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A Lean Aker BP

A study of how Lean and continuous improvement in performance management can contribute to well operations in Aker BP

by

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Abstract

The Exploration and Production (E&P) sector have lately experienced a state of depression in wake of an abating demand, low petroleum commodity prices and a high level of operating costs. This downfall has in effect driven E&P operator and service companies alike to reevaluate and reshape operations in an attempt to improve efficiency and profitability. As companies concentrates on core competencies to leverage their clout for market dominance, performance of key operations has become paramount. Managing performance is thus widely viewed as crucial to the successful implementation of the initiative. To address ongoing problems and inefficiencies in well operations and moreover ensure that underlying changes endure, some E&P operators have refocused their attention to long-term innovation by transforming traditional performance management approaches to Lean Thinking and continuous improvement.

Following an original case study design with an in-depth analysis of the department Drilling & Wells (D&W) in the E&P company Aker BP ASA, the chief undertaking of this thesis has been to determine how Lean and continuous improvement in performance management can contribute to the company's well operations. Seated at the centre of this study is a conceptual research framework with an exploratory sequential design, encompassing a thematic literature review and both qualitative and quantitative methods for analyses. The natures of the research objectives have been to determine relevant elements of current and prior practices for performance management, strategic elements and directions, critical areas of concern and new practical solutions encompassing Lean and continuous improvement principles for bettering well operations in Aker BP, D&W.

Preliminary findings recognised several important elements in current and prior performance management frameworks. On account of high investment costs and impact on bottom line, it was concluded that continuous improvement would best contribute in well development processes in the field development phase of the E&P value chain. Results moreover affirmed that directing attention to the definitions of improvement theory in terms of flow efficiency, would enable D&W in utilising Lean Key Performance Indicators (KPIs), being Takt, Cycle and Lead Time, to address waste and non-value added (NVA) time across a standardised set of activities. This facilitated the opportunity of keeping track with customer's demand and identifying low performing activities in a well development process, thus providing the means for improved planning and comparison with future projects. Findings also determined that the use of additional Lean KPIs in conjunction with the Best In Class (BIC) and Process Activity Maps (PAM), would make it straightforward to identify latent bottlenecks and loss of potential.

Adapting the foregoing in a Lean Six Sigma framework for performance management following a continuous Define-Measure-Act-Improve-Control (DMAIC) cycle, furthermore demonstrated how the above could contribute to well operations through continuous waste elimination and accurate identification of waste root causes. Findings concluded that this could in due course lead to a reduction of the total time spent on offshore installations, thus improving the company's overall costs and efficiency. Recommendations for future research were derived from the research findings and discussion, and have been included following the final conclusions. Additional data utilised in research findings and discussions have been included in the Appendix.

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Acknowledgements

This thesis marks the finalisation of my Master's degree (MS.c) in Industrial Economics at the University of Stavanger with Petroleum Engineering and Project Management as fields of study. Its completion has not been an individual experience; rather it includes the contribution of a great many people. In the ensuing paragraphs, I will attempt to do them justice by passing along my deepest appreciation.

First and foremost, my deepest gratitude goes out to my supervisor, Roy Endré Dahl at the Department of Industrial Economics, Risk Management and Planning at the University of Stavanger, for his invaluable experience, academic knowledge, support and guidance to recover when my steps have faltered.

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During my time at the university, I have been extremely fortunate as to meet and develop companionship's with so many inspiring individuals. As such, I would like to make use of this opportunity to acknowledge my fellow students in both Petroleum Technology and Industrial Economics, whose friendships and camaraderie have been immensely appreciated throughout this arduous journey.

Lastly above all, I am forever thankful for my closest family and friends for their everlasting love and support.

Adrian Anderssen Kvanvik
Stavanger 14. June, 2017

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Abbreviations

AFE Authority For Expenditure.

BIC Best In Class.

BOP Blow-Out-Preventer.

BSC Balanced Scoreboard.

CAPEX Capital Expenditures.

D&W Drilling and Well.

DMAIC Define-Measure-Analyse-Improve-Control.

E&P Exploration and Production.

EPA Environmental Protection Agency.

GE General Electrics.

HSE Health, Safety and Environment.

ILT Invisible Lost time.

ISO International Organisation for Standardisation.

JIT Just in Time.

KPI Key Performance Indicator.

KRI Key Result Indicator.

MD Measured Depth.

MLT Multi Lateral.

NCS Norwegian Continental Shelf.

NPT Non Productive Time.

NVA Non-Value Adding.

O&G Oil and Gas.

P&A Plug and Abandoned.

PAM Process Activity Map.

PCE Process Cycle Efficiency.

PDCA Plan-Do-Check-Act.

PDO Plan for Development and Operation.

PI Performance Indicator.

RI Result Indicator.

TPS Toyota Production System.

TQM Total Quality Management.

TVD True Vertical Depth.

VA Value Adding.

VSM Value Stream Mapping.

WOW Wait On Weather.

Nomenclature

λ	Rate of well development
τ	Mean service time in Kingman's formula
c_a	Coefficient of variation for service times
D	Demand by customer
D_{B-5}	Depth at Kneler B-5 well
D_e	Effective depth
K_x	Kurtosis
OTD	On Time Delivery
PCE	Process Cycle Efficiency
$Q_{activities}$	Quantity of activities
R_e	Execution rate
$R_{d.e}$	Drilling efficiency rate
R_{NVA}	Non-value adding cycle rate
R_{takt}	Takt rate
R_{VA}	Value adding cycle rate
S_x	Skewness
T_e	Excess time
T_{AFE}	Planned time
T_{AP}	Available Production time
T_a	Actual time
T_{cycle}	Cycle time
T_{ILT}	Invisible lost time
T_{NPT}	Non-productive time
T_{NVA}	Non-value adding time
$T_{prob.free,e}$	Estimated problem-free time
$T_{prob.free}$	Problem-free time

T_{takt}	Takt time
T_{VA}	Value adding time
T_{WOW}	Time spent waiting on weather
U	Utilisation
W_i	Waiting time for customer i

Chapter 1

Introduction

This first chapter presents the background for the thesis with emphasis on the resulting effects of recent events in the Oil and Gas (O&G) industry, before introducing Aker BP ASA and the department Drilling and Well (D&W). The research problem of this thesis is subsequently defined, prior to outlining the scope and delimitation of research objectives, and the overall structure of this study.

1.1 Background to Thesis

Historically, the Oil and Gas (O&G) industry is known to have experienced periods with both prosperity and downturn. In recent years however, a rapid and dramatic recession in the crude oil prices from approximately $114 United States Dollar (USD) in June 2014 to $46 USD in January 2015, coupled with a forecast of modest recovery, have resulted in the most protruding low-price environment since the 1990s and consequently reduced investments in the O&G industry [1]. To make matters worse, the end petroleum commodities have a very minimal differentiation amongst countries and companies, as market situation, environmental factors and exposure to high uncertainties are at the very least manageable. On the Norwegian Continental Shelf (NCS), the ripple-effects reverberating through the petroleum industry has resulted in a 15% decrease in oil investments [2], with more than 48 300 employees suffering layoffs since 2013 [3]. Additional research by Osmundsen et al. [4] have also reported an increased drilling expense, with root factors being declining drilling productivity and higher rig rates. This sharp rise in operating capital has prompted more attention on the cost side, as O&G companies grapple with how to pursue growth while remain low-cost [5].

At the heart of this, lies the need for measuring and managing the efficiency of actual processes, to determine where improvement efforts reaps the best results. As O&G companies on the NCS have attempted to address these downturns by reverting attention towards core competencies to leverage their clout for market dominance, performance of key operations has become paramount. The diverse subject of performance management has thus become a widely viewed indispensable requisite in performance improvement, benefiting customers, stakeholders and employees alike. In theory, performance management is a straightforward method of measuring, analysing and reporting performance through a strategy linked framework, before utilising the results to ensure that goals are consistently being met in an effective and efficient manner. Although performance management have been a common feature in most O&G companies for some time, its importance has increased significantly as a result of the recent economic decay.

With the ever-growing pressure now being leveraged upon the industry, the traditional approaches have proven themselves somewhat insufficient. This has consequently called for a revision of managerial practices and actions that are not only swift, but innovative and sustainable for O&G companies to survive, including paramount alterations in business models, asset management and technology across the value chain with intensified focus upon managing operations more efficiently and effectively. This has in effect created an opportunity to apply increased focus and rigour to performance management, and build long term stability into operational strategies by employing more streamlined and standardised work processes and methods [6]. While there currently exists a number of different methods and tools that could increase efficiency and competitive advantage, many O&G companies have over the past decade recognised the principles of Lean from Womack et al. [7, p. 11], as the essential link between performance management and ultimate value creation, in terms of providing transparency, control and continuous improvement. Traditional Lean, as defined in the existing body of literature by Wig [8], is a continuous process improvement methodology driven by customer demand, centred around rooting out and eliminating waste with emphasis on overall system efficiency. A brief review of recent academia and literature have demonstrated significant amounts of research vested into the validation of implementation and use of Lean in the construction, production and manufacturing industries. Nevertheless, its concepts and principles have also proven themselves useful in O&G and the upstream segment of Exploration and Production (E&P).

In light of the rapidly evolving need for performance improvement, several E&P players on the NCS have thus turned to Lean to improve their core competencies, operating performance and capital cost in the hopes of yielding a higher competitive advantage. The presumption is that Lean, in terms of the definition by Modig and Åhlström [9], assures continuous improvement through elimination of waste and loss of resources in drilling and completion operations, by focusing on streamlined processes and value-adding activities. In furtherance of obtaining a better understanding of the factors involved, this thesis presents an original attempt to examine the Norwegian E&P company Aker BP ASA.

1.2 Introduction to Aker BP ASA

Aker BP ASA as an independent E&P company involved in the upstream segment of the Q&G industry, with operations extending through exploration, development, production and marketing of oil and gas across the three main petroleum provinces on the NCS [10]. The company was instituted on 30. September 2016 as Det norske oljeselskap ASA (Det Norske), owned by Aker ASA, merged with BP Norge AS (BP). The company is at the time of writing considered amongst the largest independent oil companies in Europe, owning 95 licenses on the NCS, 47 of which being operatorships. With main offices in both Oslo, Trondheim, Stavanger, Harstad and Sandnessjøen, the company currently retains a workforce of roughly 1.371 employees, partitioned across a total of eight technical departments;

- Health, Safety and Environment (HSE)
- Operations
- Drilling and Well (D&W)
- Projects
- Reservoir
- Improvements
- Finance
- Exploration

The company's mission is to become an active industry player on the NCS in the coming years, as apparent from their vision of "Creating the leading independent offshore E&P Company" [11]. The company has since the merger undergone extensive work to collectively combine assets and expertise in order to integrate the two former enterprises Det norske and BP. Part of this process has been vested in a Lean and nimble business strategy. In terms of Lean, the focus in Aker BP has primarily been vested in the definition by Modig and Åhlström [9], in order to develop flow efficiency across their value chain. In virtue of limiting the extent of research, the chief focus of this study has primarily been the efforts exerted by the company's D&W department.

1.2.1 Aker BP Drilling & Well

D&W is the department through which matters concerning a well are handled. This includes planning, acreage and access, well construction, well integrity, well intervention, well plug & abandonment and rig intake e.g. [12]. The department is currently based out of two offices in Stavanger and Trondheim, and moreover divided into four teams based upon operations, rigs and fields. In Stavanger, being the focus of this study, the departmental structure consists four sub-departments.

These include feasibility & projects, drilling engineering, wells engineering and operations, and consists of multiple teams based on projects, rigs and functions as shown in Figure 1.1.

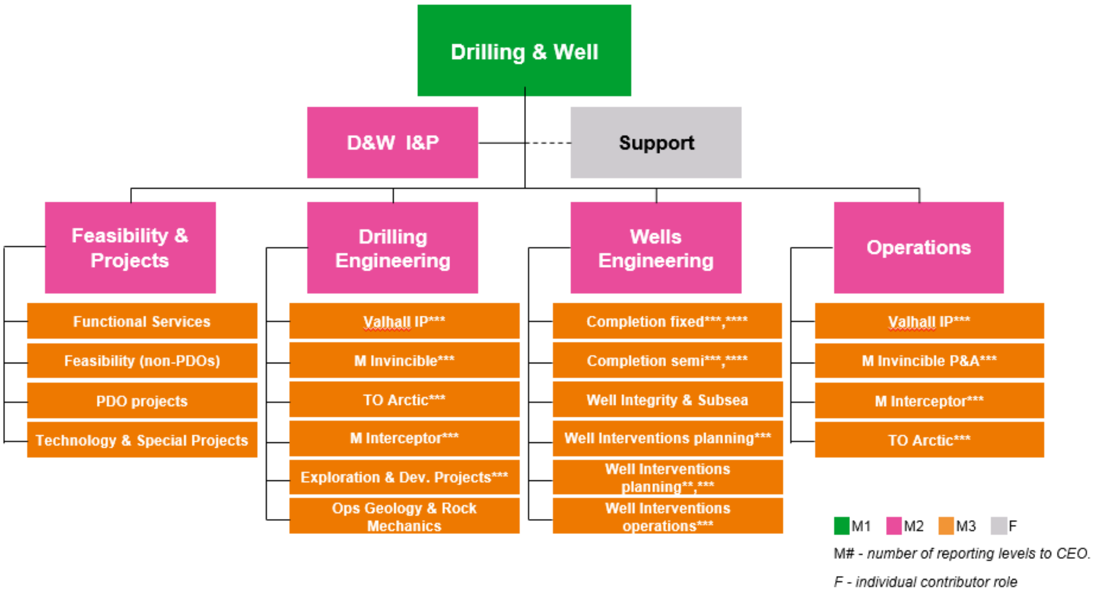

Figure 1.1: Organisational Structure of D&W, Aker BP. Courtesy of Internal Sources, Aker BP D&W

1.3 Problem Definition

Alike many operators in the upstream sector, Aker BP aims to incorporate a sophisticated performance management system across all their departments. Whereas relevant and necessary principles and methods were established early on by the company's management, the development of a performance management system for D&W was just recently initiated by the department's Senior Vice President. In light of the company's Lean business strategy, D&W engineers and analysts have culminated their efforts into developing a new framework encompassing several key elements from Lean improvement theory, and adapted to the departments ongoing process of digitising well projects.

The development process is however still ongoing, as engineers and analysts are currently working on the initial measurement phase of performance management. For the time being, this has included developing new innovative approaches to KPIs and performance dashboards for collection, analyses and reporting, based on common industry standards. However, these recent developments have not received the recognition and validation from the top of the departmental hierarchy. Hence, a clearly defined governing system for performance management has yet to be incorporated in D&W at the time of writing.

The objective with the research presented in this study has therefore been to achieve a better understanding for the factors involved. Literature gaps concerning Lean implementation in performance management systems in the E&P sector, combined with facts provided by supervisors in D&W, thus led to realisation of the following research problem:

> *"How can Lean and continuous improvement in performance management contribute to well operations in Aker BP?"*

1.4 Research Scope and Delimitation

The foregoing research problem can in brief be answered by pursuing the following key objectives:

1. Determine the current principles and frameworks for performance management and and measurement in Aker BP and D&W.
2. Evaluate the prior performance management system from Det norske to affirm limitations and possibilities for improvement.
3. Determine the most critical area related to the work performed across well operations in D&W.
4. Determine the types of waste related to this area.
5. Evaluate the practicality of prior KPIs in this area.
6. Derive a new Lean category for performance measurement in a categorical manner utilising the principles, tools and methods from literature.
7. Develop a new set of Lean KPIs for the new Lean category in alignment with the strategic direction in D&W, and determine their practicality.
8. Discuss a new framework for performance management tailored to D&W and adapted to current principles, frameworks and new Lean KPIs.

These aforesaid research objectives have required analyses of current and prior performance management principles and frameworks along with new strategic directions. From this, practical solutions for new Lean KPIs in D&W will be explored using methods and tools from a literature review. Although there currently recedes a vast variety of theory on Lean and continuous improvement methods within the existing body of literature, not all have been considered applicable in this context. Hence, as a means of limiting the scope, the literature review has primarily emphasised the definition of Lean from Modig and Åhlström [9], relevant improvement methods and tools in addition to those already implemented in D&W, or deemed applicable in this context.

As the nature of the work carried out within D&W ranges across great many areas, a further limitation of the research scope has been required. The research has in effect, included a categorical process of deduction with basis in the department's strategic direction in order to limit the extent of the research. The intention has been, in light of the research objectives, to identify the most critical area of D&W's operations, prior to investigating practical solutions for this area only.

Although it was deemed necessary by the researcher to ensure adaptability of the company´s principles for overall performance management, it must be noted the emphasis has been mostly vested in the initial phase of performance management concerning performance measurement. Notwithstanding, a proposal for a new performance management framework has been included. The proposed solution should also take into consideration the current digitalisation of well projects in D&W. As the current framework already includes strategies and establishment of cultural principles, the development of these elements has not been included in this research.

1.5 Outline of Thesis

This thesis can be divided into three parts for the benefit of the reader. The first part, comprised of chapter 1 and 2, introduces the thesis and research methodology. The second part subsequently, gives a review of essential background information in chapter 3, before presenting the research findings in chapter 4. This provides a foundation for understanding the subsequent discussion and conclusion in chapter 5 and 6, encompassed in part three. An outline of each individual chapter is included below.

Chapter 1 gives an introduction to the thesis, the company Aker BP and the department D&W, before presenting the problem definition, research scope, delimitation and overall structure of the thesis.

Chapter 2 describes the designated research methodology and presents the relevant methods for data collection and analyses, in addition research design and limitations.

Chapter 3 reviews the O&G value chain, emphasising the upper segment of E&P prior to reviewing literature in the field of flow efficiency, Lean Thinking, continuous improvement methods, performance management and measurement.

Chapter 4 presents the qualitative findings from interview and documentary analysis along with the empirical findings from the quantitative analysis. From the results, the chapter then commence identifying waste and the practicality of prior and new Lean KPIs.

Chapter 5 discuss the findings from the qualitative and empirical analyses along with their limitation, before discussing applications in the context of the existing literature.

Chapter 6 reflects on the study and its findings, its contribution to the current body of knowledge and research before giving recommendations for future research.

Chapter 2

Methodology

The selection of method is fundamentally important, as it determines the reliability and definitive value of a research. This chapter outlines the research methodology, approach and framework employed throughout this thesis, along with guiding principles to justify the selected methods. This includes both qualitative methods, being documentary analyses and interviews, and quantitative methods such as statistical analyses. The chapter then continues by presenting the collection and validity of data, before discussing the design of the conceptual research framework and its limitations.

2.1 Introduction to Research Method

Research is according to Kothari [13], based on discovering answers to questions through the application of scientific procedures. In this thesis, the primary intention with the research presented has been to analyse and thereby understand how Lean and continuous improvement methods in performance management can contribute to well operations. Due to the exploratory nature of this scope, the research in thesis has followed a case study-design with an in-depth analysis of the E&P company Aker BP ASA and its department D&W.

In a twofold definition, Yin [14] defines case studies as a method often used to investigate a contemporary phenomenon in its real-world context, before pointing to its appropriateness when combining multiple methods of data collection. Case studies are thusly often utilised to narrow down a very broad field of research into one or a few easily research-able examples before testing their application [14]. The method is accordingly proffered for answering the complicated research problem in this study, as it maintains the focus on a specific *case*, while allowing the researcher to retain a holistic perspective.

On account of the complex research objectives from Section 1.4, the case-study has moreover adapted an exploratory sequential design, combining both qualitative and quantitative research methods. Whereas the former is concerned with the subjective assessment of attitudes, opinions and behaviour, the latter involves the generation of data which can be subjected to rigorous quantitative analysis, thus identifying causal relationships [13]. In an exploratory sequential design, Watkins and Gioia [15, p. 32-34] explains that qualitative data is first collect and analysed, before using the results to build on a subsequent quantitative phase of data collection and analysis, as depicted in Figure 2.1

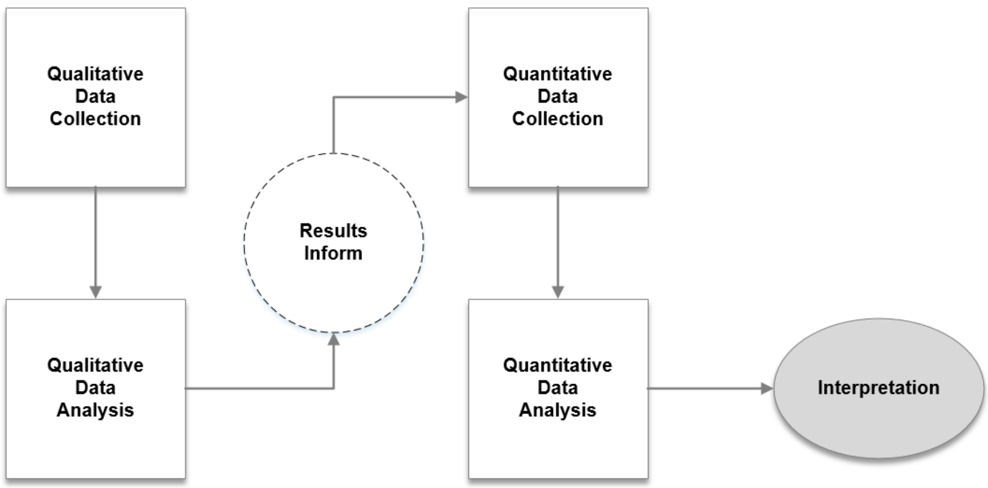

Figure 2.1: Exploratory Sequential Design Method. Adapted from Watkins and Gioia [15, p. 33]

Although this research design could potentially increase the complexity and use of resources in the case study, it was considered the most appropriate as it would to some extent reduce bias and improve the evaluation by ensuring that the limitations of both methods were balanced by the strengths of each other [15]. The qualitative and quantitative methods applied in this research are briefly described below.

2.2 Qualitative Methods

Qualitative methods were in this thesis utilised in reference to research objectives 1-3 from Section 1.4, to investigate current and prior performance management and measurement practices withal strategic directions for D&W, thus providing a frame of reference for the ensuing quantitative research. Below, the relevant methods for collection and analysis of qualitative data are further described.

2.2.1 Documentary Analysis

A documentary analysis was included on account of the limited time-frame, to distinguish elements in the current practices for performance management and measurement in Aker BP and D&W withal strategic directions in the latter, on basis of existing documentation. As Maruster [16, p. 37] argues, this method is particularly useful "[...] when situations or events cannot be investigated by direct observation or questioning". Hence, the analysis method would thus allow easy access to information that would otherwise be hard to obtain over a short amount of time. To improve the quality and validity, the findings were discussed post-analyses with the internal sources in D&W.

2.2.2 Interview

One of the most important sources of information in case-studies, is according to Yin [14] interviews. In this thesis, one single face-to-face interview was included to obtain otherwise unobtainable information related to prior practices for performance management and measurement in Det norske D&W, thus providing a better understanding of principles in Aker BP D&W. A limitation identified with having one single interview, was the high possibility of subjective opinions.

Resultantly, the interview followed a semi-structured design with an open-ended line of objective questioning to reduce as much bias as possible. In this format, the line of questioning is more flexible and less structured, which Merriam [17, p. 90] argues, would allow the interviewer to respond to the situation at hand. This would also assure that the interview covered topics and themes related to both Lean and performance management and measurement, whilst simultaneously allowing the interview prospect to elaborate on topics deemed important.

The selection process of interview prospects was strategic, focusing on selecting an individual with hands-on experience from D&W in both Det norske and Aker BP. As Dalland [18, p. 165] suggests, this could provide new perspectives and relevant information. As a result, interview subject included one previously employed D&W engineer in Det norske, now divisional manager in Aker BP D&W. Said interviewee is also responsible for the current digitisation process in D&W and conducts therefore regular meetings with engineers and analysts responsible for developing the new system for performance management and measurement in D&W.

An interview guide was developed prior to the interview, and provided to the interview subject in advance, thus allowing the interviewee to prepare and quite possibly increase the value of the information acquired [18]. The replies from the interview have been included in Appendix A.

2.2.2.1 Ethical Considerations

The ethical considerations associated with the interview method were associated with collecting, analysing and reporting the findings [18]. It was opted to hold the interview without personal information or data attached. The interview was also recorded for transcription purposes, thus providing a more accurate rendition of findings. Information on this was provided in advance and acknowledged by the interview prospect. Any recordings have been stored with password protection and will be deleted after the finalisation of the thesis.

2.3 Quantitative Methods

With basis in findings derived from the qualitative analyses, the consecutive phase in the exploratory sequential design includes the use of quantitative methods for further analysis. The relevant methods exploited when investigating and analysing the quantitative data related to research objectives 4-8 from Section 1.4 are further described below.

2.3.1 Statistical Analysis

The complex nature of the research objectives combined with the quantity of data has prompted the use of statistical analysis. In this study, statistical analysis was exploited to investigate elements from the strategic direction of D&W and the use of prior and new performance metrics. This method is also supported by Chowdhury [19, p. 11-36] who employ a similar approach when evaluating improvement potentials for KPIs of drilling operations. To overcome the possibility of wrongful collection and interpretation of the data, only fundamental statistical measures already known for the researcher were included. Below the relevant notation, terms and methods related to the statistical analysis are presented.

2.3.1.1 Empirical Average

The empirical average, commonly referred to as the mean in statistical theory, is a measure used to derive the central tendency in a collection of data. In a discrete set of values, Loevaas [20, p. 37] defines the mean as the sum of a set of values x_i divided by the quantity of values n in the same set:

$$\overline{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2.1}$$

2.3.1.2 Mode and Median

In contrast to the mean, Loevaas [20, p. 35] presents the *mode* as the most occurring value in a set of discrete values. The *median* moreover, is defined as the value that lies at the centre of the discrete data set once the values have been sorted [20, p. 35]. From basic statistics Loevaas [20] discuss that the advantage of using the median in describing data compared to the mean or mode, is that it is not skewed so much by extremely large or small values, and may therefore give a better idea of the most "typical" value.

2.3.1.3 Skewness and Kurtosis

Whereas the mean, mode and median indicates the central tendency of a set of values, dispersion in contrast refers to the spread of items on either side of the measures of central tendency. In a symmetric normal distribution with one top, the mean, mode and median are nearly identically positioned along the shape of the distribution curve [20, p. 39]. However, this synergy would change should the symmetry be slightly altered. A common statistical term employed to describe this asymmetry from the normal distribution, is *Skewness*. Loevaas [20, p. 44] presents Skewness S_x by the following equation:

$$S_x = \frac{1}{n}\sum_{i=1}^{n}(\frac{x_i - \overline{x}}{\sigma})^3 \tag{2.2}$$

Where σ is the standard deviation. Loevaas [20] argues that Skewness may come in the form of "Negative Skewness" or "Positive Skewness", depending on the whether the data values are skewed to the left and negative, or to the right and positive of the empirical average as show in Figure 2.2.

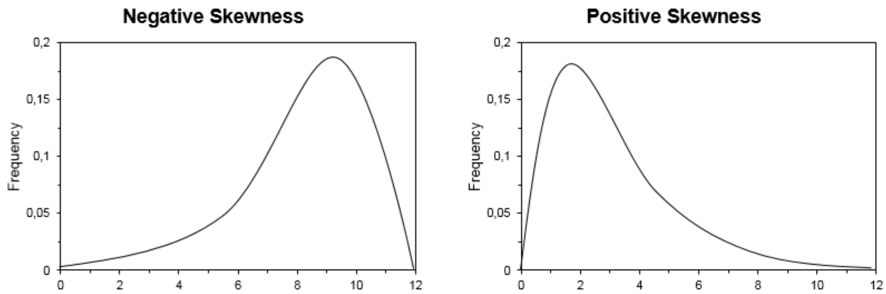

Figure 2.2: Illustration of Negative and Positive Skewness. Adapted from Loevaas [20, p. 34]

Whereas Skewness defines the shape of a distribution curve, *Kurtosis* K_x moreover describes the form of the distributions tails in relation to its overall shape [20, p. 44]:

$$K_x = \frac{1}{n}\sum_{i=1}^{n}(\frac{x_i - \overline{x}}{\sigma})^4 - 3 \tag{2.3}$$

In probability, Kurtosis is often used to measure the likelihood that an even occurring is extreme in relation to the distribution. In statistical theory however, the Kurtosis indicates whether the curve of a frequency distribution is flat or peaked. According to Gupta and Saxena [21], a peaked curve is called *Leptokurtic* whereas a flat topped curve is known as *Platykurtic*. These in turn are evaluated by comparison with an intermediate normal curve called *Mesokurtic*. Gupta and Saxena [21] states that distribution curve is:

Platykurtic if $K_x < 3$

Mesokurtic if $K_x = 3$

Leptocurtic if $K_x > 3$

2.3.2 Normal Distribution & Monte Carlo Simulation

In statistical theory, the normal distribution is used to represent the probability distribution of real-value random variables whose distribution is unknown. In this thesis, several of the analysis exploited the assumption of a normal distribution for the quantitative data in furtherance of simplifying estimations.

Monte Carlo simulation is a type of numerical method whereby repeated simulations utilising randomly sampled variables can be used to determine the underlying statistical properties of complex problems. In this thesis, the principles of the Monte Carlo approach were drawn upon when investigating the practicality of an innovative E&P industry KPI known as the Best In Class (BIC). The simulation process encompassing the principles of this method is further described at length in Subsection 4.8.6 of the research findings.

2.3.3 Analyses of Quantitative Data

The quantitative analyses in Chapter 4 and resulting numerical data have required the development of graphical presentations in the form of balanced bar charts, somewhat combined with lines, in addition to tables. As explained by Oglesby et al. [22, p. 220], balanced bar charts offer an effective way to show the interrelationships among operations and activities. By virtue of performing statistical estimations, simulations and development of graphs and figures throughout the quantitative analysis, the workbook and database application Microsoft Office Excel 2013 was utilised due to its familiarity to the researcher. Table 2.1 presents the most frequently exploited Excel functions in this study.

Table 2.1: Excel Functions Utilised in Research

Function	**Definition**
SUM()	Returns the sum of a range of values
MAX()	Returns the larges value in a set of values
MIN()	Returns the smallest value in a set of values
AVERAGE()	Returns the average in a set of values
MEDIAN()	Returns the median in a set of given numbers
PERCENTILE()	Returns the k-th percentile of values in a range
COUNT()	Counts the number of cells in a range that contain values
COUNTIF()	Counts the number of cells in a range that meet a certain condition
IF()	Checks whether a condition is met
VLOOKUP()	Looks for a value in the leftmost column in a table
RAND()	Returns a random number between 0 and 1
STDEV.S()	Calculates the standard deviation based on a given population
SKEW()	Returns the skewness of a distribution
KURT()	Returns the kurtosis of a data set

2.4 Collection of Data

In Kumar [23], a distinction is made between two main forms of data collection. The first type, known as primary data, is defined by Kumar [23, p. 57] as data collected first hand by the researcher himself. The second type, known as secondary data, is conversely any data gathered earlier by others for some other purposes. The scope of this research has required the collection of both.

2.4.1 Primary Data

The sources of primary data for this research were both qualitative and quantitative of nature, and have largely been obtained through meetings and numerous discussions with supervisors and various employees in Aker BP D&W, whose competence and hands-on experience has contributed in framing the main research objective of this thesis, including:

- Manager of subdivisions in D&W
- Drilling & Completion Engineer
- Performance Analyst
- Analyst Consultant
- Programming Consultant

The primary data has included the development of numerous Excel worksheets encompassing statistical data in the form of tables or graphs. Secondly, data from an interview were obtained, analysed and discussed.

2.4.2 Secondary Data

Throughout the writing of this thesis, admittance to the intranet and both internal and external databases at the disposal of Aker BP D&W have been granted. The culmination of both qualitative and quantitative information obtained has included:

- Excel sheets with historical data and logs of past developed wells
- Daily Drilling Reports (DDR) on past wells
- Final End of Well Reports of past wells
- Internal documents with information regarding:
  - Company Governing Models in Aker BP
  - Strategic Principles in D&W

Due to copy rights and confidentiality agreements made with the Aker BP, these data have not been included in this thesis. Instead, the information encompassed in these documents were gathered, sorted and reproduced by the researcher for use in analyses and discussion, built on a theoretical frame of reference derived from various academical sources. These included the Library at the University of Stavanger and web-based articles and literature.

2.4.3 Validity of Data

Dalland [18] argues that an important part of the research process is to validate the quality of the data obtained. Though it is often assumed that results are valid or conclusive due to the scientific nature of the research design, information is seldom exclusively objective. By cause of the large influence of external factors, the information obtained is therefore likely to pertain subjective opinions. In that event, Jacobsen [24] states that the information must be critically review and interpreted to avoid a weakened result and validity. In some cases, it may also be natural, even necessary, to include verification from several independent and unbiased sources [24]. Due to the size of the existing body of information, the focus of the literature review has been elements related to the research objectives. To identify elements related to the definition of Lean emphasised in Aker BP, and relevant elements for investigation and discussion of the alternative performance category and KPIs, the literature review has emphasised published books and research reports from independent acknowledged authors and institutions.

Furthermore, seeing as the thesis and its findings may be used in subsequent processes related to continuous improvement in D&W, all primary and secondary data are discussed and approved by internal sources D&W. To increase verifiability, the relevant data from the research findings have been included in the Appendix. Any additional data related to the findings of this thesis have been provided on hard-drives for the Faculty of Science and Technology at the University of Stavanger.

2.5 Research Framework

The conceptual research framework employed in this thesis has been divided into four stages. From Figure 2.3, stage one commence with an extensive literature review following a outlining of the research objectives and context. In stage two subsequently, the qualitative data sampling commences in the form of documentary analysis and execution of an interview. The findings from the qualitative methods are then analysed in the "Results Inform" and used as a frame of reference for the subsequent quantitative analyses on statistics, KPIs and the Monte Carlo Simulation in stage three. Results from both the qualitative and quantitative analyses are then interpreted before discussing the practicality of findings and a new performance management framework in stage four. The research then culminates in a conclusion on the chief research problem and objectives.

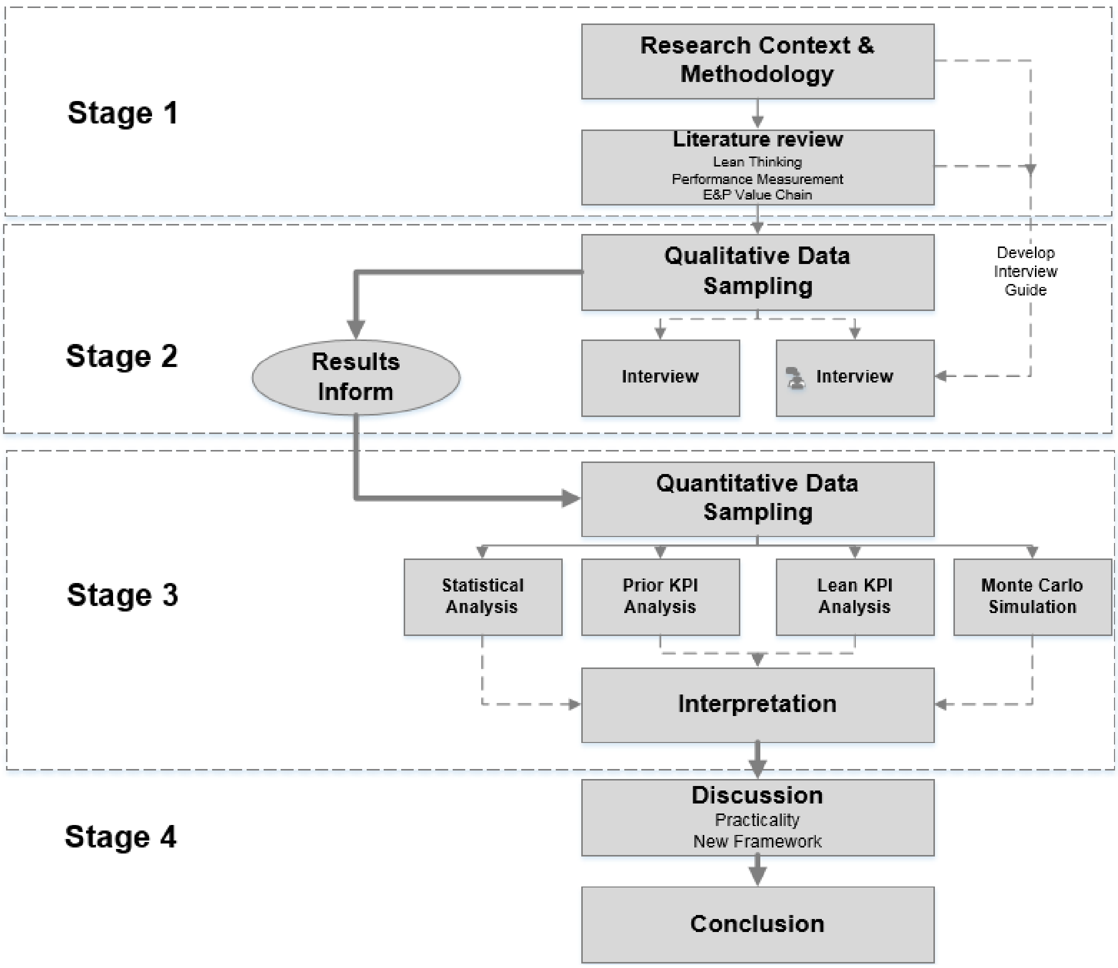

Figure 2.3: Conceptual Research Framework Adapted to Exploratory Sequential Design

2.5.1 Limitations to Method

While the above demonstrates the pragmatic advantages the exploratory sequential design provides when exploring complex research question, several limitations and challenges with said method were acknowledged. As the qualitative and quantitative methods must adhere to their own standards, ensuring quality in both can prove difficult.

