Improving decision making in offshore Brownfield projects

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Improving decision making in offshore Brownfield projects

MASTER OF SCIENCE THESIS

For the degree of Master of Science in Offshore and Dredging Engineering at Delft University of Technology

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April 5, 2016

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The work in this thesis was supported by Shell Global Solutions International B.V. Their cooperation is hereby gratefully acknowledged.
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Executive Summary

Within Shell, a Brownfield project is defined as a piece of work that occurs on an existing live facility or one that has physical tie-ins with the live facility. Compared to Greenfield projects, Brownfield projects are characterized by typical challenges caused by many interfaces between the project and the existing asset. These interfaces exist in terms of functional and physical new and old design but also in terms of execution planning.

Brownfield projects have a poor performance track record in terms of cost and schedule predictability which is also worse compared to Greenfield project performance. Cost and schedule estimates grow after main decisions are made in the project development process. This causes management to decide to do costly recycles or to accept the undesired outcome. In other words, the decision quality in Brownfield projects is suboptimal. This study therefore adopted the main objective to contribute to improve the decision quality of Brownfield projects.

By evaluating the current situation of the development process and Brownfield project performance, the following conclusions were drawn that formed a basis for further specification of this research:

- The project development process within Shell appears to be more suitable for Greenfield development. This observation is made because the existing guidance structure provides for a gradual development of project elements from the total technical and non-technical spectrum whereas Brownfield projects often have very specific scopes and challenges.

- Analysis of Brownfield projects show consistent results on root cause analysis of drivers behind cost and schedule growth.

- A need for focus on specific project elements in Brownfield project development exists.

- Identifying risks early on in project development is currently done by humans based on involved experience and expertise.

These findings resulted in a study specific objective to ‘Optimize the technical scope definition of a Brownfield project based on its project and site specifics on a moment in time during project development’.

Master of Science Thesis

G.J.P. van Berckel
To fulfill the objective, a framework was adapted that is capable of representing a large network of project parameters and interdependencies with respect to project outcome in terms of e.g. cost or schedule. For each dependency between individual parameters, a risk of change value is determined by the impact weight of the dependency times the probability of change of the information of the providing parameter.

The framework was converted into a tool capable of assessing the robustness of the project outcome. Also, the parameters that need an increase of detail of definition level because they have the highest risk for changing the project outcome can be identified which can be converted into a design activity sequence that optimizes the scope definition level over time during project development.

The tool parameters and dependencies were tailored to an archetype Brownfield project, in this study an offshore project with compression related main scope. Tailoring the tool to an archetype project is necessary because the tool assess risk on project and site specifics. The developed tool consists of over 100 parameters in total. The definition level of approximately 50 of those parameters can be increased by doing design activities. The other parameters definition level is determined by the parameters they receive information from. Furthermore, over 400 dependencies were identified.

By running the tool, the parameters or project elements most important in early phases for a robust project outcome were identified. For offshore compression projects, these parameters were:

- Functional and physical information about the site
- Project discipline specific status and design of existing equipment and new design development
- Execution constraints such as area classifications, PoB planning and HSSE case
- Detail of execution strategy

The tool was also piloted on two applicable projects to assess the outcome robustness quality and to define the next steps. The experts involved in the sessions acknowledged that the outcomes reflected the project situation appropriately at the time evaluated. The added value and intended purpose were understood and found to be valid.

The added value of the developed tool follows mostly from the dependencies that are captured within the framework. This way, all project phases and technical elements are integrated in one system that expresses the outcomes of the highly complex system in a quantitative way. The tool can be seen as a system that is capable of capturing combined experience and expertise. This ability makes it a knowledge management tool that enables the project development team to follow a more consistent and reproducible approach. Furthermore, using the tool and the results can assist in allocating project development efforts more effective.

Referring back to the main objective of this thesis, the tool use and outcomes can improve the decision quality in multiple ways during front-end development. By identifying the most important project elements to focus on and by defining an optimal design activity sequence, the concept development process can be optimized with respect to involved risks. Decisions
that need to be taken can be supported by using appropriate data and by the quality of definition level of alternatives.

The tool provides a practical opportunity for the identified rationale of tailoring the project development process more towards project and site specific risk. In addition to the technical scope definition the tool accounts for, wider implications for project development can be identified too. Management decisions on investing in early phase development should be based on the risks involved in order to avoid recycles or cost growth. Furthermore, team composition and cooperation between units and teams in the development phase can be tailored to specific needs for the project.

Key conclusions following from this study are listed below:

- Brownfield project development needs more specific focus on project risks based on the project nature or site specifications compared to Greenfield development.
- Identifying these risks is a complex procedure since many project elements are interrelated and relative importance varies with project nature and site challenges.
- The tool developed in this study provides a framework to identify risks in archetype Brownfield projects and can be used to assess outcome robustness quality and improve effectiveness of early phase development.
- The tool results and use provide a basis for better informed decision making resulting in lower probability of recycles or cost growth.
- Besides improvement to technical scope definition, the framework and results can also be interpreted to have implications for higher management decisions and development team compositions and cooperation in the front-end development phase.

The main conclusions of this study are the recognition of a potential need of changing the project development process and the development of a tool that provides support on how to change this process. From these outcomes, the following is recommended:

- Given the nature of Brownfield projects, it is recommended to incorporate the rationale of a development process more tailored to risks into practice.
- It is recommended to use the framework of the tool to define the specific risk involved. This can be done by incorporating the outcomes for development guidance or by implementing use of the tool in the process.
- From the wider implications that were identified in this study recommendations follow for a tailored development process in terms of management decisions and team compositions in order to increase quality of the process.
- The rationale behind the tool provides opportunities for use for other purposes. Non-technical risk assessment or HSSE risks can be assessed as coupled risks instead of only individually. It is recommended to investigate this opportunity.
Preface

This research report is the final result of my Master Thesis project for completion of the Master Offshore and Dredging Engineering at Delft University of Technology. The research was supported by Shell Global Solutions B.V. and carried out in Rijswijk during ten months. The entire research project proved to be a valuable experience in many different ways. Besides the intellectual challenges of the project and the steep learning curve for the research topic that was required, it also contributed significantly to my personal development. Working in a very large, international orientated organization like Shell was a unique opportunity. During my time, I met a lot of interesting people that all took time to provide me with their support and advice.

I would like to kindly thank all persons who contributed to the successful completion of my thesis research. There are a few people I would like to express my gratitude to in particular:

- Folkert Visser for taking so much time and effort for day-to-day support and for giving me the opportunity to see more of Shell than only the inside of the office.
- Peter Jongens for providing feedback from a different perspective on my study and assistance at finding the right persons and data.
- Team members for supporting me on a regular basis and involving me in activities outside my own project: Kabir, Ronald, Janice.
- Prof. Ir. Hopman, Prof. Dr. Bakker and Dr. Ir. Hekkenberg for their supervision and assistance from their position in the graduation committee.

Finally I would like to thank my friends for providing the necessary distraction during this project and my entire study. I would like my family for always supporting me and helping me to make the right decisions. A special thanks goes to Eline for her positive mindset and patience during the entire course of this project.

The author,

Govert van Berckel

Amsterdam, March 29, 2016

Master of Science Thesis

G.J.P. van Berckel
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>vii</td>
</tr>
<tr>
<td>1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1-1 Research Background</td>
<td>1</td>
</tr>
<tr>
<td>1-1-1 Introduction to Shell Projects and managing opportunities</td>
<td>1</td>
</tr>
<tr>
<td>1-1-2 Introduction to Brownfield Projects</td>
<td>2</td>
</tr>
<tr>
<td>1-2 Research</td>
<td>4</td>
</tr>
<tr>
<td>1-2-1 Research Motivation</td>
<td>4</td>
</tr>
<tr>
<td>1-2-2 Research objectives and approach</td>
<td>5</td>
</tr>
<tr>
<td>1-2-3 Scope of research</td>
<td>6</td>
</tr>
<tr>
<td>1-3 Report outline</td>
<td>6</td>
</tr>
<tr>
<td>2 Decision process analysis</td>
<td>9</td>
</tr>
<tr>
<td>2-1 Decision making in Shell Projects</td>
<td>9</td>
</tr>
<tr>
<td>2-1-1 The Opportunity Realisation Process</td>
<td>9</td>
</tr>
<tr>
<td>2-1-2 Decision Quality</td>
<td>11</td>
</tr>
<tr>
<td>2-1-3 Cost Estimation</td>
<td>13</td>
</tr>
<tr>
<td>2-2 Brownfield projects decision making</td>
<td>14</td>
</tr>
<tr>
<td>2-2-1 Brownfield decisions explained</td>
<td>14</td>
</tr>
<tr>
<td>2-2-2 Existing research and improvements</td>
<td>15</td>
</tr>
<tr>
<td>2-2-3 Internal study based on project evaluation and expert opinions</td>
<td>16</td>
</tr>
<tr>
<td>2-3 Chapter conclusions</td>
<td>21</td>
</tr>
<tr>
<td>2-3-1 Conclusions on analysis of current decision process</td>
<td>21</td>
</tr>
<tr>
<td>2-3-2 Conclusions on potential areas of improvement</td>
<td>23</td>
</tr>
</tbody>
</table>

Master of Science Thesis

G.J.P. van Berckel
3 Method development

3-1 Method basis
3-1-1 Method specification
3-1-2 Tool requirements
3-1-3 Theoretical framework

3-2 Tool development
3-2-1 Design Structure Matrix
3-2-2 Study specific adjustments
3-2-3 Tool working

3-3 Tool use modes

3-4 Chapter conclusions

4 Tool content development

4-1 Approach
4-1-1 Parameter categories
4-1-2 Input sources

4-2 Parameter identification
4-2-1 Start parameters
4-2-2 Subsurface, Process Engineering and Layout Parameters
4-2-3 Discipline Engineering
4-2-4 Execution parameters
4-2-5 Overview of tool parameters

4-3 Dependency identification
4-3-1 Subsurface, Process Engineering and Layout parameters
4-3-2 Discipline Engineering parameters
4-3-3 Execution parameters
4-3-4 Project outcome

4-4 Applicability to other project types
4-4-1 Project specifics
4-4-2 Site specifics

4-5 Verification

4-6 Chapter conclusions

5 Tool results

5-1 Results for total activity planning use mode
5-1-1 Activity parameters
5-1-2 Output parameters
5-1-3 Results comparison to compression related Brownfield projects

5-2 Results for robustness check mode

5-3 Conclusions on tool results
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Decision support by use of tool</td>
<td></td>
</tr>
<tr>
<td>6-1</td>
<td>Incorporating the tool in the project development</td>
<td>69</td>
</tr>
<tr>
<td>6-1-1</td>
<td>Tool practical use</td>
<td>70</td>
</tr>
<tr>
<td>6-1-2</td>
<td>Implementation strategy</td>
<td>70</td>
</tr>
<tr>
<td>6-1-3</td>
<td>Applicability during project development</td>
<td>71</td>
</tr>
<tr>
<td>6-2</td>
<td>Reflection on requirements and purpose</td>
<td>72</td>
</tr>
<tr>
<td>6-3</td>
<td>Wider implication of research outcomes</td>
<td>74</td>
</tr>
<tr>
<td>6-4</td>
<td>Discussion of research and framework use for decision making and project development</td>
<td>75</td>
</tr>
<tr>
<td>6-5</td>
<td>Conclusions on decision support</td>
<td>76</td>
</tr>
<tr>
<td>7</td>
<td>Conclusions and recommendations</td>
<td>79</td>
</tr>
<tr>
<td>7-1</td>
<td>Conclusions</td>
<td>79</td>
</tr>
<tr>
<td>7-1-1</td>
<td>Conclusions with respect to the decision making analysis</td>
<td>79</td>
</tr>
<tr>
<td>7-1-2</td>
<td>Conclusions with respect to the developed method and results</td>
<td>80</td>
</tr>
<tr>
<td>7-1-3</td>
<td>Conclusions with respect to the decision support using the developed framework</td>
<td>81</td>
</tr>
<tr>
<td>7-1-4</td>
<td>Final conclusions regarding the main research question</td>
<td>81</td>
</tr>
<tr>
<td>7-2</td>
<td>Recommendations</td>
<td>82</td>
</tr>
<tr>
<td>7-3</td>
<td>Suggestions for further research</td>
<td>83</td>
</tr>
<tr>
<td>A</td>
<td>Validation session transcript summaries</td>
<td>85</td>
</tr>
<tr>
<td>B</td>
<td>Tool use manual</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Bibliography</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Glossary</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>List of Acronyms and Abbreviations</td>
<td>91</td>
</tr>
</tbody>
</table>
# List of Figures

1-1 Opportunity Realisation Process ........................................... 2  
1-2 Different types of Brownfield projects on a scale from brown to green 2  
1-3 Typical offshore platform environment ................................... 4  

2-1 Opportunity Realisation Process (ORP) ..................................... 10  
2-2 Ability to influence cost during ORP phases ............................. 11  
2-3 Decision quality hexagon ...................................................... 12  
2-4 Asset development life cycle .................................................. 14  
2-5 High level options in Brownfield example project ...................... 15  

3-1 Binary DSM (a) and its equivalent in graphical form (b) ............ 28  
3-2 Risk degree matrix ............................................................... 30  
3-3 Calculated risk of two parameters A and B on C with IV value of C calculated by Equation 3-2 ........................................... 30  
3-4 ActualIV explained for activity parameters ............................... 31  
3-5 Risk matrix development for example system ........................... 32  
3-6 Model calculation sequence ................................................... 33  
3-7 Demonstration of 3 program steps for example system ............... 33  
3-8 Total project activity planning ................................................ 34  
3-9 ORP phases with corresponding IV levels, in this study assumed based on comparison to IPA established values ............................... 34  

4-1 Variability input screen for existing plot plan parameter ............. 43  
4-2 3D platform model ............................................................... 43  
4-3 2D platform drawing ............................................................ 43  
4-4 Activity parameter variability input options for MMI discipline ....... 44  
4-5 DSM with indicated parameter groups and areas ........................ 47
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6</td>
<td>DSM showing all identified dependencies between parameters</td>
<td>48</td>
</tr>
<tr>
<td>4-7</td>
<td>Numbering of dependency sections for explanation</td>
<td>49</td>
</tr>
<tr>
<td>4-8</td>
<td>Average IV level course for different categories</td>
<td>54</td>
</tr>
<tr>
<td>5-1</td>
<td>Start activity parameters with strongest IV decrease at pre-DG2</td>
<td>59</td>
</tr>
<tr>
<td>5-2</td>
<td>Start activity parameters with strongest IV decrease between DG2 and DG3</td>
<td>59</td>
</tr>
<tr>
<td>5-3</td>
<td>Subsurface, Process and Layout parameters with strongest IV decrease at pre-DG2</td>
<td>60</td>
</tr>
<tr>
<td>5-4</td>
<td>Subsurface, Process and Layout parameters with strongest IV decrease between DG2 and DG3</td>
<td>60</td>
</tr>
<tr>
<td>5-5</td>
<td>Discipline Engineering parameters with strongest IV decrease pre-DG2</td>
<td>60</td>
</tr>
<tr>
<td>5-6</td>
<td>Discipline Engineering parameters with strongest IV decrease between DG2 and DG3</td>
<td>60</td>
</tr>
<tr>
<td>5-7</td>
<td>Execution parameters with strongest IV decrease pre-DG2</td>
<td>61</td>
</tr>
<tr>
<td>5-8</td>
<td>Execution parameters with strongest IV decrease between DG2 and DG3</td>
<td>61</td>
</tr>
<tr>
<td>5-9</td>
<td>Execution output parameters with strongest IV decrease pre-DG2</td>
<td>62</td>
</tr>
<tr>
<td>5-10</td>
<td>Execution output parameters with strongest IV decrease between DG2 and DG3</td>
<td>62</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

This report is the product of a Master thesis research conducted as final part of the MSc. study Offshore and Dredging Engineering at TU Delft. The research is executed at Shell Global Solutions International B.V. in Rijswijk, the Netherlands.

