to those areas that have the greatest impact on a company's current state, rather than just those that are the weakest regarding Industry 4.0 readiness.

The test results reveal the level of maturity of each company dimension for Industry 4.0 readiness. The responses of all individuals who completed the survey is summarised in Fig. 4, in the form of a box chart. The resulting dimensions chosen for further discussion are 'employees' and 'smart operations', as these are the current strengths and resources available to Master Drilling with which the weaknesses can potentially be improved. The box plot shown in Fig. 4 displays the maximum, minimum, average, first quartile, and third quartile values from the management responses to the IMPULS readiness self-check analysis.

Employees

A further clarification of the adequacy of the company's employees is conducted, based on the strength of the company's executive management team. In Master Drilling, departments have DISC (dominance, influence, steadiness, conscientiousness) profiles that identify the strengths and weaknesses of the entire team (Marston, 1928). The DISC profile displays an individual's response patterns when put into certain environments by using a forced-choice questionnaire method. An example of such a test is that of Thomas International —specifically, the Personal Profile Assessment. This evaluates a team in nine different roles, using three measuring descriptions (International, 2018). An example of this is seen in the company's executive team, shown in Figure 68. It identifies personality traits in the company that contribute to successful growth.

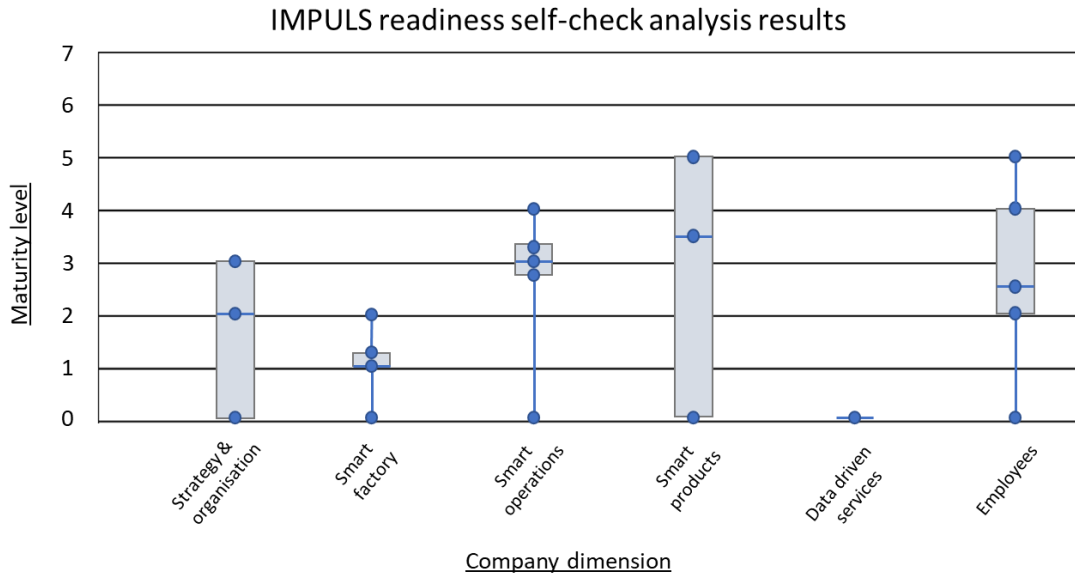


Figure 67: IMPULS readiness self-check analysis results

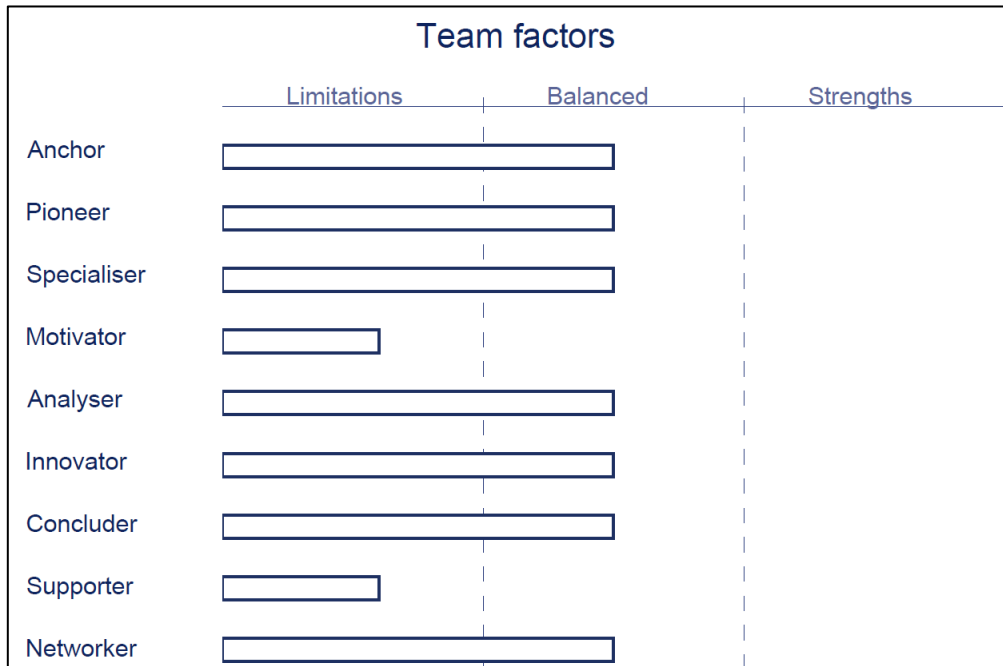


Figure 68: Executive personality analysis

It is evident that this specific team is well-balanced, with the ability to run the company successfully, as it is being run today. It contains the following team strengths:

- Working towards finding a satisfactory solution to all problems
- It is focused, and will push itself and others to reach goals
- It is good at communicating logical and analytical information to others
- It works towards a culture that achieves results through people, while maintaining high quality and standards
- It is willing to act and make decisions once accurate data and necessary facts are available

Current performance management practices at Master Drilling consist of the head-of-department having a performance evaluation criterion that matches the goals that the department is required to reach. These goals align with the company's overall strategy. When faring poorly in any of the predetermined goals, a skills gap is identified in the department, after which an investigation is launched to determine the root cause of the problem, and how it is going to be improved. These problems can be various things, such as a lack of training, language barriers, overuse of employees, unclear job expectations, etc. Each employee has a performance evaluation criterion that is designed to form a part of the function that is expected to be completed by the department. This relates to the research as summarised in Figure 65.