Whereas qualitative methods may provide deeper understanding of the research objectives, the complexity of this design may lead to a risk of unintended screening of information [24]. Furthermore, the method is quite labour extensive and requires great use of resources and time. This may have unwanted impact on the discussion and final conclusions.

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Chapter 3

Literature Review

Following Chapter 1 and 2, which outlined in the detail the overall aims and research methodology of this thesis, this chapter is structured in a thematic fashion according to two types of literature.

The first type covers in Sections 3.1-3.3, the basic concepts necessary to be understood for the comprehension of the second category. This includes a brief overview of the O&G value chain and the fundamental principles behind the concepts of flow efficiency. In an effort to provide the reader with a greater understanding of flow efficiency, a systematic overview of the efficiency matrix has also been included.

The second category investigates in detail the chosen focus areas for this thesis, in the remaining sections. Firstly, the history of Lean Thinking is explored, before the chapter continues by describing relevant methods and principles of Lean, continuous improvement methods and performance management and measurement, all instrumental to the research of this study.

3.1 The O&G Value Chain

In the O&G industry, there exist a general consensus among academics that the value chain follows the O&G commodities from the point of extraction through processing, distribution to consumption [25, 26]. To clarify, Inkpen and Moffett [25, p. 20] divides the O&G value chain into three major sectors. The first sector, known as *Upstream*, includes activities related to exploration, development and production. The second sector, commonly referred to as *Midstream*, involves storing, trading and transportation of crude petroleum commodities. The third sector lastly, being *Downstream* concerns oil refining and marketing. The focus of this literature review has mainly been vested in the upstream segment of exploration, development and production, also referred to as E&P by Tordo et al. [26].

3.1.1 E&P Value Chain

In the pursuit of hydrocarbons, E&P companies are required to execute a great variety of activities involving multiple disciplines. Exploration and production activities are commonly spread over several decades, ranging from first discovery of hydrocarbon deposits to their extraction. The value chain of these activities can be primarily divided into the five main steps depicted in Figure 3.1.

Figure 3.1: E&P Value Chain. Courtesy of Internal Sources, Aker BP D&W

3.1.1.1 Access and Acreage

The first stage of the E&P value chain is chiefly related to field discovery. O&G commodities are initially trapped in reservoir rocks buried underground, either onshore or offshore in varying amounts. In an attempt to locate these accumulation of hydrocarbons, E&P companies repeatedly perform geological surveys of the earth's subsurface to identify potential reservoirs, known as "*prospects*" [25]. An investigation license with exclusive rights to survey, exploration and extraction of petroleum within the licenses specified geographical area, is then acquired from respective authorities before the companies can commence exploration [27]. In some cases however, Olesen [27] maintains that E&P companies may already have a license to operate. Thus, respective companies may then promptly commence with development.

3.1.1.2 Exploration

To verify whether the identified prospect indeed contain hydrocarbons, exploration wells are subsequently drilling following the access and acreage stage. In terms of the definitions introduced in [28], this stage is said to involve the search for rock formations associated with oil or natural gas deposits, and involves geophysical prospecting and exploratory drilling. Once discovery has been confirmed, companies commence building advanced reservoir simulation models to estimate the initial volumes of O&G, prior to simulating reservoir fluid behaviour and optimising field development scenarios [28].

3.1.1.3 Field Development

After exploration has located an economically recoverable field, field development occurs. The stage commences with an extensive economic assessment, taking into account revenues concerning production forecasts and estimated development costs. If the required criteria are met, the companies commence establishing a Plan for Development and Operation (PDO) for the field by establishing the number of wells to be drilled to meet the production requirements. This entails recovery techniques for extraction, type and cost of installations or rigs depending on marine environment, separation systems for gas and fluids, treatment systems needed to preserve the environment in addition to hire of rig, service company, drilling company and offshore personnel. Once the PDO is approved, companies swiftly instigate the construction of one or more development or infill wells from the beginning, until either well completion or abandonment, depending on whether O&G are found in sufficient quantities [25]. The process ends with "*first oil*", signifying the start of commercial production.

3.1.1.4 Production

Following field development is production; the process of extracting and separating the mixture of liquid hydrocarbons, gas, water, and solids. The production time often varies from between 15 to 30 years depending on the reservoir, and includes the phases of increase, stabilisation, improvement and depletion. The production stage also includes removing the elements that are non-saleable, improving production and installations, and marketing the O&G [25].

3.1.1.5 Abandonment

When the production of hydrocarbons is no longer economically viable, or when a recently drilled well lacks the potential to produce economic quantities of O&G, the reservoir or site is abandoned by dismantling the facilities such as platforms, prior to plugging the well(s) and restoring the site.

3.2 The Concept of Strategy

The term *strategy* derives from the Greek word *strategia*, and is broadly defined by Saunders [29] as the direction and scope of an organisation over the long term. Saunders [29] also argue that strategy ideally involves matching one's resources to the changing environment, particularly markets, customers or clients, to meet stakeholders' expectations. A similar approach is promoted by Grant [30] who simply defines strategy as the means by which individuals and organisations achieve their objectives. Common to both these definitions is the fact that strategy is based on achieving certain *goals*, that its underlying critical actions involve *allocation of resources*, and that it implies *consistency* or *cohesiveness* of decisions and actions. As emphasised by Porter [31], strategy is thus not necessarily about doing better, but rather being different by deliberately choosing a different set of activities to deliver a unique mix of value. Hence, in the face of relentless competition and continuous change, strategy is more about developing the flexibility and responsiveness to create successive advantages [31]. In his work, Grant [30] defines two basic levels of strategy within an organisation;

1. **Corporate strategy**; defines the scope of the firm in terms of the industry and markets in which it competes.
2. **Business strategy**; how the firm competes within a particular industry or market.

For organisations to survive and create flexibility and value in the long run, Grant [30] concludes that these strategies must have certain strategic elements represented. The common key components found in successful strategies is moreover depicted in Figure 3.2.

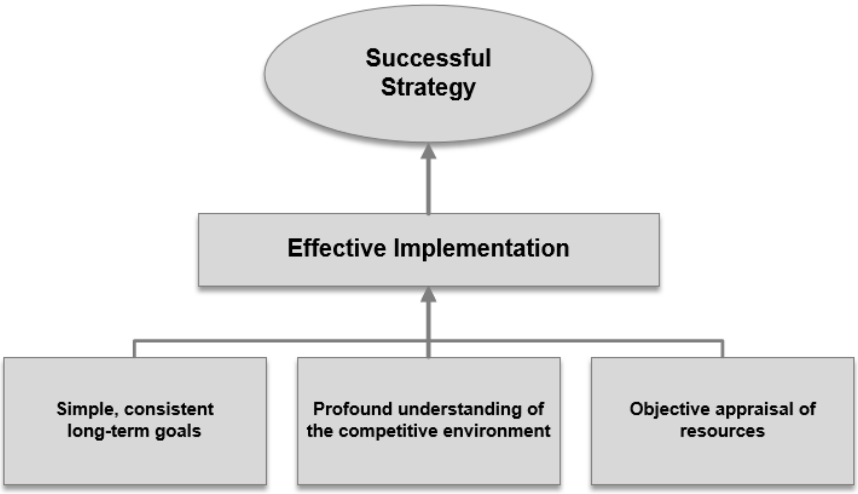

Figure 3.2: Common Elements in Successful Strategies. Adapted from Grant [30, p. 10]

3.3 Flow Efficiency

Every organisation is according to Wig [8, p. 24] a system purposely developed to deliver various forms of products or services with a certain utility. On account of more than two hundred years of industrial development, most traditional business strategies are nowadays organised to maximise the efficient utilisation of resources. Hence, various formal management and control systems have been employed to make sure that these systems function accordingly.

In their work *This is Lean*, Modig and Ählström [9] describe a new way of thinking that contrasts the traditional and natural integrated focus on resource efficiency in organisations. With basis in a new concept coined *flow efficiency*, Modig and Ählström [9] argues that organisations should refocus their attention on an arbitrary *unit* being processed and how it flows through the organisation, rather than concentrating on the resources that processes this unit. From this follows a fundamental difference; whereas resource efficiency focuses on the usage of specific resources in a process, flow efficiency conversely, focuses on how a specific *flow-unit* attain added value as it moves through said process [9]. The difference between these two measures of efficiency can be expressed in light of the dependencies between resources and units. In resource efficiency, as depicted in Figure 3.3, the emphasis is on allocating work to the workers and simultaneously make sure that all resources have at least one unit to process [9].

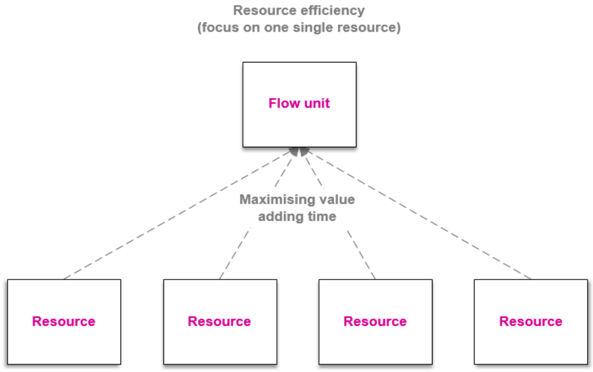

Figure 3.3: Illustration of Resource Efficiency. Adapted from Modig and Ählström [9, p. 21]

In flow efficiency conversely, focus resides on allocating workers to the units, hence making sure that they are all constantly being processed by at least one resource. Modig and Ählström [9] accordingly defines flow efficiency as a measure of how long a unit is being processed from the identification of the need, until its satisfaction.

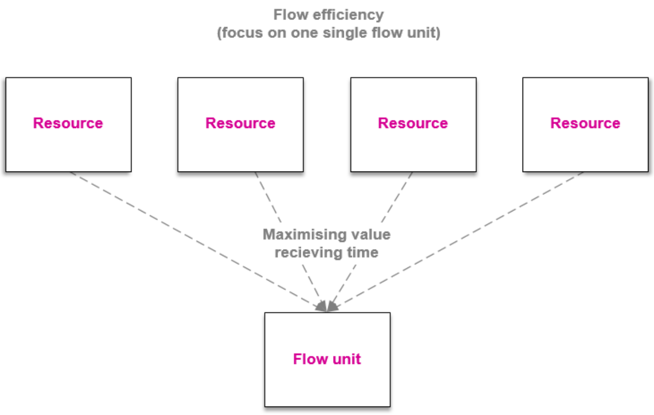

Figure 3.4: Illustration of Flow Ffficiency. Adapted from Modig and Ählström [9, p. 21]

On an executive level, flow efficiency can assert how efficiently the organisation is treating its units as depicted in Figure 3.4. A summary of the difference in dependency between resource efficiency and flow efficiency is derived based on the work of Modig and Ählström [9] and provided in the Table 3.1.

Table 3.1: Differences Between Resource Efficiency and Flow Efficiency. Adapted from Modig and Ählström [9, p. 20-29]

	Resource Efficiency	**Flow Efficiency**
Focus	Resources / Function	Customer / unit
Goal	High capacity utilisation	Fulfil needs
Organisation	Parts	System
Competence	Specialist	Multi-competence
Through-put time	Long	Short

To fully comprehend the principle behind flow efficiency, one must understand the mechanisms of processes. The word process, derives from the Latin word *processus* and *procedure*, which means to move something forward. This something being moved forward is commonly referred to by Modig and Ählström as a *flow-unit*. This flow-unit can be [9, p. 19];

- **Material**; material being moved forward by machines at a car manufacturer.
- **Information**; application for house-demolition moving between the different parts of the local building agency.
- **People**; people moving through the various amusement-park attractions.

All processes consist of a sequence of activities where the flow-unit is being processed. In effect, Modig and Ählström [9] furthermore argues that all processes contain a sequence of activities in which the flow-unit is being treated. In an internal manufacturing context, Taylor and Brunt [32] and Monden [33] both define three types of activities that can be undertaken;

1. Non-Value Adding (NVA) activities.
2. Necessary but Non-Value Adding (NNVA) activities.
3. Value-Adding (VA) activities.

The first activity type is by Taylor and Brunt [32] considered as pure waste, and involves unnecessary actions which should be eliminated. NNVA activities moreover, may be wasteful, but are necessary under the current operating procedures. Eliminating these types of operations would require major changes in the operating system. VA activities in contrast, involves the conversion or processing of raw material or semi-finished products using manual labour [32]. From the perspective of a flow-unit, VA activities add value to through transformation, or by moving the unit forward within a process [9]. Hence, to truly apprehend flow efficiency, one must understand the VA processes known as value streams.

3.3.1 Value Streams

Whereas a traditional value chain includes the complete activities of all the departments involved, a value stream on the contrary refers only to the specific parts of an organisation that actually add value to the specific product or service [32, 34]. A review of the existing body of literature demonstrates various, but similar definitions of the term.

Rother and Shook [35, p. 13] defines a value stream as "[. . .] all the actions (both value adding and non-value adding) currently required to bring a product through the production flow from raw material into the arms of the customer". Womack and Jones [36] offers a similar interpretation and describes a value stream as all the actions, both VA and NVA, currently required to bring a product through the main flows essential to its introduction. In brief, [36] summarise these actions as;

- The design of a product, from its conception through to its launch in the market.
- The flow of a product, from raw materials to delivery to the customer.
- The flow of information necessary to trigger and support the aforesaid flows.

3.3.2 Laws of Process Flow

Another significant trademark of processes is the ability to define both a definite beginning and end, henceforth referred to as system boundaries. The definition of these system boundaries successively decides the critical cycle time; the time required by the flow-unit to move through the entire process, from start to finish. Having defined both cycle time and VA activities, Modig and Ählström [9, p. 26] defines flow efficiency as "[...] the sum of all value-adding activities within the cycle time". Notwithstanding the forgoing, Modig and Ählström [9, p. 26] asserts that flow efficiency is not about increasing the velocity of VA activities, but rather maximising the value transfer relative to the end user. To achieve flow efficiency in process, Modig and Ählström [9] therefore introduces three laws.

3.3.2.1 Little's Law

The first law, recognised as Little's Law, was introduced by John Little in a paper from 1954. The law states that the long-term average number of customers in a stable system N, is equal to the long-term average effective arrival rate, λ, multiplied by the average time a customer spends in the system, T_i [9, 37];

$$E(N) = \lambda E(T) \tag{3.1}$$

Little's Law demonstrates that the cycle time is affected by two factors; the number of flow-units within a process, and the duration of the cycle time. The law moreover states the average time T_i is the total delay of the ith customer in the system, defined as the sum of the waiting time W_i and service time τ_i [37, p. 714-715];

$$T_i = W_i + \tau_i \tag{3.2}$$

3.3.2.2 Law of Bottlenecks

The law of bottlenecks was first introduced by Goldratt and Cox [38] as part of the *Theory of Constraints*, which states that the throughput of any system is determined by at least one constraint. These constraints, commonly known as bottlenecks, are per Modig and Ählström [9, p. 36-39] the stage in process with the greatest cycle time wherein the throughput is lower than in the rest of the process stages. Hence, immediately before a bottleneck, there is always a queue regardless of the type of flow-unit. In general, Modig and Ählström [9, p. 39] presents two main reasons for why bottlenecks arises in a process. Firstly, bottlenecks arise if the stages in a process must follow a certain order, or secondly due to *variation*.

3.3.2.3 Law of Variation

Variation will always have a specific negative impact on the flow efficiency. The most important impact can be explained through the relationship between variation, resource efficiency and cycle time. The relationship was first normalised by Sir John Kingman in 1961 in the *Kingman's formula* [39].

The formula, shown in Equation 3.3, demonstrates how the cycle time depends on the degree of utilisation;

$$E(W_q) \approx \left(\frac{\rho}{1-\rho}\right)\left(\frac{c_a^2 + c_s^2}{2}\right)\tau \tag{3.3}$$

where τ is the mean service time, $\rho = \lambda/\mu$ the utilisation (i.e. $\mu = 1/\tau$ is the service rate), c_a is the coefficient of variation for arrivals and c_s is the coefficient of variation for service times. The formula states that an increase in variation results in an increase in cycle time, and thus reducing the flow efficiency within an organisation, as evident of the exponential relationship between the two. Drawing upon combination of the three abovementioned laws, Modig and Ählström [9] introduces four actions to improve flow efficiency;

1. **Reduce** total number of flow-units.
2. **Reduce** cycle time by working faster.
3. **Add** more resources, thus increasing capacity and cycle time.
4. **Eliminate**, reduce and manage the various forms of process variation.

Although these actions may appear straightforward, their implementation is however rather difficult due to the highly maintained focus on resource efficiency in most organisations. Amongst the problems that follows, is the addition of NVA activities to the process, a phenomenon often referred to as *the efficiency paradox*.

3.3.3 The Efficiency Paradox

Redundant work is said to be the main reason behind the efficiency paradox. Modig and Ählström [9] devise in light of the three process laws, that any over-focus and rigour on resource efficiency in terms of through-put time, number of units, or restarts, typically results in a corresponding increase of redundant activities processing secondary needs, thusly decreasing the flow efficiency. Hence, the paradox is the wrongful assumption of efficient use of resources, as the degree of utilisation is partly generated from redundant work and NVA activities. To solve the efficiency paradox Modig and Ählström advise organisations to focus on increasing their flow efficiency rather than maximising capacity utilisation. This in turn will lower the cycle time, number of flow units within the process, and consequently increase the flow throughout the organisation. One of the most recognised approaches employed by organisations to solve this efficiency paradox, is called *Lean*.

3.4 Lean

The principles behind *Lean* are according to Wig [8], primarily related to developing and delivering products and services with the highest degree of utility and lowest possible loss of resources by focusing on flow, transparent processes and continuous improvements. Since the coining of the term in the early 1990s, a succession of organisations worldwide has managed to improve their performance through its application, resulting in a vast and wide-ranging body of knowledge. Although its principles and methods have been extensively applied to both manufacturing operations and production environments, the relative success and commercial benefits that comes from this focused enterprise-wide approach to continuous improvement, increased productivity, improved quality and improved management, has resulted in an increasing awareness amongst many small medium sized manufacturing organisations. The founding principles behind Lean are hardly novel, and can be linked to several significant events throughout the history of manufacturing.

3.4.1 From Lean Production to Lean Thinking

One of the earliest examples of linking every value creating step in a continuous sequence can be dated back to Colt's armoury in Connecticut, USA in 1855. This logic further reached its peak in 1915 at Henry Ford's assembly plant in Highland Park [32]. Whilst making the famous Ford Model T, Ford began to use interchangeable parts and standardise the work process by lining up every machine making every car component in a process sequence [40]. In effect, Ford was able to completely synchronise the whole plant, thus enabling large production runs, a term that was later coined *flow production*, or *mass production* by The New York Times in an article from 1926 [41]. This term was later defined as the process of manufacturing large quantities of standardised products, utilising assembly line principles to achieve volume, flow and quality of control [36]. By successfully implement this new philosophy, Ford was able to greatly increase throughput and simultaneously reduce the cycle time compared to his competitors, who still relied upon the principles of craft production. However, due to a lack of choice and an increasing request of product variety over the years, Ford and his General Motors eventually had to re-organise their production processes by separate departments specialising in different activities in the 1930s. In contrast to previous events, machines were now being kept busy by ensuring there would always be work waiting to be done. Rather than following the product flow, batches of different products would now wander from department to department until final assembly. This allowed engineers to concentrate on designing faster machines, optimised to produce large batches [32]. What had started out as internal parts-making shops, gradually became self-standing businesses in their own right, supplying several assembly plants. Although this system functioned well as demand grew, inherent limitations began to surface as the markets became saturated [32]. A closer examination of the flow of products through these mass production systems, revealed huge amounts of wasted effort and time. Concurrently with Ford, the founders of Toyota Motor Corporation across the Pacific developed during the 1930s their own version of the aforesaid flow production system [32, 42]. Their new system, later recognised as the Toyota Production System (TPS), was based on two key principles;

1. **Jidoka**; automatic machinery and line stopping whenever mistakes are made, preventing the interruptions in the downstream flow.
2. **Just-in-Time (JIT)**; a push-pull system where only the parts needed are actually made.

This novel TPS contributed to a shift in focus from the manufacturing engineer, the individual machines and their utilisation, to the flow of the product through the total process. It was however, not until after World War II that these principles became linked and put into operation by Taiichi Ohno, Toyotas chief of production [32]. Following a successful transfer of the principles to Japanese-owned plants in Europe and North-America, other practitioners began to take wind of this new system. Subsequently, the term *Lean Production* was firstly coined and popularised by Womack et al. [7] in their five-year long MIT study of the world's automobile manufacturing industry. The study illustrated for the first time the core principles behind the TPS and how it contrasted the mass production approach of western manufacturers;

> "Lean production [...] is *Lean* because it uses less of everything compared with mass production – half the human effort in factory, half the manufacturing space, half the investment tools, half the engineering hours to develop a new product in half time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects and produces a greater and ever growing variety of products" Womack et al. [7, p. 13].

Not only did Womack et al. [7] observe that the Lean philosophy provided a focused approach for continuous improvements, effectively eliminating waste and unnecessary actions. Their study also identified and described the principal differences between mass production and Lean production, as shown in Table 3.2.

Table 3.2: A Comparison Between Mass Production and Lean Production. Adapted from Womack et al. [7], Stefanic et al. [43]

	Mass Production	**Lean Production**
Focus	Product	Customer
Operation	Batch and queue	Synchronised flow and pull
Overall aim	Reduce cost and increase efficiency	Eliminate waste and add value
Quality	Inspection (a second stage after production)	Inclusion (built in by design and methods)
Business strategy	Economies of scale and automation	Flexibility and adaptability
Improvement	Expert-driven scale and automation	Worker-driven continuous improvement

In a subsequent volume named *Lean Thinking; Banish Waste and Create Wealth in Your Corporation*, Womack and Jones [36] extensively redefined and described the initial concepts of Lean in terms of five key principles;

1. **Specify value**; define value precisely from the perspective of the end costumer in terms of the specific product with specific capabilities offered at a specific time.
2. **Identify value streams**; identify the entire value stream for each product or product family and eliminate waste.
3. **Make value flow**; make the remaining value creating steps flow.
4. **Let the customer pull value**; design and provide what the end customer wants only when the customer wants it.
5. **Pursue perfection**; strive for perfection by continuous improvement.

With basis in the forgoing principles, Womack and Jones [36] furthermore pioneered the term *Lean Thinking*, thus providing a link between production, Lean and supply chain. Their aim was to provide means for creating a Lean organisation that sustained growth by aligning customer satisfaction with employee satisfaction, whilst offering innovative products or services profitably and at the same time minimise any unnecessary over-cost to customers, suppliers or environment. This ultimately triggered a wave of interest from practitioners across the world, ultimately spreading Lean to the general manufacturing, aerospace and electronics industries. Nowadays, it has become one of the most widespread management philosophies of modern time, present in a great variety of industries [32].

3.4.2 Waste Removal

To introduce the Lean Thinking within organisations, Womack and Jones [36] clarifies that the implementation relies on the identification and elimination of waste [32]. Womack and Jones [36] further states that waste in the context of Lean can be divided into three categories:

1. **Muda, or Product- or service-related waste**; waste related to not meeting the customer's true demand due to design flaws or shortcomings;
2. **Muri, or Process-related waste**; non value-adding activities occurring due to low process flow.
3. **Mura**; irregularities.

Taylor and Brunt [32] argues that by classifying all their processes into either of the categories defined by Wig [8], organisations can introduce actions for improving product-or service-related waste and eliminating irregularities. In terms of the *Muda* category, Taylor and Brunt [32] describes the seven most commonly occurring wastes identified by Taiichi Ohno during the development of the TPS, shown in Table 3.3.

Table 3.3: The Seven *Muda* Wastes. Adapted from Wig [8]

Waste	**Definition**
Overproduction	Making more, earlier, or faster than required
Inventory	Excess material or more information than is needed
Waiting	Idle time for staff, material, machinery etc.
Transport	Non-required transport of items or information
Over-processing	Extra effort that adds no value to product
Motion	Any movement not adding value
Defects	Defective products or services

Note: An eight waste termed *non-utilised talent*, meaning not actively engaging employees's abilities, was added during the late 1990s.

3.4.3 Defining Lean

Implementing Lean is chiefly related to the development of a learning organisation, by systematically removing barriers for continuous improvement such as the three types of waste just discussed [8]. From the foregoing sections, it should be clear that Lean is not just another improvement methodology, but a very different set of behaviours and management systems. In an attempt to elucidate a simplified definition of the term, Modig and Ählström [9] introduces a concept named *the efficiency matrix*. The efficiency matrix builds upon the two forms for efficiency, and illustrates moreover the classification of an organisation based on a combination of low or high resource efficiency, and low or high flow efficiency, as depicted in Figure 3.5. According to Modig and Ählström [9], an organisation resides in one of four possible operational states;

1. **Efficient islands**; a state with high resource efficiency and low flow efficiency. These organisations consist of sub-optimal divisions operating independently to maximise resource usage.
2. **Wasteland**; a state with both low resource- and flow efficiency.
3. **Efficient sea**; a state with low resource efficiency, but high flow efficiency. Here, the flow is efficient at the expense of the resources.
4. **The perfect state**; a state with both high resource- and flow efficiency. Often set as a theoretical ideal state, wherein organisations are able to completely utilise their resources and at the same time cover customer's demand.

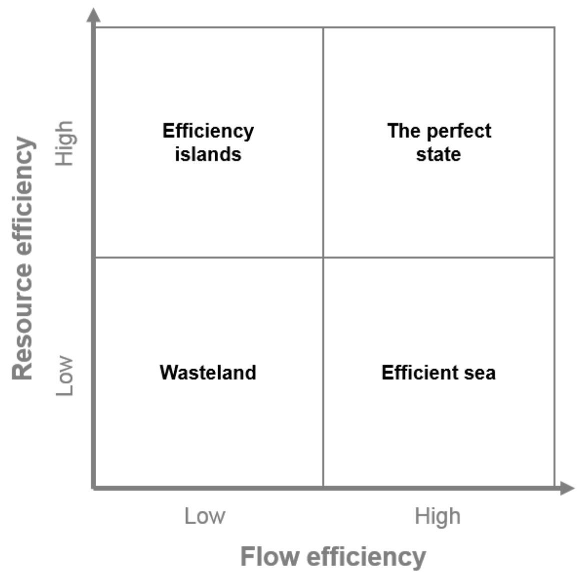

Figure 3.5: The Efficiency Matrix. Adapted from Modig and Ählström [9, p. 98]

In general, organisations can decide on their own placement in the efficiency matrix, and thus effectively their own strategy. Hence, Modig and Ählström [9] suggests that an understanding of the difference between business- and operational strategy must be present. Whereas a business strategy defines the core competencies and how to create value, the operational strategy defines how to realise and achieve this value. Lean then, can ultimately be defined as an operational strategy in which flow efficiency is prioritised ahead of resource efficiency to move an organisation towards the perfect state in the efficiency matrix.

3.4.4 Developing a Lean Culture

In his work *Lean Culture: A Leadership Guide*, Miller [44] points out that a Lean culture focuses on the importance of a total system solution in which culture is considered as part of a holistic process improvement effort. Considering that Lean is not a contemporary, but profound change in the corporate culture, Miller [44] furthermore emphasises the broader commitment organisations must make to improve in the long run. This includes not only the implementation of methods, tools, approaches and cultural change, but also considering Lean as a tool itself. The behavioural aspects of change can according to Miller [44] be described in terms of the five S's of change;

1. **Structure**; refers to how an organisation evolves over time.
2. **System**; refers to the disciplines within an organisation to make it function. Note that it is important to consider how misalignment of these functions prevent progress.
3. **Skills**; refers to human competence in technical skills and people-oriented capabilities required from people to function together.
4. **Style**; refers to how an organisation expresses its values, principles, priorities and judgements.
5. **Symbols**; refers to how things are done in an organisation that can create division or unity.

To successfully implement Lean, the engagement of people within and organisation is required. This perception correlates well with Wig [8], who argues that management within Lean, is concerned with asking the right questions and highlighting employees through coaching and mentoring. Hence, it is important that the employees contribute to shape the organisation. Implementing these methodologies in an existing business creates a talent gap that must be crossed. Furthermore, it introduces a revolutionary shift in the way work is performed, as it requires employees to take on a wider range of responsibilities, blurring the lines between formal job descriptions and ultimately changing the familiar work process. Consequently, Lean requires a willingness to change and a common understanding amongst the employees of what is required of them in the process.

3.5 Relevant Methods

Nowadays there exist a vast variety of methods that aid in the implementation of a Lean strategy and the continuous improvement of performance. Rolfsen [45] argues that these methods diverge from the Lean principles by being more concrete and specific, and containing well-defined phases and roles. In an attempt to delimit the vast number of methods for continuous improvement, the following subsections emphasises mostly those already implemented in D&W, or those with potential to contribute in well operations.

3.5.1 A3 Problem Solving

The A3 problem solving method is a continuous and structured problem solving approach originally developed within the Toyota Motor Corporation during the evolution of its manufacturing methodologies [32]. The method is based upon creating a structured plan of seven steps on an A3 sheet of paper, hence the name, and subsequently follow it through the cycle of identification of a potential for improvement, to the implementation and eventually later follow-up [45], as shown in Figure 3.6.

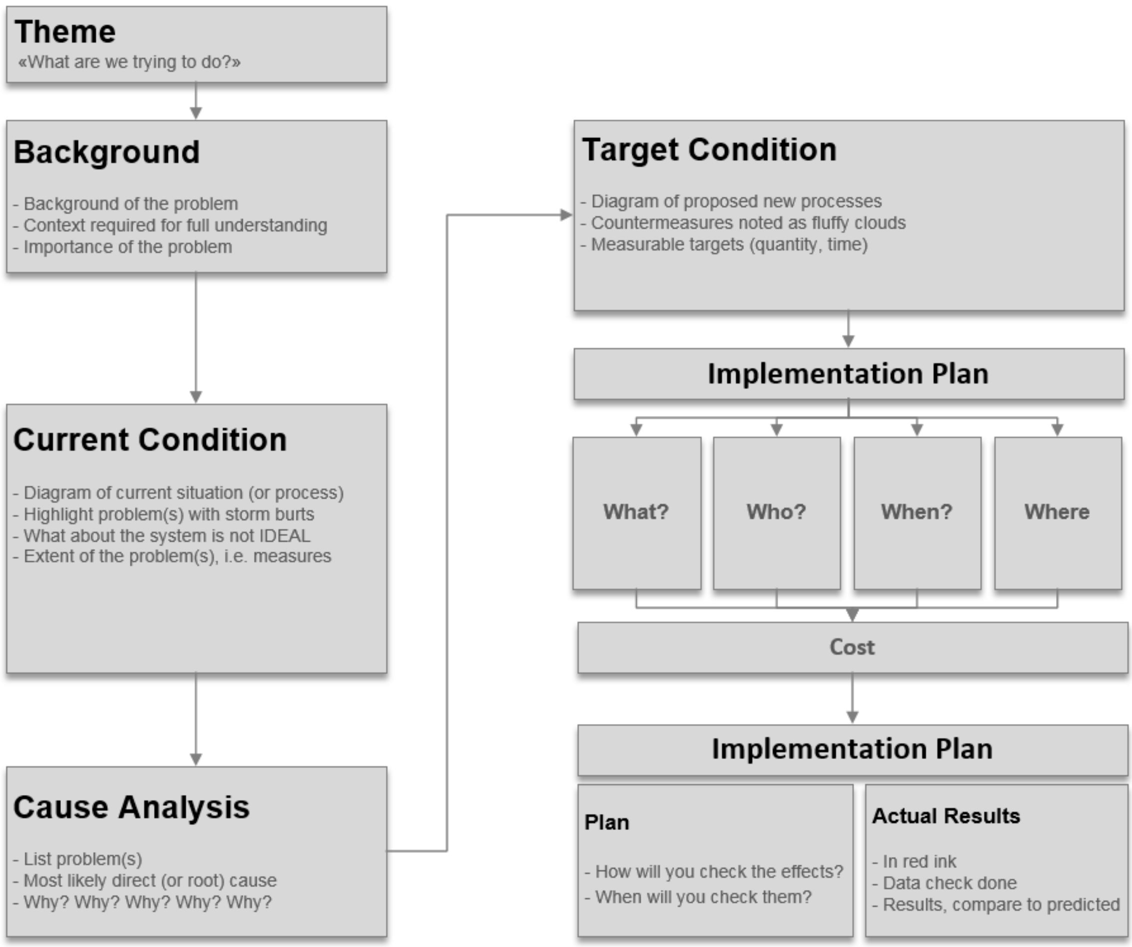

Figure 3.6: A3 Problem Solving Methodology. Adapted from Abilla [46]

3.5.2 Five Whys and Fishbone Diagram

The five whys is characterised by Taylor and Brunt [32] as an iterative interrogative technique first used in the TPS to explore the cause-and-effect relationship underlying a particular problem. The primary objective with the method is to determine the root cause of a problem by repeating the question "why" and exploring the response each time the question is asked, before the nature of the problem in addition to the solution becomes apparent [45]. In practice, the method provides no evident rules or line of questioning to explore. Even when the method is closely followed, Rolfsen [45] maintains that the outcome relies on the expertise and persistence of the people involved.

Consequently, the method is often combined with a *Fishbone Diagram*, or *Ishikawa Diagram*. In a Fishbone diagram, related causes for a specific problem are grouped together into categories and then organised into a diagram that resembles a fish skeleton, hence the name. Typical categories include items such as machines, materials, people or methods [47] as shown in the example depicted in Figure 3.7.

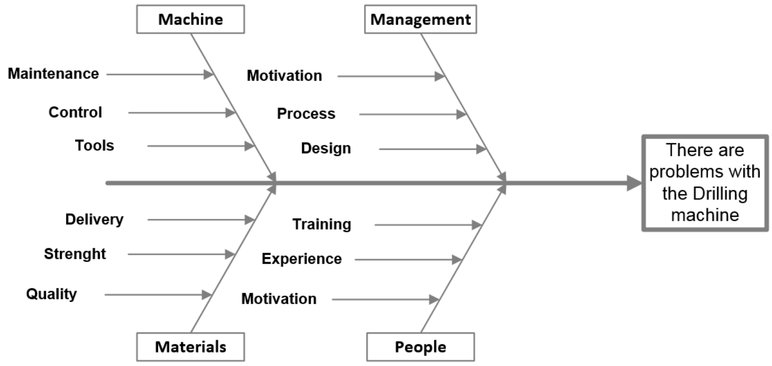

Figure 3.7: Example of a Fishbone Diagram for Investigation of a Drilling Machine. Adapted from Dobrusskin [47, p. 222]

3.5.3 Kaizen

Kaizen is a Japanese philosophy aiming at eliminating waste in all systems of an organisation through incremental improvement of standard activities and processes. Similarly, Alukal and Manos [48] view it as a strategy wherein the coordinated efforts of employees at all levels are required. Although the improvements may be small and incremental, the process brings about dramatic changes with time. Consequently, Kaizen therefore often works hand-in-hand with what's known as standardised work.

Whereas standardised work captures the current best practices for a process, Kaizen aims to find improvements for those processes. All activities along the value stream that creates value, is recognised as perfection. This perfection is pursued through a continuous cycle of improvement activities, known as Kaizen activities [49];

1. *Identify* an opportunity
2. *Analyse* the process
3. *Develop* an optimal solution
4. *Implement* the solution
5. *Study* the result
6. *Standardise* the solution
7. *Plan* for the future

3.5.4 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a key method initially developed from the foregoing TPS in 1995 with an underlying rationale for the collection and use of a suit of diagnostic tools to identify the waste in value streams [32]. The method is nowadays primarily utilised to analyse the current state of an organisation before deriving a future state based on the series of events that takes a product or service from its beginning to its end destination. The VSM methods starts as the organisation draws a current-state map to describe their current situation. Based on this, a future-state is drawn; a map that shows the state the organisation aims towards. Drawing upon both maps, an implementation plan is fashioned before the organisation starts working towards the future state. In Table 3.4, the seven most employed VSM tools are presented in terms of their correlation with the seven *muda* wastes introduced by Taylor and Brunt [32].