The first part of this dissertation is the introduction to the research. It consists of three main parts, starting with a general introduction to the research main topic, Brownfield projects. It discusses the reasons for specific focus on Brownfield projects and the typical challenges these projects face. The second part consists of an introduction to the thesis research. It starts with an identification of the problem and further explains the research objectives and scope. The third part provides the outline of this report.

1-1 Research Background

1-1-1 Introduction to Shell Projects and managing opportunities

This research is conducted at Shell Projects & Technology (P&T) in Rijswijk. P&T is established to provide business and operational consultancy, technical services and research and development expertise to both Shell activities across the globe and the world-wide energy industry. Within this organization, the business unit where this research was done is Projects. Projects aims to deliver world-class, competitive and affordable projects [1]. In this context, a capital project is defined as a project where a Capital Expenditure (CAPEX) is made in order to maintain or increase the scope of the total company operation.

In general, this means that a project can be everything from repairing a roof to building a brand new offshore facility. This thesis research will focus on projects on existing facilities, called Brownfield projects. The next subsection will introduce this specific project type.

Executing projects is the result of a process that guides an opportunity to add value all the way from identifying it to realizing it in the best possible way. To manage these opportunities and account for or reduce the accompanying risks in a proper and guided structure, within
Shell the Opportunity Realisation Process (ORP) approach is used. This approach divides the opportunity realisation into six phases as can be seen in Figure 1-1 [1],[2].

![Six Phase Opportunity Realisation Process](image)

**Figure 1-1: Opportunity Realisation Process**

In the figure, the six phases are divided by five numbered Decision Gates (DGs) that the opportunity has to pass in order to commence to the next phase. These gates are used to determine whether all aspects of the opportunity can be delivered appropriately for realizing the value. The decision to proceed to the next phase is based on information obtained from required activities and deliverables as defined by the ORP. This information is then used to evaluate the opportunities and risks of the project on the total Technical, Economic, Commercial, Organizational and Political (TECOP) spectrum.

### 1-1-2 Introduction to Brownfield Projects

In the wider industry jargon, the difference between Greenfield and Brownfield projects in general is that Brownfield projects are executed on existing sites, whereas Greenfield projects are totally new build projects. From a project design perspective, this means that Brownfield projects are much more likely to have certain constraints that need to be taken into account compared to Greenfield projects. Different terminology is used for Brownfield projects such as revamp, renovation and rejuvenation projects.

![Different types of Brownfield projects on a scale from brown to green](image)

**Figure 1-2: Different types of Brownfield projects on a scale from brown to green**

Within Shell, a Brownfield Project is defined as a piece of work that occurs on an existing live facility and / or one that has physical tie-ins with the running facility [3]. This definition gives a broad range of project types that stretches from very Brown projects to almost totally Green as can be seen in Figure 1-2. On a scale from Green to Brown, Greener projects are new-build facilities with tie-ins to old ones. Very Brown projects are site rejuvenations or modifications to existing facilities. Examples of typical Brownfield projects are: expansion, debottlenecking, enhanced recovery, technology upgrade, decommissioning and integrity and rehabilitation projects.
The main reason to do these Brownfield projects is to maximize production from existing assets. Because the production level of facilities will decline over time, upgrades or modifications are necessary to get the most out of existing assets. Other reasons to do Brownfield projects are changes in legislations or standards, changes in process conditions or to manage obsolescence or integrity related issues that cause potential risks.

Brownfield projects exist both offshore and onshore and in upstream, midstream and downstream environments. The capital expenses of these projects range from small maintenance type projects (<US$10 million) to large modification or rejuvenation projects (>US$500 million).

Reasons for focus on Brownfield projects

In the wider oil and gas industry, more specific attention is directed to Brownfield projects. Reasons behind this mentality change are both recognition of the necessity and importance of good project performance of this type of projects but also the specific benefits of Brownfield projects when compared to Greenfields.

Brownfield projects are becoming increasingly important due to the following reasons:

- An increasing number of assets is in a mature state and reaching its end of designated design lifetime. This state typically needs a lot of smaller but also larger projects to keep producing under the current standards and guidelines.

- With a significant amount of production coming from maturing assets and less production from new assets across the globe, maintaining and enhancing production of existing assets becomes more important. This causes more Brownfield projects to be executed, which makes it increasingly important to strive for good project performance.

The increasing focus on Brownfield projects is not only because it is necessary. Specific benefits compared to Greenfield developments can also be recognized when looking at this type of projects:

- Brownfield projects take place on existing assets, often with many past years of production. Therefore, less uncertainty exists on subsurface conditions making it easier to develop production forecasts. In addition to that, permits and licenses are already in place, projects have established relations with external stakeholders and an existing staff is present that is experienced with the facility.

- Brownfield projects are often high-impact projects that are essential to maximize return on big capital investments. Compared to Greenfield projects, these projects often have a quick return on investment. This could be explained by the fact that systems and organizations around the asset are already in place. The necessary investment can therefore be reduced to the functional project scope only which has more direct economic benefits.

- Brownfield projects present a good opportunity to embed new technology into existing facilities.
Brownfield specific challenges

Brownfield projects are characterized by specific challenges that are different from the challenges typical to Greenfield projects. Almost all of these challenges exist due to the fact that the projects are executed within existing facilities with ongoing operations. This causes many interfaces between the project and the existing asset, both in terms of functional and physical design and in terms of execution planning when the operational team and the project team both need to do their work onsite [3]. Furthermore, often insufficient information is easily available about the facility. This can be information about the physical or functional specifications, but also maintenance and performance reports providing capacity and integrity data. Figure 1-3 shows a typical environment where projects need to be done on an offshore platform with congested layout. It is very important the project team understands the challenges and issues at the project site in order to develop a well performing project.

In the execution phase of a Brownfield project, practical challenges are faced by the project team. Performing construction works in an operating asset present difficulties in terms of safety and logistics. In many Brownfield projects, the nature of the work requires costly plant shutdowns that need to be planned carefully to avoid additional shutdown time that causes even higher costs. Also, execution constraints need to be identified early on to avoid unforeseen cost and schedule growth. Examples of these execution constraints are limited bed spacing, physical barriers to execute the work and available platform services to support additional activities on the asset next to the ongoing operations [4].

Another complex challenge compared to Greenfield projects is the presence of many internal stakeholders, often with different or even conflicting objectives. The operations team, maintenance crews and the project team need to be aligned and must support each other for optimal project performance [3].

1-2 Research

1-2-1 Research Motivation

The overarching problem common to Brownfield projects is the tendency towards cost and schedule growth during later project stages. Projects face significant cost growth after main
decisions have been made and detailed engineering has already started. When compared to Greenfield projects, industry wide and internal Shell studies indicate that Brownfield Projects perform worse in terms of predictability of cost and schedule. [4], [5], [6].

More specifically, when looking at the average cost growth of a set of Shell Brownfield projects per ORP phase, it appears that projects considered in this sample faced significant cost growth during the Select and Define phase. This cost growth exceeds the accuracy bandwidths that Shell requires in its project estimation standards [4]. Total project costs at the end of these projects were thus much higher than initially estimated and anticipated at in the early phase development. In hindsight, decisions made between high level options in early phases were therefore taken on the basis of insufficient or inadequate information.

The consequence of this underperformance for the projects in the figure are (much) higher costs than anticipated at on the moment of decision making. Other Brownfield projects that faced the same problems had to be recycled to find another solution or were terminated and thus not executed at all [7]. Both of these outcomes result in potential unnecessary expenses in project development because the necessary information could have led to other choices earlier on.

Key drivers for this problem include growth of the scope definition and of the scope boundary [4]. Scope definition growth consists of material and work growth within the established scope as defined by the selected concept. Scope boundary growth occurs when the total project size increases when scope is added outside established scope boundaries. Both of these drivers appear to cause scope changes in later phases of a Brownfield project whereas in project development, changes are only allowed in early phases.

Several initiatives within the industry aim to mitigate this problem by developing tools and guidelines dedicated to Brownfield project development and management [4], [5], [6], [8]. Specifics of these developments are further described in the next chapter. The focus areas of current initiatives consist of identifying generalized causes for Brownfield scope growths and implementing robust estimating and planning methodologies tailored to Brownfield projects.

Despite the increasing recognition of the problem and ongoing improvement developments, much room is still left for other approaches that could be equally beneficial to Brownfield project performance as suggested by existing reports from the current initiatives [4]. These suggestions combined with preliminary studies on applicable finished Brownfield projects that faced difficulties in early phase decision making formed the basis for the motivation behind this study [7].

1-2-2 Research objectives and approach

In the context of the previous sections, the main purpose of this thesis study is to contribute to improving Brownfield project performance. Within this goal, this thesis focuses on the decision making in Brownfield project design. The main objective of this thesis is therefore to improve the quality of decision making in early phases of Brownfield project design.

This high level main goal is divided into several sub objectives that this study uses as a guideline to achieve the main purpose and objective:

- Analyse current decision process in Brownfield projects and identify areas of improvement
The subobjectives can still be considered to be high level, because no specific area within the
decision making process is highlighted yet as subject of this thesis. In addition to that, it is
also not specified yet what the nature of the improvement method is. The reason behind this
is the fact that an important part of this research is to study the current decision making in
Brownfield projects as listed as the first subobjective. Results of this study will be used to
define the specific purpose of the method and specify the requirements for development and
incorporation of the outcomes of the thesis.

1-2-3 Scope of research

Since Brownfield projects consist of a variety of different types of work on all kinds of facilities
in diverse environments, this research is scoped in order to improve the feasibility of the study
and to be able to compare more consistent project types. The research focuses on Brownfield
projects on offshore, bottom founded platforms. Furthermore, the study is done with respect
to projects with major impact on existing offshore facilities, since these type of projects often
show a higher level of complexity due to more interfaces between design and the existing
facility. The reason why offshore platforms are chosen is that projects on this type of facility
usually show a higher level of complexity due to additional execution constraints.

Furthermore, in this research, the focus will be on the technical part of the project scope.
Obviously, a project consists of much more than only technical challenges. Within Shell the
total spectrum is referred to as the Technical, Economic, Commercial, Organizational and
Political (TECOP) scope. Because of the study background of this thesis and the importance
of technical challenges in terms of project design and execution, the "T" within TECOP is
focused at.

1-3 Report outline

The report can be divided into three main parts that form the building blocks for the research
to fulfill the objective. The first part, described in chapter 2 provides the outcomes of an
analysis of the current situation with regards to decision making in projects. This analysis is
done with respect to existing processes and systems in place, Brownfield projects performance,
existing research and improvements on Brownfield projects and an analysis of a set of historic
Shell Brownfield projects. It ends with conclusions of this analysis that result in a further
specified objective that is based on an improvement opportunity within the main objective of
this thesis.

The second part consists of the steps taken to develop a method for the identified improvement
opportunity in the first part. In chapter 3, the development and working of the framework is
described. Chapter 4 provides the steps taken to fill the developed tool with content tailored
to Brownfield projects. Chapter 5 gives the results from the tool together with an evaluation and validation using Brownfield pilot projects.

The last part of this thesis is described in chapter 6. It provides the step back from the developed method and outcomes of the method to project development in practice. It describes how the tool can be used, what the added value of the tool is and what the wider implications of the outcomes of this study are. This dissertation ends with conclusions and recommendations in chapter 7.
Chapter 2

Decision process analysis

This chapter provides an analysis of the current decision process in Brownfield projects within Shell. First, existing systems and processes are described and analyzed, followed by specific Brownfield project issues are identified by literature research. Third, existing research and measures to mitigate Brownfield project problems are described and finally, findings of this chapter are supplemented and verified by a survey done on historic brownfield projects and expert interviews.

Main objective of this chapter is to identify opportunities to improve the decision making within Brownfield project development and convert these into usable research objectives for this study. As already briefly explained in the introduction section of this thesis, projects are subject to many different aspects and challenges. Therefore, creating an explicit research goal is very important for this thesis.

2-1 Decision making in Shell Projects

In formal project design procedures, Shell does not distinguish between new developments and Brownfields. This section gives an overview of the processes and guidelines that exist within the company for decision making in all projects.

2-1-1 The Opportunity Realisation Process

As briefly explained in the introduction part of this thesis, the ORP is the Decision Gated process used in Shell to guide opportunities from the Identify stage to the Operate stage. The ORP is part of the Opportunity Realisation Standards (ORS) which sets out the mandatory requirements for managing business opportunities. This process is a practical way to determine which activities, deliverables and decisions are required to manage and deliver maximized value.

The ORP consists of six different phases [9]:

Master of Science Thesis  
G.J.P. van Berckel
- **Identify**
  Identify the potential value of the opportunity and alignment with business strategy. Determining project scope and development of high level possible opportunity realizations.

- **Assess**
  Demonstrate the technical and economic feasibility of a wide-enough range of concept realizations.

- **Select**
  Selection of preferred realization concept based on value creation potential, taking into account of associated risks and uncertainties. Main strategic decisions are taken on how the project will be executed and operated.

- **Define**
  Finalization of scope, cost and schedule. Preparing the scope definition for hand-over to contractors. The milestone following this phase is also referred to as Final Investment Decision (FID) where is decided whether to execute the developed project.

- **Execute**
  Project execution within developed scope, budget and schedule. Focus is on controlling these while accounting for other targets such as HSSE.

- **Operate**
  Facility start-up after project and handover to operations. Furthermore, evaluations on the finished project are done and lessons learned are identified.

The process is intended to be decision driven, not activity or time driven. In general, the work should be planned in such way that the necessary information is generated to support the next milestone decision at the end of each phase, the Decision Gate (DG). These milestones or focus decisions are reviewed and supported by a Decision Review Board (DRB) who review assurance through a Value Assurance Review (VAR). Outcomes of these decisions can be to proceed to the next ORP phase, to do a recycle of the phase prior to the decision making or to terminate the project at all or temporarily.

![Figure 2-1: Opportunity Realisation Process (ORP)](image)

Figure 2-1 indicates a change of project behaviour between the first phases and the last. The Identify, Assess and Select phase are aimed on creating value in the project. Developing
and optimizing concept realizations in those four phases is essential to optimize the value potential. For that process, Front End Loading (FEL) is used. This practice is meant to take sufficient time and effort in the early phases of the project to assess the opportunity before major expenditure is started. During the Select phase, one preferred concept is chosen to realize the opportunity. Changes in the way the opportunity is realized should therefore only be expected to happen prior to DG3.