However, performance management should not focus solely on the employee, but also on the gap (in the department or business unit) that is an underlying result of underperformance, for whatever reason. The identified areas are referred to as an either area of weakness or area of potential, depending on the result of the evaluation. Well-faring areas are referred to as areas of potential, while the lesser areas are referred to as areas of weakness. For this gap to be bridged effectively, the company should aim to set and reach the correct goals to increase its Industry 4.0 maturity in all areas that it strategically aligns with its Industry 4.0 strategy. The company's employees are rated as a level 4 maturity, meaning that the workforce is competent to bridge the gap to Industry 4.0. In this case, it is referred to as an area of potential. This is a strength that the company could use to improve areas of weakness and to transform them into areas of potential. Department goals are thus set in the light of the Industry 4.0 maturity of each IMPULS dimension. If done correctly, the practices already in place to manage the current skill gaps can be used to manage the effective maturing of each dimension. It is very important to note that the employees form an integral role in Industry 4.0 adaptation in any company, as it is the employees who are to develop and implement the ways in which the Industry 4.0 maturity is to increase. Value can be added to employee initiatives when efforts are incentivised.

Smart operations

This can be loosely defined as the use of applications, such as information systems, wireless monitoring, field service management, cloud use, autonomous processes, and IT security, effectively to provide visibility using information and data processing to create more predictable and autonomous operations (O'Marah, 2017). It uses Industry 4.0 technologies to create the ability to manage very complex supply chains with ease.

Master Drilling challenges conventional drilling methods, and constantly seeks to improve or innovate drilling practices to improve utilisation and drill speed, reduce expenses, and reduce the time in which drilling projects of any kind are completed. The company recently released a revolutionary, mostly autonomous, mobile tunnel bore (MTB) that can expand mines many times faster than any current conventional methods (Moore, 2018b). This technology makes use of a combination of IoT, machine automation, and some big data principles to deliver this service.