Table 3.4: The Seven Most Used VSM Tools. Adapted from Taylor and Brunt [32, p. 31]

	Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	Physical structure (a) volume (b) value
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H						L
Inappropriate processing	H		M	L		L	
Unnecessary inventory	M	H	M		H	M	L
Unnecessary motion	H	L					
Defects	L			H			
Overall structure	L	L	M	L	H	M	H

H = High correlation and usefulness, M = Medium correlation and usefulness, L = Low correlation and usefulness

3.5.5 Hoshin Kanri Planning

In *Out of the Crisis*, originally published in 1982, William Edwards Deming offered a theory of management based on his famous fourteen points for management [50]. The theory, later coined as Total Quality Management (TQM), was a systematic approach to quality improvement that married product and service specifications to customer performance. At the heart of both TQM and Lean, lies a unique business operating system that emerged during the 1950s and 1960s that added to the work of Deming [51]. The system, coined *Hoshin Kanri* by Bridgestone Tire in 1964, derives from the Japanese term for strategic planning and means management and control of the organisation's direction, focus or goal [51]. The purpose behind the method is to induce performance improvement by analysing current problems and deploying response to environmental conditions. Jackson [51] maintains that the key to organisational learning is to discover problems and solve them, and argues that hoshin kanri satisfy this requirement by applying the PDCA cycle.

3.5.5.1 The PDCA Cycle

The PDCA cycle (Plan-Do-Check-Act) is a four-step generic management method developed and based on the work by William Edwards Deming [52]. The approach is used for the control and continuous improvement of activities and processes by following the subsequent stages [51, p. 2-3];

- **PLAN**; Establish the objectives and processes necessary to deliver results according to the expected output.
- **DO**; Implement the plan, execute the process, make the product. Collect data for charting and analysis in the subsequent steps.
- **CHECK**; Study the actual results and compare against expected results. Look for deviation in the implementation and completeness of the plan.
- **ACT**; If the Check-phase demonstrates that the Plan, implemented in the Do-phase, was an improvement to prior standards, then this effectively becomes the new standard for how the organisation is to Act. If otherwise, then the existing standards will remain.

By applying PDCA systematically, hoshin kanri integrates planning and execution at all levels of the organisation [53]. This is achieved by aligning the goals of the company with the plans of middle management and the work performed by all employees.

3.5.6 Six Sigma

Since its conception and popularisation of General Electrics (GE) in the early eighties [54], *Six Sigma* has evolved from a being a mere statistical quality improvement technique, into an establish methodology with a comprehensive toolkit [55]. Nowadays, the methodology is acknowledged by Aruleswaran [55] as a business management system based on the rigorous, focused and systematic implementation of proven quality assurance principles and techniques. Moreover, it is an improvement method aiming at maximising quality by identifying and eliminating sources of defects [55, 56].

The main idea behind the methodology is to identify root cause of defects, and help figure out how to eliminate them through rigorous measurement and analysis using statistical theory. A terminology often considered synonymous with Six Sigma is the DMAIC Cycle (Define, Measure, Analyse, Improve and Control) a problem solving road-map [55]. The methodology, shown in Figure 3.5, takes a problem that has been identified by the organisation, and utilises a set of tools and techniques in a logical fashion to arrive at a sustainable solution(s) [56].

Table 3.5: The Six Sigma DMAIC Methodology. Adapted from Shankar [56, p. 1-104]

Process Step	Process Components	Key Analytic Tools
Define	Identify project, champion and project owner Determine customer requirements Define problem, objective, goals and benefits Define resources/stakeholder analysis Develop project plan Map the process	Process Mapping
Measure	Determine crucial Xs and Ys Determine operational definitions Establish performance standards Develop data collection and sampling plan Validate the measurements Conduct measurement system analysis Determine process capability and baseline	Time series charts Histograms and Pareto Graphs Measurement system analysis Process capability analysis
Analyse	Benchmark the process or product Establish relationships using data Analyse the Process Map Visualise the problem Determine root cause	Statistical tests Confidence intervals modelling Root cause analysis
Improve	Design and analysis of experiments (optional) Develop solution, cost and benefit alternatives Assess risks of solution alternatives Determine root cause	Design of experiments Regression modelling Root cause analysis
Control	Statistical process control Determine needed controls Implement and validate controls Develop transfer plan Realise benefits of implementing solution Close project and communicate results Statistical process control	Statistical process control

3.5.7 Lean Six Sigma

The concept of combining Lean and Six Sigma principles began in the middle to late 1990s, and quickly took hold as organisations recognised the synergies evoked by integrating approaches from both methodologies, as depicted in Figure 3.8. Whereas Lean aims to reduce waste, Six Sigma in contrast focuses its attention on improving the quality of process outputs by identifying and removing the causes for waste and reducing the variability in processes. Consequently, Furterer [54] therefore argues that Lean Six Sigma combines the best of both worlds into one unified path in which the focus lies on both improving quality, reducing variation and eliminating the seven *muda* wastes within an organisation, following the DMAIC phases like that of Six Sigma.

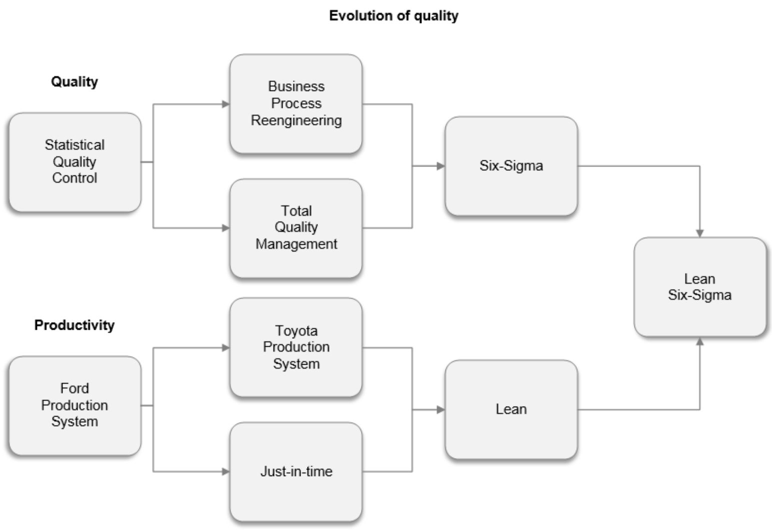

Figure 3.8: Evolution of Lean Six Sigma. Adapted from Furterer [54, p. 12]

3.6 Performance Measurement

By nature, *performance measurement* is a diverse subject, hence the terminology used by academics is often varied [57]. A straightforward definition of the term is given by Bititci et al. [58, p. 524] who presents performance measurement as "an approach by which the company manages its performance in line with its corporate and functional strategies and objectives". Neely et al. [59, p. 80-81] contrarily, express performance measurement as "the process of quantifying the efficiency and effectiveness of action". In this thesis however, performance measurement is primarily defined in line with the definition by Hatry, as "regular measurement of the outcomes and efficiency of services or programs" [60, p. 1]. The important element in this definition is the regular measurement of results or outcomes.

According to Neely et al. [59, p. 80], the level of performance a business attains, is a function of the efficiency and effectiveness of the actions it undertakes. That is to say, whereas efficiency is concerned with doing things right, effectiveness is a question of undertaking the right things. Performance measures or indicators can be defined as metrics used to quantify this efficiency or effectiveness of an action [59, p. 80]. As pointed out by Lebas [61], performance measures provide knowledge on past performance, which helps to understand the current situation in an organisation, in addition to supporting the design of actions, plans and defining future targets.

When the targets have been set, measurement needs to support continuous improvement and planning activities. In literature, different types of measures are discussed by a variety of scholars. In this thesis however, the main emphasis has been placed upon *Key Performance Indicators* (KPIs).

3.6.1 Key Performance Indicators

In their work, Badawy et al. [62, p. 1] presents four types of performance measures:

1. **Key Result Indicators (KRIs)**; tells how one has achieved in a perspective or critical success factor.
2. **Result Indicators (RIs)**; conveys what it is that has been done.
3. **Performance Indicators (PIs)**; tells what it is that must be done.
4. **Key Performance Indicators (KPIs)**; tells what to do to highly increase performance.

The relationship between these four types of performance measures have been included in Figure 3.9, wherein the layers represent the various performance and result indicators, and the core represents the Key Performance Indicator [62, p. 1].

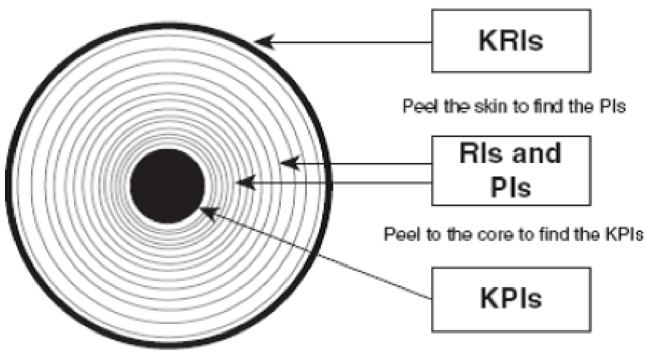

Figure 3.9: The Four types of Performance Measures. From Badawy et al. [62, p. 1]

The latter of the four, henceforth referred to as KPIs, are quantifiable measurements utilised by management to steer the focus of an organisation towards a few vital priorities that keep or bring the organisation into alignment with the demands of its markets. These vital priorities are furthermore utilised to evaluate the success of an organisation or of a particular activity in which it engages [8]. KPIs can also be defined as measurable values whose intentions are to express how well a business is adhering to its business model and strategies. Hence, KPIs very much vary between companies, depending on their priorities or performance criteria. According to Peng et al., KPIs can be divided into three types [63, p. 1];

1. **Leading indicator**; a KPI that measures activities with significant effect upon future performance.
2. **Lagging indicator**; a KPI that measures the output of past activities.
3. **Diagnostic measure**; a KPI that is neither leading nor lagging, but signals the health of processes or activities.

3.6.2 Metrics Tree

Amidst the vast number of methods providing opportunities for developing KPIs nowadays, McWhirter and Gaughan [64] presents an effective method called the "Metrics Tree" or "KPI Tree" [64]. The Metrics tree helps visualise how strategic objectives are turned into operational objectives and defined as measurable KPIs through a comprehensive list of strategic principles divided in three stages; strategic, tactical and operational.

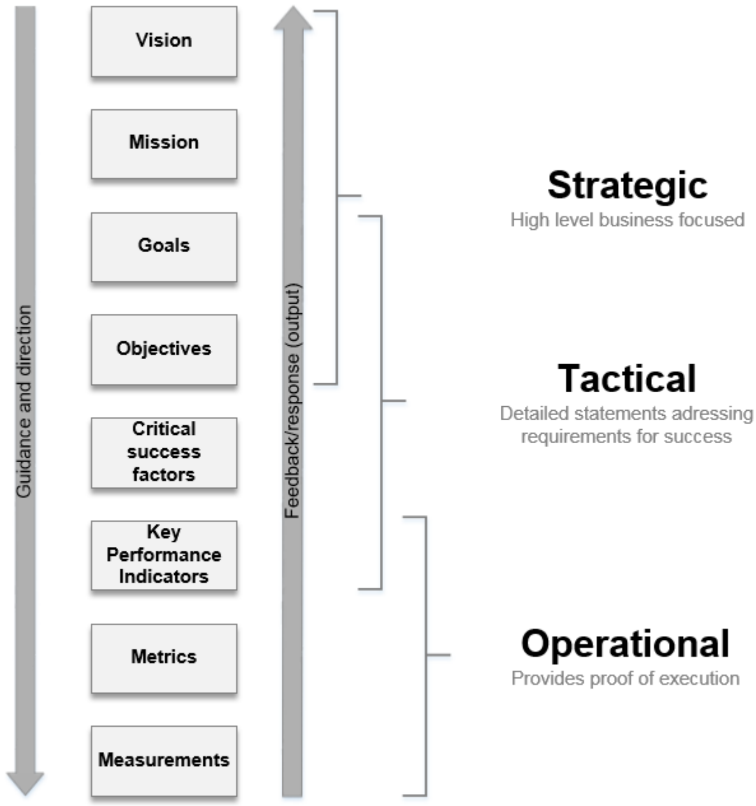

Figure 3.10: The Metrics Tree. Adapted from McWhirter and Gaughan [64, p. 26]

The tree from Figure 3.10 helps organisations establish measurement standards and purposes by ensuring that the vision and mission statements are consistently addressed at all levels [64]. From maintaining goals and objectives, critical success factors are established to ensure accomplishment. To support the critical success factors, quantifiable KPIs are determined. From these, McWhirter and Gaughan suggests to select a few quantifiable metrics which will provide the data and information required to provide feedback and response back to the higher levels of the metrics tree [64, p. 25].

In short, the metrics tree assures that the strategy objectives are implemented in the KPIs using a top-down approach, before these in turn are reported back to the higher levels using a bottom-up approach.

3.6.3 Measurement Approaches in E&P

In the wake of recent trends in the industry, wherein E&P organisations now are required to adapt to the oil-price downfall, the need for new innovative approaches are required to adequately measure and control an organisation. Conventional performance measurement approaches have from time to time been proven ill-suited for this purpose as they tend to focus on meeting budgets and avoiding risk, thus effectively penalising innovative behaviour. Among the recent innovative approaches is the Best in class (BIC) [65]. The BIC is habitually used by operators to measure and compare the actual performance to the best planned or historical performance achieved on past wells, in both sections or activities.

This type of benchmarking is a way of discovering whether performance is achieved, either internally in a company, by a competitor or by an entirely different industry. The information can in turn be utilised to identify process gaps in an organisation. The use of this measure is a suitable indicator showing whether continuous learning is being achieved or not, as it demonstrates the remaining potential of the current setup.

When using the BIC, E&P operators often begin by deciding what to benchmark in terms of processes related to well planning, construction or abandonment. The operators subsequently determine a benchmark for themselves, e.g. the fastest times ever achieved for each phase on a past well. These times are then added, thus providing a target for measuring the gap between the optimal and the actual performance. As Rushmore [65, p. 2] maintains, the gap indicates whether fine tuning or optimisation of the existing processes enables the operator to verge upon the target, or if more radical changes are required.

3.6.4 Lean KPIs

Some organisations have attempted to increase operational efficiency in their performance measurement systems by incorporating Lean. However, these efforts often fall short, due to limitations in aligning Lean objectives and strategic management. Furthermore, it remains difficult to evaluate the leanness of such systems due to the lack of relevant indicators and methods to evaluate them. The definition of Lean measures is to be realised in adequacy with a predefined objective [66]. Hence, Cortes et al. [66] argues that:

> "[...] in the case of improving a systems performance, the objective should be in line with the company's strategic objectives and in adequacy with the competitive environment and market characteristics" [66, p. 66].

According to Cortes et al., the identified performance measures for the evaluation and implementation of Lean should "[...] reflect the organisations strategic objectives and facilitate the alignment between strategic, tactic and operational performance" [66, p. 66]. For any type of industry Cortes et al. [66] classify strategic measures into five categories; Cost, Quality, Flexibility, Stock and Lead Time. Their suggestion is that the company should start using Lean performance measures as these are designed to initiate continuous improvement, rather than adjudicating the performance of individuals, thus creating undesirable competition in the value stream.

In their work, Behrouzi and Wong [67] performed an extensive review to identify Lean performance categories and respective KPIs regardless of industry, culminating in a complied list of 148 Lean KPIs. Subsequently employing four experts with hands on experience with in the field, enabled Behrouzi and Wong [67] to identify and filter out the 78 most important KPIs corresponding to the doctrine of Lean.

The list of these 78 KPIs have been included in full in Table B.1 in Appendix B. In the ensuing subsection, several of the Lean KPIs from Table B.1 have been further described.

3.6.4.1 Takt Time, Cycle Time and Lead Time

In traditional Lean, the Takt Time T_{takt}, is defined by Santos et al. [68] as the pace at which the customer requires its products;

$$T_{takt} = \frac{T_{AP}}{D} \tag{3.4}$$

Where T_{AP} is the Available Production time in days and D is the Demand by customers. The Cycle Time moreover, is defined by Santos et al. [68] as the time it takes to execute one activity from start to finish. Lead Time lastly, is demarcated as the process time of the entire value stream; the sum of all cycle times.

3.6.4.2 Additional Lean KPIs

The Process Cycle Efficiency (PCE) from Table B.1 is according to Marr [69] defined as the value added ratio; a measure of the efficiency of a process. The metric is estimated by dividing the VA time within a process by the total duration time. Waiting Time moreover, occurs when the activities have stopped for some reason, with subsequent activities having to waiting before being commenced [69]. Utilisation subsequently, is defined by Marr [69] as the fraction of actual output to the design capacity, or alternatively as the percent of the total design capacity. Whereas On Time Delivery (OTD) measures the efficiency of a process by estimating the products or services delivered within time and in full, Excess Time estimate the time spread between the total Cycle Time and the Takt Time [69].

3.7 Performance Management

A key characteristic of performance measurement is according to Hatry [60], regular tracking of vital components. Although the central function of any performance measurement process is to provide regular, valid data on indicators of performance outcomes, Hatry [60] argues that the process should not be limited to data on outcome and efficiency indicators. It should also namely include information that helps management measure the incoming workload and gain insight into the causes of outcomes. Hence, whereas performance measurement encompasses the collection, analysis and reporting of performance information in an organisation, performance management is in contrast the overall process of utilising that information to improve.

Although the phrase *performance management* was first coined in 1976, the term was not formally recognised as a distinctive approach until the mid-1980s. Since then, the term has been widely viewed as an indispensable pre-requisite for management, and illustrates in general structures and processes of an organisation. In their work, Qureshi et al. [70, p. 1856] simplify performance management as a system that continuously describes, evaluates, executes and improves organisational performance. Hence, it is an important requirement for planning and controlling through supporting information, creating transparency and support for the decision made by management.

In the E&P industry, organisations and their managements need frequent outcome information to assess the success of projects, identify where significant problems exist and not least motivate personnel to strive for continuous improvement. If the right things are not measured, or even measured correctly, those organisations who use the data may be misled, leading to badly made decision.

3.7.1 Performance Management System

In a six-volume journal, Artley et al. [71] describes a systematic approach to performance improvement through an ongoing process of establishing strategic performance objectives; measuring performance, collecting, analysing, reviewing and reporting performance data; and using that data to drive improvement [71, 72]. Artley et al. [71] argues that performance management in simplest terms, is the comparison of actual levels of performance to pre-established target levels of performance. To be effective, Artley et al. [71] notes that performance management must be linked to the organisational strategic plan. Flowing from the foregoing definition, Artley et al. presents a six steps model to establish a performance management system;

1. **Step 1**; Define organisational mission and strategic performance objectives.
2. **Step 2**; Establish an integrated performance measurement system.
3. **Step 3**; Establish accountability for performance.
4. **Step 4**; Establish a process or system for collecting data to assess performance.
5. **Step 5**; Establish a process or system for analysing, reviewing and reporting performance data.
6. **Step 6**; Establish a process or system for using performance information to drive improvement.

The model essentially uses performance measurement information to manage and improve performance and to demonstrate what has been accomplished, following a methodology like the Plan-Do-Check-Act (PDCA) cycle. Once the necessary changes have been determined in step six, the cycle restarts [71]. It should be noted that accountability for performance is established in all steps in the framework.

3.7.2 Performance Management Models

There exist nowadays a vast number of frameworks providing extensive opportunities for managing and measuring performance. Quagini and Tonchia [73] reveals that the most common models tend to emphasise one of three architectural features. In thesis only two types have been emphasised. The first type, referred to as hierarchical models, aim to synthesise low-level measurement, such as operating measurement, into higher level aggregate measures which translate into economical and financial results. The second type, referred to as Tableu de Bord models, considers the various classes of performance separately, without outlining the precise hierarchical relationships between the various performances. An example of a popular framework for each model is presented below.

3.7.2.1 Performance Pyramid

Among the most hierarchical models referred to in literature is the Performance Pyramid, also known as the SMART (acronym for Strategic Measurement Analysis and Reporting Techniques) [73]. The model includes a hierarchy of financial and non-financial performance measures. Similar to the Metrics Tree, the performance pyramid illustrates how the achievement of the vision may be cascaded down through the different levels, as depicted in Figure 3.11. Here the different bricks represent the core performances to be measured and managed. The graphic representation, and overlapping of the bricks, display the components of a higher level of performance. The performances shown to the left are externally oriented, whilst the performances on the right are internally oriented [57].

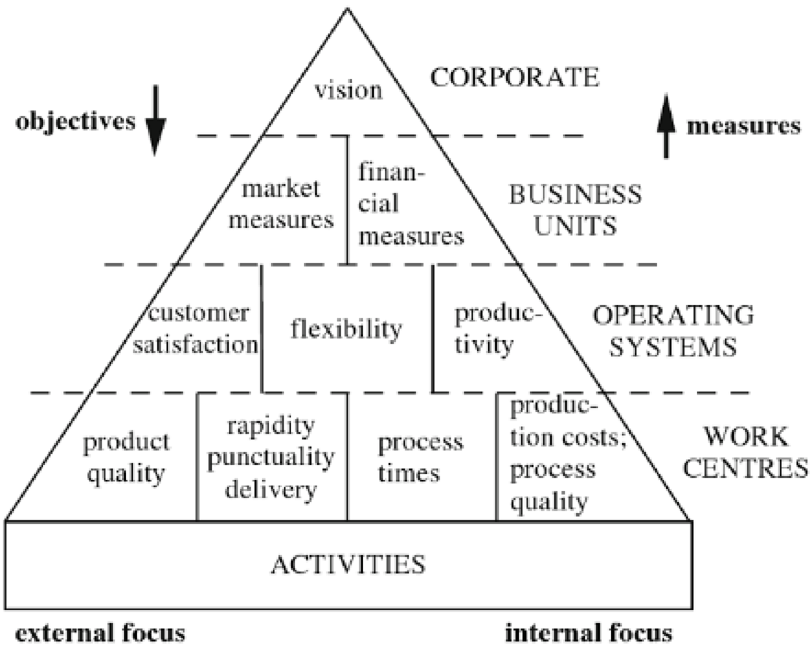

Figure 3.11: The Performance Pyramid Model. From Quagini and Tonchia [73, p. 45]

3.7.2.2 Balanced Scoreboard (BSC)

The most cited by far of Tableu de Bord models, is the Balanced Scoreboard (BSC), first developed over a year-long project by Kaplan and Norton in 1992 [73]. In general, the BSC provides managers with the opportunity to report and manage performance under four perspectives closely matching the main stakeholders of an organisation; Customer, Internal business process, Financial, and Innovation and Learning. The model thus provides a link between the espoused strategic objectives of an organisation and the performance measures it uses to monitor and control the strategy implementation [57]. By requiring no more than four performance measurement areas with centrally importance, the model helps organisations to compensate for the tendency to construct numerous performance indicators [57].

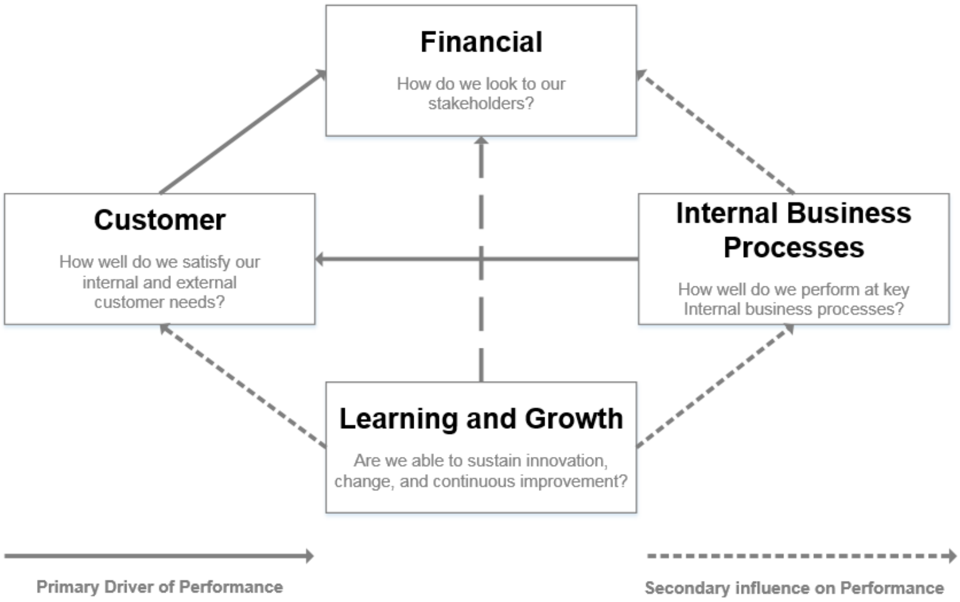

Figure 3.12: The Balanced Scoreboard Method. Adapted from Artley and Stroh [72, p. 20]

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Chapter 4

Research Findings

This chapter presents the main findings from this study derived in accordance with the methods and conceptual framework presented in Chapter 2, focusing on the chief research objectives outlined in Section 1.4. The chapter begins by determining the principles for performance management and measurement in Aker BP, D&W and Det norske, before investigating the strategic direction in D&W and determining the most critical area of operations. The chapter then continuous by investigating prior KPIs and new practical solutions for performance management in terms of Lean and continuous improvement, thus forming the basis for the discussion in Chapter 5.

4.1 Principles for Performance Management

The principles for performance management in Aker BP and D&W are briefly described in this section with basis in several documentary analyses of company governing models and internal strategy documents, accessed through the company's intranet. The purpose has been to identify critical elements to ensure compatibility with new practical solutions for performance management in D&W.

4.1.1 Performance Management in Aker BP

From a review of governing models, the documentary analyses identified four critical elements in the framework for performance management in Aker BP [74]:

1. **Performance Objectives**; Detailed direction according to strategies and plans with, specific targets and measures to state the direction.
2. **KPIs**; Identification of the right drivers and indicators to meet the objectives.
3. **Actions**; What to do in order to improve and reach objectives. This also includes corrective actions to get back on track.
4. **People**; Translation and link to what performance goals, KPIs and actions means to the employees as teams and individuals.

The performance management process, as described in governing models, begins by developing strategically focused performance objectives in the form of KPIs, before evaluating feedback using a holistic approach. To increase the flow efficiency and ensure progress control, the company has adopted both leading and lagging indicators when measuring performance. The employees in each team and department across the value chain subsequently performs the actions and planned work. Information on how the teams and departments are doing is then retrieved through data collection and made easily available by digital performance dashboards, displayed across the hierarchic levels in the company, thus capturing both financial and non-financial performance. Results are then provided for management, who in turn provides feedback to team leaders. Afterwards, performance is analysed before any deviations from the normal state is immediately addressed. This includes brief, but regularly performed improvement meetings to identify new ideas and problems, and to follow up on improvement activities.

4.1.2 Performance Management in D&W

The recent developments for performance management in D&W have been develop in line with an ongoing digitisation process, drawing upon the principles from Lean and flow efficiency described in the literature review. An illustration of the management framework is reproduced in Figure 4.1, as part of the documentary analysis. The principles for performance management in D&W have, as evidently depicted in Figure 4.1, been largely based on the PDCA- cycle, following an adapted PLAN-DO-STUDY-ACT approach in a continuous cycle. In the first PLAN stage, the teams in D&W involve all stakeholders when communicating and planning the performance objectives. In the subsequent DO stage, performance is measured according to the plan before reporting any apparent deviations. In the third STUDY stage, the performance is monitored, before feedback is provided back to respective parties. In the last ACT stage, the teams share their experiences before addressing and implementing learning.

Much like the framework at the company level in the prior section, this framework also emphasises people, based on the idea that an integrated team have closer cooperation, common understandings and run more efficient processes.

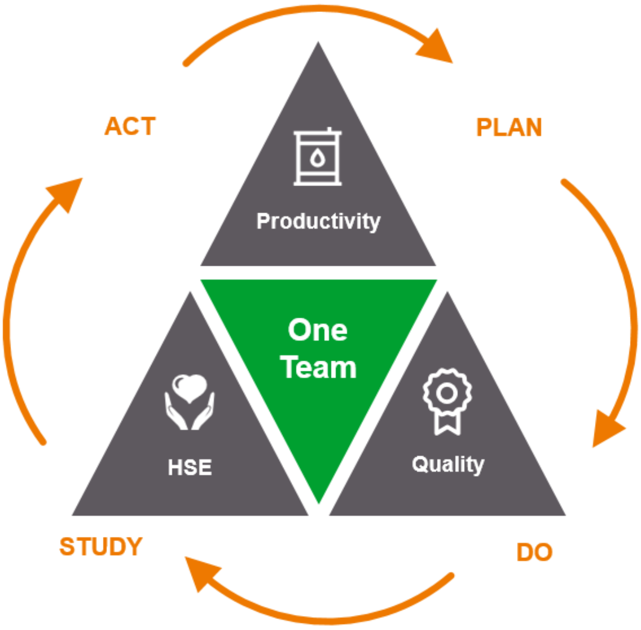

Figure 4.1: Performance Management Framework for D&W. Courtesy of Internal Sources Aker BP, D&W

To ensure good performance, the framework in Figure 4.1 relies on core focus areas being highly relevant and valuable in D&W. These were identified from analyses as Productivity, HSE and Data Volumes respectively. The target for each category moreover, was identified as being:

- **Productivity:** to be recognised as an industry benchmark in everything we do (Best In Class).
- **HSE:** to have no incidents, accidents or damage to the environment.
- **Quality:** to have all well activities and deliverables meet design intent.

For all three categories, in-house engineers are currently along with key analysts to develop new high-level KPIs for performance measurement. As the development process is still ongoing, the lack of available information resulted in the documentary analysis being unsuccessful in describing further use of these KPIs. Further research has therefore included analyses of prior practices in Det norske to describe performance management with emphasis on performance measurement.

4.2 Performance Management in Det norske D&W

This section reports in brief the prior performance management system in Det norske D&W, from 2016, as defined by an interview respondent. It should be noted that the following system is tied to the overall performance management in three main areas of exploration, field development and production. The findings from the interview have been included in Appendix A, and are described here in terms of the key concepts discovered and explored with the respondent.

4.2.1 Prior Performance Categories

In a series of initial questioning, the interview prospect explicated that the performance in Det norske D&W had been related to three categories; Subsurface data, Drilling performance and HSE, respectively. When asked, the interview prospect subsequently disclosed apparent limitations with the prior system. Evidently, findings suggested that not all the categories for performance had been incorporated successfully within the department's system at the time;

> *"Primarily we used three types of KPIs. [...] The first type was related to Subsurface data. This was however not fully incorporated in Det norske at the time. The second very important type was Drilling performance [...] The last element was HSE."* (Manager, Subdivision in D&W).

When confronted with these three categories, the interview prospect recalled that the category pertaining to Subsurface data had mostly been related to obtaining petroleum and petro-physical data from offshore surveys. For Drilling performance moreover, the interviewee particularly accentuated two KPIs, being Drilling efficiency and Well Non Productive Time (NPT); the total non-productive time not directly associated with manufacturing operations or performance of a job or task. When further asked about the category HSE, the interview subject replied that;

> *"[...] in every company there is a different definition of these [...] and what they actually measure."* (Manager, Subdivision in D&W).

For D&W in Det norske, two specific types were repeatedly mentioned, namely serious and minor incidents;

> *"One primary measure was of course serious incidents, which one does get fairly much warning for in advance [...] another included minor incidents which at a later stage could result in a serious one, such as dropped objects."* (Manager, Subdivision in D&W).

Besides measuring acute discharges from the hired offshore installations, the interviewee clarified that intention had been to measure minor incidents in order to forecast a trend and subsequently predict the feasibility of major incidents;

> *"[...]the minor incidents often indicated the potential for greater incidents [...] Measuring the trend in minor incidents could aid in the determination of when greater incidents could occur."* (Manager, Subdivision in D&W).

In furtherance of reporting, the interviewee then remarked that performance in these three categories had been primarily been reported to two areas; the company's management or their respective business unit.

In light of these discoveries, a series of follow-up questions in conjunction with findings from documentary analyses carried out beforehand, culminated in a comprehensive list of previously utilised KPIs and corresponding units. Table 4.1 below summarises the performance categories Drilling performance and HSE, their respective KPIs, units and area of reporting. Subsurface data, not being fully incorporated at the time, have not been included.

Table 4.1: KPIs from Det norske D&W Performance Reporting, 2016. Courtesy of Internal Sources, Aker BP D&W

Area	KPI	Unit
Company	Occupational safety (TRIF)	Per 1 mill. mhrs
Company	Serious incidents (SIF)	Per 1 mill. mhrs1
Company	Drilling efficiency*(1)	Meters per dry hole days
Business Unit	Well NPT*(2)	%
Business Unit	Net DRILLEX (excl. non-op exploration)*(3)	MNOK
Business Unit	Cost deviation to AFE budget	%
Business Unit	Wells drilled and completed*(4)	Qty
Business Unit	Serious well control incidents*(5)	Qty
Business Unit	Acute discharges*(6)	Qty

1: Average drilling efficiency on all Det norske operated wells drilled in 2016 (excluding coring and logging)
2: Average non-productive time on rigs, excluding WOW
3: DRILLEX ”new FC” include
- Management and rig ready costs for rig
- Tangible cost spent per previous year for wells to be drilled by rig next year

4: Including geo-pilots and work-overs
5: Red and yellow incidents according to well control classification matrix from ”Norsk olje & gass”
6: A and B incidents as defined in Det norske classification matrix

From Table 4.1, the units corresponding to drilling efficiency and well NPT, are estimated in meters per dry hole day[1] and percent NPT of total time in days, respectively. In addition, Table 4.1 also included several financial and non-financial KPIs identified during documentary analysis prior to the interview; the Net DRILLEX, costs for rig and cost of operations, cost deviations from budget, and the number of wells drilled and completed.

Besides those covered in Table 4.1, the interview subject moreover confirmed that offshore engineers regularly reporter the time and efficiency of activities performed offshore.

4.2.2 Process of Measurement

In the second part of the interview, the subject was asked specifically about the process of measurement. From the respondent's replies, there was strong evidence to suggest that the engineers in Det norske had measured performance across many levels. On account of several informal inquiries posed by the researcher, the respondent explained that the intent with the prior management system had been to monitor and control operations to deliver the required well data.

However, whereas the objective had been to deliver data of the right quality, the teams had in contrast exhibited a tendency to focus upon completing specific operations;

[1]The elapsed time in days from breaching the seabed (spud), to when the drill-bit is returned to the drill floor after reaching True Depth (TD), or at the end of logging or under-reaming of the well-bore

In Det norske, we used to manage performance on many levels. [...] Delivering data on the field was first and foremost the primary objective. [...] In D&W at the time, we had a tendency to think to much about the cementing of the well. This was as I remember our main priority [...] the main priority as it should have been, was to deliver the correct data, with the right quality." (Manager, Subdivision in D&W).

When asked about the usage of the aforesaid KPIs, the interviewee thereon explained that a plan was established to deliver a well in pre-determined sections to maintain the proper well control, wherein the actual delivery had been compared;

"The well was to be delivered by the use of certain sections [...] we were to place the casings in the ground at specific depths and maintain well control etc, in addition to plan the time and cost for these elements." (Manager, Subdivision in D&W).

Further questioning of the interviewee affirmed that the sets of KPIs had then been updated regularly over the course of well projects, by accountable parties *"[...] using excel programs and dashboards."* (Manager, Subdivision in D&W).

An illustration of a typical performance dashboard for performance management in Excel from Det norske have been included in Figure 4.2.

	Area	KPI	Measure	Target	Stretch	YTD	% Achievement	New FC	Latest update
KPIs	Company	Occupational safety (TRIF)	Per 1 mill. mhrs	< 3.5	< 2.5	0	1		31.12.2015
		Serious incidents (SIF)	Per 1 mill. mhrs	0	0	0	1		31.12.2015
		Drilling efficiency[1]	Meters per dry hole days	110	130	155	1		31.12.2015
	Business Unit	Well NPT[2]	%	< 20%	< 10%	19 %	1		31.12.2015
		Net DRILLEx (excl. non-op exploration)[3]	MNOK	2 546	2 423	2 673	1		31.12.2016
		Cost deviation to AFE budget	%	± 10%	± 5%	-5 %	1		31.12.2016
		Wells drilled and completed[4]	Qty	7	8	10	1		31.12.2016
		Serious well control incidents[5]	Qty	0	0	0	1		31.12.2016
		Acute discharges[6]	Qty	0	0	0	1		31.12.2016
		Total achievement					100 %		31.12.2016

Figure 4.2: KPI Dashboard from Det norske D&W 2016. Courtesy of Internal Sources, Aker BP D&W

Figure 4.2 demonstrates how the KPIs are regularly updated by D&W personnel in the rightmost column. To the left, a description of each KPI, main area and units is shown. When asked about any apparent drawbacks to this particular system, the interview prospect discreetly disclosed that reporting in the prior system had been primarily performed by individual engineers. A drawback to several of the KPIs was namely a high degree of complexity. Hence, as the nature of most of the KPIs were too technical, evaluations of performance were left for the respective business units' teams and engineers, rather than unbiased third parties in the department;

"The responsible party primarily consisted of the engineers responsible for the specific operations [...] it was not an own department [...] the KPIs were so heavily based on operations, that it had to be engineers who made the evaluations." (Manager, Subdivision in D&W).