Very early in the process, Opportunity Framing (OF) takes place as indicated in Figure 2-1. This feature is aimed on defining and understanding an opportunity by creating alignment and clarity amongst team members, stakeholders and decision makers. It is the starting point for the decision-driven process to achieve agreed goals and for the team’s planning process. Post DG3, changes must be strictly controlled, as scope changes can result in increased risks, cost overruns and schedule delays. As can be seen in the figure, the last three phases are therefore aimed on delivering the value that has been created in the early phases of the project. All major decisions are thus taken in the early phases of the project design cycle. When translated in terms of project cost expenditure and the ability to influence the costs, Figure 2-2 shows the relation to the different phases.

![Figure 2-2: Ability to influence cost during ORP phases](image)

In order to identify necessary deliverables and decisions during the project cycle, the Discipline Controls and Assurance Framework (DCAF) was developed. This framework records the discipline controls and the appropriate authorities to sign off when certain technical requirements have been met. Which discipline controls apply to a specific opportunity is based on the risks involved. These are listed in the Project Controls and Assurance Plan (PCAP) per ORP phase [10].

### 2-1-2 Decision Quality

The highest value potential is delivered through making quality decisions. Shell adopted the quality hexagon framework from the Strategic Decisions Group (Stanford University) to help improve decision making and hence project delivery [11]. The elements considered in this approach are shown in Figure 2-3 and shortly discussed below.
• **Appropriate Frame**
  Framing quality is characterized by three elements: clear purpose, defined scope and conscious perspective. A clear purpose must be established to align the decision group on what has to be done. The scope defines what is inside and outside the frame that is considered. It consists of every decision from the high-level 'givens' to smaller tactical decisions. A conscious perspective is necessary to have the team members to enlarge their perspectives to see the full relevant data set that is considered.

• **Creative, Doable Alternatives**
  The quality of the decision will be limited by the quality of the alternatives considered. The quality of these alternatives are defined by six factors: Creative, Achievable, Significantly different, Coherent, Compelling and Complete. Possibly, after a first round, alternatives can be refined or 'hybrid' alternatives can be developed.

• **Meaningful, Reliable Information**
  Quality of the information used for decision making is developed during framing sessions (see Opportunity Framing (OF) in section 2-1) and continues during alternative generation and decision analysis. Information quality is defined by four elements: knowing what is important, making sure the information is correct and explicit, using appropriate facts and including the effect of uncertainty in the analysis.

• **Clear values and Trade-offs**
  Decision making in this context is all about optimizing value potential. As explained earlier, this value can be expressed in different terms and more than one value can be considered in a project. Therefore, decision criteria have to be identified and developed through sensitivity studies and obtained insights during the process.

• **Logical Correct Reasoning**
  Two aspects are important for quality in this area to be able to convert many alternatives with different information and values into choices. The team needs to reason clearly when making the decisions. In addition to that, consequences of the alternatives in
terms of the decision criterion need to be developed.

- **Commitment to Action**
  This element is about the motivation and commitment of the individuals of the decision making team. An example of how this can be achieved is to involve key decision stakeholders from the beginning of the project. That way, they will understand the frame, alternatives, information, values and logic used to take the decision. Stakeholder understanding of the decisions taken and background of the considerations will also always contribute to a better execution and implementation of the project.

### 2-1-3 Cost Estimation

One of the most important aspects of decision making in projects is to understand the magnitude of CAPEX involved and the return the project potentially can generate. Therefore, cost estimation is of critical importance to the process. This subsection provides an overview of the cost estimation practices within Shell with main focus on how is dealt with uncertainties in early phases of project cycles. A cost estimate in this context is defined as the estimated total costs of a project [12].

Costs are primarily driven by scope, execution strategy and rates. Defining these inputs requires activities from various disciplines and can be constrained by resources and / or time. Therefore, the basis of the cost estimation depends on level of detail of the input and assumptions made. The undefined part of the estimation needs to be quantified as uncertainties and risks.

Guidance on what level of detail is necessary in the various ORP phases are documented in Shell standards. As can be seen in Figure 2-2 on page 11, different estimate tools corresponding to ORP phases have been established. With a maturing project cycle, the ability to influence costs decreases as more decisions are taken. These decisions and activities to support the decisions give output to the cost estimators causing an increasing level of detail.

A capital cost estimate consist of different components. With respect to the decision making considered in this thesis, the important parts of the cost build-up are the identified scope estimate, allowances for certain activities and the contingency. Identified scope is an aggregate cost of various components within the project scope. With more project detail, more separate details on equipments, materials and labor is captured here.

Allowances are defined as 'Known Unknowns' that have historically shown to occur at specific project types but are difficult to quantify. Therefore a statistical percentage is added to the scope estimate depending on the project. Different allowances exist such as activity allowances (waste, rework, weather downtime), new technology allowances (account for risks involved when using unproven technologies) and also a Brownfield allowance that accounts for typical Brownfield issues as integrity, disruption of ongoing operations and risks or Health, Safety, Security and Environment (HSSE) issues.

Adding contingency to the estimate accounts for further scope definition errors that emerge in subsequent phases. These are yet undefined risks at the time of estimating the cost in a project. Contingency also covers minor design and field changes but not major scope changes.
2-2 Brownfield projects decision making

This section will focus on the decision making for Brownfield projects in specific. The first subsection explains what decisions have to be taken in considered Brownfield projects. The nature of these decisions is discussed and the set of high level options is explained in order to understand the considerations and challenges that arise in the process.

The second part of this section describes the study that was done on analysis and improvement developments within Brownfield projects. It discusses various findings from both industry wide studies and internal Shell research.

The third subsection provides a summary of the findings that came out of internal research based on past project evaluations and interviews with involved persons.

![Asset development life cycle](image)

**Figure 2-4: Asset development life cycle**

2-2-1 Brownfield decisions explained

A facility requires maintenance and modification works throughout its asset lifecycle. Figure 2-4 shows an example of an asset life cycle where major redevelopment works are indicated on a point in time. These redevelopments are most likely required in order to maintain or extend the production as it is the case in the figure. The decisions necessary for these type of projects are the subject of this study. This subsection will give a short explanation of the nature of these decisions and the potential realization outcomes.

At the highest level of decision hierarchy, a choice has to be made whether to take action to mitigate performance or production decline or to take no action and accept the consequences thereof. In the example shown in the life cycle figure, doing nothing most likely means a much shorter lifetime. This will result in less total production, an earlier moment of platform decommissioning and possibly more smaller maintenance work that is not done during one large redevelopment operation.

When enough value potential is identified, a project cycle will be started and multiple concept realizations will be developed. The level of options considered at this point is generally at high level system configuration and adjacent major scope options are indicated as well. Through preliminary disciplines input, the options are compared in order to present them in the feasibility report to proceed with to the Select phase at DG2.
As an example, Figure 2-5 shows high level configuration options together with main scope decisions of a compression project [13]. In this example case, options are considered in order to add a compressor to a production system to make the production system compatible with a lower reservoir pressure. The grey marked options are eliminated for further evaluation based on information in the feasibility report. The main choice in this case is the high level system configuration. Options are to put the compressor on an existing (hub) platform or the existing Well Head Platform (WHP), on a new platform or onshore. These are shown in the figure in the leftmost column.

![Figure 2-5: High level options in Brownfield example project](image)

In the select phase, the considered realizations are worked out into more detail and one preferred concept is selected during the Select phase. This is a major decision that defines if the project will be a Brownfield project or a much 'greener' orientated project (see 1) with the only impact on the existing platform being the tie-ins. In this case, installing the compressor on the existing platform was preferred.

From this point on, smaller, tactical decisions need to be taken that give more detail to the project in terms of design and execution strategy. Examples of those decisions are:

- **Construction considerations:** Choice of designing a module that contains all project scope and is constructed onshore or separately design all scope into the existing platform design, also known as stickbuild or piecemeal installation.

- **Execution considerations:** Design for implementing the scope onto the existing platform all during ongoing operations or choosing a shutdown period where the work is done.

- **Logistic considerations:** Make use of existing platform services like accommodation facilities for the project or look for other options as hiring a living quarter vessel.

All of these choices together will define the total project scope and execution method. Many choices are interrelated and can result in having major impact on the existing site with respect to the design and / or the ongoing operations.

### 2-2-2 Existing research and improvements

**Literature on Brownfield projects**

When looking at available academic studies on Brownfield projects, only very little research has been done. Therefore, this study has predominantly made use of industry or Shell internal...
research that will be discussed below. A short summary of the academic work on Brownfield projects that is found is listed here.

- A study on describing and demonstrating the practical application of techniques of performance measurement to the control and execution of modification projects in the offshore oil industry was done by Fouche [5]. This study is based on qualitative and quantitative analysis of close-out data from 38 modification projects. To mitigate the primary premise that modification projects are subject to quantity and complexity growth during the course of detailed engineering as a consequence of the indeterminate interface with the existing facility, a portfolio of project control methods is presented.

- Ersdal [14] studied the evaluation of possible life extension of existing offshore jacket structures. The thesis proposes that a risk evaluation of an ageing structure is needed as a part of the assessment. Different risk evaluations were suggested together with preventive actions to limit the risks.

**Industry research**

**Construction Industry Institute**

[this paragraph is not shown in this report version for confidentiality reasons]

**Independent project analysis**

[this paragraph is not shown in this report version for confidentiality reasons]

**Shell internal research**

[this paragraph is not shown in this report version for confidentiality reasons]

**2-2-3 Internal study based on project evaluation and expert opinions**

This section discusses the findings of a study that was done at the orientating phase of this research within Shell. First, conclusions from an analysis of representative projects are discussed. Secondly, a summary of findings from interviews with involved persons and experts within Shell are listed. The last section shortly adds insights with respect to Brownfield projects at other facility types.

**Historic Brownfield project evaluation**

A survey study was done on representative finished Brownfield projects in order to compare the findings from the literature study described above to project results. It appeared to be very challenging to collect a bundle of subsequent reports from a project since no structured approach exists within the company to capture and store these documents. Reasons for this
issue include the fact that projects often have multi-year duration, involved persons switch jobs during a project cycle and differences in systems exist at different locations around the globe. Improvements are being put in place on this matter, but the absence of easy access to applicable internal benchmark and learnings material is not beneficial to project performance.

For the survey case study, five comparable Brownfield projects were analyzed based on documents and reports and where possible, input from involved persons within Shell was asked. Below, main findings are listed.

All projects were executed on offshore platforms and all main scope purposes were to add compression functionality to the platform in order to keep producing gas with a decreasing reservoir pressure. Furthermore, all projects were finished between 2003 and 2011. One project was not executed as Brownfield project even though the initial selected concept was a Brownfield solution. After a recycle, a Greenfield solution was chosen. The four other projects were executed as Brownfield projects, but all had significant total CAPEX growths between 30-50% when compared to original estimates. The projects together cover a range of total CAPEX from EUR10 million to EUR200 million. Project 3, 4 and 5 were executed in a similar timeframe under similar conditions. The report therefore indicated some similar issues among the projects.

Main conclusions from documents and expert opinion sources to explain the cost growth were found to be:

**Project 1** [7], [15]

- Concept decision was based on options that had different levels of detail of cost estimation. Therefore, a substantiated decision could not be made.
- Management pressure on project development schedule led to almost all focus of project team on developing one concept, which led to a skewed decision.
- Increasing project main scope due to integrity issues that were recognized with maturing project definition.
- Many smaller scope increases that were individually manageable, but added together they resulted in a significant scope growth at a later stage of the project.
- No sufficient maturation of Brownfield execution strategy at decision moment, increasing the possibility of underestimated offshore manhours and related costs.
- Cost estimation done by using estimation tool that did not account for Brownfield specific project elements

**Project 2** [16]

- Cost underestimation most likely due to insufficient detail in design and execution strategy at concept select stage.
- Cost estimation done by using estimation tool that did not account for Brownfield specific project elements.
• Scope growth due to unforeseen addition of major equipment part necessary to mitigate Brownfield integrity issues.

• Minor CAPEX spending for secondary scope items was not included in the original estimate.

**Project 3** [17]

• Major concept changes to the module compared to original basis including design development issues.

• Unexpected issues with the accommodation vessel required the final hook-up and commissioning activities to be completed using only the limited bed space available on the platform.

**Project 4** [17]

• Existing equipment on facility did not perform as originally designated, resulting in increase of Brownfield project scope.

• As built situation was not completely reflected on the as-built drawings causing unexpected work increase.

**Project 5** [17]

• Limited availability of accommodation vessel causing schedule delay.

• After replacement of obsolete platform crane by a new one, severe lifting capacity restrictions were caused by dynamic vibrations when lifting higher loads. These restrictions impacted the logistics for the project.

**Project issues similar for project 3, 4 and 5**

• Lower achieved work productivity than expected.

• High external specialist service costs during construction and commissioning periods due to technical capability limitations of contractor workforce.

• Brownfield element in workscope was underestimated.

• Underequipped fabrication contractor caused delay in the hook-up and commissioning stage resulting in gas production deferment.

• Incomplete construction and pre-commissioning activities for the modules required offshore completion. This required many additional offshore manhours.

• Incomplete engineering and design changes required additional unplanned construction and hook-up activities offshore resulting in additional offshore manhours.
Summarizing these findings, many identified drivers for cost growths in the evaluated projects resemble the outcomes and suggestions of the analyses and research described in section 2-2-2. The major part of the list can be identified as cost growth driver that is Brownfield specific, meaning that this type of issue will not or less likely occur at Greenfield projects. These Brownfield specific project issues include major and minor scope growth due to integrity issues on existing platform, unplanned work scope growth due to incomplete asset data and unforeseen execution constraints caused by circumstances on the existing asset. Five main themes can be recognized in almost all identified cost drivers that have a more technical nature:

- Increasing project main scope due to integrity issues
- Many smaller scope increases
- Insufficient detail in design
- Insufficient execution strategy maturity resulting in risk of underestimation of offshore manhours
- Underestimated impact of execution constraints

In addition to these factors that confirm the findings in the research for the evaluated project, additional cost drivers with a less technical nature were identified as well. These are management pressure that resulted into suboptimal decision making because only one concept was at a appropriate level of scope maturation and using a estimation tool that was not tailored to Brownfield projects.

**Expert opinion study**

Because project development and management performance is strongly dependent on the people that are involved, a orientating survey was done for this study in order to incorporate opinions and insights from exSpers into this research. To aim for insights from a complete set of different perspectives, meetings were arranged with persons within Shell with various backgrounds and expertises and from different locations.

Most importantly, persons involved in developing the project and managing the project execution were interviewed. In addition to that, input was asked from persons with discipline engineering backgrounds and with project services backgrounds such as cost estimation. To complete the picture, two field trips to offshore platforms in the North Sea were organized in order to incorporate the view of operational teams on Brownfield project performance as well.

The most important summarized findings that contribute to the objective of this chapter are listed below.

- The main difference between project development in the early phases and project execution is the difference between maximizing the value of the opportunity and delivering
developed value realization in the best possible way. The mindset of the persons involved in both parts of the project is therefore different. This can cause several problems. Project development teams can lack focus on incorporating execution strategies into the project design which can result in cost growth due to unforeseen execution constraints. On the other hand, input from project execution into early phase project development is sometimes insufficient and characterized by a mentality of saying that everything can be done. Brownfield projects seem to be more vulnerable for these two problems since more execution constraints often exist compared to Greenfield projects.

- A cost and schedule growth driver that is often recognized in Brownfield projects is scope growth due to existing facility status such as integrity issues of equipment. Ideally and according to standards and guidelines, an asset should possess up to date information about its integrity and performance captured in maintenance or operational reports. In reality, this information is often not available causing problems for the project team. When this is the case, retrieving the correct information from the platform by surveys or operational and maintenance crews is crucial to avoid late scope changes of growths.