The MTB is not the only technology in the company’s development pipeline that is bridging the technology gap from manual to automated. Current raiseboring practices are being developed to a more autonomous state, and to be remotely controlled. When aligning the company strategy and goals, the use of smart operations not only adds increasing value to current operations, it also creates the potential for added value propositions to emerge in the company. Reducing complexities in operations and supply chains can create better use of company resources by removing unnecessary steps from the process (O'Marah, 2017). Smart operations decrease the risks associated with employees working underground and increase employee productivity.

SWOT and TOWS analysis

Master Drilling’s strategy is to deliver specialised and adaptive drilling solutions to its customers (Drilling, 2017). To understand better the situation and context of Master Drilling, and the Industry 4.0 applications, a TOWS analysis was performed. This consists of a matrix revealing four different strategies:

1. Strengths used to maximise opportunities: ‘Maxi-Maxi’ strategy
2. Strengths used to minimise threats: ‘Maxi-Mini’ strategy
3. Taking advantages of opportunities to minimise weaknesses: ‘Mini-Maxi’ strategy
4. Minimising weaknesses while avoiding threats: ‘Mini-Mini’ strategy

This approach uses the company’s existing strengths and weaknesses as inputs, which in this case are identified by using the maturity indexing tools. Note that these strengths and weaknesses solely refer to the Industry 4.0 readiness of the company.

Table 17: Industry 4.0 readiness: Strengths and weaknesses in Master Drilling

Strengths	Weaknesses
<ul style="list-style-type: none"> • Employees • Smart operations 	<ul style="list-style-type: none"> • Strategy & organisation • Data-driven services • Smart factory • Smart products
Opportunities	Threats
<ul style="list-style-type: none"> • VR technology • Automation technology • IoT 	<ul style="list-style-type: none"> • Data leakage • Natural disasters • Health & safety incidents • Competitor gaining market advantage

The TOWS analysis is shown in Table 2. It is these technological advances in the company that create the opportunity to adopt Industry 4.0 initiatives better. Having the necessary skillsets in-house, the technology and processes are being developed to lay the foundation for the rest of the

dimensions in the company that are still maturing regarding Industry 4.0 readiness. This further emphasises the incorporation of Industry 4.0 initiatives in the company.

Table 18: TOWS analysis of Master Drilling for Industry 4.0

	External threats (T)	External opportunities (O)
Internal strengths (S)	<p>Maxi-Mini</p> <ul style="list-style-type: none"> Employee skills used to maximise information integrity and security Smart operations increase advantage over competitors, decreasing possibility of competitors gaining market growth (MTB, Automated drills) Combination of employees and smart operations decreases the risk of safety incidents on-site Natural disasters can't be avoided, but competent employees can help mitigate the risks and effects associated with them 	<p>Maxi-Maxi</p> <ul style="list-style-type: none"> Create disruptive technologies such as MTB with employee and operational strengths Increase global advantage by developing new technologies and automating drill machines Develop VR training methods to improve safety practices in company operations Facilitate multiskilling of workers with better training capabilities
Internal weaknesses (W)	<p>Mini-Mini</p> <ul style="list-style-type: none"> Increase company's Industry 4.0 strategy to increase vision for future technologies and initiatives Better product designs and manufacturing methods lead to safer working environments and consistent outputs 	<p>Mini-Maxi</p> <ul style="list-style-type: none"> Use IoT technologies on company operations and exploration to increase the data capabilities and unlock potential business cases from it Automation technologies can increase speed of production when focused on developing a smart factory and smart products

Towards a maturity improvement process

A company looking to adapt to new Industry 4.0 initiatives should assess the need for the new technologies before simply starting to implement new initiatives. This will create a clear vision for which technologies should be focused on, and what value they will add to the company when implemented.

Analysis phase

If new initiatives are needed, the current maturity of the company is to be determined with regard to certain dimensions. This can be done using one of many Industry 4.0 maturity index models. These models can be adjusted to an organisation's needs. In the case of Master Drilling, an existing maturity process was used. Customised maturity models can be used, but they must have a dimension-based framework to work successfully when following this process.