The interview subject furthermore maintained that the system in Det norske had mainly emphasised defining strategic performance targets, in terms of data acquisition, production of hydrocarbons, cost and time of execution, before measuring accordingly;

> *"[...] we wrote down the objectives with the wells in terms of data acquisition to be delivered, production of hydrocarbons or in the shape of cost of execution to deliver the production or data [...] Primarily time, budget, HSE, Weather, Invisible Lost Time and Effective Time were our primary concerns. We then estimated whether we had delivered."* (Manager, Subdivision in D&W).

The process commenced by estimating a median cost (P50) from an international database called Rushmore Reviews[2], prior to ordering equipment, and measuring and reporting the actual performance according to the plan and budget;

> *"We initially made a budget for the well based on a P50 estimate from Rushmore Reviews. We then made our own P50 for the budget for the well, prior to ordering equipment and start measuring the real performance compared to the plan, or budget."* (Manager, Subdivision in D&W).

Rather than focusing on delivering the correct data at the right quality, a main criterion interestingly discovered, was the objective of coming within the planned budget and time, known as the Authority For Expenditure (AFE);

> *"One of the main criterion was to be within the planned budget and time set by the AFE. That was probably our main focus, delivering the well within the time and budget[...]" (Manager, Subdivision in D&W)*

Additional sub-questioning of the interviewee regarding the planning of the well, also identified a tendency of over-budgeting amongst D&W engineers. This implied that the teams in Det norske D&W were seldom pressed on delivering high performance, thus limiting both learning and efficiency;

> *"There was a tendency to make the budgets as comfortable as possible [...] This meant that the engineers were not pressed to cut cost or time."* (Manager, Subdivision in D&W).

An evaluation on whether the department had delivered according to plan was lastly given before the teams *"[...]would report back to Rushmore, thus continuously updating our own data-foundation."* (Manager, Subdivision in D&W).

[2] International Service Company that collects, analyses and publishes offset well data for participating operations in the oil industry

4.3 Strategic Direction for D&W

The purposes of the previous sections were to determine current practices for performance management in Aker BP and D&W, and moreover the critical elements encompassed the prior system in Det norske D&W. To delimit the scope of research, the accentuation of the subsequent section has been to identify the most critical area related to the work performed across well operations in D&W, based on a consecutive documentary analysis of an internal document coined "How We Work" [12]. The document represents the culmination of efforts invested by the teams in D&W to define and describe the department's strategic direction. Due to confidentiality agreements, the document have not been included in this thesis. Instead, a concise summary of its contents has been validated and replicated in Table 4.2, including strategic elements and correspond brief descriptions.

Table 4.2: Strategic Direction for D&W. Courtesy of Internal Sources, Aker BP D&W

Strategic Element	**Description**
Vision	*Simply the best and most attractive wells team in the world*
Mission	*Deliver world class well activities*
Values	**S**økende (enquiring) **A**nsvarlig (responsible) **F**orutsigbar (predictable) **E**ngasjert (committed) **R**espectfull (respectful)
Principles	1. Customer in focus
	2. Efficient decision making
	3. Radical and continuous Improvement
	4. High information flow
	5. Fit for purpose
	6. Consistency
Overall targets	1. Building the world's best and most attractive wells team
	2. Focusing on D&W role in the E&P value chain and deliver value to Aker BP
	3. CAPEX (Capital Expenditure) reduction of 50%

At the top in Table 4.2, the vision for D&W is defined as "Simply the best and most attractive wells team in the world". This defines what D&W would like to accomplish in the long-term future, and serves as a clear guide for choosing current and future courses of action. Their mission to "Deliver world class well activities" conversely, defines what D&W would like to accomplish. What's more, Table 4.2 also highlights the departments principles, wherein *Customer in Focus* is mentioned first. To make their strategy operational, three targets were established. In light of the company's' focus on Lean, two of the three targets were deemed more critical; focusing on their role in the E&P value chain and reducing their Capital Expenditures (CAPEX) with 50%. In consequence, these targets have been predominantly emphasised when exploring areas most critical to D&W.

4.3.1 D&W Role in the Value Chain

Both in the interview and through several rounds of discussion, internal sources in D&W made abundantly clear their shift in attention from cost management and internal headcount towards improvement efforts on core competencies. One element repetitively mentioned was the department's drilling cycle; the elapsed time it takes from when a license is awarded, to the point when oil is first produced during the lifetime of a field.

Internal sources in D&W have estimated that by reducing the drilling cycle, shown in Figure 4.3, from its current state from fifteen to seven years, thus putting wells into production in a timely manner, could thereon result in cost-avoidance and an increased number of wells produced. This could in turn profoundly extend the company's competitive advantage as well as accelerate profitable growth.

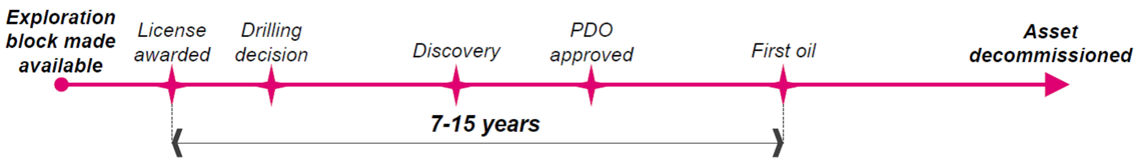

Figure 4.3: The Drilling Cycle Time Line. Courtesy of Internal Sources, Aker BP D&W

A modest VSM encompassing the entire drilling cycle was established in Figure 4.4, in furtherance of visualising the various phases.

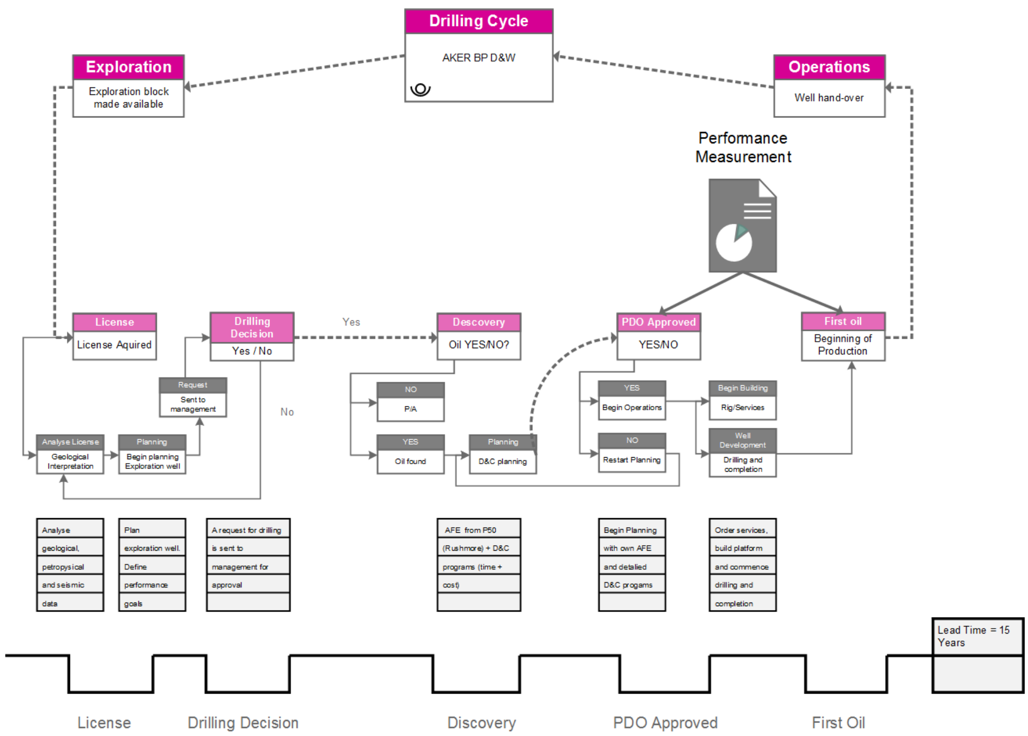

Figure 4.4: VMS of Drilling Cycle in D&W

The phase between Plan for Development and Operation (PDO) and first oil in Figure 4.4, is hereby referred to as *field development*. For an average offshore operator as Aker BP, the interview subject in D&W suggested that field development activities; rig operations and drilling and completion of O&G wells; accounts for;

> *"[...] an estimated 40 percent of the company's total cost."*
> (Manager, Subdivision in D&W)

These costs include the development of different well types; exploration, development, and sometimes also plugging and slot recovery. On average, half of these costs are spent on leasing rigs, with the remaining half being invested in equipment, engineering services, consumables or project management. For D&W, the interview prospect furthermore affirmed that approximately;

> *"40 percent of the total time is heavily invested in rig time* (Manager, Subdivision in D&W).

This suggested that any compression and optimisation of the activities making up the latter part of field development in Figure 4.4, hereby referred to as *well development*, would have a direct benefit to the company's bottom line.

4.3.1.1 Well Development

A brief description of the well development process has been elaborated below to provide the reader with a better understanding of the current problem and its context. The emphasis has been on describing the most typical and cost-influential activities occurring on offshore installations as identified upon review of daily drilling and completion reports. The process consists in general of the development of one or more vertical or horizontal wells, or supplementary infill wells should the potential production volumes exceed the initial estimates.

Depending on the offshore rig type, the process typically commences by transporting the rig-installation to the well-site. Upon arrival, the rig is anchored (moored) to either pre-existing or new-run anchors, prior to the construction of well-pads, access roads, gathering of pipelines, and other ancillary facilities. Subsequently, the rig-crew commence rigging up the necessary equipment for drilling. As the well is drilled by third-party drilling operators in sections, casings are subsequently placed in the well to stabilise the hole and isolate water bearing and hydrocarbon bearing zones. The casings are then cemented in place using a cement-stinger, placing the cement outside the full length of the casing, and inside at the casing-shoe.

Drilling then commences by drilling out the casing-shoe cement, before continuing along the planned trajectory. Having drilled the two first sections, a Blow-Out-Preventer (BOP) is commonly placed on top of the well-bore to seal, control and monitor the well, and prevent potential blowouts. Depending on planned number of side tracks, one or more Whipstocks[3] may be placed along wellbore the ensure the correct trajectory. In addition, pilot holes may be drilled to investigate the geology, before being Plug and Abandoned (P&A).

Usually the operator will from time to time have third-party service companies on board to perform and or run logging serves, cementing operations and control of drilling tools. The service company also places the necessary completion tools along the well-bore during drilling of the sections. Having drilled the well to the final True Vertical Depth (TVD) at the reservoir, a final production string is inserted, extending the full length of the well-bore and encasing the down-hole production equipment. The last completion equipment is then placed in-hole before securing the well, pulling back the BOP, recovering anchors and handing the well over to operations.

[3] Angular casing tool used to control trajectory

Additionally, the well development process also includes a variety of minor activities; maintenance, rig move, surveys, circulation of cuttings debris, rig up and down of drilling, cementing and completion equipment, communication with onshore and repair work. These activities does not directly contribute to the physical drilling and completion down-hole, but are quite necessary regardless. For any further descriptions regarding the well development process, reference is made to Table B.2 in Appendix B.

4.3.2 Capital Expenditure (CAPEX)

The CAPEX are funds D&W utilise to acquire or upgrade a physical asset, such as a property, well or equipment. These funds are also commonly used to undertake new projects or investments to maintain or increase the scope of operations. Hence, these may include everything from rig rental to purchasing a new piece of drilling equipment, or the development of a new well.

In the following subsections, a statistical analysis of the CAPEX, based on the work of Soebye [75], was included to identify the most typical investments made in the extraction of O&G on the NCS. Seeing as Soebye [75] considered general investments for all operators on the NCS, it was expected that his results would be helpful in identifying the greatest overall investments related to the drilling cycle.

4.3.2.1 Investments on the NCS

Statistical data regarding the total amount invested in the extraction of oil and gas in the period from from 1971 to 2017 was extrapolated in current prices (MNOK) from [75]. The data have subsequently been reproduced in Figure 4.5, wherein the amount invested have been sorted in an increasing manner from left to right according in the six most typical categories; Exploration, Field Development, Field in Production, Onshore Operations, Abandonment and Piping Transport.

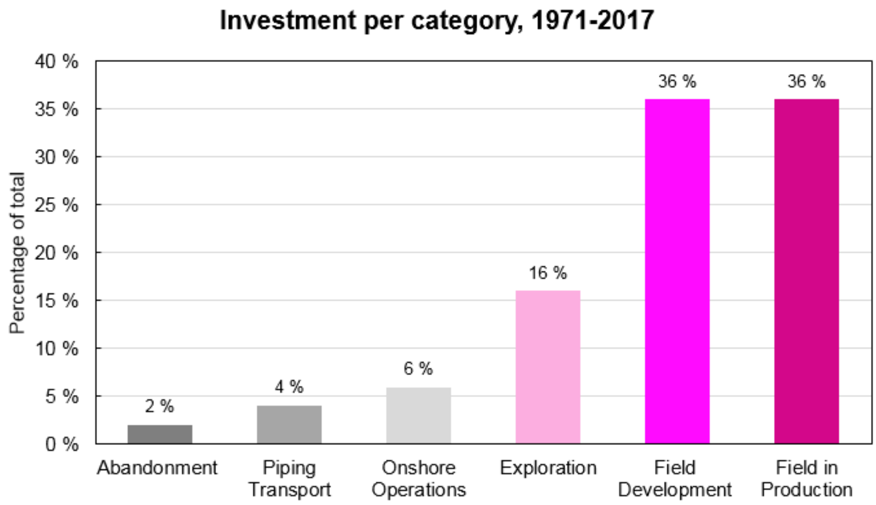

Figure 4.5: Investments Across Six Main Categories on NCS in the Period 1971-2017. Data Adapted from Soebye [75]

From Figure 4.5, approximately 72% of the total investments on the NCS were related to the two rightmost categories field development and field in production. Moving from right to left, another 16% corresponded to exploration, whereas the remaining 12% were distributed between onshore operations, abandonment and piping transport respectively.

In terms of exploration, the investments were tied to the process of exploration drilling and prospecting of formations that could potentially hold deposits of oil or natural gas. For field in development subsequently, the investments were related to the planning and identification of potentially viable fields, and the number of wells required to satisfy production demand. This included to the method of extracting the O&G, being drilling and completion operations. These costs also considered the site, offshore or onshore, with designs for systems used to facilitate environmental protections. Field in production lastly, included investments in activities related to production of hydrocarbons, including repair and improved recovery operations during the lifetime of a field.

In Figure 4.6, the investments in these three influential categories were subsequently further investigated by plotting the quarterly investments from the period 1971 to 2071. From the upward trend, in Figure 4.6, one can infirm that investments in all three categories gradually increased from 1971, before peaking in 2013 and 2014 respectively. Similar to Soebye [75], it is believed the registered increases are not only as a result of increased real-economic activity, but also partially due to the favourable prices for drilling, goods and services.

The subsequent decrease, following the peaks in 2013 and 2014, coincided befittingly with the starting recession of the crude oil price in 2014. Notwithstanding, it was estimated that this decrease occurred not only due to the fall of the oil price, but also due to the completion of work, developments and drilling programs at the time. Withal, companies who supplied goods and services to offshore operations during the foregoing period of strong investment growth, may also have falsely predicted a continuation, thus establishing dispositions which ultimately result in significant over establishment.

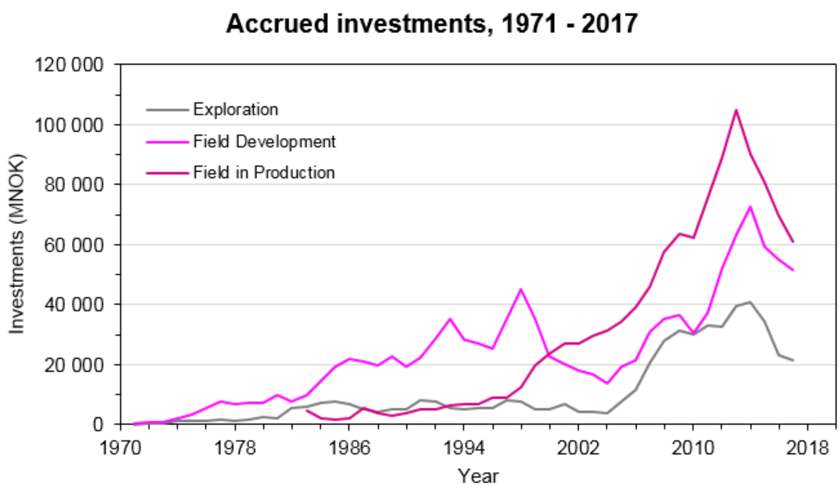

Figure 4.6: Accrued Investment from the Period 1971-2017. Data adapted from Soebye [75]

What's more, Figure 4.6 also maintains that field development exerts the lowest decrease following the peak. A statistical analysis was included in Table 4.3 for the three above categories, to make further evaluations.

Table 4.3: Statistical Summary for Investments in Exploration, Field Development and Field in Production on NCS, 1971-2017

Statistics	**Exploration**	**Field Development**	**Field in Production**
Observations	47,00	47,00	47,00
Mean	10734,09	24410,26	23863,66
Median	5519,00	21316,00	6753,00
Total	504502,00	1147282,00	1121592,00
Maximum	40716,00	72726,00	105096,00
Minimum	115,00	576,00	0,00
Std. Dev.	11723,12	17528,68	30263,51
Kurtosis	0,54	0,345	0,25
Skewness	1,39	0,84	1,21

Note: Based on investments in MNOK

From Table 4.3, the estimated mean and median concludes that field development accounts for the highest investments on the NCS throughout the period 1971-2017, regardless of the high increase field in production between 1996-2013 in Figure 4.6. Furthermore, all three categories exhibit a low kurtosis; lower than three. This is from Subsection 2.3.1.3 known as a *platykurtic* distribution, meaning the investment distribution of each category have smaller tails compared to a normal distribution, which leads to smaller outlying investments. The skewness furthermore explains how the curve of the distribution for each investment category is shaped. A positive skewness, as shown in Figure 2.2, means that more of the distribution leans towards an increase from the mean of the distribution. To visualise this for the benefit of the reader, the investment categories and their corresponding density distribution were plotted in Figure 4.7.

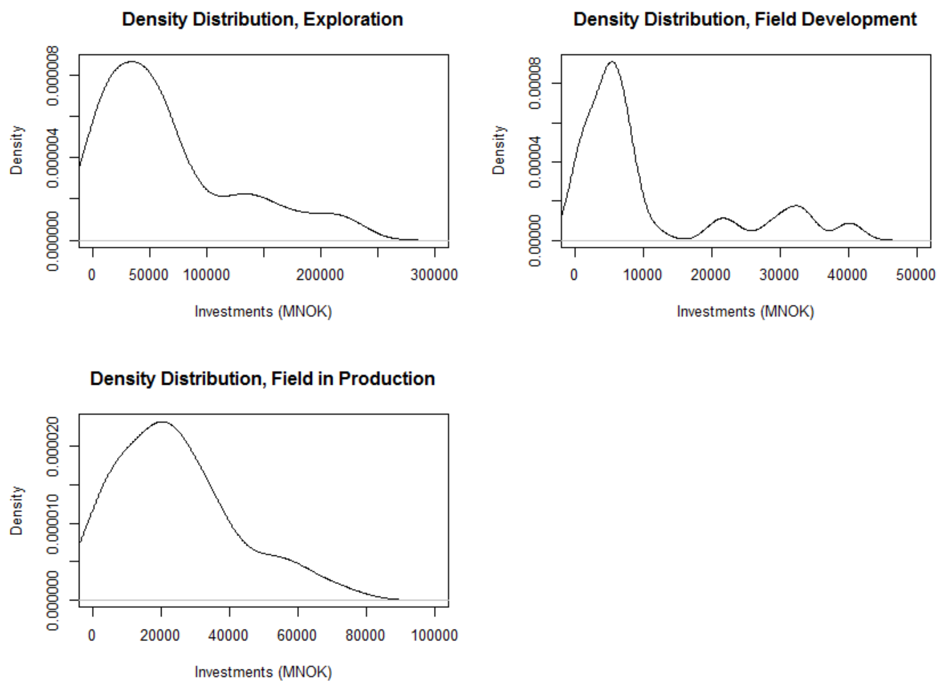

Figure 4.7: Density Distribution of Investment Categories in the Period 1971-2017

From Figure 4.7, the investment distribution for field in production is positively skewed, whereas the investment distribution is negatively skewed for exploration. The distribution for field development in contrast, appears more symmetrical around its mean while still being positively skewed.

4.3.2.2 Awarded Licenses

The following analysis was included to determine whether the investments devoted to exploration, field development and field in production could be linked to the number of licences awarded by Norwegian authorities on the NCS during the same period. Data sampled from the work of Soebye [75] concluded that Norwegian authorities have assigned in all 540 investigation licenses with exclusive rights to survey, exploration and extraction of petroleum within the licences specified geographical area from 1971 to 2017.

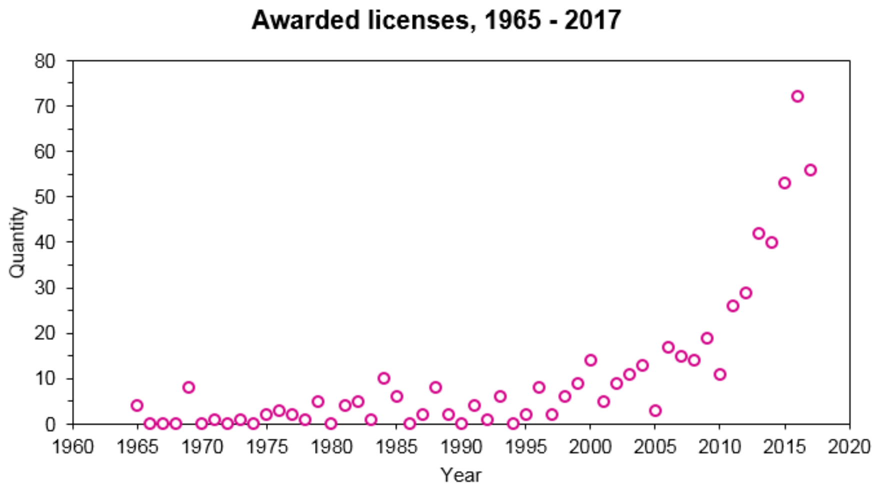

Figure 4.8: Awarded Licenses on the NCS in the Period 1965-2017. Data Adapted from Soebye [75]

From Figure 4.8, one can infirm an exponential increase in the number of licenses awarded during the period 1971-2017. The most noticeable increase, from 2006 to 2017, emerged during a period wherein authorities annually awarding licenses in predefined areas, in addition to regular licensing rounds. These were areas with existing platforms and infrastructure with spare processing and transport that could be used to extract small discoveries in the vicinity that would otherwise not be profitable. This suggested that recent investments in exploration, field development and field in production were somewhat related to already operational fields.

4.3.3 Summary

With basis in the documentary analysis of D&W's role in the value chain and the above statistical analyses of investment categories on the NCS, findings suggested that the most critical area, and therein the main focus for performance management and measurement in D&W's operations should emphasise field development, more specifically the well development process.

4.4 Breakdown of Well Development

The well development process was above defined as a number of activities completed in a particular sequence. Each of these activities have specific limiting conditions under which they can be performed; capabilities of employees, equipment or safety considerations. A breakdown of the most common activities performed offshore is included in the Fishbone Diagram in Figure 4.9.

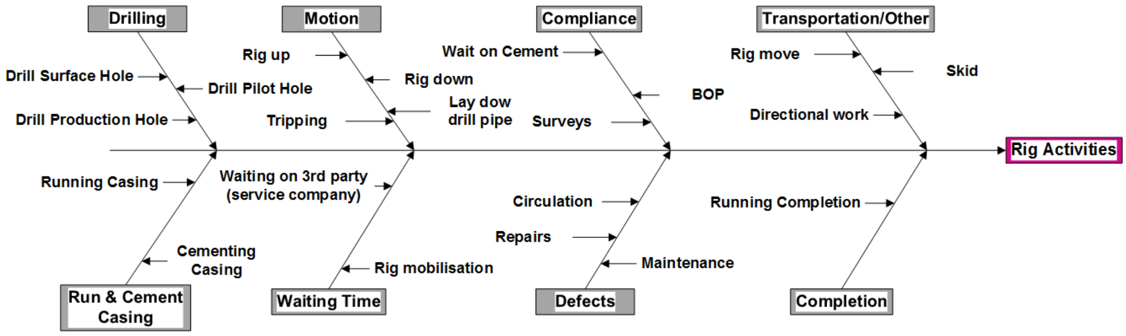

Figure 4.9: Fishbone Diagram of Well Development Activities. Adapted from Burk and Fink [76, p. 2]

4.4.1 Breakdown of Activities

In addition to those depicted above in Figure 4.9, there are typically hundreds of minor processes occurring during the development of a well. Hence, for the sake of convenience, better control, and ease in implementation, an investigation was carried out over 19 single, multilateral and trilateral wells located across 4 different fields wherein Aker BP is the current license owner, to establish the most common activities. The wells in question were developed by the former operators Marathon Oil and Det norske, now known as Aker BP, during the time from 2009 to 2016. Further information pertaining to these wells have been included in Table 4.4.

Further review of previous daily drilling and completion reports from all nineteen wells, culminated in the establishment of a comprehensive list consisting of the 47 most common major activities in the well development process. The list in its entirety has been included in Table B.3 in Appendix B. For the betterment of future analysis and comparisons of data, each activity in Table B.3 has been ordered according to category type; as either drilling or completion; and moreover categorised in terms of operation type; related to either rig, BOP, drilling, cementing, completion or running of casing operations. Make note that the list does not represent an all-inclusive collection of activities, but merely recognises those most occurring over the course of the 19 wells investigated.

Table 4.4: Overview of Wells and Fields

Field	Well name	Acronym	Operator	Year developed	Type
Volund	24/9-P-3	**P3**	Marathon oil	2009	Single
Volund	24/9-P-6	**P6**	Marathon oil	2012	Single
Vilje	25/4-F-1	**F1**	Marathon oil	2013	Single
Bøyla	24/9-M-1	**M1**	Marathon oil	2014	Single
Bøyla	24/9-M-2	**M2**	Det norske	2015	Single
Bøyla	24/9-M-3	**M3**	Marathon oil	2014	Single
Alvheim	25/4-L-4	**L4**	Det norske	2015	Single
Volund	24/9-P-7	**P7**	Det norske	2016	Single
Volund	24/9-P-9	**P9**	Det norske	2016	Single
Volund	24/9-P-2	**P2**	Marathon oil	2010	MLT / Trilateral
Alvheim	24/6-B-4	**B4**	Marathon oil	2010	MLT / Trilateral
Alvheim	25/4-L-2	**L2**	Marathon oil	2011	MLT / Trilateral
Alvheim	25/4-L-3	**L3**	Marathon oil	2011	MLT / Trilateral
Alvheim	25/4-L-1	**L1**	Marathon oil	2011	MLT / Trilateral
Alvheim	24/6-B-5	**B5**	Marathon oil	2012	MLT / Trilateral
Alvheim	25/4-K-6	**K6**	Det norske	2015	MLT / Trilateral
Alvheim	24/6-A-5	**A5**	Det norske	2015	MLT / Trilateral
Volund	24/6-P-8	**P8**	Det norske	2016	MLT / Trilateral
Volund	24/9-P-10	**P10**	Det norske	2016	MLT / Trilateral

4.4.2 Breakdown of Time

A data-set was provided in Excel by D&W engineers, encompassing data from all nineteen wells from Table 4.4. From this, the problem-free time and actual time[4] (in days), and depth (in meters) for each activity executed on each individual well, were extracted into two prime data-bases. Adopting the same classification as Table B.3, a pivot table in Excel was utilised to estimate the median time (in days) for each activity, before displaying the percentage of the total time (in %) for each category, operation type and activity, respectively. The percentages of the actual time for the drilling and completion categories are depicted in Figure 4.10 with basis in Table B.4 from Appendix B.

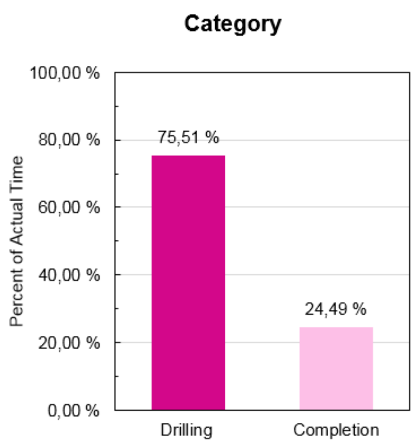

Figure 4.10: Percentage of Actual Time per Category

[4]Actual time spent on operations, including problem-free and problem-related time

According to Figure 4.10, roughly 76% of the median actual time during development of the nineteen wells from Table 4.4, are related to drilling, with roughly 24% being associated with completion. The intent with using the median rather than mean as a measure of central tendency, was to avoid other extreme values in the data sets. With basis in the same approach and Table B.5 in Appendix B, Figure 4.11 reports the percent of the actual time for each operation type; BOP, casing, cementing, completion, drilling or rig- related.

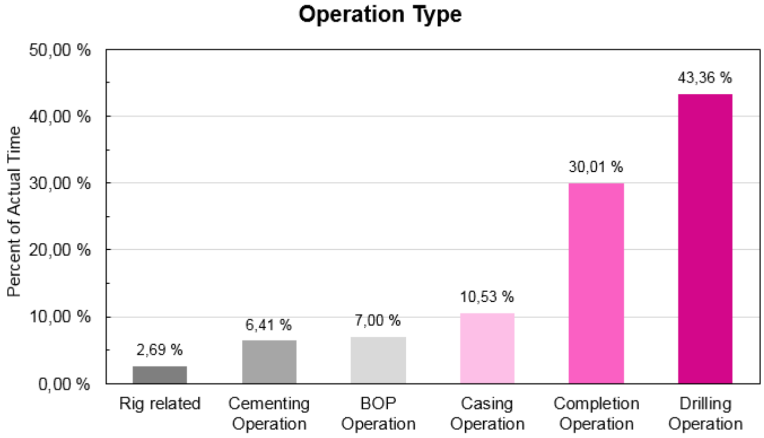

Figure 4.11: Percentage of Actual Time per Operation Type

In an increasing manner from left to right, Figure 4.11 affirms that the greatest amount of the actual time of 43.36% is associated with drilling operations, more specifically drilling regular sections, reservoir sections and pilot holes. Completion operations subsequently, makes up a total of 30.01% of the total actual time, leaving a remaining 26.73 % to be spread across casing, BOP, cementing and rig related operations. In furtherance of determining the most prominent activities in terms of actual time and problem-free time, both of the aforementioned data-bases were utilised to estimate and display the top ten most influential activities in Figure 4.12, with basis in Table B.6 from Appendix B.

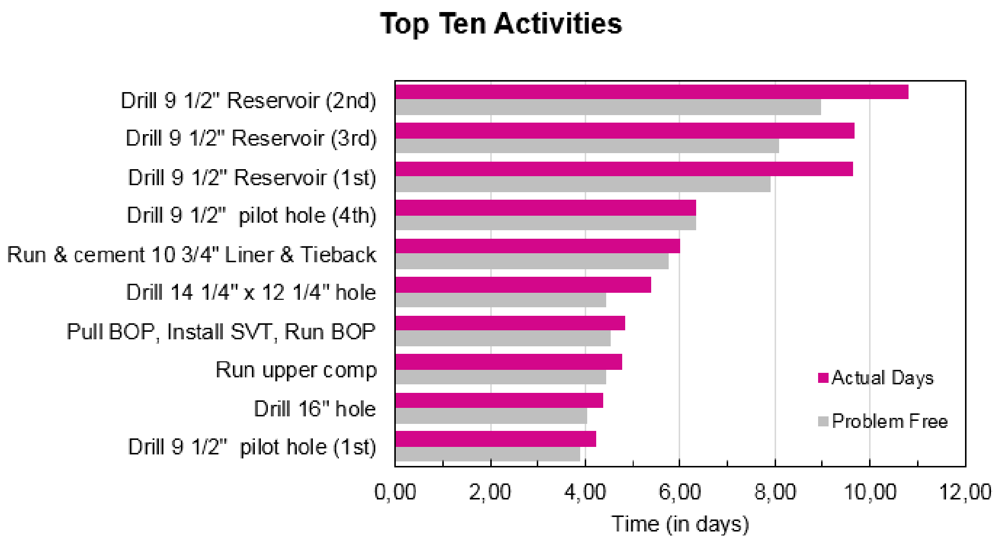

Figure 4.12: Top Ten Time Consuming Activities in Well Development

In a decreasing fashion, Figure 4.12 summarises the ten activities responsible for the greatest amount of problem free and actual time (in days). Of the ten activities, a total of 7 were drilling activities, with the remaining being either BOP or completion related. For all activities except for one, the actual time exceeded the problem-free time. For the three topmost drilling activities, the gap exceeded 1.5 days.

4.5 Waste in Well Development

A reoccurring term in the theory of Lean and flow efficiency was the identification of waste and NVA time in activities. In D&W, the interview subject recognised three terms as synonyms for waste and NVA time, being Non Productive Time (NPT), Wait on Weather (WOW) and Invisible Lost Time (ILT). Whereas NPT was simply defined as the time not directly associated with manufacturing operations or the performance of a job or task, WOW in contrast pertained to the time when drilling, completion or other operations were suspended due to bad weather. ILT conversely, was regarded as the losses of time accumulating due to the difference between actual operation duration and a best practice target. Hence, ILT accumulated if the offshore operations were not carried out as efficiently as possible with the currently available technology and best practice knowledge. These three categories of waste are illustrated in Figure 4.13 using a Fishbone Diagram.

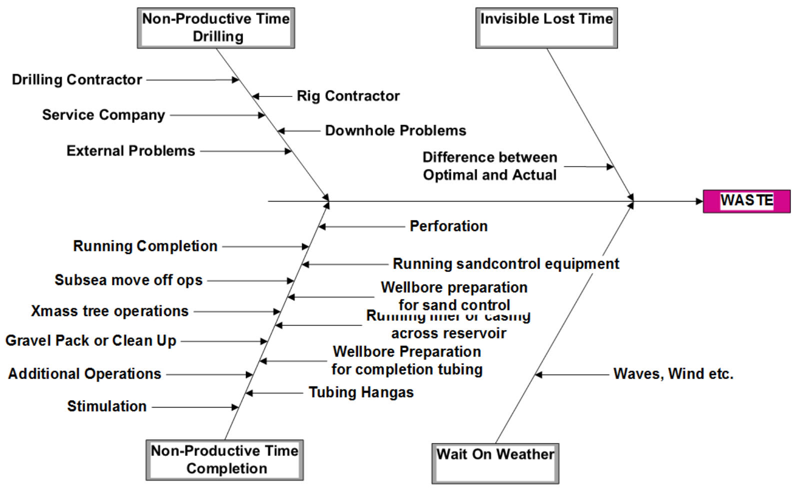

Figure 4.13: Fishbone Diagram of Most Common Wastes in Well Development

The Fishbone Diagram in Figure 4.13 have purposely divided NPT into drilling and completion. The different types of wastes for each term are moreover established in correspondence with definitions from Rushemore Reviews. When calculating the Actual Time T_a spent on well development activities offshore, engineers regularly employ the following relationship between the three wastes, shown in Equation 4.1;

$$T_a = T_{prob.free} + T_{NPT} + T_{WOW} + T_{ILT} \tag{4.1}$$

Where $T_{prob.free}$ is the problem-free time in days, T_{NPT} is the non-productive time in days, T_{WOW} is the time in days spent waiting on weather, and T_{ILT} is the invisible lost time in days.

When logging the actual data for a well development project, engineers most typically categorise NPT and WOW, being the two most frequently measured. In consequence, the focus in the subsequent analyses has therefore been vested in NPT and WOW. To determine the effect of NPT and WOW related to both drilling and completion, thus the entirety of the well development process, NPT and WOW data was extrapolated from the database Rushmore Reviews using the following parameters:

- New Wells
- By Operators BP, Det norske and Marathon Oil (now part of Aker BP)
- Norwegian Continental Shelf
- From 2000 to 2016

For drilling, the total NPT and WOW were analysed across a total of 144 wells from 2000 to 2016 as percentages of total dry hole days. Similarly, the total NPT and WOW were subsequently estimated for completion across a total of 143 wells from 2000 to 2015. Using the methods and principles introduced in Chapter 2, a statistical analysis was carried out to investigate NPT and WOW in both drilling and completion.

Table 4.5: Statistical Summary of NPT and WOW in Drilling and Completion

	Drilling		**Completion**	
Statistics	NPT	WOW	NPT	WOW
Minimum	2,50 %	0,00 %	0,00 %	0,00 %
Maximum	70,00 %	42,10 %	79,80 %	51,80 %
Median	18,55 %	0,00 %	15,90 %	0,00 %
Average	22,91 %	2,33 %	20,33 %	4,77 %
Std.Dev	15,51 %	5,61 %	18,24 %	8,89 %
P5	4,38 %	0,00 %	1,03 %	0,00 %
P50	18,55 %	0,00 %	15,90 %	0,00 %
P95	52,40 %	11,34 %	57,56 %	25,96 %

Note: estimated as a percentage of total dry hole days

According to Table 4.5, the median of NPT, corresponding to the P50, is equal to 18,55% and 15,90% for drilling and completion, respectively. The median for WOW, representing waiting time, is in contrast estimated as 0,00% and 0,00% for drilling and completion, respectively, an interesting observation considering the estimated maximum of WOW. This suggested that the mean WOW is most likely affected by extremely high values of a few specific wells.