- Due to management decisions and focus or lack of asset data, initiation of Brownfield projects can be late causing a pressure on the project team to deliver the project. Oftentimes, this is driven by contractual obligations that require certain production levels to be maintained or integrity and HSSE issues that can potentially result in production shutdowns. In these cases, the pressure from management on the project team can lead to weak concept maturation or a lack of worked out concept alternatives. This can result in late scope growth when the project definition is matured.

- A perception shared by more persons towards Brownfield projects is that more or different attention should be given to the FEL development in the early phases of the project. However, with insufficient asset data it is difficult to have the right focus since the problem can exist on different aspects of the project. Decisions on how to improve the scope definition are based on experience of involved persons. In addition to that, in early phases, limited resources are available for optimizing the FEL of the project. No or few specific guidelines exist on this matter. Because a system of job rotation exists and capturing documentation and lessons learned is not done well, corporate learning on project development is insufficient.

- During several different interviews, the way the development process works within Shell and the way it was developed was discussed. Summarizing thoughts on this topic, it appeared that the structure for project development has been formed from many years of experience. Learnings and captured data provided a basis for determining what information type and level on average is necessary at each decision gate to have enough confidence that the project would not spin out of control. This gradual process has been converted into guidelines and requirements for all project types. This process appears to be much more suitable for developing large building ‘blocks’ of which the required efforts and materials can be estimated based on experience. A very fundamental reason for Brownfield project underperformance could therefore be that Brownfield projects have a unique nature which makes the existing development structure less suitable.
Analysis of Brownfield projects on different facility types

Because the scope of this research is offshore Brownfield projects, no specific study was done on other Brownfield project types. From a high level perspective, this research focuses on Brownfield upstream projects on offshore platforms. Other upstream projects could be projects performed on different offshore facility types such as on Floating Production, Storage and Offloading (FPSO) vessels or projects on onshore production facilities. Brownfield projects are also performed on downstream production facilities. The IPA study described in this chapter is focused on projects on offshore facilities. The other research described which was performed by CII however, is done for Brownfield projects in general for the wider construction industry. This study did not distinguish between up- and downstream projects within the oil and gas sector. The outcomes of this wider study suggest equal challenges and underperformance of Brownfield projects in general.

Eventhough the CII study suggest similar conditions and outcomes for Brownfield projects from a wider perspective, it might still be an interesting opportunity to take a closer look to the differences between Brownfield projects on different facility types. This assumption is also substantiated by expert opinions from interviews suggesting that differences in approach and performance exist. Therefor this study suggests this as further research possibility to obtain more understanding of root causes and best practices. From learnings obtained and described in this chapter, some differences between facility types that could influence Brownfield project performance are listed below as a starting point for further research.

- Existance of logistic challenges for crew and material transport, but also for project development teams.
- Nature of facility building and onsite work location challenges; for example congested or confined areas or working at height.
- Exposure to weather conditions.
- Complexity of necessary modifications or additions.
- Longer term asset management plan in relation to project nature and / or maintenance status. An upstream asset for example has a designed end of lifetime when the hydrocarbons are produced. Downstream assets have much longer design lifetimes.

2-3 Chapter conclusions

This section of this chapter provides a summary of the processes and learnings described above in order to fulfill the first subobjective of this thesis being to identify areas of improvement in order to identify the next steps in this research.

2-3-1 Conclusions on analysis of current decision process

Looking at the existing processes that are in place to ensure good decision making in projects, it appears that almost no supplementary processes are in place to account for Brownfield
specific challenges. In the ORP, a process flow is followed that accounts for all types of projects whereas research described in section 2-2-2 suggests that Brownfield projects need focus on specific areas in order to mitigate risks that are common to this type of projects.

Cost estimation techniques account for Brownfield risks by adding allowances or contingency to estimates in early phases of the project cycle. Historical data shows that these standard factors do not reflect actual project outcomes as the predictability of the projects appears to be low. In fact, the predictability in terms of cost and schedule is even outside the accuracy bandwidths that are set by the business. Decisions taken at DG2 and DG3 in certain past Brownfield projects to proceed to the next phase were therefore based on unreliable data. This argument can be supported by looking into completed projects data showing large cost and schedule overruns in later phases or even recycles where the entire project was set back into an earlier phase.

The research done on Brownfield projects so far shows consistent results on the question what the drivers behind the cost and schedule growth and predictability are. A thorough understanding of the scope in terms of design and execution strategy is crucial for good project performance. Both of these depend strongly on the existing asset specifications that need to be verified and accounted for in engineering. Particular elements depend on the specific site info and the design basis for the Brownfield project. Other consistent findings are that Brownfield design is heavily constrained and complex scheduling is necessary to account for issues emerging when constructing in live environments.

Methodologies and practices that are developed ensure insights and learnings are embedded in Brownfield project design. Predominantly, these improvements focus on better estimation tools supported by improved benchmarking and Brownfield specific factors that are derived from historical data. Other studied areas are engineering procedures and solutions created in order to avoid Brownfield scopes in design.

Research done in this particular study based on historic projects and expert input supports the findings above. It also adds insights to the problem concerning management pressure on projects and challenges on how to obtain a good FEL while lacking resources and guidelines for Brownfield specific issues.

An important part of this study is to understand the potential drivers behind the identified difference between Brownfield and Greenfield project performance that follow from the various perspectives discussed in this chapter. Considering the structures and processes in place that guide project development, it appears that those are more tailored to Greenfield projects because no specific attention for the project nature exists. Instead, a gradual development approach is in place that appears to be more suitable for development of large building units as is the case in Greenfield projects. In addition to that, existing constraints and unknown facility data typical for Brownfield projects do not exist for Greenfield projects. Furthermore, in Brownfield projects several existing teams have to work together whereas in Greenfield projects, one development team can oversee the entire project. Finally, the risks that are common to Greenfield projects are often subsurface uncertainties and non-technical risks regarding the location of the new facility. These two risks are often less significant for Brownfield projects.
2-3-2 Conclusions on potential areas of improvement

In the context of the findings summarized above, this last section of this chapter will explain the considerations that form the basis of the improvement method development in this study. These considerations follow from understandings and insights obtained by the analysis of the current processes and Brownfield specific issues.

In order to fulfill the main objective of this study to improve Brownfield decision making, several areas of improvement were identified. Because the scope of this thesis is on technical aspects of the problem, the research direction is chosen accordingly. However, conclusions concerning obtained non-technical areas of improvement are important as well, since improvements on technical aspects can also lead to improvements on the non-technical side. Main found areas of improvement on non-technical aspects are:

- Involvement of the appropriate expertise from persons working outside the project team such as technical disciplines or operations at different phases of project development.
- The effect of management influence or other circumstances causing time pressure on the project development process. A potential improvement is to define minimum requirements of the Front-End process to improve the decision making.
- Proper management of asset data on facility design, conditions and performance can be very beneficial for Brownfield project development. If such data is known, early decision making can be improved because more information is available. Development of standards in this field is therefore an area of improvement.

Main found areas of improvement on technical aspects are:

- The development of concept solutions that avoid typical Brownfield projects such as modular solutions are more cost-effective Greenfield options. With additional alternatives that present lower uncertainties while the costs are not higher at the same time, decision making can be improved on the Alternatives aspect (see section 2-1-2).
- Identification and development of technologies that assist in improved information supply to support the quality of the decision making.
- Improving cost and schedule estimation techniques that account for Brownfield specific technical and logistical risk instead of the traditional techniques. With better cost estimation, the quality of decision making can be improved because options can be compared with more confidence on the cost estimation side.
- Improving standards or guidelines that assist in making choices and developing procedures for Brownfield project development. By doing the right design activities in early phases based on experience from earlier projects, risks are mitigated that have potential large influence on the main decisions.

This study will focus on the last listed technical area of improvement. The main reason for this choice is because this area appeared to be the largest 'gap' in improvements developed
and incorporated within Shell at the time of this research. When experts were asked about the rationale behind choices on how to plan Brownfield project development, the final answer was that this was done based on experience from involved persons or making use of systems more tailored to Greenfield developments such as DCAF. In addition to that, sources suggest that implementation procedures to drive the appropriate level of scope definition and execution considerations is equally important as robust planning and estimation methodologies [4]. This study is thus directed towards improving front end development in order to improve the decision making.

The other identified areas are definitely considered to be important as well to improve Brownfield project performance. However, more effort is already put in developing ideas and solutions in these areas.

Based on the conclusions above, the specific objective for this study is defined as to 'optimize the scope definition of a certain Brownfield project on a certain moment in the project design cycle based on its project specifics and site conditions'. This objective covers the suggestion that Brownfield projects demonstrate a higher complexity in identifying risks because these projects address only specific parts of facilities instead of developing entire units. In addition to that, existing constraints in terms of design and executability need to be identified. By doing the appropriate design activities in the right order, an optimal sequence can be aimed for to reduce the risks as required for different phases in the ORP. In reality, this means that some project elements should have more focus in certain development phases than others, based on the characteristics of the project and the project site. The objective also addresses the challenge of project teams having limited time and resources to do front-end work, which requires guidance on making the right choices where to focus on in the early phases.

This study objective fulfills the main objective of improvement of decision making in early phases by assisting in obtaining the appropriate information to make the decision (see section 2-1-2). Also, assessment of the doability of alternatives is improved. The quality of the decision therefore increases.

The next chapter of this dissertation demonstrates the process of developing a method to fulfill the study specific objective.
This chapter describes the development of a method for improving the identified Brownfield project development optimization opportunity as described in chapter 2. The steps that are taken for this part of the thesis are first to develop specifications for the basis of the method followed by defining the requirements for the method. Then, supported by a literature study, a decision is made about the framework used and it is demonstrated what adjustments were made for an appropriate functional working of the method. The next chapter will then describe the second step of the method development being the contentual input tailored to Brownfield projects.

3-1 Method basis

3-1-1 Method specification

The purpose of the method is to optimize the scope definition of a certain Brownfield project on a certain moment of time in the project cycle or ORP based on its project specifics and the site conditions. As stated before, this assists or potentially replaces a process that is currently mainly done based on human input based on expertise and experience.

To fulfill this objective, a more specific look is taken the description above. The study purpose requests a method that is applicable to all Brownfield projects but the outcome should be based on project and site specifics. In the context of the explanation of the specific objective of this study in section 2-3-2, this means that the method should identify risks coming from the project and site specifics. These risks are defined as risks for changes to project outcome in terms of for example costs or schedule since that was the starting point of this thesis.

Summarizing this logic in order to specify the basis of the method, it appears that an approach is required that is able to demonstrate relations between project and site specifics and project outcome for Brownfield projects dynamically with respect to time in the design process. A quick survey to approximate the number of possible relations based on data from the previous chapter demonstrated a high number of relations, both qualitative and quantitative. This
high number represents the complexity of the process which can potentially explain a part of the historic errors in the design process of Brownfield projects. A person or groups of persons representing the design development team can only have experience and knowledge to a certain level. The process of identifying potential risks out of a very high number of potential causes could therefore be suboptimal, especially when these causes are interrelated too.

To mitigate this issue, the adopted method for this study was to develop a tool that can assist in this process. The next subsection will elaborate on the requirements of the tool based on the described method specifications and the subobjectives of this study as specified in section 1-2-2.

3-1-2 Tool requirements

A number of requirements should be met by the tool in order to contribute to the main purpose of this study. These requirements can be split into functional and non-functional parts. The functional requirements describe what functions the tool should perform which is mainly based on the considerations in the previous section and the specified method purpose that came out of the analysis in the previous chapter. The non-functional requirements are related to the future usability of the tool. These are important to fulfill the subobjectives from this study that require the results of this study to be implemented (see section 1-2-2).

Functional requirements

- Representing Brownfield projects in terms of project and site specifics
- Relating these specifics to potential risks on change in project outcome values
- Identifying the most important relations and largest risks
- Providing output based on these risks that can be incorporated into the project development process

Non-functional requirements

- Workable and functional visual layout
- Tool should be understandable for users
- Incorporation of tool outcomes in the development process should be feasible
- Adjustment of tool settings should be possible

These requirements are both used to develop the framework of the tool and to evaluate the result in the end.
3-1-3 Theoretical framework

With the defined method specifications and requirements, this section explains the choice for the theoretical framework used to develop the tool.

In order to fulfill the functional requirements, the project is simulated as a system of project parameters representing the project and site specifics. As indicated above, it is expected that a large number of parameters can be identified (100+). By linking all parameters to each other and finally to the project outcome being cost or schedule and adding weights to these dependencies, the most important parameters to the outcome can be identified.

Academic literature was consulted to find a workable way to achieve this while at the same time fulfilling the non-functional requirements as the tool is expected to be large and complex due to many parameters and interdependencies. Several comparable frameworks exist to model or represent entire systems by aggregating individual interactions between system elements. These elements can be components, activities or parameters [18]. Examples are the Structured Analysis and Design Technique (SADT) and its subset IDEF0, the Quality Function Deployment (QFD), the Program Evaluation and Review Technique (PERT) and the Design Structure Matrix (DSM) framework [19], [20], [21]. All of these techniques are studied for applicability in a variety of industries among which the oil industry and the construction industry have the most affinity with this particular study [22], [23].

When comparing the techniques for the study purpose, one important criteria is the simplicity of representation of the parameter network. With a large network, the DSM and the QFD techniques provide simpler representations compared to the other techniques. Furthermore, DSM has an advantage over QFD because it enables the parameter network to have directional correlations whereas QFD can only capture if a relation exists or not [18]. When comparing DSM to the SADT technique, literature indicates a higher difficulty and less possibilities to adjust the SADT model for study specific purposes [24].

Based on the comparison above, for the study purpose, a choice was made to use the DSM framework.

The next section will first explain the DSM framework and then elaborate on the adjustments made to the tool to serve the specific purpose of this study.

3-2 Tool development

3-2-1 Design Structure Matrix

As a basis of the tool, the Design Structure Matrix (DSM) framework is used. This technique has been used to assist in better design, development and management of complex engineering systems. It is a tool that is used to represent a network of elements and their interaction. This representation is in such a way that it is visually structured and beneficial for performing analytic calculations on a system. This subsection will provide a short explanation of the working of the DSM [25].

The DSM is a square $N \times N$ matrix, showing dependencies between a set of $N$ system parameters. It is a very flexible tool which has been used to model many types of systems.
Figure 3-1 shows an example of a binary DSM (a) and its representation when the dependencies are graphically visualized (b) [25]. This system consists of eight system parameters that are labeled 'A' through 'H'.

Every off-diagonal cell \((i,j)\) with an X mark represents a dependency between the system parameter represented on row \(i\) and the system parameter represented on column \(j\). The convention used in this thesis is that the row parameter is dependent on the marked column parameter(s) in its row. In the example in the figure, this means that parameter 'B' depends on providing parameters 'D', 'F' and 'G'. Similarly, it means that parameter 'E' gives output to receiving parameters 'A', 'F' and 'H'.

By comparing (a) and (b) in the figure and realizing that the intended tool of this study consists of many more parameters and dependencies, it can be noted that using the DSM framework adds evidently to an improved visual layout as set in the requirements.

In addition to a binary DSM that is shown in the figure to understand the basic concept, dependencies can also be expressed in numerical terms that indicate the magnitude of the dependency as absolute or relative to the other dependencies. This feature of the DSM is important for this thesis and will further be explained in the next subsection.