Maturity improvement phase

The dimensions for which the maturity is evaluated can be focused on either collectively or independently. One can thus either focus all resources on one specific dimension to improve it or tackle numerous dimensions with the goal of collectively improving overall company maturity. This is, however, only advised when enough resources are available. It is advisable, firstly, to place enough focus on the dimensions that are low in maturity and on those that will create more value for the company. This is very similar to critical chain theory (Bergland, 2016), except that the process aims to use the company's strengths better to influence and improve its weaknesses.

Action plans should be developed successfully to improve the dimensions that are focused on. These action plans will be company-specific and dimension-specific, as they will depend on the exact environment in which the dimension is to be improved. It should also be noted that some companies will adopt certain initiatives and action plans in the same dimension at different speeds, as their company cultures and priorities differ.

The action plans must then be successfully implemented, after which the resulting implementation needs to be evaluated. This evaluation confirms whether the Industry 4.0 need was in fact addressed properly, validating the solution. The results of the action plans are critical to capture, as their evaluation will reveal whether the company's maturity has in fact been increased through the implementation of these action plans.

Contribution phase

The resulting technology or initiatives can then be deployed in the applicable sector. This will create potential in the industry to improve, which in turn creates new opportunities for companies in the sector.

The method followed throughout this study delivered the successful identification of both areas of weakness and areas of potential in Master Drilling. The resulting information, if applied correctly, enables the company to identify improvement opportunities and which strengths could be used better to develop them. A maturity improvement process is developed and is shown in Fig. 6. This process can be replicated in any organisation to understand better and improve its maturity with regard to any specified dimensions.

Concluding remarks

Future research

The mining sector in South Africa holds vast potential for productivity and technological improvements. These can be made effectively if the dimensions are individually approached for improvement. The sector can really benefit from an in-depth analysis on how each of the dimensions, listed by the IMPULS readiness self-check analysis, can be approached to become more mature. This will enable a company not only to identify its areas of weakness and potential, but also to provide

the necessary action plan or roadmap for improvement. More research efforts can be aimed at new opportunities being created in industry when new technologies are implemented. Further value could be created if the focus of this study shifted to all sectors in the South African industry, for the country to adapt to the ever-changing nature of global industries.

This article forms a part of a master’s study aimed at improving the maturity of a company with regard to Industry 4.0. The study will focus on the effect of new technologies and initiatives in the mining sector by using Master Drilling as a case study. The company itself is increasingly adopting new technologies and expanding its value offering by doing so.