In summary, the statistical analysis confirmed that NPT was the most influential of the two types, thusl accounting for the greatest share and variation of waste in well development. For drilling, definitions from Rushmore Reviews suggested that total NPT during the whole dry hole period could be related to either external problems, operator problems, rig contractors, service companies or down-hole problems. In an increasing manner from left to right, Figure 4.14 depicts the percent of NPT estimated during drilling across all the 144 wells investigated, according to the aforesaid five categories.

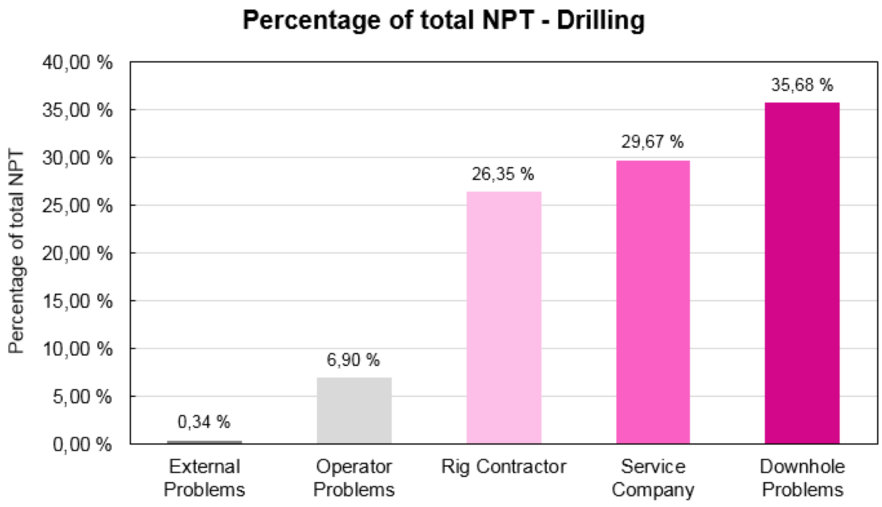

Figure 4.14: Non Productive Time in Drilling

From Figure 4.14, the greatest cause of NPT is related to problems downhole at 35.68%. From Rushemore Reviews, this included time interrupted due to down-hole operational, mechanical or geological problems, or service companies; service equipment, personnel or procedures. A similar analysis was also carried out for completion in Figure 4.15 across 143 wells.

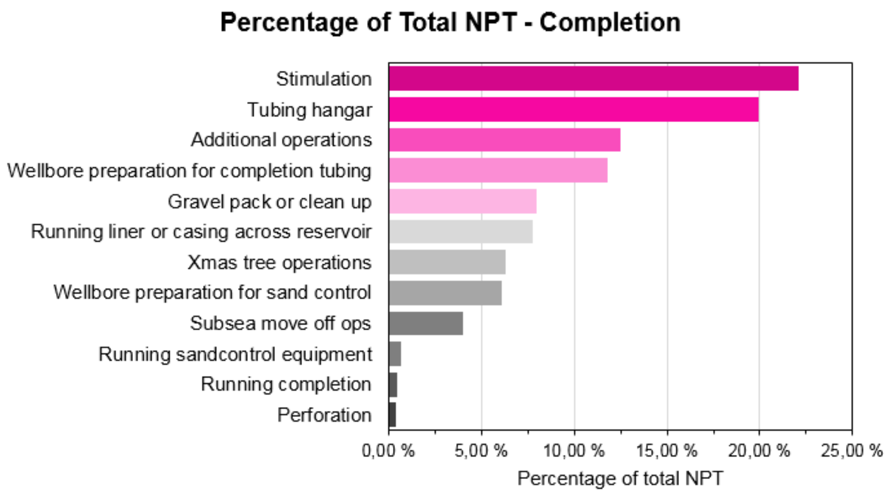

Figure 4.15: Non Productive Time in Completion

According to findings from Figure 4.15, the greatest percentage of NPT iss related to the two topmost categories; stimulation with and running of tubing hangar; each with a NPT of 22% and 20%, respectively.

With basis in these findings, it was concluded that the greatest share of NPT occurred due to down-hole problems, service companies and personnel during drilling, and stimulation and tubing hangar operations during completion. It should be noted that the above analyses considers primarily NPT and WOW when investigating waste, as these two are commonly reported during the development of a well. The effect of ILT, not being regularly visible for operators, have thus not been further emphasised, due to the lack of data.

4.5.1 Effect of NPT and WOW

In order to account for the effect of NPT and WOW, alterations were made to the analysis in Subsection 4.4.2. By solving Equation 4.1 for the NPT and WOW, the amount of waste for each individual activity was estimated. For the benefit of the reader, the combination of NPT and WOW has in this subsection been coined as waste. From Table B.7 in Appendix B, the amount of actual time (in days) for each activity was thereafter plotted versus with the corresponding problem-free time (in days) in the balanced bar chart in Figure 4.16. The gap between the two, signified by the grey colour, would aid in the determination of activities related to occurrence of waste.

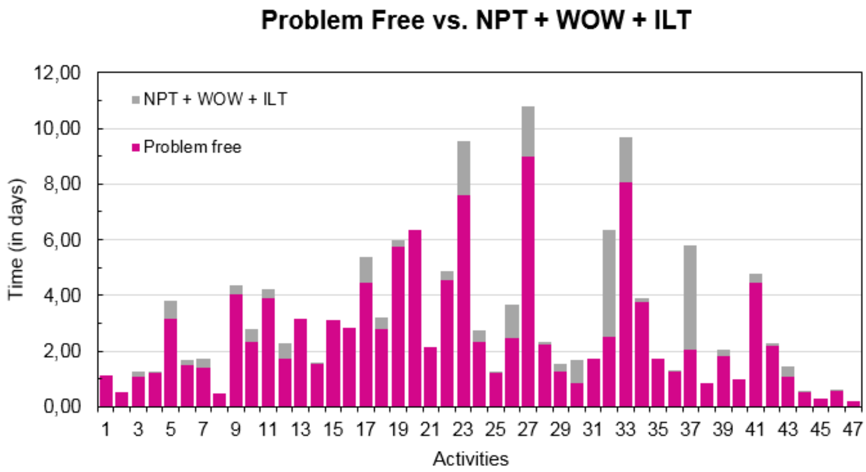

Figure 4.16: Problem Free Time versus Actual Time

In summary, the comparison between the problem-free and actual time in Figure 4.16 yields a varying difference across the different activities. The comparison between the two successfully moreover identifies activities 27, 32, 33 and 37 as those encompassing the greatest amount of wasted time, signified by the grey colour. Interestingly, these were primarily long duration activities, related to either drilling and completion operations.

4.6 Introduction to Performance Analysis

The following have considered one specific well in an attempt to perform several in-depth analyses of performance using KPIs. The well in question was *24/6-B-5*, hereby referred to as Kneler B-5, in license PL203, situated within the Alvheim field on the NCS. The Kneler B-5 was developed by the previous operator Marathon Oil Norge AS, now part of Aker BP. The well was moreover drilled and completed using Transocean Winner, previously named Treasure Saga, a semi-submersible drilling rig. The Kneler B-5 well in its entirety, consisted of one conventional landing pilot and a horizontal Tri-Lateral oil producer with one main bore and two laterals.

The Transocean Winner rig was anchored to the wellsite prior to spudding[5] the Kneler B-5 well at 150 meter measured depth (MD) Relative to Kelly Board[6] at 1. April, 2012 at 12:00 hours. Prior to reaching a final depth of 5654 meter MD in the upper lateral on 10. August, 2012, the well was completed. After finalising well clean-up, development activities ended by pulling the anchors at 00:00 hours on 7. September, 2012. A brief summary of the general information regarding the Kneler B-5 well is shown in Table 4.6.

Table 4.6: Information on Kneler B-5

General information	**Data**
Wellbore name	24/6-B-5H AY1H, AY2H, AY3H
Main area	North sea
Final surface location [m]	N6601461.7, E 442782.2
Drilled in production licence	PL203
Drilling operator	Marathon Oil Norge AS
Drilling facility	Transocean Winner
Spud date	01.04.2012
Type of well	Development
Purpose	Oil producer
RT - MSL elevation [m]	26
Water depth [m]	124
Total depth [m MD] 24/6-B-5 AYH3	5654

where RT-MSL is relative to mean sea level

The complete activity sequence for the Kneler B-5 well was subsequently reproduced for analyses purposes. The sequence includes the development of a trilateral well encompassing rig anchoring, drilling, BOP installations, casing running & cementing and completion operations.

For each activity, the corresponding depth (in meters), AFE time (in days), Actual time (in days), NPT (in days), WOW (in days) and Problem-free time (in days) have been included in Table 4.7. For the benefit of the reader, each activity is from this point on, referred to by its corresponding activity number in the leftmost column in Table 4.7.

[5] Drilling through the seabed

[6] Depth in meters relative to platform drill floor

Table 4.7: Data for Kneler B-5 Activity Sequence. Courtesy Internal Sources, Aker BP D&W

#	Activity	AFE	Depth (m)	NPT	WOW	Prob. Free
1	Run Anchors	1,76	150,00	0,52	0,00	1,19
2	Drill 36" hole	1,08	204,00	0,00	1,73	1,60
3	Run & cement 30" casing	1,22	204,00	0,04	0,00	1,54
4	Drill 26" hole	4,73	821,00	0,50	0,00	4,96
5	Run & cement 20" casing	1,62	821,00	3,56	0,00	1,48
6	Run BOP	2,16	821,00	0,77	0,00	1,25
7	Drill 16" hole	7,02	1651,00	0,10	0,00	3,54
8	Run & cement 13 3/8" casing	3,11	1651,00	0,04	0,00	2,67
9	Drill 9 1/2" pilot hole (1st)	6,08	3343,00	0,50	0,00	4,00
10	Plug & Abandon pilot hole (1st)	2,16	1657,00	0,60	0,00	1,73
11	Drill 14 1/4" x 12 1/4" hole	9,05	2910,00	4,23	0,00	4,73
12	Run & cement 10 3/4" Liner & Tieback	8,37	2910,00	0,06	0,00	5,75
13	Drill 9 1/2" Reservoir (1st)	12,83	4998,00	0,13	0,54	8,88
14	Lower completion (1st)	3,39	4998,00	0,06	0,00	2,69
15	Install Whipstock (1st)	2,30	2827,00	0,00	0,00	2,60
16	Drill 9 1/2" Reservoir (2nd)	13,50	5268,00	3,17	0,00	6,48
17	Lower completion (2nd)	3,39	5268,00	0,10	0,00	2,71
18	Intall Deflector & Junction	4,23	5268,00	0,10	0,00	3,08
19	Pull BOP, Install SVT, Run BOP	5,54	5268,00	8,60	0,00	8,65
20	Install Whipstock (2nd)	2,30	2724,00	7,63	0,00	2,50
21	Drill 9 1/2" Reservoir (3rd)	17,55	5654,00	1,94	0,00	10,29
22	Lower completion (3rd)	3,81	5654,00	0,00	0,00	4,88
23	Pull Whipstock (2nd)	2,55	5654,00	0,00	0,00	0,88
24	Intall Deflector & Junction	4,23	5654,00	0,04	0,00	3,48
25	Clean up well (separate)	2,36	5654,00	0,25	0,00	2,75
26	Run upper comp	6,05	5654,00	0,46	0,00	5,63
27	Secure well (Pull BOP Included)	2,83	5654,00	0,08	0,00	2,69
28	Recover anchors	1,12	5654,00	0,00	1,71	0,69

Note: AFE, NPT, WOW and Prob. Free are all estimated in dry hole days

4.7 Analyses of KPIs from Det norske

It was concluded on account of findings from Sections 4.4 and 4.5, that the greatest amounts of time and waste were primarily related to drilling activities. Hence, the subsequent analyses of KPIs from the Det norske mainly prioritised the category Drilling performance and the non-financial KPIs drilling efficiency and well NPT from Table 4.1.

4.7.1 Drilling Efficiency

The drilling efficiency from Table 4.1 was commonly measured as an average on all Det norske operated wells drilled in 2016. In furtherance of using findings in comparison with well NPT and subsequently with new Lean KPIs, the measurement of the drilling efficiency was alternated and calculated for each individual activity. The analysis commenced by measuring the effective depth for each activity; the estimated depth over which the activity was executed. The drilling efficiency for each activity in the Kneler B-5 activity sequence was then calculated by the adapted Equation 4.2;

$$R_{d.e} = \frac{D_e}{T_a} \tag{4.2}$$

Where $R_{d.e}$ is the drilling efficiency rate in meters per day and D_e is the effective depth in meters over which each activity was executed. It must be mentioned that certain activities; plug and abandonment, BOP, clean-up, securing well and anchoring activities; were executed either when cementing back, at the drill floor or sea bottom, respectively. Hence, the effective depths were assumed equal to zero for activities 1, 6, 10, 19, 25, 27 and 28 from Table 4.7, seeing as the activities did not contribute down-hole. The results from the calculations are included in Table B.8 in Appendix B. In Figure 4.17, the drilling efficiency rate in meters per dry hole day for each activity is depicted following the activity sequence for Kneler B-5.

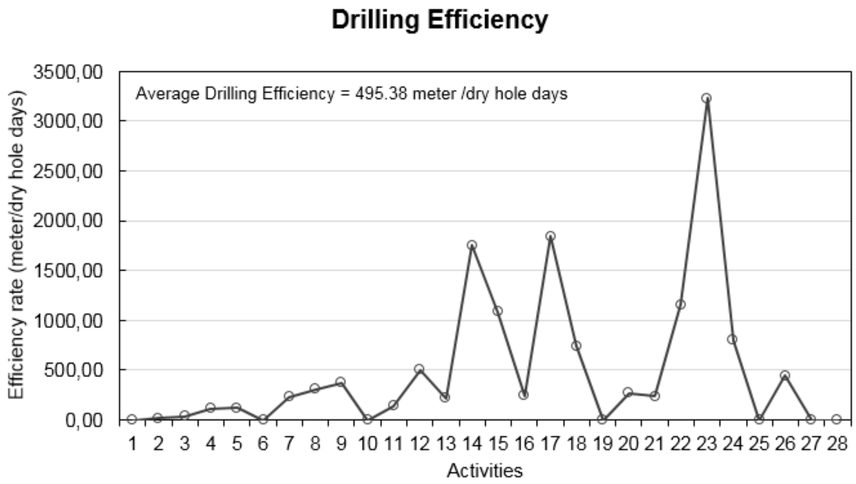

Figure 4.17: Drilling Efficiency for Each Activity on Kneler B-5

The drilling efficiency exhibits a highly varying tendency with particularly high rates for certain activities. According to Figure 4.17, the drilling efficiency rate for activities 14, 17 and 23 all exceeds 1500 meters per dry hole day, a rate being three times greater than the average rate of 495.36 meters per dry hole day. For activity 23 moreover, the rate exceeds more than 3000 meters per dry hole day, a rate more than six times greater than the average. The explanation for such a high variation for these activities was the great effective depth and corresponding short duration, thus yielding a very high efficiency rate.

4.7.2 Well NPT

The second KPI well NPT from Table 4.1 was commonly reported as the average percent of NPT on all Det norske operated rigs, excluding WOW. Based on the data at hand, the well NPT was adapted and calculated in similar fashion, for each activity by Equation 4.3;

$$NPT = \frac{T_{NPT}}{T_a} \tag{4.3}$$

Where NPT is given as the ratio of NPT to the actual time T_a. The results from the analysis are included in Table B.9 in Appendix B. The well NPT is furthermore depicted in Figure 4.18 as a ratio for each activity following the Kneler B-5 activity sequence.

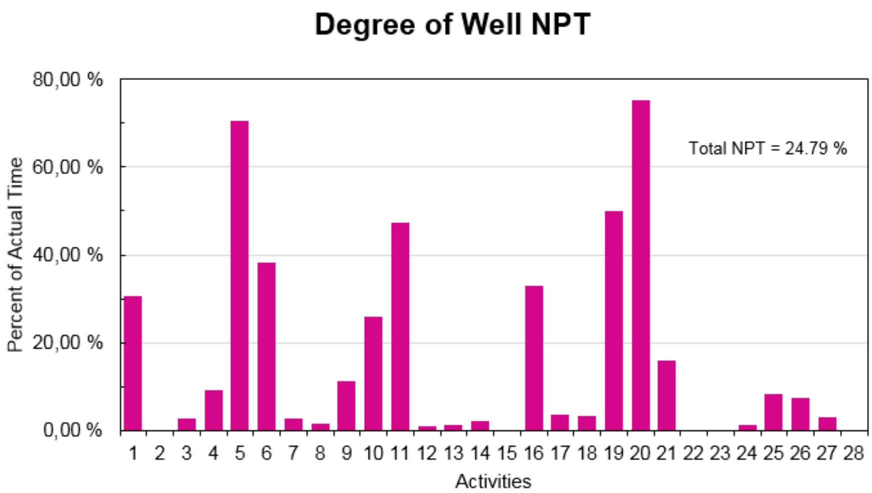

Figure 4.18: Well NPT for Each Activity on Kneler B-5

According to findings from Figure 4.18, the highest percentages of Well NPT is located at activities 1, 5, 6, 10, 11, 16, 19 and 20. For these activities, the percent of Well NPT exceeds 35% of their total actual time. A high percentage of well NPT is also identified at several other activities. Nevertheless, most of these were assumed negligible in comparison. What's more, the figure estimates a total well NPT of 24.79% during the entire development of the Kneler B-5. By comparing the percent of well NPT with the results for from drilling efficiency, one can infirm that those activities with a high percent of well NPT, in contrast exhibit very low drilling efficiency.

4.8 Lean Performance

The ensuing research employed several of the principles introduced in the literature review when deriving a new Lean performance category for D&W in alignment with the department's principles for performance management and strategic direction. A main criterion accentuated during this process was compliance with the data already at hand. In line with the strategic direction in D&W and abovementioned findings, a new potential category for performance measurement was therefore defined as *flow efficiency*. The reasoning behind the selection of this performance category was its ability to more easily visualise waste and moreover streamline the activities in the well development process. For further information regarding the selection of this performance category, reference is made to Section 5.2.1 in Chapter 5. When exploring new Lean performance metrics for this performance category, the ensuing analysis mainly considered the list of 78 Lean KPIs from Table B.1 introduces in Section 3.6.4.

A review of the principles of the existing body of information from the literature overview, therein the definition of Hoshin Kanri, suggested that some of the KPIs were better at measuring the flow and waste in the well development process than others.

Following a comprehensive selection-process, the initial list in Table B.1 was thusly filtered down to include only a critical few KPIs that would best measure flow and identify the sources of waste, defined above as NPT and WOW. Consequently, the collection of new Lean KPIs were Takt Time, Cycle Time and Lead Time. In addition, these KPIs would also enable the use of both leading and lagging indicators, thus allowing ratios and ranges to quantify performance objectives.

4.8.1 Takt Time, Cycle Time and Lead Time

Takt time is useful measure to identify and eliminate wasteful over-and under usage of time and synchronise interdependent activities, thus increasing the efficiency of the activities sequence. The measure can also be used to optimise process, by matching itself with the customer's demand to ensure that the teams and equipment in D&W waste neither resources nor time. By measuring the takt time, D&W can ensure that all activities are synchronised from start to finish in the well development process.

In the subsequent analyses, the takt time was defined in terms of the AFE for the Kneler B-5 well. During the development of the Kneler B-5, the AFE time was set as the probable time it would take to complete all development activities. However, not every activity would with certainty exploit the exact amount of time as planned, as there may be equipment failure, down-hole problems or waiting due to weather. In effect, D&W therefore took into consideration weather fluctuations and potential increases in time when estimating the AFE. Based on experience from prior wells, D&W then calculated the time for each activity, before adding a buffer to address NPT and WOW. The AFE was therefore simply put, the time required to complete the well-development sequence, incorporating a buffer for NPT and WOW. In subsequent analyses, the takt time T_{takt} for each activity is adapted to the data at hand, and defined by Equation 4.4 as;

$$T_{takt} = \frac{T_{AFE}}{Q_{activities}} \tag{4.4}$$

where T_{AFE} is the planned time in days, and $Q_{activities}$ is the number of activities executed. Since the takt time was calculated for each individual activity, $Q_{activities}$ was assumed constant and equal to one. The cycle time subsequently, was defined in Subsection 3.6.4.1 as the time it takes to produce one unit from start to finish. In subsequent analyses, the cycle time T_{cycle} for each activity is alternatively defined by Equation 4.5 as;

$$T_{cycle} = \frac{T_a}{Q_{activities}} \tag{4.5}$$

Based in Equation 4.5, the cycle time is furthermore decomposed into Value Adding (VA) time T_{VA}, or Non-Value Adding (NVA) time T_{NVA} in Equation 4.6;

$$T_{VA} = \frac{T_{prob.free}}{Q_{activities}} \qquad T_{NVA} = \frac{T_{NPT} + T_{WOW}}{Q_{activities}} \tag{4.6}$$

Lead time lastly, is defined as the process time of the entire value stream; the sum of all cycle times. Whereas the takt and cycle times are measured by the amount of time per activity, the lead time is in contrast measured as the total elapsed time in days, including problem-free time, NPT and WOW, as shown in Equation 4.7;

$$\sum_{i=1}^{n} T_{a,i} = \sum_{i=1}^{n} \Big(T_{prob.free} + T_{NPT} + T_{WOW} \Big)_i \tag{4.7}$$

By comparing the lead time with the VA and NVA cycle time for each activity, the efficiency of the job sequence can be established, in addition to identify those activities wherein waste accumulates.

4.8.2 Takt Time vs. Cycle Time

The intent with the subsequent analysis was to compare the takt and cycle times to determine whether they could identify those activities in the Kneler B-5 well-development sequence with low flow. The takt time and the cycle times for each activity was thus calculated using Equations 4.4 and 4.6. The results from the calculations can be found in Table B.10 in Appendix B. In Figure 4.19 the estimates for the takt, VA and NVA cycle times for each activity from Table B.10 are compared in a combined bar and line graph. Here, the vertical axis specifies the time in days, whereas the horizontal axis depicts the activities in the Kneler B-5 development process.

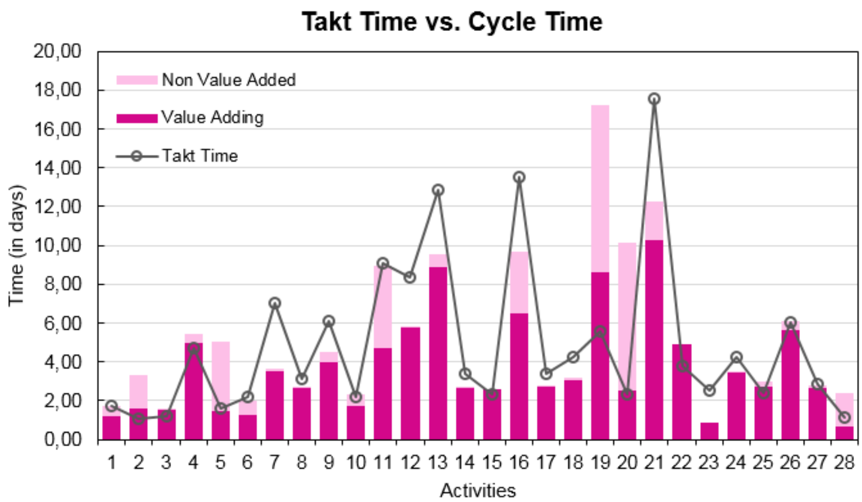

Figure 4.19: Takt Time versus VA and NVA Cycle Time for Kneler B-5

From Figure 4.19, a dissimilar trend in the takt and cycle times is identified. For activities with a generally long duration, the takt time is identified as high. When comparing the takt time with the cycle times, Figure 4.19 concludes that a total of twelve activities; 2, 3, 4, 5, 10, 15, 19, 20, 22, 25, 26 and 28 respectively; all have cycle times exceeding their respective takt time, indicating where D&W were unable to keep up with demand in the development of Kneler B-5. Interestingly, several of these activities had not been indicated by the drilling efficiency nor the well NPT.

For activities 4, 5, 10, 20 and 25, moreover, the NVA cycle times were identified as the primary reason for exceeding the takt time. For activities 2, 3, 15, 19, 22 and 25 in contrast, the VA cycle times were single-handily not enough to execute the activity per the required demand. It was concluded by comparing the total takt time to the total cycle times, that the well-development of the Kneler B-5 came in 4.47 days behind schedule, primarily due to a total NVA cycle time of 37.48 days.

A similar analysis was subsequently performed on the takt and cycle rate, to observe whether the rate would yield any contradicting result. The effective depths for each activity were estimated prior to calculating the takt, VA and NVA cycle rates, using data from Table B.10 in the following equations:

$$R_{takt} = \frac{T_{takt}}{D_e} \qquad R_{VA} = \frac{T_{prob.free}}{D_e} \qquad R_{NVA} = \frac{T_{prob.free} + T_{NPT} + T_{WOW}}{D_e} \tag{4.8}$$

.

Where, R_{takt}, R_{VA} and R_{NVA}, is the takt, VA and NVA cycle rates respectively. From comparison in Figure 4.20, the cycle time of activity 2, 3, 4, 5, 10, 15, 19, 20, 22, 25, 26 and 28 were all as before, not executed within the required takt time.

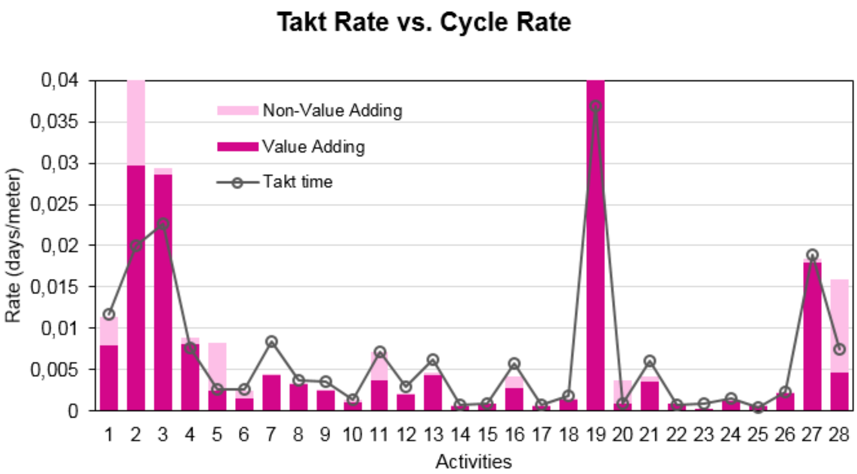

Figure 4.20: Takt Rate verus VA and NVA Cycle Rate for Kneler B-5

4.8.3 Cycle Time vs. Lead Time

An analysis of the NVA and VA cycle times and lead time was included to further determine activities accumulating waste. In Figure 4.21, the NVA, VA cycle times (in days) and lead times (in days) from Table B.11 in Appendix B, were plotted across the entire activity sequence for Kneler B-5, with the x and y axis showing the time (in days) and activity sequence respectively.

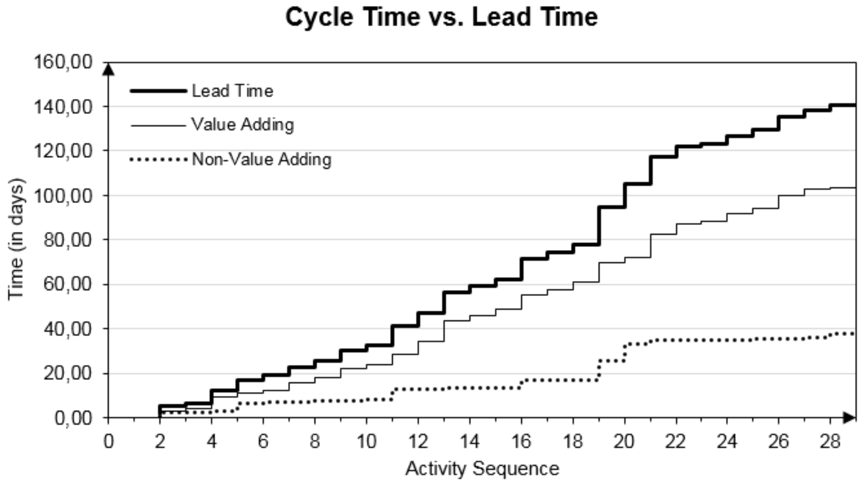

Figure 4.21: Cycle Time versus Lead Time for Kneler B-5

Findings from Figure 4.21, suggests that the NVA cycle time, already apparent from activity 2, continuously grew throughout the well development, adding more and more waste to the cycle times and consequently increasing the lead times. When comparing the NVA and VA cycle times, Figure 4.21 clearly identifies activities 2, 5, 11, 16, 19, 20, 21 and 28 as being the main capacity constraints and reason for the Kneler B-5 falling behind the AFE.

4.8.4 Additional Lean KPIs

With basis in the new Lean performance category, several additional Lean KPIs from Table B.1 were also included to aid in the identification of potential bottlenecks in the flow of activities; being Process Cycle Efficiency (PCE), Waiting Time, Utilisation, On Time Delivery (OTD) and Excess Time.

4.8.4.1 Process Cycle Efficiency (PCE)

The Process Cycle Efficiency (PCE) from Table B.1 is known as the value added ratio; a measure of the efficiency in a process. The PCE is in this thesis defined as the ratio of the VA cycle time to the total actual time, from the following formula;

$$PCE = \frac{T_{VA}}{T_a} \tag{4.9}$$

4.8.4.2 Waiting Time

Waiting time occurs when activities have stopped for some unknown reason, with subsequent activities having to wait before commencing. In well development, this can include unplanned down-time, long setup times, waiting of crews, up and down rig of equipment, waiting on equipment, personnel or weather, being amongst the most significant.

An analysis on the total NPT and WOW was therefore carried out on Kneler B-5, based on data logged in Rushmore Reviews to determine the most common types of waste, emphasising waiting time. The results can be found in Table B.12 in Appendix B. From Table B.12, more than 80% of the total NPT on Kneler B-5, was related to service companies. Seeing as the amount of different types of waiting were negligible, it was assumed that the main factor for waiting time on the Kneler B-5 well was WOW. The KPI waiting time T_{wait} was thus dubbed as the ratio of WOW to the total actual time for each activity in Equation 4.10;

$$T_{wait} = \frac{T_{WOW}}{T_a} \tag{4.10}$$

4.8.4.3 Utilisation

The utilisation KPI from Table B.1 is measured as the fraction of actual output to the design capacity; that is the percent of the total design capacity. In terms of the data available for the well development process, the utilisation U was in this thesis defined as the ratio of the total cycle time to the takt time for each activity in Equation 4.11;

$$U = \frac{T_{VA} + T_{NVA}}{T_{takt}} \tag{4.11}$$

4.8.4.4 On Time Delivery (OTD)

OTD measures the efficiency of a process by estimating the products or services delivered within time and in full. Hence, it can be used in conjunction with the PCE measure to determine how efficiently agreed deadlines are met. In this thesis, the OTD is calculated as a percentage of the total number of activities executed within the AFE in Equation 4.11;

$$OTD = \frac{\sum N}{\sum N_{tot}} \tag{4.12}$$

Where OTD is the number of on time deliveries, $\sum N$ is the number of activities executed ahead of AFE, and $\sum N_{tot}$ is the total number of activities on the Kneler B-5.

4.8.4.5 Excess time

Excess time is defined as the time spread between the total cycle time and takt time. If activities are performed within the planned time, the available spare time would yield the excess time in Equation 4.13;

$$T_{excess} = (T_{VA} + T_{NVA}) - T_{takt} \tag{4.13}$$

4.8.5 Summary of Additional Lean KPIs

Each of the abovementioned KPIs were subsequently estimated for each activity on the Kneler B-5. A comprehensive summary have been included in Table 4.8. From Table 4.8, the PCE identifies particularly activities 2, 5, 11, 19, 20, and 28 as being critical due to their low percentage. Furthermore, the total PCE for the Kneler B-5 well is estimated to 73.35%. In consequence, a total of 26.65% of the total time was dubbed as NVA. From Table 4.8 moreover, only three activities experience a high waiting time T_{wait}, culminating in a total waiting time of 2.83% of the total actual time. For utilisation, an extremely high percentage is identified for the same activities as indicated by the PCE, adding to a total of 103.28%, yielding a utilisation of 3.28% more than available from planning. Furthermore, of the 28 activities, only 16 are delivered on time, resulting a completion rate of 57.14%. Of the same 28 activities, the top five with the greatest amount of excess time available was identified as activity 7, 12, 16, 21 and 23.

Table 4.8: Summary of KPIs for Kneler B-5

#	**PCE**	T_{wait}	U	**OTD**	T_{excess}	**Bottleneck**
1	69,51 %	0,00 %	97,06 %	Yes	2,94 %	No
2	48,13 %	51,88 %	308,64 %	No	0,00 %	Yes
3	97,37 %	0,00 %	129,78 %	No	0,00 %	Yes
4	90,84 %	0,00 %	115,40 %	No	0,00 %	Yes
5	29,34 %	0,00 %	311,21 %	No	0,00 %	Yes
6	61,86 %	0,00 %	93,56 %	Yes	6,44 %	No
7	97,14 %	0,00 %	51,93 %	Yes	48,07 %	No
8	98,46 %	0,00 %	87,08 %	Yes	12,92 %	No
9	88,89 %	0,00 %	74,01 %	Yes	25,99 %	No
10	74,11 %	0,00 %	108,02 %	No	0,00 %	Yes
11	52,79 %	0,00 %	98,99 %	Yes	1,01 %	No
12	98,92 %	0,00 %	69,44 %	Yes	30,56 %	No
13	93,01 %	5,68 %	74,37 %	Yes	25,63 %	No
14	97,73 %	0,00 %	81,12 %	Yes	18,88 %	No
15	100,00 %	0,00 %	113,22 %	No	0,00 %	Yes
16	67,17 %	0,00 %	71,45 %	Yes	28,55 %	No
17	94,89 %	0,00 %	84,19 %	Yes	15,81 %	No
18	96,73 %	0,00 %	75,35 %	Yes	24,65 %	No
19	50,12 %	0,00 %	311,37 %	No	0,00 %	Yes
20	24,69 %	0,00 %	440,22 %	No	0,00 %	Yes
21	84,16 %	0,00 %	69,68 %	Yes	30,32 %	No
22	100,00 %	0,00 %	127,95 %	No	0,00 %	Yes
23	100,00 %	0,00 %	34,31 %	Yes	65,69 %	No
24	98,82 %	0,00 %	83,23 %	Yes	16,77 %	No
25	91,67 %	0,00 %	127,12 %	No	0,00 %	Yes
26	92,47 %	0,00 %	100,55 %	No	0,00 %	Yes
27	96,99 %	0,00 %	97,91 %	Yes	2,09 %	No
28	28,70 %	71,30 %	213,91 %	No	0,00 %	Yes
Total	73,35 %	2,83 %	103,28 %	57,14 %	0,00 %	12

Note: Here PCE is Process Cycle Efficiency, T_{wait} is waiting time, OTD is on time delivery, U is utilisation and T_{excess} is the excess time

4.8.6 Best in Class (BIC)

This study also considered the innovative BIC KPI from Subsection 3.6.3 in addition to the aforesaid Lean KPIs, due to its ability to pinpoint those activities not delivering according to their potential. The BIC was in the literature review defined as an internal measure often used by operators to measure themselves against the best performance achieved on past wells. To demonstrate its applicability, an adaptation of the principles behind the BIC was in this section included by deriving the optimal time (in days), being the problem-free time on past wells, using a Monte Carlo Simulation. This optimal time was subsequently compared to the current problem-free time (in days) on the Kneler B-5 in an attempt to derive the loss of potential on said well. In the current application, the use of the Monte Carlo simulation method included the development of 1000 random time samples for problem-free time on activities from past wells. The data-base including the problem-free time was firstly filtered, leaving only the data pertaining to same activities from the Kneler B-5 present at each well. To account for the variation of depth across all wells, the analysis commenced by initially calculating the inverse execution rate of problem-free dry hole days per meters of effective depth for each activity;

$$R_e{}^{-1} = \frac{T_{prob.free}}{D_e} \tag{4.14}$$

Where $R_e{}^{-1}$ is the inverse execution rate for each activity. Assuming a constant execution rate for each activity across each well would thus in theory yield an identical rate, had the activity been executed on the Kneler B-5 well. In effect, the following relationship was established in Equation 4.15;

$$\frac{T_{prob.free}}{D_e} = \frac{T_{prob.free,e}}{D_{B-5}} \tag{4.15}$$

Where, $T_{prob.free,e}$ is the estimated problem-free time in days, hereby referred to as the BIC, and D_{B-5} is the depth in meters of the corresponding activity on the Kneler B-5. The BIC for each activity in each well was then estimated by solving Equation 4.15 for the estimated problem-free time $T_{prob.free,e}$ in Equation 4.16;

$$BIC = T_{prob.free,e} = \left(\frac{T_{prob.free}}{D_e}\right) * D_{B-5} \tag{4.16}$$

Followingly, the minimum and maximum BIC for each activity on each well was calculated, prior to running a thousand simulations for each respective activity. This was achieved by creating 1000 random examples of the BIC in days for each activity, made up with a normally distributed time randomly ranging between the minimum and maximum BIC. From the simulation results, the P1, P50 and P99 percentiles representing the optimistic, probable and deterministic BIC time for each activity respectively, were estimated. Results from the percentiles were included in Table B.14 in Appendix B. In subsequent analysis, the P50 percentile was used as a representation of the most likely BIC. A final comparison with the BIC time was then performed by plotting the P50 versus the actual problem-free time in days on the Kneler B-5 well in Figure 4.22 with basis in Table B.13 in Appendix B.