DSM frameworks can be used to model systems with different data types. Four main types are task-based, parameter-based, team-based and component-based. Task-based and parameter-based are more frequently used for systems that have a certain time flow, like design systems. Team-based and component-based DSMs often represent more static systems. As indicated, this study is looking for dependencies between parameters in the system of designing a Brownfield project. Literature suggest that DSM frameworks are suitable to simulate processes at a low level, close to the project architecture using a parameter based DSM [24].

An important feature to take into account is to manage the granularity of the model. Every process can be evaluated at several levels of decomposition. The trade-off that has to be made here is that higher levels will need less modeling, but result in less information whereas lower levels will require major effort and possibly a less usable tool [25].

G.J.P. van Berckel Master of Science Thesis
3-2-2 Study specific adjustments

The way the DSM is used and filled with content need to be adjusted to fit the tool requirements. Two main features are explained in this subsection.

Risk based dependencies As a final output, the tool needs to identify the parameter in the total project system that shows the largest potential in terms of influence on the project outcome rating expressed in for example costs or schedule. Therefore, an approach is adapted from Clarkson et al, 2001 that studies a model on change propagation in product design [26]. Parameter dependencies are expressed in a numerical risk. This risk is defined as the likelihood of change of the providing parameter multiplied by the impact of this change to the receiving parameter. This approach and terminology is adapted from conventional risk assessments that more often assess safety aspects of a situation.

The impact of change of a providing parameter onto a receiving parameter is defined as Parameter Sensitivity (PS). This impact is relative to the other providing parameters on the same receiving parameter. The PS is expressed on a scale from 5 (high sensitivity, high impact) to 1 (low sensitivity, low impact).

The likelihood of change of a certain parameter is defined as Information Variability (IV). For this approach, it is assumed that by putting more effort into studying a certain parameter, the IV decreases. The magnitude of the IV is qualitatively assessed and expressed on a scale from 4 (high variability) to 0 (no / low variability).

Equation 3-1 shows how the risk of a certain parameter in the DSM is thus defined:

\[ \text{RISK}_{i,j} = \text{PS}_{i,j} \times \text{IV}_{i,j} \]  

Figure 3-2 shows the different possible magnitudes of the risk. Figure 3-3 shows the most simple way of two parameters A and B providing information to a parameter C with different IV values and different PS values. With the values as indicated in the figure, it appears that parameter A has the largest risk value on parameter C because in this case, a change of parameter A is more likely to happen than a change of parameter B and the impact of a change of parameter A has more influence on parameter C compared to parameter B.

Parameter types To account for this study specific parameter model, three different types of parameters are used for the model: input parameters, output parameters and activity parameters.

Input parameters are defined as parameters that are fixed and known. Therefore, the IV value is equal to zero. (or a fixed value that indicates a variability that cannot be decreased - this is not used in this study) These parameters only provide input to other parameters and do not depend on parameters itself. In the DSM, the input parameter row is thus empty. The reason why these parameters are used in the model is only to show particular relationships for better understanding. An example of an input variable is the location of a considered field on the world map.
Output parameters are defined as parameters that are defined by information provided by other parameters. Therefore, the variability of an output parameter is calculated as the average IV of its providing parameters, corrected for their individual PS scores as defined by Equation 3-2 and demonstrated for parameter C in Figure 3-3. An output parameter should never be provided by only input parameters. Typical output parameters in this study are 'procurement costs’ or ‘installation offshore manhours’. The parameter that represents the outcome parameter of the entire project (cost or schedule) is also an output type parameter.

$$IV_{output} = \frac{\sum (PS \times IV)_{i,j}}{\sum PS_{i,j}}$$  \hspace{1cm} (3-2)

Activity parameters are defined as parameters of which the variability can be decreased by putting effort to it. These are the 'tools' the project team has to increase the level of detail of a project to obtain better scope definition. The variability is thus defined by the level of effort that has been put into obtaining more details on the considered activity parameter. Examples of activity parameters are 'mechanical scope definition’ or 'construction strategy’.

To increase the details on the model output, activity variabilities are decreased for a specific relation only, not for all receiving parameters at once. This is further explained in the next section. Also, it should be noted that an activity parameter can only get more definition (a decreased IV) when the parameters that provide information to the activity parameter have a lower average relative IV score than the considered activity parameter. This accounts for the fact that it is not possible to obtain more definition of a certain parameter when its providing parameters are not on the same level of definition. To incorporate this in the model, the average IV score from parameters an activity parameter depends on is calculated in similar way as Equation 3-2. This value is referred to as actualIV. Stepwise explanation is added in Figure 3-4.
Table 3-1: Parameter types and corresponding Information Variability (IV)

<table>
<thead>
<tr>
<th>Parameter type</th>
<th>Information Variability (IV)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>0</td>
<td>Field location</td>
</tr>
<tr>
<td>Output</td>
<td>$\sum (PS \times IV)_{i,j}$</td>
<td>Procurement cost</td>
</tr>
<tr>
<td>Activity</td>
<td>Defined by level of effort</td>
<td>Mechanical scope definition</td>
</tr>
</tbody>
</table>

3-2-3 Tool working

With the basic adjustment to the conventional DSM model explained in the previous section, this section explains the working of the total model. To support the explanation, the working will be demonstrated by an example matrix and an equivalent graphical representation of the same steps taken.

At first, the PS and the IV matrices are developed. The dependencies and PS values are defined based on the system characteristics. The IV values are filled in for the same dependencies. By multiplying these two matrices, the risk matrix is developed. Figure 3-5 demonstrates the development of the risk matrix for a system of 6 parameters, named A to F. The graphical representation shows that all parameters are directly or indirectly providing information to parameter F, meaning that in this network, parameter F is the only outcome parameter.

In the example, all three parameter types are present indicated by the color of the parameter boxes. Green, blue and purple represent respectively an input parameter, an activity parameter and an output parameter. The IV values of the activity parameters B and C are respectively defined as 2 and 4, which can be seen in the matrix in all cells of other parameters where parameters B and C provide information to.
In the risk matrix, each average relative IV value is calculated and demonstrated in the IV column. At this point, the example system thus has an outcome variability of 2.9 on a scale of 4, represented by the IV value at parameter F. Last to mention is that in this system, no dependencies above the diagonal exist, meaning that no iterative loops are present. This is done for simplicity and also because the system developed in this study does not contain many iterative dependencies. If such a dependency exist, the working of the system is still the same.

The next step is to run the sequence as shown in Figure 3-6. In short, this sequence will search for the highest risk value on parameter rows starting at the bottom parameter which is the system outcome parameter. The highest value is connected to another parameter that provides information to the parameter of the evaluated row. Next, in the row of the highest risk value parameter will be searched for the highest risk value on that row. This modelling sequence is created in Visual Basic for Applications (VBA) macros in excel.

This sequence will continue until an activity parameter is identified of which the IV value can be decreased according to the principle with actualIV as described above in Figure 3-4. For each calculation sequence, all steps taken are recorded in a dependency report. The result from one program run is thus the activity that needs to be performed and the parameters in between that realize an improvement to the system outcome in the end.

The explained program sequence is demonstrated in Figure 3-7 for the same system as developed in Figure 3-5 for three subsequent tool runs. In the risk matrix, the parameter path the tool follows is shown. For the same matrix cells, in the IV matrix, the colored outlined cells are indicated of which the IV value is suggested to be decreased by the tool. The last demonstrated step thus requires both the IV values of activity parameters B and C to be decreased simultaneously because the risk values are identical. Furthermore, when looking at the outcome IV value of parameter F, running the sequence from step 1 to 3 realizes a decrease from 2.9 to 2.5.

Furthermore, as shortly explained at the parameter type description, it is demonstrated that
IV values only decrease by steps of one for a specific relation only. For example, after the first step, only the IV value of C to F decreases from value 4 to 3 and not all IV values of C to its receiving parameters. This feature of the model is included to be able to demonstrate more specific steps to improve the variability of the outcome. Activity parameter IV values are expressed in the average value of all individual IV values of their dependencies. Therefore, these values can be non-integers as well. In Figure 3-7, this can be seen in step 3, where the IV value of parameter C (3,3) is the average of the IV values of the dependencies to the parameters it provides to (IV values: 3, 4 and 3 on the vertical below C in the IV matrix).

### 3-3 Tool use modes

The developed model can be used in two different modes.

The first use mode is to let the model demonstrate what the optimal IV value course is when simulating a total system project. This is done by running the model starting from a point where the IV level is set to 4 for all activity parameters until all are down to zero. The sequence of activities determined by the model shows which activities should realize improved definition of parameters before others at all project phases. Results from this used mode can demonstrate project managers what particular focus is necessary in different phases of the project. It can also assist in planning project development.

This use mode will in this study be referred to as 'total project activity planning' and the result from the example system is shown in Figure 3-8. The graph shows the linear decrease of the outcome F IV value together with optimal IV values of activity parameters B and C. It appears that parameter B is suggested to have a lower IV value in all phases of the project or in other words, more definition is requested from parameter B in early phases and during
Figure 3-8: Total project activity planning

the entire project course of this system project compared to parameter C and compared to the overall project course represented by parameter F.

The second use mode is to assess and also compare existing projects on their variability and thus the robustness of the project outcome. A project manager or team can fill in the levels of definition for each activity parameter at a certain point in time of the project development. Using this input, the model calculates a numerical expression of the average overall variability of the project. From that point, the project management can decide if they want improvement of the variability and to what extent. By running the tool until the desired IV value is reached, the best sequence of activities to reduce this variability in the most efficient way is calculated and reported. This use mode is referred as 'project robustness check'.

In this study, based on comparison with the IPA FEL method, it is assumed that an outcome value of 3 should correspond to DG2 and an outcome level of between 2 an 1,5 corresponds to DG3 [6]. The IV value range below that corresponds to the Define phase working up to FID. This is illustrated in Figure 3-9. In the future, these values could be changed according the new insights and learnings. Because this study is looking to early phases of project development, the project IV course until approximately a value of 1,5 will be evaluated.

Figure 3-9: ORP phases with corresponding IV levels, in this study assumed based on comparison to IPA established values

Figure 3-7 is an example of this use mode. When the IV scores are filled in for parameter B and C, the outcome IV score is 2,9. If the team would require this value to be 2,5, the optimal steps are calculated by the model.

The developed tool was verified by prototype testing of the example system that was also used for demonstration in this chapter. It was decided that the functionalities of the tool proved to be sufficient for the intended purpose and enough potential was identified to fulfill the requirements.
3-4 Chapter conclusions

In this chapter, the first part of the method development to fulfill the objectives of this study was described. The result is a tool that shows sufficient potential to serve the specific purposes and requirements as specified in the first section of this chapter. The subsequent steps that were taken to achieve this were the development of the method specifics and requirements followed by a literature study on potential frameworks to use. Based on the requirements, a framework was chosen and adjusted to be applicable for the study specific goal.

The next phase of this study is the second part of the method development. This part is described in the next chapter. It describes how the developed tool is filled with content in order to simulate the project type that is studied in this research.
Chapter 4

Tool content development

In the previous chapter, the framework and working of the tool used were explained. This chapter will provide a step-by-step description of the procedure that was followed to generate the content of the tool. This content exists of the project parameters, their interdependencies and relative dependency weights. The tool was developed in such a way that it can be improved by adding new insights and experience from projects in the future. Therefore it is very important to show all considerations and reasons behind the elements of the tool the way it was developed in this study.

In addition to that, the relations between elements of a Brownfield project that were defined in this chapter can be a result of this study itself. Many relations are recognized by people with experience in projects, but never explicitly stated or demonstrated. Also, people with different expertises will recognize different relationships between project parameters. This tool aims to capture all relationships of a project, within the study specific boundaries and project scope as set in chapter 1 and further explained in this chapter.

This chapter is divided into five main sections and closed out by the sixth section providing conclusions on the chapter. The first section describes the approach used for tailoring the tool to a Brownfield project. The second and third section provide an explanation of the identified parameters and interdependencies. The fourth section discusses the expected differences for the tool when tailored to other project types. With the tool filled with the appropriate content, the fifth section verifies its working and general correctness of outcomes.

4-1 Approach

This section describes the approach used to generate the input content to the tool. Project parameters need to be determined and relations between those parameters must be identified and weight-based according to the impact of one to another. To do this in a structured and understandable way, the parameters were divided into four categories that reflect different areas of project development. This is explained in the first subsection. The other subsection describes what sources are used to define the parameters and dependencies.
Before the building of the tool content can be described, it is important to understand the applicability of the tool in project development. During early design phases, in most cases in the assess phase, different concepts are developed to deliver the value. This process is described in chapter 2. The tool developed in this study can be used to optimize the steps taken for the development of each of the Brownfield concepts. Most appropriate use of the tool is thus from the moment the concepts are identified. Further details on how the tool can and should be used are provided in chapter 6.

4-1-1 Parameter categories

To ensure better understanding and to enable more simplicity in interpreting the results, four parameter categories were defined:

- Start parameters
- Subsurface, Process and Layout parameters
- Discipline Engineering parameters
- Execution parameters

Each of these category can contain all three types of parameters, as explained in the previous chapter. The start parameter category contains parameters that reflect functional and physical design of the existing facility and other existing information about the facility that is important for the concept development such as execution constraints.

The Subsurface, Process and Layout parameters category contains parameters that reflect the high level concept specifics. Subsurface data provides the input for the high level necessary functional change to the process layout. This can be converted into general physical design.

The Discipline Engineering parameters reflect the activities and design development done by the different technical disciplines. This is the more detailed design part of the concept development.

Execution parameters reflect parameters of which the information need to be developed to develop the execution plan.

The parameters and dependencies of these four categories are explained in sections 4-2 and 4-3.

4-1-2 Input sources

Four main sources were used as input for the parameters and dependencies: input from existing processes, reference projects, earlier research data and expert input. These sources are shortly described in this section.

G.J.P. van Berkel

Master of Science Thesis
Input from existing standards and guidelines

For project development a few guidelines and standards exists within Shell that provide guidance on what an involved unit in a project should deliver. For example, the engineering disciplines have discipline delivery plans that provide a high level guidance on what should be delivered per phase for any project. Furthermore, within the ORS framework, the Discipline Controls and Assurance Framework (DCAF) exists that provide guidance and requirements for project development in certain phases too. Both of these systems were analysed for input to the tool in terms of parameters and dependencies but also what different levels of information maturity for each parameter exists.

Reference projects

In chapter 2, the need for a project and site specific approach was identified. Therefore the tool is calibrated on a high level project type, in Shell often referred to as an archetype project. A trade-off must be made here. The level of the archetype project should be high enough to capture enough projects in one archetype tool, but low level enough to account for project specific focus areas.

In this study, a choice was made to use offshore compression projects as case for the tool developed. Compression projects are necessary when the reservoir pressure of a gas field is decreasing over time towards a level where the receiving facility is not compatible with the pressure anymore. In order to extend the gas (or oil with associated gas) production, compression stages need to be added to keep the pressure on the required level. These type of projects are often characterized by a large equipment and/or work scope and have thus a potential large impact on an existing facility. In addition to that, these type of projects is common these days and will even be necessary more in the future with many existing maturing gas production facilities and an increased focus of Shell on gas production.