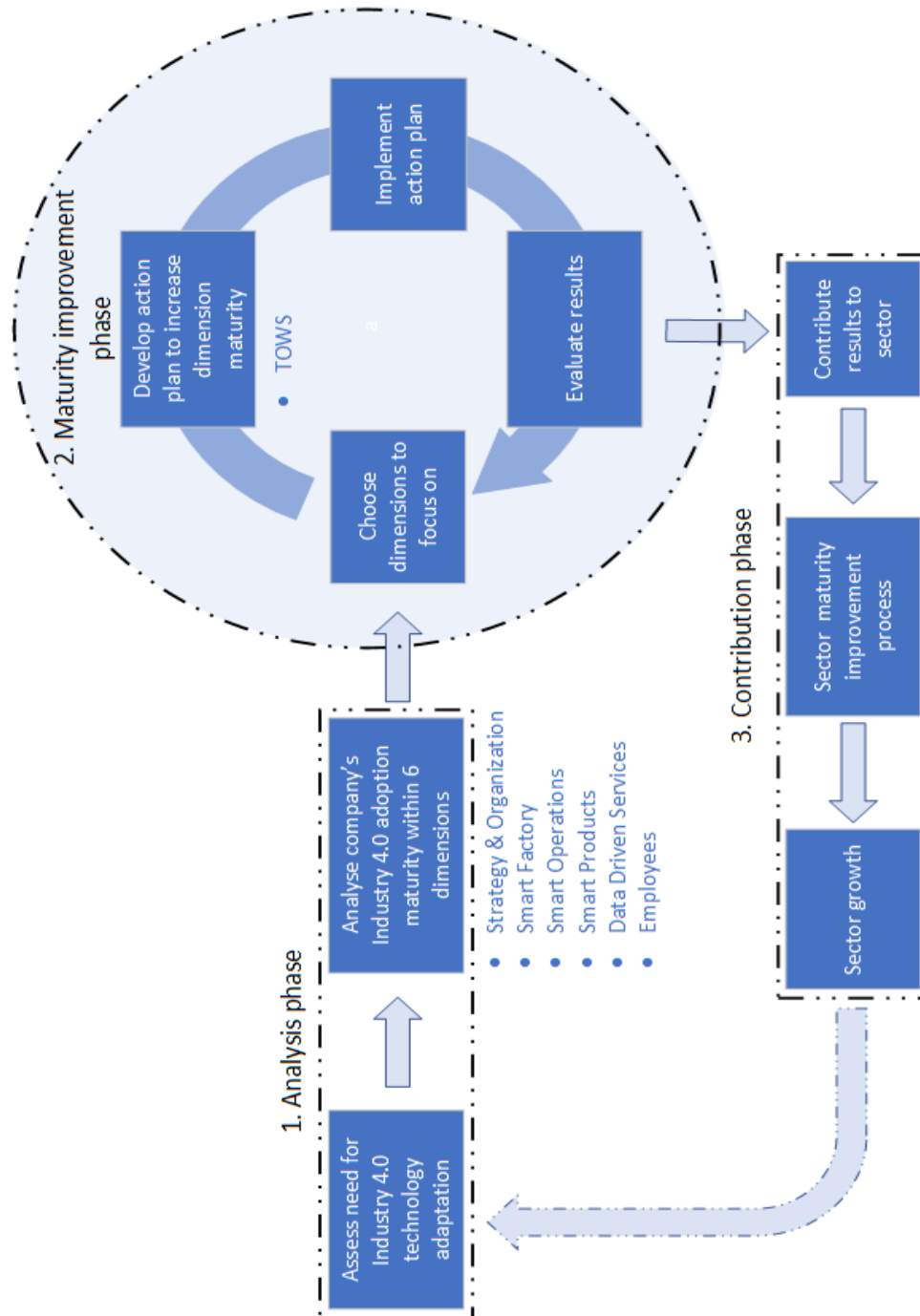


Figure 69: Company maturity improvement process

Note on sector readiness

Mines in South Africa are facing constant challenges to become more productive, including an increase in haul distances, lower ore grades, increased expenditure, and decreasing improvement opportunities with conventional ways of thinking. The productivity of the mining sector has decreased over the past decade, shifting the sector's focus to incorporating more Industry 4.0 technology innovations, with the goal of both saving costs and reversing productivity losses.

The ability to capture vast amounts of data is becoming more affordable, while the skills in technology improvements are also increasing exponentially. All the potential exists for improvement — but it requires a proper mind shift away from conventional methods to incorporate the technological advancements found in industry today.

However, many challenges face the South African mining sector. Because of its complexity, a simplified approach is taken to evaluating the Industry 4.0 readiness of the sector itself — that is, by focusing on the Industry 4.0 maturity of Master Drilling, a company in the sector. The underlying challenges in the company will likely correlate with those found in the rest of the sector, as a case study is done on a company that aims to challenge the global status quo about its operational practices.

Conclusion

The use of technology in a corporate environment has revolutionised business models and practices for many years. New innovations can lead to gains in efficiencies, use of man and material, safety capabilities, and profitability if incorporated correctly into the current business structure. As seen with Master Drilling, the correct focusing of a company's strengths can benefit the maturing dimensions that are still in their infancy in respect of Industry 4.0. The development and acquisition of new skills is increasingly growing in importance in the mining sector and is required for the technological advances that are likely in the future (Preis & Darwish, 2016).

This revolution has the potential to change how mining in the South African context is approached, extracting the potential already residing in it. It is, however, a collective approach to industrialisation that creates a quicker adoption of Industry 4.0 in an entire sector. Not only Master Drilling, but all companies, will benefit from the maturity analysis and the development of action plans to bring the country back on a par with its global competitors.