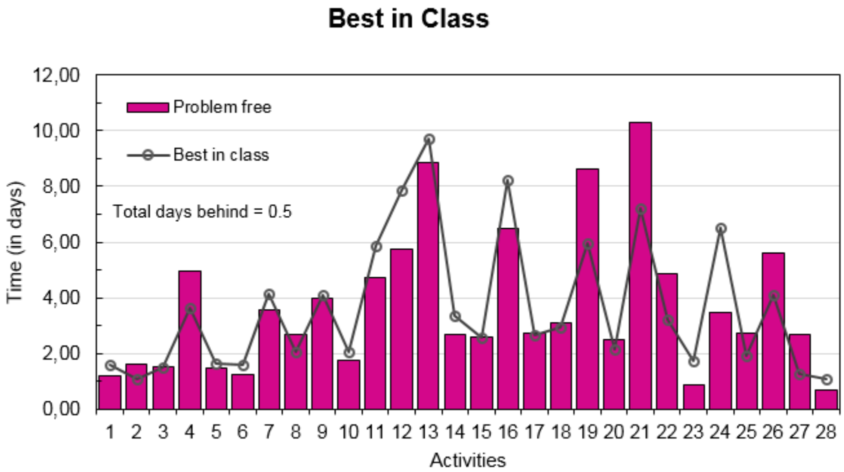

Figure 4.22: Best in Class versus Actual Problem-Free Time on Kneler B-5

In summary, the results in Figure 4.22 shows that 50% of the activities are executed ahead of the BIC. For activity 2, 4, 8, 18, 19, 20, 21, 22, 25, 26 and 28, the gap between the line and bars indicates that actual problem-free performance was less than optimal BIC. In terms of the definition of waste from Section 4.5, the total amount of ILT by not performing at the optimal potential was estimated as 14.32 days, by subtracting the actual problem-free performance from the BIC for all activities.

The probable durations of each of the thousand total job sequences were furthermore calculated based on the mean and standard deviation and the assumption of a normal distribution. The duration in days for each of the thousand job sequence were subsequently estimated and included in in Figure 4.23. In Figure 4.23, the thousand job sequences along with their frequency of occurrence are shown. In summary, the figure estimates that the most probable duration for the total job sequence is 102.787 days. By comparison with Figure 4.22, it was concluded that the Kneler B-5 well came in 0.5 days behind the BIC.

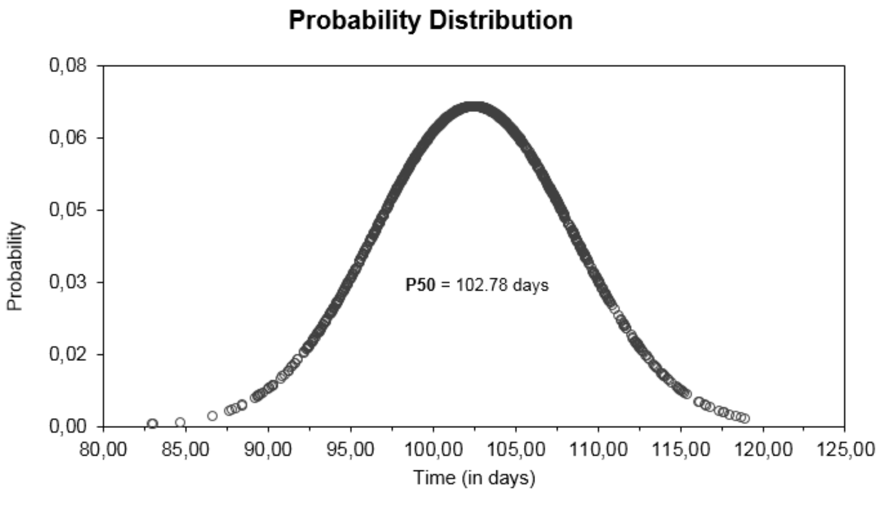

Figure 4.23: Probability Distribution of Total Job Sequence Duration

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Chapter 5

Discussion & Application

This chapter begins by discussing the chief findings from Chapter 4 with emphasis on their limitations and validity. The chapter then continues by discussing how the findings in context of the existing bodies of literature can be subjugated in a new framework for performance management in D&W, encompassing Lean and continuous improvement.

5.1 Summary of Research Findings, Part I

Among the chief objectives of the research in Chapter 4 were the assessment of principles from current and prior performance management and measurement systems, the usage of corresponding KPIs and the determination the of critical operations and wastes in D&W. A summary of the main research findings corresponding to objectives 1-5 is discussed in this section, highlighting the viability and restraints of the analyses.

5.1.1 Performance Management in Aker BP and D&W

The documentary analysis of governing models encompassing the framework for performance management in Aker BP, identified several important features, amongst them being a holistic approach for KPI evaluation and reporting. Holistic in this context suggests that the KPIs must be clearly defined for all team members across the hierarchy in the company, thus reflecting the company´s business priorities at all levels. The analysis also affirmed that performance is mainly measured in a bottom-up approach through the company´s hierarchic levels. In combination, these features bear a distinct resemblance towards the Metrics Tree defined by McWhirter and Gaughan [64], wherein the company's vision and mission are first addressed at all levels in a top-down approach, culminating in a set of business oriented metrics which in turn is measured bottoms-up. Another distinctive feature recognisable was the use of leading and lagging KPIs. From the definition by Peng et al. [63], this combination of assessing both future and past performance, warrants the best possible process control. The usage of digital performance dashboards also signifies an intent of visualising performance to address deviations.

What´s more, subsequent documentary analyses were also able to ascertain a few interesting aspects pertaining to the performance management framework in D&W, chief among them being the use of the PDCA-cycle defined by Kiran [52]. Adapting the elements from the company framework to this methodology, allows D&W to follow a continuous and ordered plan for both management and measurement of performance.

5.1.1.1 Limitations

The documentary analyses were carried out with basis in somewhat incomplete information, being primarily simple slides in PowerPoint presentations with incomplete descriptions of certain elements in the frameworks. In consequence, the analyses were largely based on the researcher's own interpretation and assumptions. Consequently, there exist a possibility in which essential information may have been misinterpreted.

5.1.2 Performance Management in D&W, Det norske

Both understanding and questioning how work is currently performed is a crucial factor in the search for improvement. As explained by Oglesby et al. [22, p. 212], the current method and circumstances surrounding it must be explained in a way that clarifies the attempt and desire. An interview was therefore carried out in the interest of exploring principles from past practices of performance management. Due to the restricted timeframe, the selection process of the interview prospects emphasised individuals with a familiarity to both Det norske and Aker BP, and hands on experience from an engineering and a managing position. In effect, a process of deduction culminated in one formerly retained engineer in Det norske, now currently employed as a sub-divisional manager in Aker BP D&W.

In a brief but informative interview, the interviewee contributed with several chief observations regarding the past performance management system in Det norske. From a series of open-ended questions, the interviewee revealed that the performance had mainly been reported to either company management or respective business units, in the context of three categories; subsurface data, drilling performance and HSE. In comparison with common frameworks in the existing body of literature, the measurement model from Det norske display several similarities with the Performance Pyramid, as both financial and non-financial KPIs were utilised and reported in a hierarchic fashion. As the performance category drilling performance was emphasised on several occasions by the interview subject, the subsequent research has consequently emphasised its corresponding KPIs; drilling efficiency and well NPT.

The interview also reveal certain limitations to the prior management process, being performance evaluation in modest Excel worksheets and regular reporting by individual engineers. A critical drawback was also the highly complexity of the KPIs, resultantly requiring evaluations by respective business units. Furthermore, a tendency of over budgeting was identified. This implies that the teams in Det norske D&W were seldom pressed on performance. With basis in these findings, the later selection of new Lean KPIs therefore emphasises a critical few, but easily understandable KPIs to encourage performance amongst the teams in D&W.

5.1.2.1 Limitation

In total, one single interview was conducted. Whereas the selection of the interview prospect ensured a high quality of the information obtained, the high possibility of subjective opinions from having one prospect severely reduced the overall neutrality in findings.

5.1.3 Strategic Direction in D&W

Artley et al. [71] states that an integral first step towards identifying performance categories and subsequently establishing clearly defined measures, is to define the strategic direction; defining the mission, vision, values and strategic performance objectives. As Artley et al. [71] argues, the lack thereof could increase the risk of both internal misalignment and likelihood for failure. To avoid non-lean behaviour while fostering change through continuous improvement and waste removal, a necessity is aligning activity outcomes with strategic goals and performance measures across functions. In findings from the documentary analyses in Section 4.3, two crucial targets for D&W were emphasised; the departments role in the E&P value chain and a 50% reduction in the CAPEX.

Concerning D&W´s role in the E&P value chain, discussions with both engineers and management highlighted the reduction of the company’s drilling cycle; the time from licence to the production of first oil; as a chief focus area in D&W. From interviews, the latter part of the drilling cycle, referred to as field development in the VSM shown in Figure 4.4, is said to have momentous impact on the company’s overall cost. From Figure 4.4, this includes the phase between PDO Approved and first oil. What´s more, interview prospects also explained that rig hire accounts for roughly 40% of the total time, thus indirectly 40% of the total costs. In effect, this suggests that the latter part of field development, known as well development, should be the focus of attention concerning D&W’s role in the E&P value chain.

Regarding the reduction of CAPEX, findings identified exploration, field development and field in production as the most influential investment categories on the NCS. From the statistical data in Table 4.3, both the mean and median suggests that field development is the most influential. In the density plots from Figure 4.7 moreover, the distribution for this category appears symmetrical around its mean while still being positively skewed. Whereas the positive skewness implies outer extremities in the right-end tails, the symmetrical shape of its distribution suggests that the mode is closer to the mean and median. This implies that the outer extremities in the tail is to the right. Combined with the statistical data, this advocates that field development dominates the investments made on the NCS. In an analysis of awarded licences, findings suggested that most licences in recent time were awarded in areas with existing infrastructure. On account of the above, it is concluded that the most critical area related to well operations in D&W, is field development, more specifically offshore operations or activities related to well development.

5.1.3.1 Limitations

The VSM of the drilling cycle and the description of the well development process were established based on the researcher's subjective experience and knowledge. Furthermore, due to the lack of financial data, the analysis of the CAPEX was largely based on the work by Soebye [75]. As this considers the total investment made on the NCS, it was assumed that this would by directly comparable investments made by operator companies, therein Aker BP. In effect, the above findings are considered somewhat bias, lacking proper validation by internal sources in D&W.

5.1.4 Breakdown of Well Development

Having established well development as a critical area, a comprehensive breakdown of well development activities adapted from Burk and Fink [76], was included in Figure 4.9. As this included all activities on rigs regardless of significance and contribution, further investigation was required. In discussions with D&W engineers, particularly drilling and completion were emphasised. When planning well development, engineers typically draw up drilling and completion programs containing essential activities to be carried out for a well. Post well development, the drilling and completion data are moreover logged in databases such as Rushmore Reviews, and would therefore be easily obtainable. In the breakdown of the well development process, the two drilling and completion categories were therefore emphasised.

The subsequent breakdown considered nineteen recent wells developed by previous operators Marathon Oil Norge AS and Det norske oljeselskap ASA, culminating in a list of 47 activities, each categorised as either drilling or completion and subsequently dubbed per operation type. In virtue of developing the most inclusive and standardised list possible, the breakdown considered both single, multilateral and trilateral wells[1]. With basis in data provided by D&W engineers, two comprehensive data-bases encompassing the depths and times for each activity in each of the nineteen wells were developed. In subsequent analyses, the median time have been emphasised rather than the other measures of central tendency, based on the assumption that this would better indicate the most "typical" time. This hypothesis was later validated by D&W engineers. Taking into consideration the abovementioned findings, the ensuing analyses of KPIs were based one specific well containing most of the critical observed drilling operations and waste NPT; the Kneler B-5.

[1] Multi- and Trilaterals are wells with more than one main wellbore oil-producer

5.1.4.1 Limitations

A prominent limitation with the data provided was the number observations for the type of activities executed. Due to the difference in construction, each well differed in quantity and sequencing of activities. In addition, none of the wells were constructed under the same circumstances, by the same operators, rigs, service companies, equipment or across the same depth and geological formation. Hence, as not every activity was performed at each well, hence some observations included but one observation for time and depth. In consequence, some activities contained at minimum only three observations. Statistically speaking, this serves as a major impediment, reducing both the statistical significance and viability of the findings.

5.1.5 Waste in Well Development

Findings from the an analysis on waste in the well development process, identified in brief three terms related to waste; Non Productive Time (NPT), Wait on Weather (WOW) and Invisible Lost Time (ILT). In the context of the three categories of Lean waste defined by Womack and Jones [36], the three aforesaid terms display several similarities to the definition of service related waste, also known as *muda*. In further comparison to Table 3.3, ILT is very much similar to the *muda* not utilising talent, whereas WOW display the same characteristic as waiting time. It should be mentioned that waiting time is not exclusively related to WOW, as waiting may occur due to other reasons; rotation of crew, transport of equipment and personnel. Notwithstanding, it is assumed with basis in Table B.12 that waiting time is mainly caused by WOW. NPT lastly, being the most critical of the three, display many of the same characteristics as the remaining six types of *muda*. Due to the lack of data, the subsequent analysis considered only WOW and NPT.

Findings from the analysis concluded that WOW exhibits negligible impact on the well development process, compared to NPT. Seeing as WOW is mostly depending on weather and is thus not a factor under control of the department, D&W should direct their attention towards minimising NPT and improve the actual drilling and completion time. The waste NPT was therefore further investigated for both drilling and completion. For drilling and completion, findings approximated that roughly 35.68% and 22% of the observed NPT occurred due to down-hole problems and stimulation operations, respectively. It should be mentioned that the reason for not including wells from 2016 in the analysis for completion, was due to lack of data thereof. In light of Table B.12, findings suggested that most NPT occurs due to the waste known as defects.

5.1.5.1 Limitations

The identification of waste exclusively emphasise those specifically related to drilling and completion, in terms of WOW and NPT, due to the data at hand. Whereas this examination offers somewhat insight into the impact of WOW and NPT, it also serves as a limitation by excluding ILT and any other possible sources for waste from deliberation during the offshore development, such as rigging of equipment, rig move, transportation to and from rig, unplanned meetings with onshore offices with more. Due to the lack of data, it was presumed that ILT, being the difference between best practice and actual performance, would be present in the NPT. Ideally, an evaluation of the ILT and the aforesaid operations should have been included to verify this assumption and to further assess any other plausible cause of waste, respectively.

5.1.6 Traditional KPIs

In the performance dashboard from Figure 4.2, the drilling efficiency in meters per dry hole day is essentially measured as an average across all Det norske operated wells drilled in 2016, and reported back as a single number. Well NPT similarly, is reported as the average percentage of NPT on rigs, excluding WOW. Nowadays, almost all operators in the E&P industry use these two KPIs as a measure for drilling performance, concluding that a well drilled a low percentage NPT and a high drilling efficiency represents "better" performance than a well with a high percentage NPT and low drilling efficiency. This however, is not necessarily always true. If one were to consider two identical wells both developed with 10 days NPT each, wherein the first takes 100 days with a total of 10% NPT and the second is developed in just 50 days with a total of 20% NPT. According to the definitions of drilling efficiency and well NPT, the second well clearly has the better drilling performance as it was developed in a shorter amount of time, despite the higher percentage of NPT. From this one can conclude that the percentage of NPT and drilling efficiency may signifying contradicting overall performance. The drilling efficiency in meters per dry hole days and the well NPT in percent of total actual time across all activities per the development of Kneler B-5, have been compared in Figure 5.1.

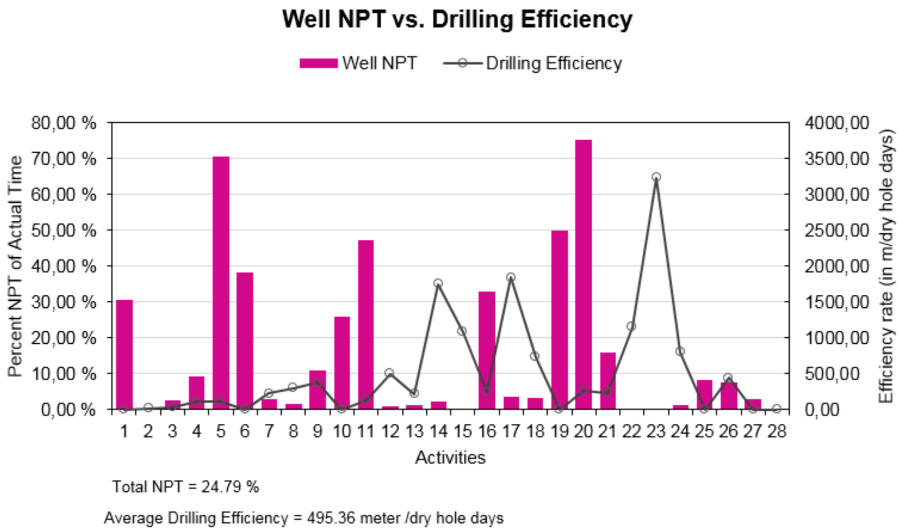

Figure 5.1: Drilling Efficiency vs. Well NPT for Kneler B-5

From Figure 5.1, the drilling efficiency rate is observed significantly higher for those activities with great effective depth, therein particular drilling activities. In contrast, for these same activities, the degree of NPT appears low. In effect, the visualisation of the two in conjunction easily signify where in the flow drilling performance is low. However, when used alone, the KPIs are unable to measure performance for certain activities. This furthermore substantiates the claim that the two KPIs provides no meaning standing alone.

5.1.6.1 Limitations

The estimations for drilling efficiency and well NPT on Kneler B-5 were utterly based on the data provided by internal sources in D&W and the researchers own interpretation of the performance metrics. In effect, misinterpretation of the definition of drilling efficiency and well NPT may have occurred, leading to falsely produced results.

5.2 Summary of Research Findings, Part II

A summary of the main research findings for objectives 6-7, regarding a new Lean performance category and the use of corresponding Lean KPIs are discussed in this section, before the chapter returns to reflect on research objective 8 and the key research problem.

5.2.1 Developing a Lean Performance Category and KPIs

An original Lean performance category was explored using the methodology delineated from the Metrics Tree [64]. From the documentary analyses in Section 4.3, the vision and mission in D&W highlighted two targets; the department's role in the E&P value chain, and the reduction of CAPEX. From two comprehensive analyses in Subsections 4.3.1 and 4.3.2 moreover, findings recognised field development, in particular well development, as an area of high importance in D&W. With this as an abiding foundation, subsequent analyses were executed to establish critical success factors, as recommended by McWhirter and Gaughan [64]. A list of the most typically reoccurring activities in well development was established, following a breakdown of the well development process. The analyses in Section 4.4 subsequently indicated that some activities exhibits greater impact on the process than others. Further investigation into the matter in Subsection 4.4.2 revealed that drilling operations and activities are particularly related to high duration and waste in terms of NPT and WOW. The analysis in Section 4.5 furthermore affirmed that NPT and WOW are the primary sources for waste, with NPT being predominant.

In consideration of two aforesaid targets and the existing body of Lean theory, a critical success factor identified was the necessity of increased flow amongst the activities in the well development process, thus minimising the main sources of waste being NPT and WOW. Although there exist several core principles from Lean and continuous improvement theory which can be used to achieve value delivery and reduction of these wastes, the idea of flow is predominantly fascinating. In a perfect Lean state for D&W, the work performed across each activity would flow continuously from start to finish, meeting the exact needs of the customer, thus culminating in a developed well at a pace that matches their customer's demand. This in turn depends heavily upon balancing the capacity. However, the capacity is often hidden away or lost in processes due to capacity constraints, or bottlenecks. From the theory of flow efficiency, Modig and Ählström [9] discuss that the capacity of any manufacturing process is limited by its capacity-constraining resources. In well development, these bottlenecks can be defined as the activities in the value chain with the greatest execution time. These bottlenecks define in general the throughput in the well-development process. Hence, if said bottlenecks can be identified and subsequently improved, the throughput will surge, yielding a better and more efficient well development.

Thus, a new Lean potential category for performance measurement was therefore termed "Flow Efficiency". Having defined a critical success factor in alignment with the strategic direction in D&W and the Lean business strategy of the company, the list of 78 lean KPIs in Table B.1 from Behrouzi and Wong [67] was subsequently used to derive a set of Lean KPIs, embodying the principles of flow efficiency and adaptive to the data at hand.

Following a thorough selection process, quite a few of the Lean KPIs proved to be unfeasible due to the uniqueness of the well development process, the restrictions posed by the activity sequence and the designated input defined as the time spent on each activity. Resultantly, the list was ultimately filtered down to include the following KPIs;

- Takt Time
- Cycle Time
- Lead Time

The implementation of these Lean KPIs is supported by Ali and Deif [77], who presents a model to examine the dynamics associated with the application of takt time. Results from their study confirms that working on adjusting the system's cycle times to follow takt time will improve the overall lead time and performance [77, p. 1]. For a more detailed definition of each KPI and unit, reference is made to section 4.8.1 in chapter 4.

The analysis in Section 4.8.2 reveals that some activities on Kneler B-5 were not keeping up with demand when comparing the takt and cycle times in Figure 4.19. In this regard, the takt time requires further explanation. In a traditional manufacturing or production setting, the takt time represents the average time spent on producing one unit to meet customer's demand. In this study, the production of units has been replaced by the completion of activities. In effect, each activity exhibits a diverse execution time. Hence, the takt time was therefore estimated for each individual activity rather than as an average.

By furthermore comparing the NVA and VA cycle times with the total lead time in Figure 4.21, one can easily infirm the whereabouts of waste and how it accumulates throughout the well development process. From Figure 4.21, the NVA time is already apparent from activity number 2. As the development process continues, more and more NVA time accumulates, thus increasing the total lead time and waste.

5.2.2 Limitations

The process of deriving new Lean KPIs is mostly qualitative based upon the researchers own subjective interpretation, and can therefore be considered as biased. Optimally, the selection process should have encompassed quantitative estimations for all Lean KPIs before being validated by an unbiased third party.

5.2.2.1 Comparison between Prior and Lean KPIs

The drilling efficiency and well NPT were used as lagging KPIs to report past performance in terms of averages in Det norske. This in consequence provides little opportunity for D&W to make alterations and improve during the well development. Whereas drilling efficiency makes it easy to identify activities exerting high drilling performance and equivalently difficult to identify those with a low performance, the opposite appears to be the case for well NPT. A major limitation of these KPIs, is their impracticality when comparing performance between different wells.

Takt, cycle and lead time conversely, utilises both lagging and leading principles, wherein low performance is represented by cycle times greater than takt times. Using these Lean KPIs facilitates measurement of both past and real time performance by estimating the actual occurring VA and NVA cycle times and comparing them with the takt and lead time. This in turn is utilised to pinpoint the stages in the work flow where waste is currently accumulating, thus allowing the teams in D&W to better understand the rate at which they need to operate. The usage of these three Lean KPIs are furthermore compared to the prior drilling performance KPIs in Table 5.1.

Table 5.1: Prior KPIs vs. Lean KPIs

Category	KPI	Low Performance	High Performance
Drilling Performance	Drilling Efficiency	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 16, 19, 20, 21, 25, 26, 27, 28	12, 14, 15, 17, 18, 22, 23, 24
Drilling Performance	Percent of NPT	1, 5, 6, 10, 11, 16, 19, 20	2, 3, 4, 7, 8, 9, 12, 13, 14, 15, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28
Flow Efficiency	Takt vs. Cycle times	2, 3, 4, 5, 10, 15, 19, 20, 22, 25, 26, 28	1, 6, 7, 8, 9, 11, 12, 13, 14, 16, 17, 18, 21, 23, 24, 27
Flow Efficiency	Cycle vs. Lead times	2, 5, 11, 16, 19, 20, 21, 28	1, 3, 4, 6, 7, 8, 9, 10, 12, 13, 14, 15, 17, 18, 22, 23, 24, 25, 26, 27

For drilling efficiency, high performance is defined as rates greater than the average of 495.36 meters per dry hole days. For well NPT, low performance is defined as NPT greater than the total average NPT of 24.79%. The estimates for low performance in the flow efficiency KPIs moreover, are defined as cycle times exceeding the takt time, or high NVA cycle times. From Table 5.1, certain disparities are encountered, wherein the new Lean KPIs are able to individually indicate a greater amount activities with low performance.

5.2.2.2 Limitations

Takt, cycle and lead time are in Lean theory predominantly related to the production of units in a manufacturing setting. Their definitions are therefore slightly altered by replacing number of units with activities to accommodate the data at hand. For takt time, this alteration produces several implications. In literature, the takt time is defined as the ratio of available production time to the demand set by customers, excluding unplanned downtime; planned meetings or breaks. For this analysis, the takt time was defined in agreement with prof. Jan Frick at the institute of *Handelshøyskolen ved UiS*, as the AFE time. Considering that the AFE has added time to account for unplanned downtime such as NPT and WOW, the takt time should ideally have been defined as the AFE problem-free time.

5.2.3 Additional KPIs

In addition to the takt, cycle and lead time, a selection of additional Lean KPIs was included; Process Cycle Efficiency (PCE), Waiting Time, Utilisation, On Time Delivery (OTD) and Excess Time. The assumption is, with basis in the theory on flow efficiency, that these additional Lean KPIs in conjunction with the takt, cycle and lead times, enables the identification of potential bottlenecks in a well development process.

The percent of utilisation U, and excess time T_{excess} are for further research purposes, plotted against the percent PCE in Figure 5.2 to distinguish potential bottlenecks in the Kneler B-5 development.

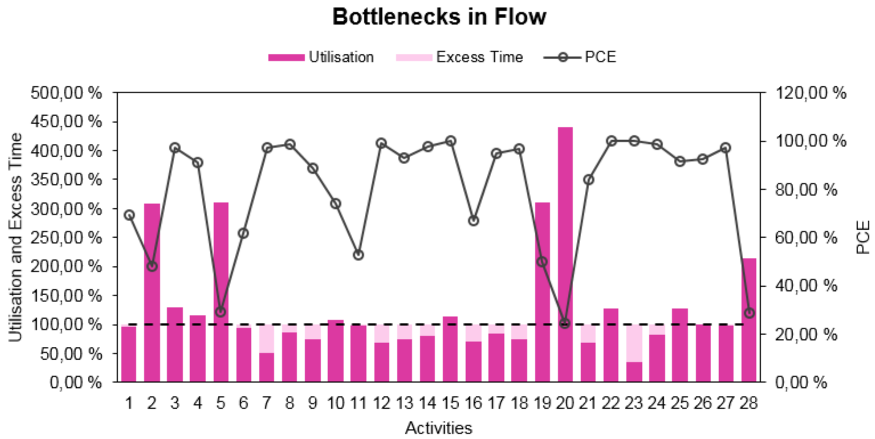

Figure 5.2: Identification of Bottlenecks Using Additional Lean KPIs

In Figure 5.2, a total of twelve bottlenecks are identified, in which five are deemed critical; activity 2, 5, 19, 20 and 28 respectively. These are congestion points in the flow made easily recognisable by their low degree of PCE, zero available excess time and contrariwise high utilisation. Furthermore, rather than just identify bottlenecks, the aforesaid utilisation and waiting time in particular, can also be used in conjunction with the cycle times to estimate degree of variation from the Kingman's formula in subsection 3.3.2.3. As explained by Kingman [39], variation will always have a specific negative impact on the flow efficiency. As the relationship between the cycle time and variation is exponential, an increase in cycle time will result in an increase in variation, thus reducing the flow efficiency. The information from Table 4.8 is subsequently used to develop a Gantt chart in Figure 5.3.

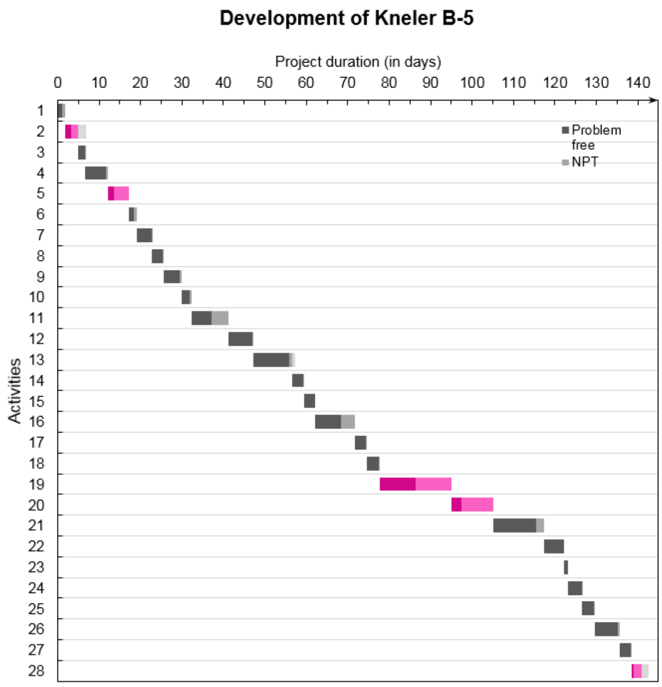

Figure 5.3: Gantt Chart Illustrating Bottlenecks in the Kneler B-5 Development

From Figure 5.3 the most critical bottlenecks have been highlighted in pink graded colours. The idea would be to use the Gantt chart cumulatively over the course of a development project, to immediately respond to the bottlenecks with counteractive measures.

5.2.3.1 Limitations

The additional KPIs are, like the takt, cycle and lead time, estimated based on the data already obtained from previous analyses and in terms of activities rather than production units. Thus, the interpretation of the KPIs may vary slightly from their definition in literature. This may have resulted in improper estimations, limiting the use of Little's law, Work in Process (WIP) and throughput. In addition, the utilisation is defined in simple terms. Due to the lack of data, it is therefore not possible to estimate the other variables in the Kingman's formula, rendering it unusable.

5.2.4 Best In Class (BIC) Approach

In the interview, included in Appendix A, the interview subject revealed that simulation methods similar to Monte Carlo, exploiting data from past well performance, are currently utilised in well development planning. These simulations are to the extent of the researcher's understanding commonly acquired from third party service companies; Rushmore Reviews or Schlumberger Limited[2].

In effect, the BIC approach is introduced to this work, as findings suggested that the similarities to recently developed practices would make it easy to implement and utilise in conjunction with the Lean KPIs. In Subsection 4.8.6, the BIC was estimated using a Monte Carlo simulation to develop a BIC estimate for each individual activity. Result concludes that performance in approximately 50% of activities on Kneler B-5 exceeds the BIC, suggesting extremely varying degrees of potential performance. Furthermore, findings from estimates on the total job sequence concluded that the problem-free time exerted on the Kneler B-5 well, was 0.5 days more than the optimal BIC.

5.2.4.1 Limitations

To derive the appropriate estimate for the BIC on the Kneler B-5, findings assumed that activities performed across different wells would be executed with the same rate. This was a simplified assumption at best, as the execution rate depends on a great variety of variables.

For the Monte Carlo Simulation, a normal distribution was assumed to derive a random number ranging between the minimum and maximum of the observed times for each activity. This was a simplified assumption at best, considering that some activities had only three observations for time. For some activities, moreover, this also included the time on the Kneler B-5 itself. As this time was neither minimum of maximum on any activity, its impact on the simulation was assumed negligible.

[2] Multinational oil & service company providing technology for reservoir characterisation, drilling, production, and processing to the O&G industry

5.3 Application of Findings

The ensuing sections have in response to research objective 8 and the chief research problem from Section 1.3, been aimed at discussing the application of research findings from Chapter 4, in terms of a new framework for performance management, and how it may contribute to well operations. To ensure adaptability and ease of use, the new framework also been adapted to the principles for performance management in Aker BP and D&W from Section 4.1.

The new framework presented in Figure 5.4, draws upon the principles and methods of Lean, Six Sigma and continuous improvement presented in the literature review, following the main steps of the DMAIC-cycle from Six Sigma defined by Aruleswaran [55]. The framework bears a somewhat resemblance to the Lean Six Sigma Framework (LSSF) developed by Cortes et al. [66], who supports this solution in their paper regarding the integration of operational performance indicators for strategic Lean management [66, p. 1].

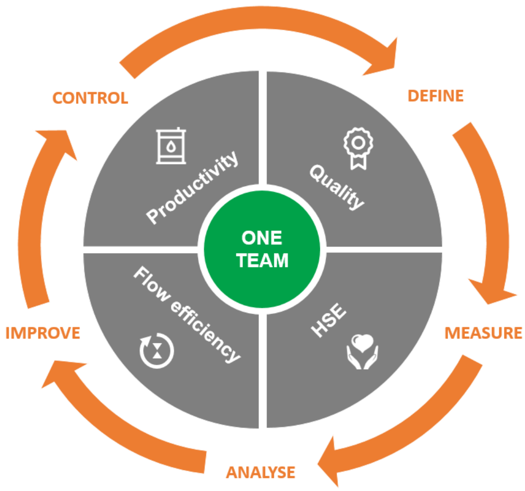

Figure 5.4: Lean Six Sigma Framework for Performance Management in D&W

Contrary to the rudimentary PDCA-cycle employed in the current performance management framework in D&W, the pragmatic advantage of DMAIC-cycle includes the use of Lean principles and methods to identify waste, flow and bottlenecks, and moreover elements from Six Sigma to analyse the performance using statistical methods. Somewhat similar to the frameworks from Section 4.1, the intent is for D&W to measure performance in four categories; productivity, quality, HSE and flow efficiency; in a continuous DMAIC-cycle for each well development project. This also includes managing deviations, implementing learning to drive improvement and reporting the performance according to departmental hierarchy in D&W. The emphasis in the ensuing sections has been to describe this new framework in terms of the performance category flow efficiency, following the five DMAIC steps depicted in Figure 5.4;

- Step 1: **Define** critical performance objectives.
- Step 2: **Measure** performance across the well development process.
- Step 3: **Analyse** data to estimate flow efficiency and identify critical bottlenecks.
- Step 4: **Improve** absent performance in bottlenecks.
- Step 5: **Control** and monitor performance.

5.3.1 Define

The first step in the new performance management framework for D&W is similar to all performance management systems as explained by Artley et al. [71], to *define* the strategic performance objectives for the current well development project. For these to be effective, Artley et al. [71] implies that the objectives must be linked to the strategic direction in D&W and consider both the vision and mission for the department from Section 4.3. To ensuring operational alignment, this first step employes a holistic approach like the principles from the Metrics Tree [64], when deriving these objectives.

In addition to the targets identified in Table 4.2, a major objective affirmed in the interview from Section 4.2 is to obtain the correct well data. Although there exists some degree of variation in the terminology, a review of the existing body of literature also confirms that performance objectives should always include a number and a unit of measure. Hence, the performance objectives should be written statements that quantitatively describe the desired outcome of a well development project in terms of data acquisition, design and costs. For flow efficiency moreover, this also includes the allowable waste. Besides estimating time and budget, the teams in D&W should also define the desired performance in terms of quantitative estimates for the Lean KPIs and BIC from Section 4.8, respectively. This includes defining the necessary data for measurement and the ideal takt time required to meet their customer's demand. Rather than focusing on high capacity and the best utilisation of resources, a suggestion is to contemplate the well project as a flow-unit, focusing on how it receive added value as it "moves through" the development process [9]. Once the strategic performance objectives are defined, the planning of the well design in terms of trajectory, sectioning and depths may commence. Here, the emphasis should be on delivering the best well possible with the right specification and quality according to the requirements and demand set by the company's customers.

As a typical development process follows a strict sequence of activities with little room for alteration, a suggestion is to develop a standardised set of operations and activities for the planning from which to improve and remove waste. As defined in line with the principles of Kaizen [48], this could improve the department's control over performance deviation and simultaneously make it easier to benchmark and compare performance in future projects. A starting point such a baseline should be the activities from Table B.3. These activities should in turn be categorised as either drilling or completion, and moreover according to a similar classification of the six operations types presented in table B.3; BOP, casing, cementing, completion, drilling or rig related. For each of these activities, the teams in D&W should also incorporate a list of every minor activity or process required in each section of the well. Such standardisation could per Alukal and Manos [48] thereon result in increased consistency, production, work process stability, quality and employee involvement, whilst reducing the probable cause of defects. Considering that every well and reservoir is different, the set of activities should be adapted to the respective setting and parameters for the well being developed.