High level choices are described in the Brownfield example in chapter 2. The tool developed in this study is capable of evaluating the option(s) with a high degree of Brownfield scope, being the installation of the necessary equipment on an existing platform.

Because data collection proved to be very difficult and time-consuming, main information of three reference projects was assembled and used as source for qualitative input data on parameters and dependencies. By looking at the maturing project definition, considered important parameters could be identified and by comparing these to the output metrics, their link to project outcome was determined. The three reference projects are described below:

Two projects are comparable in development process. Both are offshore gas production platforms that faced declining production some years after being brought on-stream. To keep the facility production on maximum production capacity, a strategy was adopted to make the facility suitable for lower pressures and keep the influx on level by tie-ing in new fields. Different main concepts were developed. One concept was to install a new platform with compression and tie-in facilities (Greenfield solution) and other were Brownfield concepts with different configurations of necessary equipment divided over platforms in the facility cluster.

In the select phase, a concept was selected to install the necessary equipment on one existing platform with a module to minimize Brownfield work. In terms of execution strategy, the
main difference between the two projects was that one platform used the existing platform crane to move several smaller module packages onto the platform whereas the other project used an Heavy Lift Vessel (HLV) that lifted one larger module onto the platform.

The third project that was used as source is also an offshore gas production facility. While being in the early phase of a project that was aimed on modification and simplification of a platform with existing compressors, it was identified that the integrity of compressor trains was not sufficient. This was added to the project scope. A concept was selected to perform offshore work to mitigate the integrity issues together with the other necessary scope. With this concept maturing, it appeared that the offshore manhours related costs escalated significantly causing too high total costs to realize the opportunity. The entire project was recycled at that point and finally, a solution on a new platform tie-ing in to the old one was chosen. This project is particularly a good example for identifying the important parameters as it shows how a growing scope can have major impact on the execution and subsequently the costs.

**Earlier research data**

In reports described in chapter 2, relations between elements of Brownfield projects were identified. These relations and the elements itself are used in estimation tools, but can also be used as input to the tool of this study.

- Discipline specific: relations between main and supplementary (un-engineered, see section 2-2-2) scope elements on procurement, fabrication and implementation (if applicable)
- Relations between discipline main scope cost and total cost estimate
- Relations between main installing cost categories and total cost estimate
- Relations between discipline construction scopes and total construction scope

These relationships can be used as supplement to the relations defined from the reference projects. In addition to that, these relations can form a basis in quantifying the PS between parameters. Very strong and weaker dependencies can be confirmed by these metrics.

**Expert input**

Because a very good understanding of the considered type of projects is essential, expert input from various different expertises was essential to develop the tool. The two main expertise groups that were questioned on the relations were people involved in front-end development planning and people involved in project execution. Contribution from both groups is essential since their view on the project is different as explained in chapter 2: front-end development is focused on creating the value whereas execution is focused on delivering the value. In reality, this means that parameters and relationships identified by the front-end group are more exploratory, assessing the potential of the situation. Execution people such as Project Managers will much more identify potential issues and risks that a certain concept contains. Both groups were involved in creating the matrix and their opinions were used in considerations on establishing certain relationships and relative weights thereof.
4-2 Parameter identification

This section describes the individual parameters that were identified for the four parameter categories described in the previous section. Some notes are made below in this introductory part for better understanding of the considerations and trade-offs made in choosing the parameters:

- **Level of detail:** as earlier explained, with increasing level of detail of the parameters, the usability of the tool decreases whereas only using high-level parameters will show less usable output. Therefore a constant trade-off was made during identifying the parameters to have a good balance in this perspective.

- **Sequence of parameters:** the order the parameters were identified and written down in the tool follows the four categories. It is important to understand that the list does not represent activities that need to be done in chronological order from top to bottom. The order that needs to be followed is actually the output of the tool. However, because the order of the four categories is followed, it is more likely that a parameter lower on the list receives information from one that is higher. This improves readability since most of the parameters are now recorded on the left side of the diagonal.

- **In accordance with the study scope that was set out in 1, the technical scope is considered in this tool. Crucial non-technical elements of the projects that directly impact or are directly impacted by the technical scope are recorded in the tool as well.**

Parameters are explained in subsections below.

4-2-1 Start parameters

The parameters in this group represent existing specification and characteristics about the project related field and/or facility. This information is available, but in most cases a certain amount of effort is still required to obtain the desired level of definition. Therefore, most of these parameters have the type 'activity'. A good example is the 'existing plot plan' parameter. The layout of a facility is physically available to see and verify. However, to capture this in a usable format, activities are needed ranging from obtaining documents to perform full-scale 3D laser scanning surveys. Also, parameter states can vary over time when project phases take years to complete causing extra uncertainties.

Start parameters can be divided into low-level subgroups:

- **Input**
  These parameters are fixed and are thus 'input' type parameters (see section 3-2-2). The reason this type is present in the tool is to include the possibility to show relationships for better understanding, even though it is not possible to obtain more definition.

- **Platform functional**
  This group represents the existing functional layout and configuration of the considered platform. This is expressed in two parameters: existing process scheme and operating
philosophy. Process schemes represent the process layout of a facility. This representation can range from a simple block drawing to detailed layout maps full specifications on equipment and pipelines. The operating philosophy represents the general working of the entire system. It describes what utilities and other systems are in place to ensure proper working.

- **Platform physical**
  These parameters represent the physical properties of the platform. They express this in terms of geometric space but also in weight capacity. In addition to that, site-specific hazardous area classifications that could be limiting certain operations are captured in this group.

- **Platform operational**
  This parameter group represents ongoing operational elements that can be of importance to a project. Operational crews and management should be the providers of information that is important in this category.

- **Platform services**
  The existing platform services are of major importance for designing a project on a facility. These parameters represent the services that could be used when executing a project. It is important to note that not only the capacities of parameters such as platform crane systems should be obtained, but also its integrity issues as this could result into a growing scope. Personnel on Board (PoB) planning is crucial for execution planning. Not only the person capacity should be checked and verified, also HSSE related requirements and planning with respect to other projects should be noticed when defining this parameter.

- **Platform planning**
  Platform planning parameters represent both the operational planning parameters and the longer-term asset planning. Operational consists of maintenance and other projects planning and longer lead planning of future design requirements and design life.

- **Execution planning start parameters**
  These parameters represent potential crucial information that is necessary for planning execution. It consists of availability of suitable construction yards and vessels and also capabilities of workforces that are present in the platform location.

In order to provide understanding of the way the variability levels are defined in the project, Figure 4-1 demonstrates a single input interface the way it exists in the tool. For every activity parameter, the variability can be inserted in this interface in the ‘score’ column. In this case, the variability level is 2 which corresponds to the description of the level of definition in the column below 2.

To illustrate the difference between the two extremes of variability level which is equal to the level of scope definition, two pictures from project reports are shown on the next page. The left one corresponds to a definition level of 0. It is a 3D model based on laser scanning that provides exact locations of all platform elements. The picture on the right corresponds to a definition level of 4. It is a 2D drawing of a platform. This type of information can still be found in project development reports and assumptions are made based on it.
For every activity parameter, in the tool the description that corresponds to different variability levels is provided.

<table>
<thead>
<tr>
<th>SCORE</th>
<th>0 = detailed definition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4 = none or very limited definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>existing plot plan</td>
<td>2</td>
<td>3D model based on up-to-date 3D scan providing detailed locations and sizes, accounted for planned changes</td>
<td>Plot plan based on up-to-date drawings supported by visual confirmation collected during site visit</td>
<td>Plot plan based on out-of-date drawings</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4-1:** Variability input screen for existing plot plan parameter

**Figure 4-2:** 3D platform model

**Figure 4-3:** 2D platform drawing

### 4-2-2 Subsurface, Process Engineering and Layout Parameters

As explained in the earlier section of this chapter, subsurface and process engineering are main input for developing a concept. The functional requirements for the new design can be converted into information for high level layout options.

- **Subsurface**
  The subsurface input considered in this tool is the input necessary to define the scope by the technical disciplines. Parameters that represent the subsurface properties give information on the phase of the product (liquid/gas ratio), potential contamination such as CO2 or H2S and pressures and flow rates at arrival.

- **Process Engineering**
  Process Engineering parameters provide input to the functional requirements of the workscope that is necessary for the project. The parameters consist of the new required process flow scheme and the corresponding product properties in the system. Process engineering also provides the requirements for main equipment.

- **Layout**
  With the functional requirements, main necessary equipment can be determined. With the main equipment known, high level sizes and weights can be used for development of the new plot plan design.
4-2-3 Discipline Engineering

The next parameter category is the design and scope development by the various disciplines involved in the project. Disciplines engineering activities are captured in this study as developers of scope definition, each within their own boundaries of expertise. Discipline work is considered to consist of similar parameters to obtain increasing scope definition. These parameters are divided in a part where the existing discipline specific elements on the platform are assessed and a part where the project specific scope definition is determined.

Assessing the existing equipment or structures is divided into two parameters: status and design. Status represents the actual state and integrity of the equipment that can be expressed in terms such as capacities, operational performance or obsolescence. Design is related to the way the discipline specific platform element is built. This can be expressed in functional and physical configurations. Both of these parameters are activity parameters because effort is needed to develop more understanding and definition.

![Figure 4-4: Activity parameter variability input options for MMI discipline](image)

Project specific (new or modificational) design is represented by the discipline equipment and material parameter. This is also an activity parameter. Output parameters of disciplines are the supplementary scope, equipment datasheets and the work scope. Figure 4-4 shows the various levels of variability for the Mechanical, Materials and Integrity (MMI) discipline. Input options for the other disciplines are embedded in the tool in similar way.

Below is a short description of the disciplines field of expertise.

- **Mechanical, Materials and Integrity (MMI)**
  This discipline is also referred to as mechanical static. Areas of expertise include mechanical design of (pressurized) equipment, materials and corrosion engineering and inspection and pressure system integrity. It also covers piping design according to fluid and fluid flow specific requirements on a facility.

- **Rotating Equipment (REQ)**
  This discipline is also referred to as mechanical rotating. Engineering activities done by this discipline include design of compression systems, gas turbines and pumps and monitoring conditions and safeguarding of existing systems.

- **Utilities, Water, Energy and Heat Transfer (UHT)**
  The UHT discipline provides engineering activities and solutions in areas covering indus-
trial activities (e.g., steam and power systems, nitrogen, fuel systems), water preparation, treatment and integration, heat transfer and CO2 management.

- **Electrical (ELEC)**
  The Electrical engineering discipline covers the entire electrical spectrum including design, monitoring and maintenance of electrical systems.

- **Process Automation, Control and Optimization (PACO)**
  PACO areas of expertise include controlling and automation processes and measurement and instrumentation systems.

- **Pipelines, Flow Assurance and Subsea (PFAS)**
  The pipeline engineering discipline covers pipeline design of pipes between facilities and areas. The design is done for fluid flows and multiphase systems for both offshore and onshore pipelines. Also, integrity measurement and maintenance work is covered. This discipline is not considered crucial for the project type modeled here and does therefore not impact the project outcome.

- **Civil, Structures and Offshore (CSO)**
  CSO engineering consists of three main subdisciplines: Civil Engineering, Offshore Structures Engineering and Metocean Engineering. The areas of expertise that these three parts cover include design of structures and site plannings, integrity measurement and life extension design, metocean data collection and applications and offshore construction related design and maintenance solutions.

Because all the engineering disciplines together determine the total scope in terms of equipment and material and in work scope, certain total scope capturing output parameters are recorded in the tool below all discipline parameters. These include total project weight, total project equipment size and total work scope.

### 4-2-4 Execution parameters

The next step in the general project development sequence is execution. With the scope definition brought to a certain level by concept engineering and input from disciplines, a strategy has to be developed how to execute the project. Different elements of the execution strategy are detailed engineering, procurement, fabrication, transport and installation, hookup and onsite construction and commissioning and startup. All of these execution elements are shortly described below and parameters that represent these parts in the tool are explained. In general, execution parameters in this tool are considered to be a result of the scope and high level execution strategy. Therefore, many parameters are output parameters. This is further explained below.

- **General construction strategy**
  This important activity parameter determines the high level construction strategy that is developed and matured during the design process of the project. This construction strategy represents the level of modularity and subsequent required construction works on and offsite. A lower variability for this parameter thus means a construction plan with a higher level of detail.
• **Engineering effort and Project Management**
  Depending on the nature of the project, more or less onshore hours for (detailed) engineering and project management are required. This is represented by these two parameters that are both output parameters.

• **Contracts and Procurement**
  Procurement is usually connected to contracting strategies. In this tool, the assumption is made that the actual workscope is reflected in the necessary contracts, which means that the contract type does not crucially influence the outcome of the project. It should be possible to embed this feature in the tool, which will increase the tool scope more outside its current technical scope. Procurement however, is accounted for in the tool since it follows directly from the developing scope and has a large influence on the project outcome. It is divided into the activity parameter procurement strategy, which represents the strategy in terms of planning and vendor selection and into three output parameters: main equipment costs, bulk costs and procurement lead times.

• **Fabrication**
  Fabrication represents the onshore fabrication works necessary for the project. Parameters representing this element are the activity parameter fabrication strategy that determines the high level strategy in terms of planning and contractor selection. Output is expressed in costs.

• **Transport and Installation**
  This element of execution represents the scope of all necessary transport to and from the platform and the lifting of the project equipment and materials from and on the platform. Parameters representing this scope are the high level strategy activity parameter and several output parameters on transport, handling and lift requirements, weather windows and necessary offshore manhours.

• **Hookup and onsite construction**
  When equipment and materials have been transported and installed, onsite construction works are necessary to hook up the new equipment to the existing system and perform the necessary construction works to secure the scope. These construction works can also be necessary before the equipment arrives. A high level strategy activity parameter defines the planning of activities for the work scope. Output parameters include work scope in terms of construction and deconstruction, tie-in requirements to all system types, type of work, location of work onsite and necessary supporting systems and equipment. Further parameters recorded are the expected productivity, HSSE requirements related to the project work and logistic requirements.

• **Commissioning and start-up**
  The last phase of project execution is represented by this parameter group. It stands for the necessary activities to get the constructed new facility layout onto working again. These activities are testing and performing start-up activities and procedures. Different project types require more or less of these activities and necessary equipment or specialisms.

Summarizing output parameters are recorded in the tool below the execution part. These
include total offshore and onshore manhours, vessel rent requirements and necessary support services.

4-2-5 Overview of tool parameters

In total, the elements identified above are represented by more than 100 different parameters in the tool. Figure 4-5 gives an overview of the DSM with the different project steps described and the area in the tool that the groups are parameter providers for.

4-3 Dependency identification

With the parameters identified in the previous section, the dependencies are explained in this section. Because more than 400 dependencies were identified in the tool, only an overview of important relations is given below. In the tool, a function is built in that can list all parameters and their dependencies.

As explained in section 4-1-2, dependencies were recorded on a qualitative basis because it was not feasible to obtain statistical dependency values for all relations given the lack of data collection within the company and the limited time. If the tool shows good results, future quantified data on dependencies could be inserted to improve the applicability of the tool. However, not all dependencies can be quantified since not always a numerical relation exists.

When looking to all identified dependencies in Figure 4-6, it appears that almost all dependencies are recorded on the left side of the marked diagonal. When dependencies are shown on the right hand side, it means that a parameter provides output to a parameter that is recorded above it in the list.