Having established the necessary activities and resources required to develop a well, the planning in the *define* step should also including the VSM method as defined by Taylor and Brunt [32]. From table 3.4, the best suitable method for this scenario would be *Process Activity Mapping* (PAM), considering its ability to identify all of the seven *muda* [32]. In this first phase, the teams should establish an initial PAM for the standardised set of activities used in the planning of the well.

By updating this later on in the process, D&W would be able to identify the flow of activities in addition to the management and information systems that support the development process. A rudimentary suggestion for such an initial PAM is shown in Figure C.2 in Appendix C, using the Kneler B-5 as an case. In the PAM from Figure C.2, the activities have been visualised vertically according to sequence and respective depths, with the estimated time for each activity shown in the time-line below. It should be noted that this illustration only includes the AFE time in days. When estimating both the problem-free and unplanned NPT and WOW time using acquired data from third-party service companies, additional in-house simulations particularly emphasising the problem-free time should be included, thus enabling the use of the BIC.

5.3.2 Measure

Once the performance objectives and targets for the well have been set and the PDO has been approved, D&W can begin to acquire the necessary resources, equipment and third party personnel, before commencing with well development. At this point, Lebas [61] suggests commencing measurement of performance to support the continuous improvement and planning of activities. During this second *measure* step, D&W should follow a pre-determined plan for data collection and sampling. Emphasis should be on acquiring the necessary information for analysis of the KPIs. In addition to the problem-free time, NPT and WOW, the NVA and VA cycle and lead times should also be recorded. Furthermore, it is suggested to also include measurement of the elements shown in Table B.15 in Appendix B, thus simplifying the identification of waste. It should be noted that the table only includes an initial starting point, and should be developed over the course of future projects.

To obtain the necessary performance information, D&W should incorporate solutions for automatic collection of real-time data from the offshore installations using high-level algorithms and software integrated as part of the ongoing digitisation process in D&W. Formerly, this data has been continuously recorded by respective parties; either in-house engineers, or third parties such as hired drilling operators, rig- or service companies; in 15 minute intervals. This data includes the individual responsible for overseeing the work, time, depths and additional relevant information related to each minor sub-activity. The data is then extrapolated into Excel and made easily available at intranets. In this thesis, much of these minor activities have been dubbed as one primary activity as explained in section 4.4. The work has furthermore emphasised days related to these primary activities rather than minutes per minor sub-activity.

For future purposes it is suggested that the data logged per 15 minutes for each minor activity or process should be initially prioritised rather than the data used in this work. This would result in a more comprehensive data-set, thus increasing the accuracy of subsequent analyses. From this, each minor activity or process can be dubbed according the activities, operations and category type as in Table B.3. By prioritising automatic collection of these data using digital solutions incorporating advanced software, and algorithms defined by D&W engineers and subsurface professionals, D&W ensures standardisation of the *measure* step.

5.3.3 Analyse

The third step in the proposed framework is somewhat intertwined with the previous step. A recommendation is to review the data collected during the *measure* step, as the teams may decide to adjust the data collection plan to include additional information. This continues while the teams *analyse* the real-time data in an effort to determine how actual levels of performance differs from the pre-established performance objectives defined in the first step.

The intent is to analyse the automatically measured real-time data for each activity per execution, using analytic software to develop combined bar charts similar to those developed in Excel throughout Chapter 4. The charts offers D&W and third party operators an effective method of visualising the interrelationships among operations and activities, and to appraise the amount of value or non-added value [22, p. 220]. This information is thereon used to distinguishing those activities or third parties responsible for poor performance. The usage includes estimation and visualisation of the takt, cycle and lead times to determine the gap between planned and actual performance, indicating how the activities are performing per the required development rate. An illustration of the relationship between the three is shown in Figure C.1 in Appendix B. For a more detailed definition, reference is made to Section 4.8.1 in Chapter 4.

In like manner, the BIC is estimated by comparing the simulated estimated problem-free time from the *define* step and the actual problem-free time from the currently executed activity. From this, D&W can determine whether the activity is performing per its potential. What's more, the additional Lean performance metrics; PCE, waiting time, utilisation, OTD and excess time; are then analysed to determine the degree of waste and NVA time related to the activity being executed, thus indicating whether the activity represents a bottleneck. Once D&W have recognised a potential bottleneck, the activity should be tested to determine whether it is the true cause of the problem. For this purpose, the Lean Six Sigma methodology introduces several tools [56].

The iterative interrogative technique "The Five Why's" can be utilised conjunction with the estimates from the additional Lean KPIs to identify the nature of the problem, before narrowing down and verifying the root causes of waste. The problem is then formalised and described completely, prior to asking repeatedly why it occurred until the root cause is identified [45]. This technique can also be used in combination with "Fishbone Diagrams" to explore all potential or real causes of waste in a structured format, thus focusing on the content of the problem rather than its history [32]. With basis in automatically collected data from the *measure* step, D&W can thereon develop a current PAM to pinpoint the accumulation of waste, delays or congestion points. The map should be drawn in accordance with the activities performed, and include the necessary inputs, activity being performed, decisions required and outputs [32]. Lastly, if multiple wells are being developed in sequence, Little's law from Modig and Ählström [9] can be utilised to easily estimate rate of the well development from the following equation;

$$\lambda = \frac{WIP}{T_{lead}} \tag{5.1}$$

Where λ is the rate of developing one well, WIP is the number of activities for said well and T_{lead} is the lead time for developing the well.

5.3.4 Improve

Once satisfied and confident that additional analysis will not add to the understanding of the problem, the *improve* step commence. The *improve* step in this framework occurs concurrently with the subsequent *control* phase, in contrast to the PDCA-cycle from the current framework in D&W. This allows D&W to address the identified wastes whilst simultaneously reporting and controlling the performance, thus ensuring that the development does not encounter any delays from implementing the improvement measures. Although improvement ideas are most likely collected throughout the execution of activities, a structured improvement plan should be in place.

Having identified the type and root causes for waste and visualised the flow with basis in information from the previous *analyse* step, the teams in D&W should begin to brainstorm solutions for waste reduction, considering risk and cost factors. For each proposal, D&W should develop PAMs based on different solutions and evaluate the benefit from each. Once the decision on an improvement proposal has been made, mini testing PDCA-cycles can be employed to help refine the solution while collecting valuable stakeholder feedback. These cycles are a simple way of find out if small improvements are viable in a fast and low impact way. Once a decision has been made, improvement of the root cause of waste can commence utilising the selected proposal.

At this point, it is necessary to point out that the intent is not so much to improve the current activity being executed, but rather the processes and minor activities making up the primary activity. To further explain this chain of thought, consider for instance the main activity "Drill 16" hole". Once the hole is drilled, there is little that can be done to repeat the activity besides drilling a new hole. However, the activity itself is made up of numerous minor processes and sub-activities; transportation-, waiting- and rigging up of drilling equipment, running of slips[3] running in and out of hole with string, pumping of mud, drilling formation, removing drill-waste to performing un-planned change of defective equipment and more. By improving and eliminating the root cause for waste amongst these minor processes and sub-activities, D&W ensures the probability of higher performance in any subsequent drilling operations.

5.3.5 Control

The final stage in the new performance management framework is to *control* the performance. This includes automatic visualisation of the real-time performance using digital KPI dashboards, to ensure that the development process is being monitored properly. In this framework, the control and reporting of performance have been design according to a hierarchical approach similar to the current management framework in Aker BP from Section 4.1, to ensure operational alignment. The overall aim is, much like the principles of the performance pyramid by Quagini and Tonchia [73], to synthesise low-level measurement into higher level aggregate measures for management, by dividing the category flow efficiency into three levels; strategic, technical and operational performance. These three levels are in turn visualised according to the departmental hierarchy in Aker BP and D&W using a bottom-up approach shown in Figure 5.5.

[3]A device used to grip the drill-string and suspend it in the rotary table

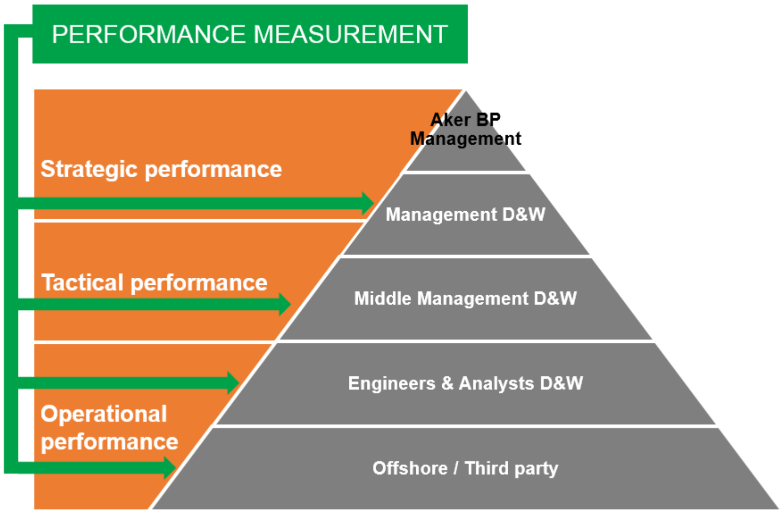

Figure 5.5: Performance Reporting, Using a Hierarchic Bottoms-Up Approach

At the lowest level, the frequent day to day operational performance is presented to the respective engineers and analysts in D&W in addition to offshore or third party personnel, allowing them to make short-term decisions. In the second level, the operational performance is synthesised into tactical performance for top and middle management in D&W, allowing them to see the status of the operations and current progress. This in turn culminates into the strategic performance for the company and departmental management in Aker BP and D&W, allowing them to make long term decisions on behalf of the company.

The basic principle behind this reporting model is based on a bottom-up approach wherein the performance at the lower levels are used to estimate the performance at the upper levels. This way, only the necessary information required to make decisions at the different hierarchy levels in D&W is visualised, thus keeping the most essential performance internally, on a need-to-know basis. Naturally, if more information is required, the top levels should be able to access the performance at the lower levels.

An example of a KPI dashboard for the new performance category flow efficiency is demonstrated in Figures 5.6 and 5.7. Here, the overall performance, using the Kneler B-5 as an example, is visualised using various graphical presentations of the Lean KPIs introduced in Chapter 4 in conjunction with the BIC. It should be noted that the two dashboards both demonstrate the final performance after having fully completed development on Kneler B-5. This was done to best illustrate each individual graph. The intent is to utilise these dashboards in accordance with the execution of each activity, thus visualising the real-time performance. The first dashboard for the takt, NVA and VA cycle and lead times (in days) is shown Figure 5.6, using an adapted approach to visualise the gap between the planned NVA and VA and cycle times and required takt time against the actual NVA and VA cycle times. This easily showcases the actual performance according the planned performance objectives defined in the *define* step, following the colour-coding theme defined in the topmost graph for management. To illustrate whether development is meeting the customer's demand, all graphs on have been marked as green or pink for "yes" and "no" respectively.

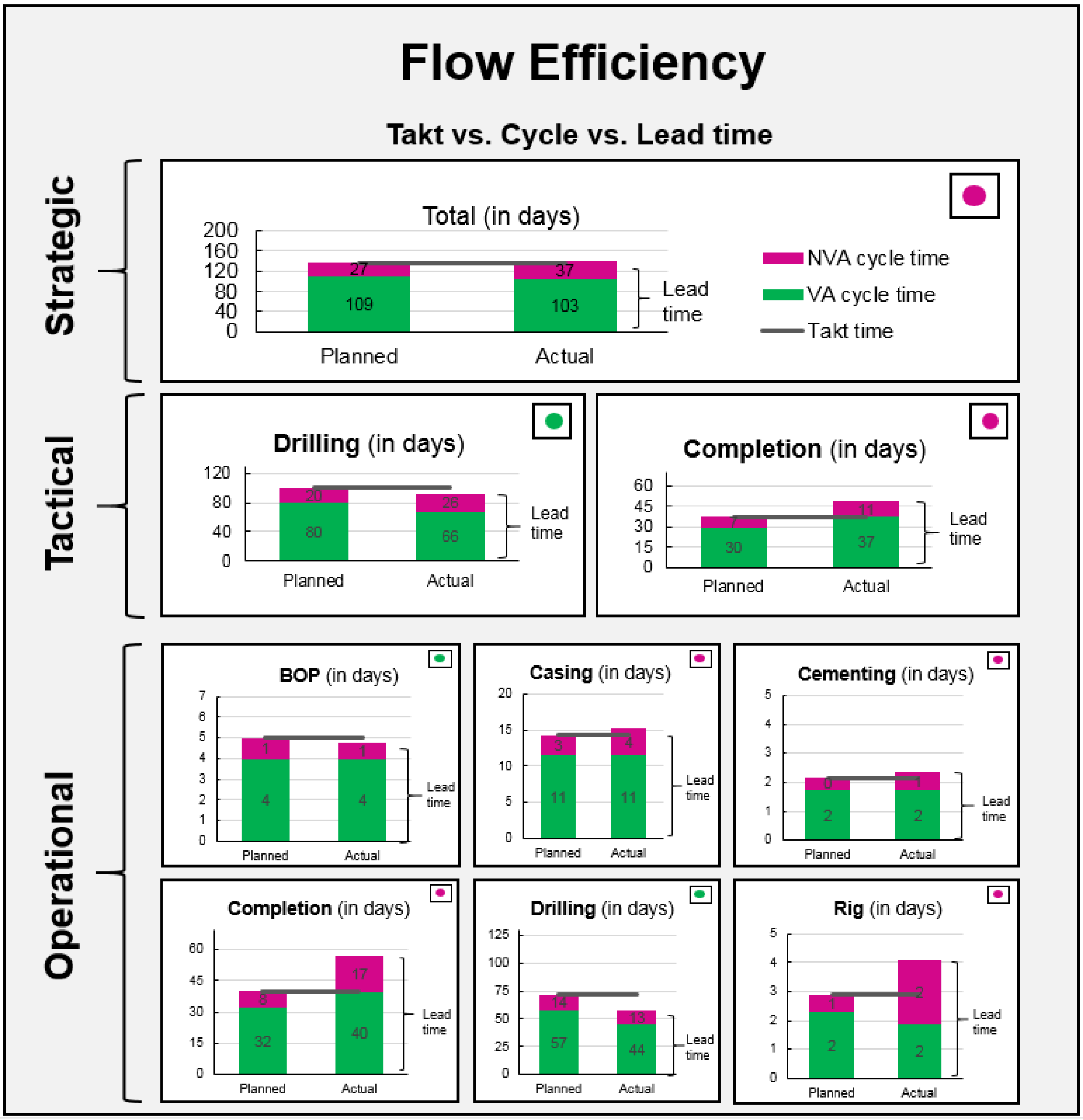

Figure 5.6: Dashboard 1, Takt Time, NVA and VA Cycle Time and Lead Time

The dashboard is moreover broken down and visualised according to the reporting model in Figure 5.5. At the lowest level, the operational performance for the various operation types are shown for the middle-management and in-house engineers. The results from these are then utilised to estimate and illustrate the tactical performance for the two categories drilling and completion for the top and middle management in D&W. From this, the strategic performance of the overall development process is exemplified for the company management. Additionally, the intention was to include the operational performance for each activity in an additional operational level at the bottom. However, these have not been included in this dashboard due to mere quantity graphs this would require.

In Figure 5.7 moreover, the same breakdown structure is utilised to visualise the additional Lean KPIs from Subsection 4.8.4 and the BIC from Subsection 4.8.6. From the dashboard, six different types of graphical presentations are used to determine the flow, bottlenecks and loss of potential in the development process.

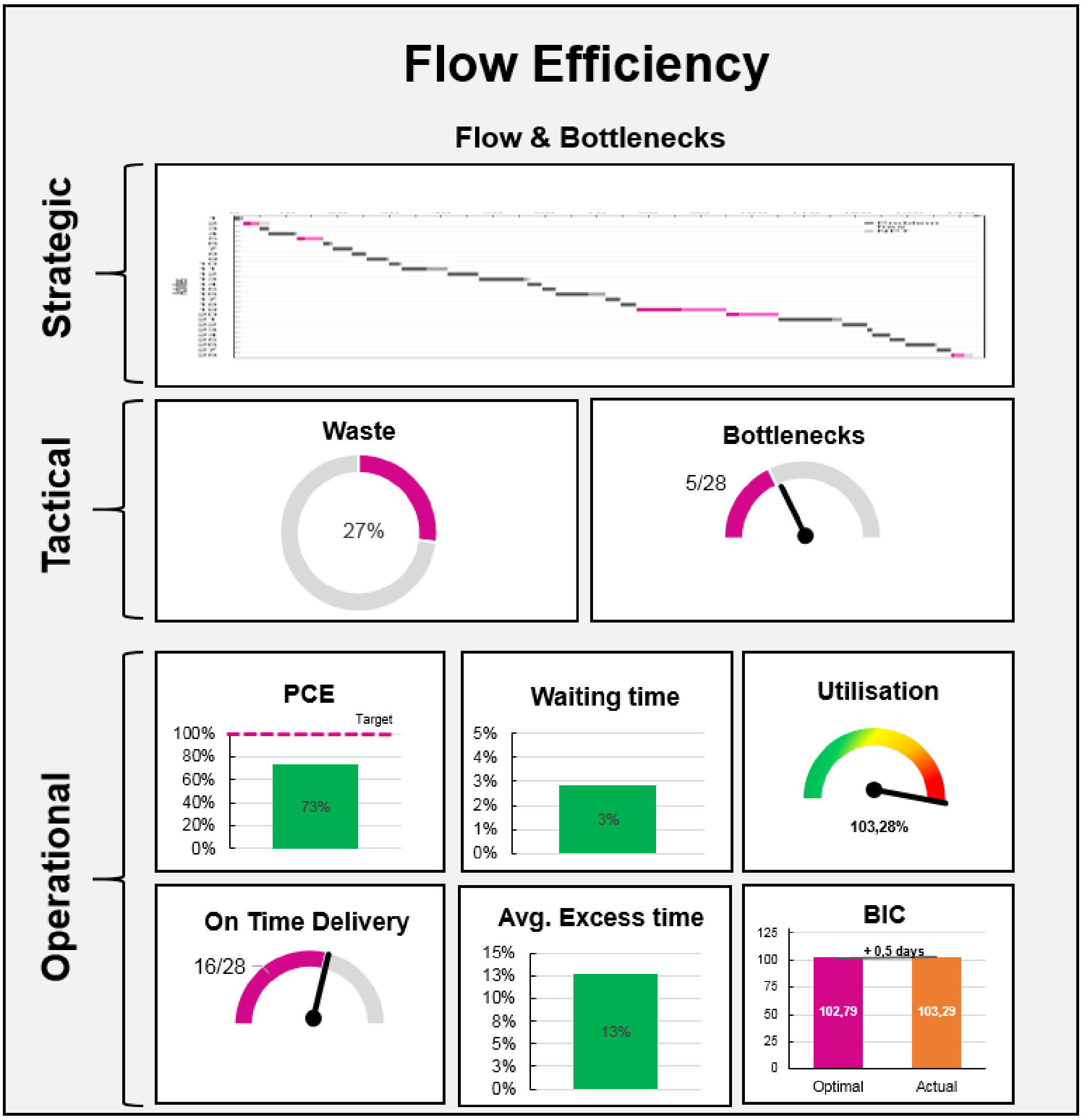

Figure 5.7: Dashboard 2, Bottlenecks and Waste

At the lowest level, Lean KPIs and the BIC are utilised to visualise the operational performance for the middle-management and in-house engineers, wherein:

- The PCE shows the overall process cycle efficiency of activities as a percentage. Here the optimal target has been set at 100 percent, but can be changed accordingly, depending on the strategic objectives.
- The Waiting Time shows how much time is spent on waiting as a percentage of total actual time.
- The Utilisation shows how much of the available time (AFE) that is utilised.
- On Time Delivery shows the number of activities executed within AFE.
- Average Excess Time shows the average time available after completing each activity.
- The BIC shows internal potential by comparing the actual performance against optimal performance.

From this, the tactical performance is estimated and visualised for the top and middle management in D&W, in terms of percent of waste and number of bottlenecks. At the top strategic level, the overall flow and bottlenecks are visualised for the top company management using a Gantt chart identical to that in Figure 5.3. The results from both of these dashboards can thereon be utilised in conjunction with a future state PAM. An simplified example shown in Figure C.3 in Appendix C with basis in the Kneler B-5 well. For best utility, this map should also include the necessary inputs, sub-activities, decisions and outputs. Once the development process has concluded, the teams in D&W should log all the data and experience obtained in a data-base for use in later projects, thus ensuring continuous learning.

In summary, the above framework illustrates the pragmatic advantages of Lean and continuous improvement in performance management for well operations D&W. In important distinction is to utilise the framework in a continuous cycle for each activity. By emphasising a holistic approach for both management and measurement, the framework ensures the engagement of all employees, thus allowing them to work as one unified team. The framework also provides management with the means to evaluate the performance of D&W teams and third party operators, and moreover to utilise this information in the planning of future projects.

Chapter 6

Conclusion

This chapter presents the overall conclusions of this thesis in terms of the key research objectives and research problem. The chapter then outlines achievements and contribution to the existing body of research and literature, before providing suggestions for future research.

6.1 Research Objectives and Main Findings

The chief research problem of this thesis has been to determine how Lean and continuous improvement in performance management can contribute to well operations, following a case study of the department D&W in the E&P company Aker BP. Due to the nature of the research scope, the case study was adapted to an exploratory sequential design, encompassing both qualitative and quantitative methods for analyses, with the latter being predominant. In effect of the task at hand, the chief research problem was furthermore divided into eight key research objectives.

An extensive literature review following a thematic fashion was firstly undertaken in consideration of the research aim, thus establishing a structured understanding for the background of this research. As a means of limiting the scope, the literature review primarily emphasised in the following order the E&P value chain, flow efficiency, Lean and continuous improvement related subjects, and performance management and measurement.

Findings from a documentary analyses concerning the first objective successfully recognised four key elements in the current framework for performance management in Aker BP, being performance objectives, KPIs, actions and people. An interesting feature also distinguished was a holistic evaluation approach encompassing both leading and lagging KPIs and performance dashboards in a hierarchic reporting fashion. For D&W moreover, findings affirmed a management framework largely adapted to the principles of the PDCA-cycle and three main categories for performance measurement; productivity, quality and HSE.

As the development of current performance measures was ongoing in D&W, an interview was carried out to evaluate prior practices for performance management and measurement carried out in Det norske D&W in alignment with the second objective. Findings from the interview recognised in brief three performance categories with corresponding KPIs being reported to either management or corresponding business units. Amongst these, the category drilling performance and its corresponding KPIs drilling efficiency and well NPT were largely emphasised. Two critical drawbacks with the prior practices were the highly complex nature of the KPIs and the resulting individual evaluation by respective engineers. Due to lack of information and limited time-frame of this study, any further investigation of prior practices was omitted. Notwithstanding, the aforesaid findings were recognised in the final discussion to ensure verifiability with new practical solutions.

For the third objective, a documentary analyses of the strategic direction in D&W was included to determine the most critical area related to the work performed across well operations in D&W. On account of two strategic objectives; E&P value chain and CAPEX reduction; ensuing documentary and statistical analyses recognised the latter part of field development, known as well development as being most critical. Following a breakdown of the well development process, findings across 19 wells culminated in a standardised set of 47 well activities. Three statistical sub-analyses across the 19 wells and 47 activities thereafter, collectively affirmed that drilling activities accumulated the greatest problem-free time and waste.

In response to the fourth objective of determining waste in well development, documentary findings concluded in brief with three main types of waste; NPT, WOW and ILT. Due to the lack of data, subsequent research chiefly considered NPT and WOW. Following a quantitative investigation across extrapolated NPT and WOW data pertaining to roughly 144 and 143 developed wells for drilling and completion respectively, NPT was found to be the determinative factor of waste in the well development process.

In an effort to conclude on the fifth objective regarding the practicality of prior KPIs; drilling efficiency and well NPT in well development; further work took basis in Kneler B-5, a trilateral well exhibiting high degrees of NPT. Statistical findings affirmed that the prior KPIs of drilling efficiency and well NPT, yielded contradicting overall performance when combined and diminutive meaning when presented independently.

The sixth objective was followingly achieved, as a new Lean performance category coined *flow efficiency* was derived with basis in the above findings, utilising the principles from the literature review. This category was emphasised, considering that Lean was predominantly defined in terms of flow efficiency in D&W, thus suggesting an ease of implementation and understanding. The intent with said category was the betterment of improving throughput and controlling the flow of activities in the well development process, by improving the response to congestion points and bottleneck activities

In alignment with the new Lean performance category, the seventh objective involved a comprehensive process of deduction, ultimately culminating in a set of three Lean KPIs; Takt Time (T_{takt}), Cycle Time (T_{cycle}) and Lead Time (T_{lead}), wherein the Cycle Time was further subdivided into NVA Time (T_{NVA}) and VA Time (T_{VA}). Having defined these KPIs with basis in the data at hand, two quantitative analyses were included to determine their practicality using the Kneler B-5 as a case. In the first analysis, the comparison between takt and the two NVA and VA cycles times proved efficient in determining activities exerting low performance compared to the required development rate set by the takt time. The second analysis moreover, successfully demonstrated how the comparison between the NVA and VA cycles times and the lead time, could recognises the whereabouts of waste occurrence in the form of NPT and WOW.

Further comparison between the new Lean KPIs and prior KPIs in the discussion, confirmed that D&W would in due course stand better equipped at determining the efficiency of the development process. Furthermore, an additional set of Lean KPIs; Process Cycle Efficiency (PCE), Waiting Time (T_{wait}), Utilisation (U), On Time Delivery (OTD) and Excess Time (T_{excess}); were subsequently explored, yielding successful results and a satisfying ability to identify bottlenecks in the flow. Analyses of the innovative BIC were also included. Following a Monte Carlo simulation using the Kneler B-5 as case, the BIC proved efficient in determining the optimal performance in a set of well activities, and the lack thereof in subsequent comparison with actual performance data.

The eighth objective of this thesis was lastly realised by proposing a new framework for performance management and measurement in D&W. The new framework, based on Lean and Six Sigma, was fashioned according to the DMAIC-cycle and adapted to the existing principles for performance management and measurement from both Aker BP at the company level and D&W. The framework presented in brief the process of performance management and measurement in well development by using Lean tools and methods in a continuous cycle of improvement. The discussion of this framework also culminated a comprehensive performance dashboard, illustrating how the newly derived Lean KPIs could be visualised across the hierarchy in D&W to report performance.

6.2 Final Conclusion

The final conclusion have been provided in light of the accomplishments of the foregoing research objectives. In terms of contributions to well operations, findings conclude that the emphasis should be on the well development process in the category field development in fields already operational, on account of its high cost and impact on the bottom line. By focusing on the definitions of Lean in terms of flow efficiency, the takt, cycle and lead time can be measured across a standardised set of activities developed in line with the Kaizen philosophy. This facilitates the possibility of keeping track of customer's demand and to identify low performing activities in the well development process. In addition, this also provides the means for better comparison between team members and third party operators, leading to improved planning in future projects.

The use of additional Lean KPIs in conjunction with the BIC and Lean visualisation tools such as PAMs contributes to the identification of both potential bottleneck activities and loss of potential. Adapting the foregoing in a framework for performance management based on both Lean and Six Sigma principles, following an ordered plan alike the DMAIC-cycle, moreover contributes to well operations. This assures that the Lean KPIs are rooted in strategic objectives and easily visualised using performance dashboards across the hierarchic structure of D&W, thus encouraging the involvement of all team members whilst motivating a common performance culture. This in turn provides an efficient tool for continuous improvement through efficient waste elimination and accurate identification of waste root.

In effect, the above demonstrates how Lean and continuous improvement in performance management ultimately can contribute to successful identification and addressing of waste and non-value added time in a continuous cycle across well operations. This can consequently lead to a reduction in the total time that is spent on offshore installations and rig activities, thus reducing the drilling cycle and overall cost, whilst simultaneously improving the competitive advantage and overall performance in well operations.

6.3 Contribution to Research and Theory

The significant contribution of this thesis emerges from small gaps within saturated research areas as practical application of current ideas. Much of the existing body of research and literature on Lean and continuous improvement in performance management, primarily accentuates the production of units in a supply chain, manufacturing or production setting. This study in contrast present a novel attempt at understanding their usage in an alternative setting concerning activities and operations in well development in the E&P industry. Resultantly, this study has theoretically to some degree filled a gap of knowledge regarding an alternative application of Lean KPIs.

In existing research and literature, Lean KPIs ordinarily emphasise waste and inefficiency in terms of NVA time concerning a production line or task on a production floor. In this study however, the particular contribution concerns adapting the concepts of takt time, cycle time and lead time to perform quantitative estimations on NVA time and waste in the execution of activities in a well development process, pertaining to commonly produced well data from offshore installations. With focus on one particular case company and actual data from a previous developed well, this study moreover demonstrates the above in factual context, rather than being limited to theoretical assumptions.

This thesis has also contributed to theory by exploring the synergy between Lean KPIs in practical solutions for performance dashboard using actual performance data. Although existing research have been previously vested in the use of such dashboards for performance management, there is to the extent of the researcher's cognisance little evidence that suggest that these have incorporated Lean KPIs to visualise waste and bottlenecks in a similar hierarchical fashion, as demonstrated in this thesis. By its very nature, this contributes to the understanding of performance visualisation in betterment of improving well operations.

Notwithstanding its contributions, there are however inevitably bound to be limitations related to the findings, in addition conceptual and methodological shortcomings. These limitations and shortcomings have been comprehensively discussed in Chapter 5, in addition to highlight ways to continue and improve this research.

6.4 Recommendations for Future Research

The research encompassed in this thesis has developed an appreciation of the large number of broader future opportunities for research that could be pursued. The following are recommendations for future research, derived with basis in the findings and limitations of this study;

- Firstly, the determination of practices for performance management and measurement could be improved by a more thorough investigation of existing documentation and data systems. For future research purposes, additional interviews with both engineers and analysts with varying responsibilities concerning performance management and measurement across the departmental hierarchy in D&W, should be included to increase the objectivity of findings. This could provide more hands-on experience and more correctly determine all significant elements.

- Secondly, a thorough statistical investigation across financial data pertaining to the investments made by Aker BP and D&W could be included prior to comparing results with similar operators. This could confirm whether operations in field development poses the most significant impact on total costs.

- Furthermore, future research should also include quantitative analyses of data pertaining to a broader collection of identical wells developed across the same geological formations by the use of similar activities, equipment and personnel. This would both limit the degree of variation among well parameters, and improve the statistical validity of findings. Ideally, this collection should include more than 50 developed wells. In effect, the data for each activity would pertain 50 observations for time and depth, thus fulfilling the requirements of a normal distribution. This would ultimately enable more rigorous statistical analyses and probability estimations for activity duration. Concerning the foregoing, it is also suggested that future research should incorporate and compare the analyses of KPIs across several wells in order to identify possible variation, trends or similarities. This would provide more validity and conceivably remove bias in findings.

- Another recommendation for future research would be to expand the quantitative approximation of the takt time, cycle time and lead time, by incorporating data for all the minor sub-activities and processes that makes up the primary activities from Table B.3. This would in effect, yield a more correct rendition of the metrics in terms their theoretical definition from literature.

Resultantly, future research could in turn investigate the applicability of Little's Law and Kingman's formula to estimate waiting time and explore the synergy between utilisation, cycle time and variation.

- With basis in a broader collection of well data, further research should also include a more thorough Monte Carlo simulation for the Best in Class, wherein the random numbers are drawn based on a more statistically correct assumption of a normal distribution and an approximation of the mean, standard deviation and skewness of each activity duration.

- To facilitate the ongoing development of digital solutions in D&W, future research would benefit from identifying practical data software or programs for performance management and measurement. This includes investigation of solutions for automatic measurement and analysis of real-time data from offshore installations, in addition to solutions for automatic comparison between planned strategic objectives and actual performance.

- Lastly, there is also a need for future research using a different research design and methods. Given the nature of the existing research, this study had a strong exploratory element. A recommendation would therefore be to adopt an explanatory sequential design; wherein quantitative analyses are validated by subsequent qualitative analyses. In effect, interviews or questionnaires could be used to verify results from findings with individuals encompassing hands-on experience regarding the field of study, thus delaminating inappropriate results.

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Appendix A

Interview Reply

This Appendix includes an overview of replies from the interview with an interview prospect in Aker BP D&W. The interview, along with the interview guide, have also been included on a hard-drive for the administration at the Institute for Industrial Economics, Risk Management and Planning at the Faculty of Technology Of Science for the University of Stavanger.

Part 1: Information regarding the Interview prospect

Interviewer: *What is your position in D&W?*

Interview respondent: Manager for Technology and Special Projects within Feasibility and Projects in Drilling & Wells.

Interviewer: *What is the nature of your work at D&W?*

Interview respondent: My role is to identify what is being developed in terms of technology related to ongoing operations, and subsequently couple new technology, or technology that is missing, from what's being developed in research and development environments or other companies, in order to implement, solving problems or optimisation needs within D&W. In other words my work is operational related to the development of technology in D&W. This includes equipment, procedures or software meant to solve specific problems related our operations.

Interviewer: *How is the nature of your work associated with performance management in D&W? (If not, disregard this question)*

Interviewer: Interview respondent: Not directly related, but somewhat involved.

Interviewer: *How long have you been an employee at D&W?*

Interview respondent: I have been employed in D&W related departments ever since my employment back in the 80s. This adds up to an estimated experience of 30 years within the field of drilling.

Part 2: Implementation of Lean and Digitalisation in D&W

Interviewer: *What is the purpose of implementing Lean Thinking in Aker BP and D&W?*

Interview respondent: The purpose is first and foremost to become more cost efficient when drilling wells. In addition, this is in many ways "be or not to be", meaning if the teams in D&W are not efficient, they will not be provided with activities or work. Consequently, one can say that there is a strong connection between cost, efficiency and activity. For D&W, it is particularly important to incorporate continuous improvement in all our operations. To put in perspective, we in D&W often plan wells at a cost of 200-800 million NOK. Hence if we have some unalignment in the planning or organisation and consequently not the proper execution, then this could result in high consequences. If we are talking about a 10% out of an estimated 500 million NOK, then that would result in an added cost of ca. 50 million NOK. Most companies who operate in our business would run under if they miss with such an estimate.

Interviewer: *What tools and methods have been implemented?*

Interview respondent: When it comes to Lean, we known that this is an old process which is reoccurring in other industries. We have been using its principles partly over a long period of time, but we have not been defined as Lean, and that is neither something we strive to be. But the underlying principle with Lean as we see it, is continuous improvement and focus upon quality of delivery. And that is something that we have been working with over a long time and in many shapes and forms. I believe it to be important for all operators such as Aker BP, to have internal focus upon this in our business, thus hindering unwanted culture and behaviour.

Interviewer: *How does the work in D&W benefit from merging Lean Thinking with Digitalisation?*

Interview respondent: When it comes to digitalisation, I believe this is a tool to be used in order to execute Lean more consequent, automatic, optimally and rule-based. Whereas Lean makes it possible to remove subjective opinions and incorporate objective and data-related decision making, digitalisation would moreover make it possible to fully implement Lean. In all we think about digitalisation, lies optimisation as a foundation, in addition to quality. Basically, one can say that Lean and digitalisation are two different sides on the same coin, thus complementing one another. Digitalisation would make sure that experienced and learning could be captured in algorithms, and not in the minds of individual employees. The goal would be to systematic use Lean and digitalisation to capture learning and improvement into a system rather than in the head of the individual employee. Making sure that the learning is incorporated in a system and that the decisions are partly data based and subjectively and analogy. Developing a greater data foundation would also aid in Lean.

Interviewer: *How is Lean and Digitalisation related to performance management?*

Again, digitalisation is meant to solve all of the above. If you consider traditional project management, there is a variety of element which are important, such as having clearly defined goals, communication across functions, risk-control, communication towards stakeholders, quality. All of these elements can be solved by digital techniques, software, databases, systematics and a clearly defined work flow, which has been worked and goal-defined towards optimal performance and improvement.

The most important element in continuous improvement is according to my opinion is actually measuring what you are doing, thus having a base to improve from. Hence, measuring improvement initiatives. KPIs lies at the centre of this and is a fundamental factor in classic project management.

Part 3: Current Performance Management System in D&W

Interviewer: *In your own words, please give brief description of the current performance management system in D&W Det Norske.*

Interview respondent: In Det norske, we used to manage performance on many levels. We measured in project level, meaning we wrote down the objectives with the well in terms data acquisition to be delivered, production of hydrocarbons or in the shape of cost of execution in order to deliver production or data. Primarily we used three types of KPIs. The first type was related to subsurface in form of petroleum-related data. This was however not fully incorporated in Det norske at the time. Most of my time in Det norske was related to exploration drilling. Delivering data on the field was first and foremost the primary objective. In drilling and well at the time we had a tendency to think too much about cementing the well. This was as I remember our main priority.