Because the tool is used for evaluation of a single concept realization, only few crucial dependencies are shown that provide information to earlier steps in the sequence. These crucial
'iterations' have to do with plot plan design, discipline scope definition and high level construction strategy. During project development, constant iterations occur between all involved teams. It is assumed that these iterations are handled by the tool as long as they do not change the concept that is evaluated. Then, the tool must be used as for a new concept with variability input for that new concept must be used. For example, if a certain piece of equipment appears to be too large to fit in a concept plot design, the concept has to be changed by choosing another configuration or equipment type. For this new concept, the tool has to be used from the start.

This section explains the dependency structure of each identified group with relation to the other groups. It starts with the subsurface, process engineering and layout category since the start parameter group does not depend on other parameters as explained in the previous section. Figure 4-7 indicates the different cross-group sections in the DSM that are discussed below.

4-3-1 Subsurface, Process Engineering and Layout parameters

Section A1 in the figure corresponds to the dependencies of the start parameters to the subsurface, process engineering and layout development parameters. First, the functional requirements are developed and put in the new process flow scheme design. This design depends to large extent on the existing process scheme and some of the subsurface information which dependencies are indicated in section A2.

From this new process flow scheme design, the corresponding new fluid properties inside the system can be determined as well as the main equipment list indicating the large pieces of equipment that become part of the project. The main equipment list also depends on the
operating philosophy as certain supporting other than process equipment such as utilities or electrical systems can become part of the scope as well.

With output from the main equipment list, and information on the existing physical layout from the considered platform, a plot plan design is generated. This design also depends on the total scope as defined by the engineering disciplines and the high level construction strategy. This iterative property of this parameter is explained above.

4-3-2 Discipline Engineering parameters

The dependencies within discipline engineering are strongly subjective to the nature of the project, which is in this case a compression project. That means that when looking at the total scope, a stronger tendency towards both static and rotating mechanical scope can be expected.

However, especially since this is Brownfield design, assessing all systems and constructions that are impacted by the design early enough is necessary to prevent scope growth in later stages.

Every discipline scope development depends on the current functional working of the platform represented by the operating philosophy of the facility. Furthermore, in this case, piping design is expected to be important considering the nature of the project, so MMI design quite strongly depends on the plot plan design since that determines where piping is necessary to be designed or changed. These are all dependencies in section B1.

The output in section B2 is dominated by the main equipment list since that determines most of the scope that needs to be designed. Furthermore, fluid or gas properties following from the subsurface assessment and newly expected properties within the system are important to certain disciplines.

In section B3, the most important interdependencies within the discipline engineering group are displayed. Within each separate discipline, the scope to be determined depends on the new design but also the integrity and layout of the existing design. The value of the Parameter Sensitivity (PS) assigned to those three inputs depends on the relevance of this matter.
Furthermore, the relationship between main and supplementary scope for each discipline is captured in the dependency of both elements on the equipment datasheets for procurement and on the work scope for execution. These relationships are based on average metrics obtained from Brownfield research.

Interdiscipline dependencies exist as well. For example, the equipment choice that REQ makes has impact on the type of utilities that is required such as fuel systems. Also, CSO scope covering the structural design of the concept depends on most of the disciplines.

Each discipline is depends also on the high level construction strategy because this determines for example if all new equipment must be designed in a single module or that parts of the existing design should be used or changed.

4-3-3 Execution parameters

Execution parameters dependencies are well represented in all three sections C1, C2 and C3. Starting at the top of the execution parameter list, construction strategy depends on the physical scope properties being weight and size information. As explained, this is a parameter which is determined on the basis of iteration with concept development (plot plan design) and scope development.

Engineering and project management hours depend on the work scope as defined by the discipline parameters and according to project specifics. The procurement parameters main equipment and bulk costs are dependent on disciplines output with the weights based on earlier research and reference projects. Lead times follows the philosophy that main equipment and large amount of bulks have the longest lead times.

The fabrication parameters depend strongly on the construction strategy and the total work scope as defined by the various disciplines. Also, location-specific parameters such as yard availability and workforce capabilities are providing output to the fabrication parameters.

Transport and installation parameters depend on start parameters that provide information on the capacities and capabilities of the existing platform services such as the crane and the deck space capacity. Also, the new physical locations of the work scope and the geometric sizes and weights are important output parameters to assess the lift and transport requirements. The strategy that follows from defining all these requirements gives output to necessary offshore manhours for executing the project.

The hook-up and onsite construction parameters strongly depend on the scope definition and existing platform design and services. Depending on the onsite location that is decided as project location, offshore work must be performed to prepare the site for the project. Also, all interfaces between the new design and existing platform have to be determined to identify all required tie-ins and construction work. The tie-ins parameter thus depends on work scope from almost every discipline, with weights according to the project nature.

In order to execute all the work onsite, the project requires certain supporting services for specific types of work depending on the scope. These worktypes, on their turn, define the requirements for working simultaneous with operations and what productivity rate can be expected. Productivity depends on many parameters ranging from the work location on the platform to logistic arrangements and type and scope of work. All execution work leads to the offshore manhours required for the developed scope that are necessary.
4-4 Applicability to other project types

The required commissioning and startup activities depend on the subsurface properties and the operating philosophy. Commissioning properties also strongly depend on the construction strategy, as many commissioning activities can be done onshore if the design and engineering have accounted therefor.

4-3-4 Project outcome

The project outcome weights on CAPEX are based on research providing indicational metrics how costs are divided on average for typical projects. Main drivers on the CAPEX are procurement costs, offshore manhours and rent of required vessels.

4-4 Applicability to other project types

In section 4-1-2, it was explained that a concession was necessary to tailor the dependencies and parameters of the tool to specific archetype projects to fulfill the tool purpose of project planning based on project specifics. For the reasons described in that section, offshore Brownfield projects with a compression scope were chosen as case model in this study. In order to make the tool applicable to other archetype projects as well, this section explains the expected necessary adjustments.

This section only explains to what extent the content in terms of parameters and dependencies need to change for other project types. Chapter 6 will explain more about added functionality to the tool that assists on how to make the necessary changes.

Because the purpose of the tool is to incorporate project and site specifics into project development planning, differences in parameters and dependencies will be necessary when applying the tool for projects with differences in these specifics. First, main expected necessary adjustments with different project types will be discussed followed by adjustments for different site specifics.

4-4-1 Project specifics

The project specifics are characterized by the main purpose of projects, which will determine the focus of the project main scope. In the evaluated case in this study for example, the main purpose of the project archetype is to create the possibility for the production facility to produce with a lower suction pressure than originally designed. This will predominantly result in a main scope of both mechanical static and rotating equipment. In addition to that, on average, addition or replacement of typical main scope equipment in this case has a large impact on the weight and space specifics of the facility. Also, since this type of project often has a large impact to the existing facility, relative strong dependencies from discipline scope to onsite work exist.

When tailored to other project types, these specifics are potentially different. Examples of other Brownfield archetype projects can be tie-in projects with much less impact on the existing facility, upgrades with strong construction scope such as accommodation block replacement or rejuvenation and system specific additions, replacements or modifications to for example electrical systems or process modules.
All these different project types can be characterized by the strongest weights of discipline input to the project scope. Therefore, the first major differences with the tool developed in this study are different dependency weights from specific discipline scope to the necessary work. The second difference follows from the impact of this project specific scope on the existing facility which determines the dependencies from the work scope and execution strategy to the outcome of the project. For example, if the change out of a certain process equipment piece has no or very little impact on its surroundings in terms of functionality and physically, experience and learnings from the past will probably demonstrate low potential impact on the amount of onsite work.

As a final note on changes with project specifics, this tool can also potentially be used for Greenfield developments. Because much less or almost no uncertainty exist concerning interfaces between design and existing constraints, it can be expected that major risks could be identified between subsurface data and design development.

4-4-2 Site specifics

In this case study, the evaluated site for the project was an offshore fixed platform. The identified parameters and dependencies for this specific type can be characterized by certain typical aspects. First discussed are aspects that are typical to fixed platforms. The state or value of parameters such as weight budget or integrity of the structure can cause issues or limits to certain projects. Furthermore, logistic challenges can be present for the fact that this type of platforms often have large airgaps that can potentially limit activities involving heavy lift operations for example. Changes in parameters and dependencies when projects on other type of offshore platforms can therefore be expected in these directions.

Major differences can be expected when the tool is tailored to onshore projects. Potential risks in offshore platforms that exist to less extent in onshore environments are caused by the fact that offshore facilities are often highly congested facilities causing HSSE issues for the project and logistical challenges for doing the necessary work on the required onsite location. Furthermore, logistical challenges exist for offshore facilities for all required support around the project such as accommodation, necessary equipment and vessel requirements.

4-5 Verification

In the previous sections, it was explained how the tool was filled with content. With all parameters and dependencies defined, the tool can now be runned for the intended purpose. This section explains how the tool working is verified in order to evaluate the consistency and general correctness of outcomes from the tool.

Verification of general tool working

The first checks were done on the developed prototype as explained in chapter 3. These checks were aimed on checking the overall functionality of the tool by searching for inconsistent or incorrect outcomes or behavior. For example, checks were performed to verify that decreasing individual IV level of parameters always resulted in a decrease of the outcome IV level. All
errors found in this preliminary phase were corrected to aim for minimal problems when applying the system to a large number of parameters.

When applied to the large number of parameters, several errors were found that needed to be corrected during simulation tests. For example, due to certain iterative relations, the tool would suggest to decrease the IV value of a certain parameter two times in one step. Logically reasoned, this is not correct and therefore extra functionality was needed in the tool modeling code. Furthermore, errors in the code were found during tests that caused some IV levels to decrease to below zero. The checks and subsequent error solving resulted in a tool that shows consistent behavior, also during tests with input from people with no previous knowledge of the tool during validation steps, as described in the next chapter.

Verification in terms of content consistency and correctness is a challenge in this case, since a large number of dependencies is identified on a subjective level with input from experts as described in the previous chapter. The most important check that was done after finishing the generation of contentual input was to go through the list of all dependencies that were specified which is generated automatically in the tool. By asking the question for each dependency if it is a direct dependency or if it should be indirect through one or several other parameters, at least potential double recorded dependencies were erased. The best test for verifying the correctness of the dependencies however, should come from the validation steps as incorrect dependencies would lead to incorrect outcomes of the tool.

**Verification of general tool outcomes**

This part of the tool verification is used to check if the tool is reliable and if plausible and logically correct results are generated. In this case with the approach of an experimental project simulating tool developed, this verification step is very important to verify if and to what extend the tool reflects a logical project development course.

The total activity planning use mode shows the optimal sequence of activities for the project archetype the tool is tailored to. This is done by assuming all activity parameters are at the highest level of IV value and then running the tool down to a point where all IV levels are at zero. The average overall outcome of the tool is evaluated to check if the project development activities show a logical correct course and sequence. This step can be compared with an extreme value analysis that is conventionally used in tool verifications. The only difference is that in this case, this extreme values are used as functionality for the tool, to run an entire project simulation sequence. However, by looking at the average courses of the IV levels for the four different parameter categories, a validation step can be made to see if these courses are plausible.

Figure 4-8 shows these outcomes in similar way to the outcome of the example system tool in section 3-3. The flow of the average IV values of the different activity parameter categories shows logically correct shapes. Main reason to conclude this from the picture is the difference between suggested variability levels at certain points in the total project cycle. The strongest decrease and lowest IV levels can be identified for parameters in the subsurface, process and layout category, followed by parameters in the discipline engineering category. The category that shows the least strong decrease of IV average value is the execution. These differences make sense when compared to a project situation, since only in this order the project can be developed. The main scope needs to have a certain level of definition to provide information
for further specifications in the disciplines. Only after more is clear from the disciplines, an execution strategy can be developed. Since the start parameters provide information to all three other categories, its average course is somewhere in between.

Furthermore, certain behavior of the tool demonstrated in the graph can be explained by its modeling settings. The subsurface, process and layout category shows two moments of sharp decline. Because the definition of parameters receiving information from the parameters in this category can only be improved when its providing parameters have a low enough IV score, apparently during the beginning and in the middle of the project cycle a decline of the IV values is required to proceed to next project phases.

Another feature that comes up by looking at the graph is the fact that the total project outcome is below the other average values for the last part of the project. It even appears that three of the four average parameter IV values are around 0.5 when the total project outcome is zero. This can be explained by the way the tool works with activity parameters that require information from other parameters. This feature is explained in section 3-2-2 by introducing the actualIV value and indeed allows parameters at lower positions in the matrix to have lower IV values when the providing values were initially higher before the decrease was made.

Conclusion from this verification step is thus that the average tool results show logically correct results, both in terms of logical correct outcomes and functionality.

4-6 Chapter conclusions

This chapter described the approach followed for filling the tool with content tailored to an archetype project, being an offshore compression project. Subsequent steps were demonstrated of identifying the project parameters and their interdependencies.

When all parameters and dependencies were determined, the tool was ready for test runs. Section 4-5 described the way the tool working was verified. Conclusion drawn from this
section was that the tool working appeared to be correct and the high level outcomes seem plausible. The next chapter will provide the results from the tool together with a validation and evaluation of added value of the outcomes.
Chapter 5

Tool results

With the tool developed and its working verified as described in the previous chapters, results can be drawn for the total activity planning use mode by running the tool from its highest variability level (4) down to the lowest level (0). The results obtained by this project simulation are provided in the first part of this chapter and can be used for project development planning activities or as guidelines where to focus on in early phases. Further explanation on incorporation and use of the results is discussed in the next chapter.

The second part of this chapter provides the results for the other use mode, where the robustness of the project outcome is checked and further steps to proceed are calculated by the tool. This is done by piloting the tool on two applicable projects both at a point in time during an early phase of project development.

Main objectives of this chapter are to provide an explanation of how the results should be interpreted as a basis for practical use of the results and to show which results come out of the model to validate and evaluate them. Also, by piloting the tool on projects, a session is tried out that reflects intended future use of the robustness check mode on projects. Furthermore, by evaluating the outcomes with experts and with project data it is determined to what extent the outcomes of the tool are appropriate and if added value can be expected by future use of the tool and results.

5-1 Results for total activity planning use mode

The first part of this chapter provides the results with respect to CAPEX outcome together with an explanation and evaluation on logical correctness. This evaluation is supported by expert opinion obtained during a validation session. For every project parameter category, results are shown in this section of activity parameters that show the strongest decrease of definition variability based on the tool outcomes.

Only the most important parameters are shown that come out of the model. In this case, most important parameters are defined as the ones that require the strongest decrease of IV
value in early project phases according to the model. In other words, the definition level of these parameters need to be improved early on in the project to reduce the risk of project outcome changes. When using the results for purposes described in the next chapter, it is important to recognize the fact that all parameter variability courses should be taken into account, not only the ones provided in this chapter.

The results in this chapter are calculated by the tool in this study that is tailored to the archetype Brownfield compression projects. Therefore these results can be used for implementation for this type of projects only. For other archetypes, the parameters and dependencies should be changed first and will be different according to expected changes as described in section 4-4.

The results in this section are shown in graphs similar to the outcome graph of the example system project in section 4-3-4. A point in the graph on an activity parameter curve thus represents its suggested IV level indicated on the y-axis for the moment of time in the project cycle as indicated by the outcome IV level on the x-axis, calculated in steps of 0,5.