However, the main priority as it should have been, was to deliver the correct data, with the right quality. Hence, having a well-function program for data collection and deliver upon this, was one of the key goals. The second very important type was drilling performance. We had a plan which was to be executed. The well was to be delivered by the use of certain sections. We were to place the casings in the ground at specified depths and maintain well control etc, in addition to plan the time and cost for these elements. The last element was HSE, meaning collecting all the correct KPIS. In every company there is a different definition of these KPIs and what they actually measure.

One primary measure was of course serious incidents, which one does get fairly much warning for in advance. Another included minor incident which at a later stage could result in a serious one, such as dropped objects. A dropped object may initially bear any considerable consequence, but we did in fact measure these types in order to estimate the possibility of a major one could occur. The minor incidents often indicated the potential for greater incidents. In relation to HSE KPIs we did in fact have some proper systematic in place. The difficult part was to estimate the major ones such as blow out. This is the foundation of our work, trying to control. These are often occurring without warning. Measuring the trend in minor incidents could aid in the determination of when greater incidents could occur.

Interviewer: *How is performance measured?*

Interview respondent: In D&W the main focus was primarily drilling and projects related to drilling, using excel programs and dashboards. We initially made a budget based upon a mean (P50) estimate from Rushmore Reviews. We then make our own mean (P50) for the budget for the well, prior to ordering equipment and start measuring the real performance compared to the plan, or budget. One of the criteria was to be within the (AFE). That was probably our main focus, delivering within time and budget. Furthermore the HSE KPIs have been based upon either success or failure. Meaning, if you have serious incidents you would fail. If you on the other hand have several minor incidents, but non serious, you could pass.

There exit nieces, but these are primarily pass or not pass. Primarily time, budget, HSE, weather, invisible lost time and effective time were our primary concern. We then estimated whether or not we had delivered accordingly. Lastly, we would report back to Rushmore, thus continuously updating our own data-foundation.

Interviewer: *Who was responsible for the old performance management system in Det norske D&W?*

Interview respondent: The responsible party primarily consisted of the engineers responsible for the specific operations. It was not an own department.

Interviewer: *How were they measured? By whom?*

Interview respondent: The KPIs was primarily measured by engineers. The KPIs were so heavily academically based on operations, that it had to be engineers who made the evaluations.

Interviewer: *What are the (if any) main drawbacks with the system?*

Interview respondent: There was a tendency to make the budgets as comfortable as possible, thus creating comfortable goals. This meant that engineers were not pressed to cut cost or time. Much of the focus was upon achieving the budget. This somewhat resulted in a tendency to over-budget so that one would not have any strong element of focus upon performance, but rather avoid NPT. In the recent time, we realised that it is not wrong to have NPT as long as the risk is calculated and evaluated. This way we could take calculated risk.

Part 4: Cost, Time, Value chain and Drilling Cycle time

Interviewer: *In your own words, please describe how D&W fit in the E&P value chain.*

Interview respondent: D&W stands for an estimated 40% of the company's total cost in drifting the fields and an estimated total 50% of the companies CAPEX, i.e. the capital expenditure for drifting the fields and investments made upon finding and drifting new fields. Consequently, there have of recent time be a greatly focus upon performance and continuous improvement in D&W. There are primary two reasons for that being the case:

1. It is extremely cost intensive, probably more so than in any other industry because we have so high daily operational costs. Furthermore, the number of days is more or less directly proportional with the cost (NOK). Historically there have been much focus on D&W being best in class in terms of reducing costs, because we make up such a great part of the company's total cost.
2. We need to control the operations in terms of performance and HSE, because if we lose HSE control, we consequently loose the license to operate. Hence having many serious HSE incidents is very disrupting for our business. A lot attention from unplanned work in order to normalise those incidents is not good for daily operations.

Interviewer: *In your own words, describe the different well development stages.*

Interview respondent: There is a lot of work made by the teams in exploration, reservoir and petroleum in exploring and identifying. They purchase and obtain licenses in areas which they believe contain hydrocarbons. They furthermore interrupted geological data-sets in order to determine whether the areas a prone to hydrocarbons.

They make estimates on seismic based upon business related objectives, risk for discovery. Based upon this, they hand over a mission for us to drill. In its simplest for, this is a location in the ground from which they want us to acquire data. The data we collect is temperature, pressure, geology, formations etc. Based upon this, we can suggest whether or not to drill a production well. We then begin to plan an approximate solution for a well, including a budget, risk and time-frame both technically and economically. Then a decision whether to drill or not is made. If exploration believes this to be good business, in terms of hydrocarbons or good data volumes, we then commence making detailed well plans regarding location, construction, pressure control, which contracts and service companies to include in order to deliver parts of the delivery.

On an exploration well, there is typically 40-50 contracts with service companies established, included down-hole services, analytics, emergency services, logistics, choppers airplanes, specialists, drilling engineers, operation control etc. After the planning, much of the work is based upon organising the project financially, organising communicating between service companies, and making sure every contingency have been considered. On infill wells, wells located on already obtained licenses, the process is a bit simplified. We then model the reservoir before commencing building well tracks, before building a complete estimate for cost, time, risk and technical solutions. We then decide whether or not to commence before commencing a detailed planning of all operations.

Interviewer: *Which stages accounts for the greatest costs?*

Interview respondent: The largest and most cost-based contract is directed towards rig hire. If we don't have a rig on contract, we have to get a contract. This includes:

- Involving finance departments to develop budgets
- Including juridical in order to obtain contracts, gathering offers and tenders, and studying possible liabilities
- Involving technical departments in order to make sure that the rig can perform and execute the required operations and deliver according to plan.

For Exploration, this may take many years. Transport, boats and planning also make up the biggest amount of the total costs.

Interviewer: *Which stages accounts for the greatest time? How can these be reduced?*

Interview respondent: 40% of the total time is heavily invested in rig time. An additional day of rig hire is an additional day with rig cost, thus 40% of the daily cost. Our KPIs are most based upon NPT, WOW and invisible loss (inefficient time use). We measured actual time as:

Actual time spent = Actual time + NPT + Waiting on weather + invisible lost time

Part 5. New Performance Management System in D&W

For this part of the interview, several of the questions included in the interview guide were not answered due to the lack of time.

Interviewer: *What additional category of performance do you believe is missing?*

Interview respondent: We should fully integrate lean thinking within our organisation, within our culture and operations. We have for a long period of time being employing continuously improvement, but we should try to incorporate a much strong element of this in our business.

We also observe that digitisation would change our daily operations, as it would release routinely time spent on routinely work. Having data control systems helps us make decision in planning but also during operations, thus aiding is in continuous improvement.

Interviewer: *What do you believe is most important to measure in order for D&W to continuously improve and achieve flow efficiency?*

Interview respondent: Both planning and control can be performed across three levels:

1. Management levels using strategic KPIs on time cost and efficiency
2. Engineering levels, coordinating services
3. Service, crew or delivery

We have good control on the two first, but are missing some on the latter. It is important to achieve learning across all these abovementioned levels.

Appendix B

Tables

This Appendix includes the relevant tables pertaining information utilised in and derived from the literature review and research findings, respectively.

Table B.1: Lean KPIs. Adapted from Behrouzi and Wong [67, p. 5244]

No	Performance Measure	No	Performance measure
1	Supplier rejection rate	37	Total supply cost
2	Cash-to-cash cycle time	38	Service cost
3	Cycle time	39	Manufacturing lead time
4	Delivery to committed date	40	Risk costs
5	Manufacturing cost	41	Supplier rejection rate
6	Supply chain response time	42	Set up time
7	On time delivery	43	Downtime
8	Inventory accuracy	44	On time production
9	Shipping errors	45	On-time-delivery to customers
10	Labor costs	46	Delivery flexibility
11	Raw material cost	47	Information processing cost
12	Takt time	48	Product development cycle time
13	Capacity utilisation of containers	49	Utilisation of economic order quantity
14	Distribution cost	50	Customer response time
15	Delivery reliability	51	Commitment to customer
16	Forecast accuracy	52	Information quality
17	Inventory cost	53	Material quality
18	Warranty cost	54	Production quality
19	Defects	55	On-time shipments
20	Defects rate	56	Planning cycle time
21	Customer complaitns	57	Total inventory days of supply
22	Manufacturing costs	58	Forecast volatility
23	Process cycle efficiency	59	Forecast versus order
24	Delivery lead time	60	Order fill rate
25	Document accuracy	61	Degree of utilisation
26	Labor productivity	62	Production plan versus results
27	Supplier fill rate	63	Inventory days
28	Defects rate of production	64	Production quality flexibility
29	Value added productivity	65	Cost of work-in-process
30	Time to market	66	Cost of inventory
31	Cost of goods sold	67	cost of finished goods
32	Excess time	68	Total revenue
33	Degree of information sharing	69	New product flexibility
34	Delivery reliability	70	Response delay
35	Customer satisfaction rate	71	Sales volume
36	Waiting time	72	Total number of suppliers

Table B.2: Current Well Development Process. Courtesy of Internal Resources, Aker BP D&W

Development Step	Operation
Appraise	Kick off Team & Workflow D&W + Subsurface
	Geological Prognosis
	Pressure & Temperature
	Identify Reference Wells
	Offset Analysis, Offset Lessons, Do's and Dont's
	Standard Well Design
	LLI / Contracts / Rig
	Time & Cost Evaluation
	Risk, Environment, Auth, Applications
Select	Site Survey
	Develop well concept and options
	Perform Engineering, Casing, Blowout
	Time & Cost Definition
	Risk options
	Rank and select best option
	Approve selected design, Internal and with Partners
Define	Engage Extended Team
	Prepare Drilling Program and Completion Program
	Risk Assessment
	Deterministic timing and AFE
	Authority Approvals, Oil Spill and Emerg. Response
	MEL and PO's
	Rig Move / Start-up procedures
	DWOP, Handover to Offshore
Execute	Mobilize / Rig Move / Well handover
	Supervision
	Communication / Reporting
	Drilling Optimization
	Risk Management
	Cost Control
	Ops Geology
	Logistics
	After Action Review
Operate	Handover Well
	End of well reporting, FWR, FCR
	Service Company Reports
	Cost Reconciliation
	HSE Report, Discharge reporting
	QA of As-Built data

Table B.3: Overview of Well Development Activities

Category	**Operation**	**# Number**	**Activity**
Drilling	Rig related	1	Run Anchors
Drilling	Rig related	2	Use Pre-Laid Anchors
Drilling	Drilling Operation	3	Drill 36” hole
Drilling	Casing Operation	4	Run & cement 30” casing
Drilling	Drilling Operation	6	Drill 26” hole
Drilling	Casing Operation	6	Run & cement 20” casing
Drilling	BOP Operation	7	Run BOP
Drilling	BOP Operation	8	Jump BOP
Drilling	Drilling Operation	9	Drill 16” hole
Drilling	Casing Operation	10	Run & cement 13 3/8” casing
Drilling	Drilling Operation	11	Drill 9 1/2” pilot hole (1st)
Drilling	Cementing Operation	12	Plug & Abandon pilot hole (1st)
Drilling	Drilling Operation	13	Drill 9 1/2” pilot hole (2nd)
Drilling	Cementing Operation	14	Plug & Abandon pilot hole (2nd)
Drilling	Drilling Operation	15	Drill 9 1/2” pilot hole (3rd)
Drilling	Cementing Operation	16	Plug & Abandon pilot hole (3rd)
Drilling	Drilling Operation	17	Drill 14 1/4” x 12 1/4” hole
Drilling	Casing Operation	18	Run & cement 10 3/4” casing
Drilling	Casing Operation	19	Run & cement 10 3/4” Liner & Tieback
Drilling	Drilling Operation	20	Drill 9 1/2” pilot hole (4th)
Drilling	Cementing Operation	21	Plug & Abandon pilot hole (4th)
Drilling	Drilling Operation	22	Drill 9 1/2” Reservoir (1st)
Completion	Completion Operation	23	Lower completion (1st)
Completion	Completion Operation	24	Middle Comp (1st)
Drilling	Completion Operation	25	Install Whipstock (1st)
Drilling	Drilling Operation	26	Drill 9 1/2” Reservoir (2nd)
Completion	Completion Operation	27	Lower completion (2nd)
Drilling	Completion Operation	28	Pull Whipstock (1st)
Completion	Completion Operation	39	Run deflector (1st)
Completion	Completion Operation	30	Run junction & packer (1st)
Drilling	Completion Operation	31	Install Whipstock (2nd)
Drilling	Drilling Operation	32	Drill 9 1/2” Reservoir (3rd)
Completion	Completion Operation	33	Lower completion (3rd)
Drilling	Completion Operation	34	Pull Whipstock (2nd)
Completion	Completion Operation	35	Run deflector (2nd)
Completion	Completion Operation	36	Run junction & packer (2nd)
Completion	Completion Operation	37	Dirty Displacement (X-FC)
Completion	Completion Operation	38	Clean up well (separate)
Completion	Completion Operation	39	Clean up well (Combined)
Drilling	BOP Operation	40	Pull BOP, Install SVT, Run BOP
Completion	Completion Operation	41	Run upper comp
Completion	BOP Operation	42	Secure well (Pull BOP Included)
Completion	Rig related	43	Recover anchors
Completion	Rig related	44	Recover Pre-Laid Anchors
Completion	Cementing Operation	45	Temporary P&A
Completion	BOP Operation	46	Pull BOP
Completion	Rig related	47	Suspend well

Table B.4: Percentage of Actual Time per Category

Category	Percentage of Actual Time
Drilling	75,51 %
Completion	24,49 %

Table B.5: Percentage of Actual Time per Operation Type

Operation Type	Percentage of Actual Time
Rig related	2,69 %
Cementing Operation	6,41 %
BOP Operation	7,00 %
Casing Operation	10,53 %
Completion Operation	30,01 %
Drilling Operation	43,36 %

Table B.6: Top Ten Activities

Activity	Problem-Free Days	Actual Days
Drill 9 1/2" pilot hole (1st)	3,90	4,23
Drill 16" hole	4,04	4,38
Run upper comp	4,44	4,79
Pull BOP, Install SVT, Run BOP	4,53	4,85
Drill 14 1/4" x 12 1/4" hole	4,44	5,38
Run & cement 10 3/4" Liner & Tieback	5,75	6,00
Drill 9 1/2" pilot hole (4th)	6,35	6,35
Drill 9 1/2" Reservoir (1st)	7,90	9,65
Drill 9 1/2" Reservoir (3rd)	8,08	9,66
Drill 9 1/2" Reservoir (2nd)	8,98	10,79

Table B.7: Effect of NPT and WOW

#	Activity	Problem free	Actual	NPT + WOW + ILT
1	Run Anchors	1,10	1,10	0,00
2	Use Pre-Laid Anchors	0,51	0,51	0,00
3	Drill 36" hole	1,08	1,27	0,19
4	Run & cement 30" casing	1,21	1,27	0,06
5	Drill 26" hole	3,14	3,82	0,68
6	Run & cement 20" casing	1,48	1,67	0,19
7	Run BOP	1,39	1,72	0,34
8	Jump BOP	0,46	0,46	0,00
9	Drill 16" hole	4,04	4,38	0,34
10	Run & cement 13 3/8" casing	2,34	2,81	0,47
11	Drill 9 1/2" pilot hole (1st)	3,90	4,23	0,33
12	Plug & Abandon pilot hole (1st)	1,73	2,27	0,54
13	Drill 9 1/2" pilot hole (2nd)	3,17	3,17	0,00
14	Plug & Abandon pilot hole (2nd)	1,52	1,54	0,02
15	Drill 9 1/2" pilot hole (3rd)	3,13	3,13	0,00
16	Plug & Abandon pilot hole (3rd)	2,85	2,85	0,00
17	Drill 14 1/4" x 12 1/4" hole	4,44	5,38	0,94
18	Run & cement 10 3/4" casing	2,79	3,23	0,44
19	Run & cement 10 3/4" Liner & Tieback	5,75	6,00	0,25
20	Drill 9 1/2" pilot hole (4th)	6,35	6,35	0,00
21	Plug & Abandon pilot hole (4th)	2,15	2,15	0,00
22	Pull BOP, Install SVT, Run BOP	4,53	4,85	0,33
23	Drill 9 1/2" Reservoir (1st)	7,60	9,54	1,94
24	Lower completion (1st)	2,33	2,75	0,42
25	Middle Comp (1st)	1,21	1,27	0,06
26	Install Whipstock (1st)	2,46	3,67	1,21
27	Drill 9 1/2" Reservoir (2nd)	8,98	10,79	1,81
28	Lower completion (2nd)	2,23	2,33	0,10
29	Pull Whipstock (1st)	1,25	1,52	0,27
30	Run deflector (1st)	0,83	1,69	0,86
31	Run junction & packer (1st)	1,71	1,71	0,00
32	Install Whipstock (2nd)	2,53	6,34	3,81
33	Drill 9 1/2" Reservoir (3rd)	8,08	9,66	1,59
34	Lower completion (3rd)	3,77	3,91	0,14
35	Pull Whipstock (2nd)	1,71	1,71	0,00
36	Run deflector (2nd)	1,26	1,28	0,02
37	Run junction & packer (2nd)	2,03	5,81	3,78
38	Dirty Displacement (X-FC)	0,87	0,87	0,00
39	Clean up well (separate)	1,83	2,04	0,21
40	Clean up well (Combined)	0,99	0,99	0,00
41	Run upper comp	4,44	4,79	0,35
42	Secure well (Pull BOP Included)	2,19	2,27	0,08
43	Recover anchors	1,08	1,44	0,36
44	Recover Pre-Laid Anchors	0,51	0,58	0,08
45	Temporary P&A	0,30	0,30	0,00
46	Pull BOP	0,56	0,61	0,05
47	Suspend well	0,19	0,19	0,00

Table B.8: Drilling Efficiency Data for Kneler B-5

#	T_{actual} **(days)**	$D_{effective}$ **(meters)**	$R_{efficiency}$
1	1,71	0,00	1,71
2	3,33	54,00	16,20
3	1,58	54,00	34,11
4	5,46	617,00	113,04
5	5,04	617,00	122,38
6	2,02	839,00	415,18
7	3,65	830,00	227,66
8	2,71	830,00	306,46
9	4,50	1692,00	376,00
10	2,33	0,00	2,33
11	8,96	1259,00	140,54
12	5,81	2910,00	500,65
13	9,54	2088,00	218,83
14	2,75	4825,00	1754,55
15	2,60	2827,00	1085,57
16	9,65	2358,00	244,46
17	2,85	5268,00	1845,72
18	3,19	2358,00	739,76
19	17,25	0,00	17,25
20	10,13	2724,00	269,04
21	12,23	2930,00	239,59
22	4,88	5631,00	1155,08
23	0,88	2827,00	3230,86
24	3,52	2827,00	802,93
25	3,00	0,00	3,00
26	6,08	2721,00	447,29
27	2,77	0,00	2,77
28	2,40	0,00	2,40
Total	140,81	49086,00	511,26

Table B.9: Degree of NPT on Kneler B-5

Activity	NPT	Actual time	NPT
1	0,52	1,71	30 %
2	0,00	3,33	0 %
3	0,04	1,58	3 %
4	0,50	5,46	9 %
5	3,56	5,04	71 %
6	0,77	2,02	38 %
7	0,10	3,65	3 %
8	0,04	2,71	2 %
9	0,50	4,50	11 %
10	0,60	2,33	26 %
11	4,23	8,96	47 %
12	0,06	5,81	1 %
13	0,13	9,54	1 %
14	0,06	2,75	2 %
15	0,00	2,60	0 %
16	3,17	9,65	33 %
17	0,10	2,85	4 %
18	0,10	3,19	3 %
19	8,60	17,25	50 %
20	7,63	10,13	75 %
21	1,94	12,23	16 %
22	0,00	4,88	0 %
23	0,00	0,88	0 %
24	0,04	3,52	1 %
25	0,25	3,00	8 %
26	0,46	6,08	8 %
27	0,08	2,77	3 %
28	0,00	2,40	0 %
Total	33,50	140,81	23,79 %

Table B.10: Takt Time versus Cycle Time Results

#Activity	T_{takt}	T_{VA}	T_{NVA}
1	1,76	1,19	0,52
2	1,08	1,60	1,73
3	1,22	1,54	0,04
4	4,73	4,96	0,50
5	1,62	1,48	3,56
6	2,16	1,25	0,77
7	7,02	3,54	0,10
8	3,11	2,67	0,04
9	6,08	4,00	0,50
10	2,16	1,73	0,60
11	9,05	4,73	4,23
12	8,37	5,75	0,06
13	12,83	8,88	0,67
14	3,39	2,69	0,06
15	2,30	2,60	0,00
16	13,50	6,48	3,17
17	3,39	2,71	0,10
18	4,23	3,08	0,10
19	5,54	8,65	8,60
20	2,30	2,50	7,63
21	17,55	10,29	1,94
22	3,81	4,88	0,00
23	2,55	0,88	0,00
24	4,23	3,48	0,04
25	2,36	2,75	0,25
26	6,05	5,63	0,46
27	2,83	2,69	0,08
28	1,12	0,69	1,71
Total	136,34	103,29	37,48

Note: All estimations are rendered in days

1

Table B.11: VA and NVA Cycle Times versus Lead Time Results

Lead Time (in days)	VA Cycle Time (in days)	NVA Cycle Time (in days)
1,71	1,19	0,52
5,04	2,79	2,25
6,63	4,33	2,29
12,08	9,29	2,79
17,13	10,77	6,35
19,15	12,02	7,13
22,79	15,56	7,23
25,50	18,23	7,27
30,00	22,23	7,77
32,33	23,96	8,37
41,29	28,69	12,60
47,10	34,44	12,67
56,65	43,31	13,33
59,40	46,00	13,40
62,00	48,60	13,40
71,65	55,08	16,56
74,50	57,79	16,71
77,69	60,88	16,81
94,94	69,52	25,42
105,06	72,02	33,04
117,29	82,31	34,98
122,17	87,19	34,98
123,04	88,06	34,98
126,56	91,54	35,02
129,56	94,29	35,27
135,65	99,92	35,73
138,42	102,60	35,81
140,81	103,29	37,52

Table B.12: Analysis of Non-Productive Time on Kneler B-5

Activity	NPT	Description	WOW
Run Anchors	0,52	Anchor Slippage	0,00
Drill 36” hole	0,00	-	1,73
Run & cement 30” casing	0,04	Other	0,00
Drill 26” hole	0,50	Leak in hose	0,00
Run & cement 20” casing	3,56	Tubular	0,00
Run BOP	0,77	BOP / PGB clash	0,00
Drill 16” hole	0,10	Other	0,00
Run & cement 13 3/8” casing	0,04	Other	0,00
Drill 9 1/2” pilot hole (1st)	0,50	Losses of mud	0,00
Plug & Abandon pilot hole (1st)	0,60	Losses of mud	0,00
Drill 14 1/4” x 12 1/4” hole	4,23	Rerun on underreamer	0,00
Run & cement 10 3/4” Liner & Tieback	0,06	Other	0,00
Drill 9 1/2” Reservoir (1st)	0,13	Other	0,54
Lower completion (1st)	0,06	Running Completion	0,00
Install Whipstock (1st)	0,00	-	0,00
Drill 9 1/2” Reservoir (2nd)	3,17	Damage on bit	0,00
Lower completion (2nd)	0,10	Running Completion	0,00
Intall Deflector & Junction	0,10	Other	0,00
Pull BOP, Install SVT, Run BOP	8,60	Seal assembly, BOP and Swarf	0,00
Install Whipstock (2nd)	7,63	Whipstock not set	0,00
Drill 9 1/2” Reservoir (3rd)	1,94	MWD Failure	0,00
Lower completion (3rd)	0,00	-	0,00
Pull Whipstock (2nd)	0,00	-	0,00
Intall Deflector & Junction	0,04	Other	0,00
Clean up well (separate)	0,25	Other	0,00
Run upper comp	0,46	Other	0,00
Secure well (Pull BOP Included)	0,08	Subsea moveoff	0,00
Recover anchors	0,00	-	1,71

Table B.13: Results from Monte Carlo Simulation

BIC	Problem free actual	Difference (+/- days)	Best in Class?
1,58	1,19	-0,39	Yes
1,06	1,60	0,55	No
1,49	1,54	0,05	No
3,63	4,96	1,32	No
1,65	1,48	-0,17	Yes
1,57	1,25	-0,32	Yes
4,17	3,54	-0,62	Yes
2,06	2,67	0,61	No
4,11	4,00	-0,11	Yes
2,03	1,73	-0,30	Yes
5,88	4,73	-1,15	Yes
7,84	5,75	-2,09	Yes
9,73	8,88	-0,85	Yes
3,36	2,69	-0,67	Yes
2,57	2,60	0,03	No
8,21	6,48	-1,73	Yes
2,67	2,71	0,04	No
2,95	3,08	0,13	No
5,96	8,65	2,69	No
2,14	2,50	0,36	No
7,21	10,29	3,08	No
3,23	4,88	1,64	No
1,75	0,88	-0,87	Yes
6,50	3,48	-3,02	Yes
1,90	2,75	0,85	No
4,10	5,63	1,53	No
1,26	2,69	1,43	No
1,08	0,69	-0,39	Yes

Table B.14: Percentiles from Monte Carlo Simulation

#	**Activity**	**P1**	**P50**	**P90**
1	Run Anchors	1,01	1,58	2,22
2	Drill 36” hole	0,54	1,06	1,59
3	Run & cement 30” casing	0,80	1,49	2,22
4	Drill 26” hole	2,26	3,63	4,93
5	Run & cement 20” casing	1,10	1,65	2,21
6	Run BOP	0,93	1,57	2,17
7	Drill 16” hole	2,69	4,17	5,56
8	Run & cement 13 3/8” casing	1,24	2,06	2,84
9	Drill 9 1/2” pilot hole (1st)	2,61	4,11	5,66
10	Plug & Abandon pilot hole (1st)	1,42	2,03	2,68
11	Drill 14 1/4” x 12 1/4” hole	3,68	5,88	7,87
12	Run & cement 10 3/4” Liner & Tieback	3,21	7,84	12,23
13	Drill 9 1/2” Reservoir (1st)	6,23	9,73	13,45
14	Lower completion (1st)	2,13	3,36	4,71
15	Install Whipstock (1st)	1,51	2,57	3,57
16	Drill 9 1/2” Reservoir (2nd)	6,53	8,21	9,92
17	Lower completion (2nd)	0,70	2,67	10,03
18	Intall Deflector & Junction	2,14	2,95	3,78
19	Pull BOP, Install SVT, Run BOP	3,47	5,96	8,55
20	Install Whipstock (2nd)	1,76	2,14	2,49
21	Drill 9 1/2” Reservoir (3rd)	4,29	7,21	10,24
22	Lower completion (3rd)	1,52	3,23	5,07
23	Pull Whipstock (2nd)	0,89	1,75	2,52
24	Intall Deflector & Junction	2,70	6,50	10,49
25	Clean up well (separate)	1,06	1,90	2,73
26	Run upper comp	2,54	4,10	5,60
27	Secure well (Pull BOP Included)	0,43	1,26	3,63
28	Recover anchors	0,70	1,08	1,45
	Total Time	89,40	102,79	116,22

Note: All estimations are rendered in days

Table B.15: Overview of Proposed Elements for Additional Measurement

Measure	**Definition**	**Unit**
Working time	Real-time spent on productive work	Hours/days
Resource requirements	Requirements for executing activities	Qty
Planned shits	Time for crew shifts	Hours/days
Idle time	Real-time spent idle	Hours/days
Defects	Activities with defects	Qty
Waiting	Time staying idle during working time	Hours/days
Waiting (service company)	Waiting on service companies	Hours/days
Waiting (drilling operator)	Waiting on drilling operator	Hours/days
Waiting (set up)	Time spent rigging up and down equipment	Hours/days
Transportation	Time spent on transporting (crews, equipment etc.)	Hours/days
Movement	Operator's transportation between work stations	Hours/days
Unplanned activities	Activity not originally planned but necessary	Qty
Unnecessary activities	Activities not performed	Qty
Un-utilised inventory	Un-utilised equipment or materials	Qty

Appendix C

Figures

This appendix includes the relevant figures utilised in the discussion in Chapter 5.

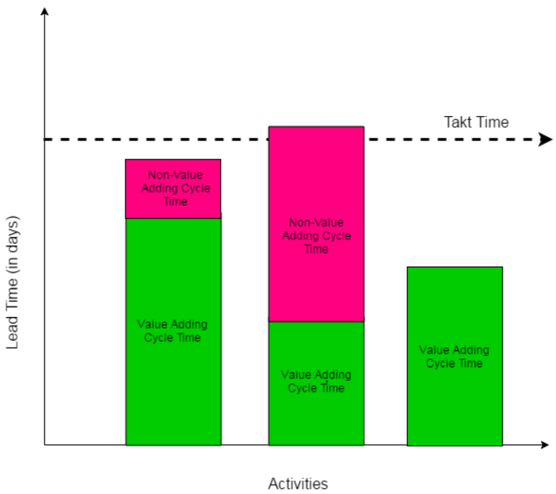

Figure C.1: Relationship between Takt Time, VA and NVA Cycle Times and Lead Time

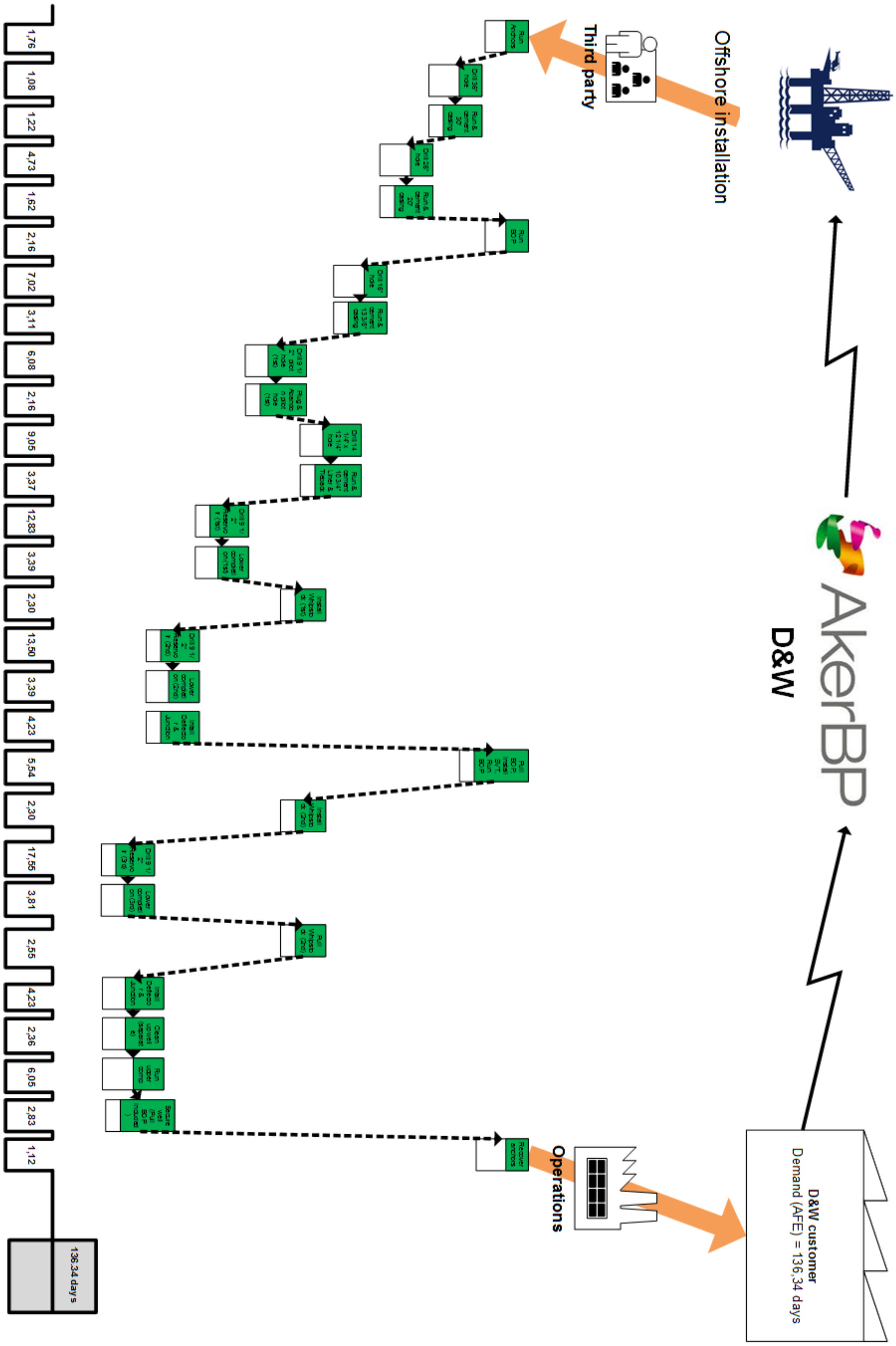

Figure C.2: Initial Process Activity Map for Kneler B-5, Showing Each Activity According to Effective Depth

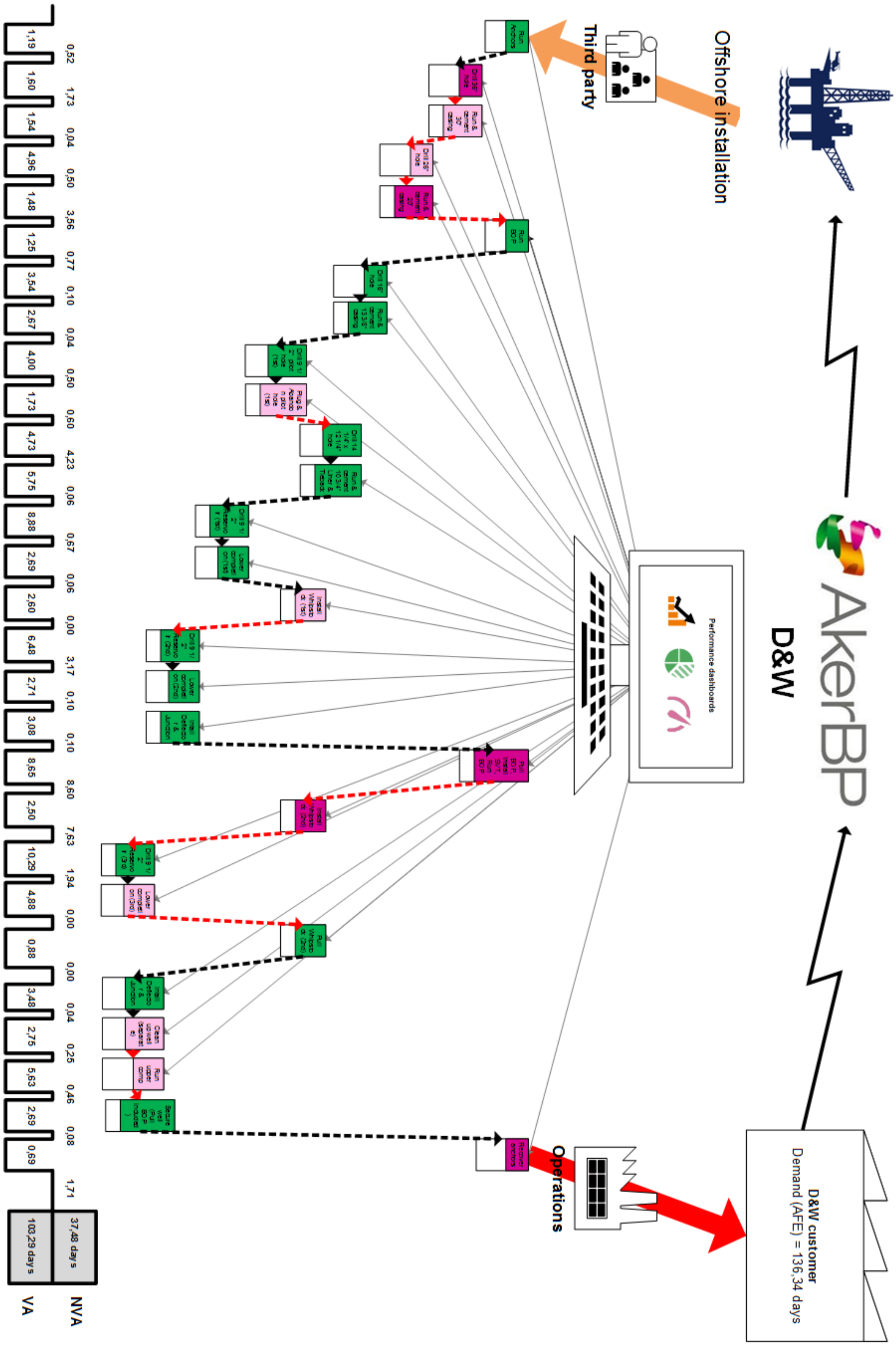

Figure C.3: Current Process Activity Map for Kneler B-5, Showing Each Activity According to Effective Depth. Here Minor and Critical Bottlenecks have been Reported in Light- and Dark Pink, Respectively.