Because this study focuses on the early phases of Brownfield projects in order to improve the decision making, the variabilities of parameters in those early phases are shown in this chapter. This means that the indicated parameters are the ones that show the strongest decrease of IV level in the early phases. Therefore, the range of the project outcome variability on the x-axis is shown between 4 and 1,5 which is assumed to reflect project phases from project initiation until the end of select or the beginning of define as explained in section 3-3.

Two different graphs are shown for each category. The graph on the left demonstrates the parameter variability course with the strongest decrease of IV level pre DG2 or the Identify and Assess phase. The graph on the right shows the course for parameters with the strongest variability decrease between approximately DG2 and DG3.

Parameters that are shown in the graphs of this chapter have suggested parameter decrease levels that are higher than the outcome IV decrease in the phase represented by the graph. Some parameters are therefore represented in both graph because in both phases they are suggested to have a stronger IV decrease than the outcome.

5-1-1 Activity parameters

Start parameters

Figure 5-1 shows seven start parameters that are suggested by the tool to be the most important parameters to increase the level of definition of in very early project phase until DG2. Elements of the project or site represented by these parameters are mainly functional and physical properties of the facility. This can logically be explained by the fact that information about the existing site should be one of the starting points of a project concept design, as all Brownfield projects will have interfaces with existing parts of a facility.

On the right, Figure 5-2 shows the most important parameters in the subsequent phase, between DG2 and DG3. Some parameters appear to have no suggested increase in definition in the first outcome IV steps, but show very strong decreases in the last steps. An important difference between the suggested parameters on the left and right graph is the nature of the
parameters. The activity parameters on the right graph are much more related to execution constraints whereas on the left, the focus is on functional and physical aspects of the site.

During the validation session, the expert agreed on the fact that in general terms, these parameters would indeed be most important for the project development. However, when looking more specifically, the expert highlighted that he would consider some parameters not as most important compared to others. For example, in the graphs, 'hazardous area classifications' was given the lowest IV level at the outcome IV level of 1.5. Although this is definitely an important project parameter, it is not considered as the most important one.

**Subsurface, Process and Layout parameters**

The same analysis was performed to this second parameter category. Results for pre-DG2 parameters are shown in Figure 5-3. Almost all identified parameters for this category are shown in the graph, meaning that almost this entire category is suggested to obtain an increased amount of definition in this early phase. This conclusion is supported by the average overall project IV graph used for validation in section 4-5 that shows the strongest average decrease of IV values for this category in the very early project phase. This decrease can be explained by the fact that project design for the considered archetype here strongly depends on functional requirements that follow from subsequently subsurface data and process equipment design. Information from parameters representing these two will be the basis of layout design which is very important for the total project design both in terms of scope development and execution planning.

With almost all parameters having strong decreases of variability level before DG2, only two parameters also show strong decreases in the subsequent phase as shown in Figure 5-4. Apparently, the strong decreases of values before DG2 provide enough information to discipline engineering and execution planning to work up a concept to DG3 level. For understanding however, it must be noted that the absence of many parameters in the graph on the right does not mean the IV does not decrease in those phases. The decrease is only not strong enough to be marked as important parameter in that phase.

The expert opinion was also that these parameters form the basis of concept development for compression projects. However it was commented that since subsurface data is often available
for Brownfield facilities, no or fewer activities actually need to be done to obtain information to the sufficient level. This does however not mean that these parameters should not be highlighted by the tool.

**Discipline Engineering parameters**

The most important parameters for the disciplines are shown in Figure 5-5 for pre DG2 phases. Main comment here is that it can be seen that four disciplines out of six assumed involved parameters are suggested by the model to obtain increased definition early in the project cycle. These four indeed represent the disciplines that would develop the largest part of the total project scope for compression projects according to the expert. More specific, it can be identified that for all these four parameters, Brownfield integrity check activities are suggested, because the 'status' parameters are indicated here.

In Figure 5-6, the other two disciplines are listed as well for the phase until DG3, however only Brownfield assessment of functionality and design are listed. This seems to be logically, since in general the scope part for this type of project for ELEC and PACO is small, unless insufficient capacity or integrity issues cause scope growth for elements specific for these disciplines.

A comment the expert made when reviewing these parameter discipline graphs was that some parameters are suggested to remain on the highest IV value which seems to suggest that no
effort should be taken at all to include some of those project elements into account in certain phases. An example here is PACO design. This is obviously not correct, as in a general design sequence in early phases, all scope parts that are related to the project should at least be identified. The expert therefore advised to emphasize this in a manual or tool description that would be supplied with the tool.

**Execution parameters**

Figure 5-7 shows the most important execution strategies that need to be developed pre-DG2. As was already indicated during the verification step in section 4-5, the tool showed the lowest decrease for average execution parameter IV compared to the other categories. This is reflected in the curves shown in the graph, since none of the parameters in this category actually shows a decrease rate that would be highlighted as was done for the other categories. Therefore, the three execution parameters that did show a suggested decrease in the very early phases at all are shown here. This outcome of the tool was explained already in the validation section by the fact that without preliminary scope development, it is not possible or not practical to develop matured execution strategies. However, since some increase of definition is shown, for this type of projects it is definitely important to take these strategies into account.

![Figure 5-7: Execution parameters with strongest IV decrease pre-DG2](image)

![Figure 5-8: Execution parameters with strongest IV decrease between DG2 and DG3](image)

Post DG2, all execution parameters are represented in the graph, as apparently for this type of projects it is important to have sufficient level of detail of all elements in the execution plan before the decision can be made to proceed to the Define phase.

Expert view on this resulted in a comment that it is difficult for a tool to represent all Brownfield concepts within one archetype, since different ways of doing the project in terms of execution can lead to significant different dependencies and relative importance of parameters. This is something that is important to understand and to examine for further development of the tool. However, when choices are made within a concept at a certain moment, it means that the risk of changes for many other parameters decrease. Part of this will be covered in the tool by the ‘construction strategy’ parameter since this one represents these high level choices. Also, by tailoring the tool more specific without changing the dependencies itself by rating certain parameters as ‘not applicable’ before running the tool, more importance will be focused to the other parameters.
5-1-2 Output parameters

To obtain more understanding about the dependencies that result into the findings described in this chapter, an analysis of the output parameters IV level results is added in this section. All activity parameters provide information to one or more other parameters that finally provide information to drivers of the project outcome. Direct dependencies on project outcome being CAPEX in this case all follow from output parameters in the execution category as explained in the tool building chapter in section 4-3-4.

For this reason, understanding can be improved best by showing and analyzing the suggested most important execution output parameters. Output parameters in the Subsurface, Process and Layout and Discipline Engineering categories follow more directly from their providing activity parameters. For example, the MMI discipline equipment datasheets and workscope parameters will demonstrate strong decreases of variability in early phases because the activity parameters from MMI also had decreasing IV values.

![Figure 5-9: Execution output parameters with strongest IV decrease pre-DG2](image1)

![Figure 5-10: Execution output parameters with strongest IV decrease between DG2 and DG3](image2)

Figure 5-9 shows the variability course of the top six execution output parameters having the strongest IV value decrease pre-DG2 due to changes in activity parameter variability. Because the tool changes the highest risks for every step by following each time the highest risk path in the matrix, these parameters were apparently the ones that needed IV decrease the most. In other words, the activities highlighted in the previous sections were needed to result in decrease of variability of these parameters resulting in a lower risk in the outcome in the end.

The six indicated parameters represent execution elements that relate to the onsite workscope and manhours. With the experience on scope growth and execution constraints resulting into increasing onsite manhours in later project phases, these parameters seem to be correct to be the most important output parameters. Furthermore, the main equipment costs shows a strong decrease as well. This can be explained by the fact that compression related project tend to have large main equipment costs because new equipment needs to be procured.

Figure 5-10 shows different execution output parameters that have the strongest decrease between DG2 and DG3, apart from the main equipment costs. These other parameters compared to the left graph show are more varied range of execution parameters. These include also parameters that have influence on onsite work and manhours, but also on vessel rent requirements. Furthermore, the necessary HSSE arrangements parameter is suggested.

G.J.P. van Berckel Master of Science Thesis
as one of the more important ones that can be logically explained when looking at previous projects.

5-1-3 Results comparison to compression related Brownfield projects

In the previous section, for all four parameter categories, the results were visualized and most important parameters were identified and discussed in terms of logic and validity. In this section, the results are compared to the identified cost drivers from projects in hindsight as listed in this report in section 2-2-3. The five main themes within the cost drivers are listed below. For each of these themes, the identified important parameters by the tool that would contribute to improved definition and potential better project performance in the end are indicated.

- **Increasing project main scope due to integrity issues**
  - Start parameters: operating performance and weight budget
  - Discipline Engineering parameters: Compression related scope disciplines status and design definition. Pre-DG2 the core scope disciplines MMI, REQ and UHT status and design are identified as important together with CSO discipline scope since compression projects often involve heavy weight equipment parts. Pre-DG3 secondary disciplines ELEC and PACO status and design are added too.

- **Many smaller scope increases**
  - Start parameters: operating performance
  - Discipline Engineering parameters: Compression related scope disciplines status and design definition

- **Insufficient detail in design**
  - Discipline Engineering parameters: Compression related scope development: MMI, REQ and UHT equipment and material.

- **Insufficient execution strategy maturity resulting in risk of underestimation of offshore manhours**
  - All execution parameters, where more emphasis can be identified for execution strategies directly related to offshore manhours being Transport and Installation Strategy and Hook up and Onsite Construction Strategy and Construction Strategy in general.

- **Underestimated impact of execution constraints**
  - Start parameters: Hazardous Area Classifications, Existing HSSE Case, PoB Planning, Workforce Capabilities and Vessel Availability. Existing Plot Plan can also improve insights of execution constraints because difficulties in work locations can be identified.
All five themes are thus represented in the results from the tool. Furthermore, when looking to the output parameters in section 5-1-2, the tool results indicates a strong focus on offshore execution efforts which are defined by design activities and execution strategy development. The dependencies between these activities and outcome in terms of execution is thus reflected appropriately by the tool.

5-2 Results for robustness check mode

The robustness check mode allows the tool user to fill in IV values for the evaluated project on a certain point of time in the project cycle. Based on these scores, the tool calculates the robustness of the considered outcome parameter. If necessary, the optimal sequence of design activities to obtain the required robustness for the project outcome can then be generated. Since the duration of project development often takes many years, for the validation of this use mode it was not possible to apply the tool on an actual project and see if the results would be beneficial to the project development and outcome.

Instead, two different ways of validation were done by applying the tool on two different Brownfield projects. One project that has already finished but that encountered serious issues in the project cycle was evaluated. The other project is a project that at the time of this thesis writing is at a certain point in the project cycle. Both projects fit within the archetype the developed tool in this study is tailored to. The evaluation of both projects was done by interviewing two experts involved in the project. The transcript of these interviews can be found in Appendix A. The most important findings from these interviews with respect to the validation purposes are described below.

Validation on historic project

The validation on the finished project was done for a project that started about ten years ago and was recently finished. The project fits well into the archetype because a large part of its main scope consists of compression related scope. Furthermore, this project encountered serious issues that resulted into multiple recycles at DG3 of Brownfield concept realizations until it was decided to proceed with a Greenfield solution. For this reason, applying the tool to this project on an early moment in the project cycle is interesting since the project definition was not sufficient when viewed in retrospective. The most important question is then if the tool could have been of value to identify the issues early on in order to avoid the recycles.

The interviewee is a person that was involved both in the early phases and in later phases of this project. His position in the project organization entitles him as a suitable person to estimate the different variability levels at a certain point in time since he had overview over the project development.

The interview consisted of five different parts. First, an introduction was given on the tool with an high level explanation of its working and outcomes. Second, the interviewee was asked what steps should have been taken in hindsight in the project development at the considered point in time of the project that is evaluated in this meeting. Third, the interviewee was asked to fill in the IV scores for all activity parameters in the tool. Then, the tool was runned
to calculate the outcome variability and steps were identified on how to obtain the desired value for the moment in the project cycle. These steps were discussed with the interviewee on correctness and helpfulness to the project in hindsight. At the end, the interviewee was asked about his confidence in the tool and feedback on non-functional aspects.

The moment of project evaluation was chosen to be at pre-DG2 and based on input from the expert supported by evidence found in the feasibility report [27]. At this moment, a range of different concept options was evaluated on feasibility and choices were made which concepts were chosen to work up to concept selection. The concept chosen for this validation session was the concept that was initially selected being the Brownfield option with piecemeal installation and replacements of facility equipment.

The interviewee specified the following issues that caused problems later on in the project cycle that could be identified by the tool and should have been identified in earlier project stages:

1. A combination of small individual scope growths leading to large total scope growth
2. Large underestimation of offshore manhours due to integrity issues, as-built designs and design definition
3. Not enough focus on project execution strategy
4. Not enough involvement of operational team experience in decision making
5. A number of above described issues were identified as risks, but not worked out extensively enough

The next step was to fill in the IV values for all activity parameters. The interviewee provided all input for this and scored the largest part of the values as a 4 or 3. A few scores of 2 were given and also some activity parameters were specified as not applicable to this project type.

Based on these scores, the outcome variability of this project at the evaluated point in time was 3,3. In chapter 6, it is explained that at DG2 level, the assumed required level in this study is 3 out of 4. Therefore, the tool was put to calculate the necessary activities to obtain this robustness score.

In Appendix A, the evaluation of the parameters per group can be found. Overall, the interviewee indicated that the calculated improvement steps for the project show good resemblance to the project issues determined in hindsight. A few comments were made on unexpected suggestions by the tool or parameters that were not indicated as important while the interviewee would think so. Also, elements of the project that were not represented clear enough by the parameters were suggested. All comments were noted and taken into consideration for potential improvements of the model.

At the final part of the validation session, the opinion about the tool in total was asked. The interviewee indicated he was confident that the model shows results that could have been of assistance at the evaluated point in time of this project for better decision making between the concepts considered for this project. He also indicated the added value when compared to other existing tools. He recognized that the value of this tool is limited to the technical
part of project development. The tool should be useful for people working in pre-DG3 phases of projects.

Most important feedback on non-functional aspects of the tool that was given by the interviewee was the usability of the tool and the way the results are presented. More programmed functionality and an overview sheet that quickly shows the most important result would improve the usability of the model. These comments were taken into consideration and put into actions or recommendations in this study.

**Validation on current project**

The second validation on a Brownfield project that is currently at the concept select point in the Select phase of the project cycle. The project is currently on hold but is still applicable to use for this validation. Main scope of the project is about adding compression capacity to the platform so it fits in the archetype project description. The facility is a fixed platform that is in mature asset state.

The interviewee is a person with many years of experience in front-end development. He is the manager of the project team for this project and therefore a suitable person for the pilot session. Furthermore, because of his extensive experience in front-end development, his insights and comments on the tool can also be useful outside the particular purpose of this validation step. All insights are recorded in Appendix A and most important findings that contribute to this chapter its conclusions are described below.

This interview consisted of the same parts as the previous described validation. The only difference was that no learnings from a hindsight perspective could be shared to compare the outcomes with. Instead of those learnings, before the IV scores were filled in, the status of the asset and the level of knowledge of the asset were shared.

The point in time in the project cycle for this project was thus at concept select. Inputs from the expert were therefore supported by information from the concept select report of this project [28]. Several concept options are compared in this report for selection. For this validation session, the preferred concept as advised by the report was evaluated. This concept was to install an extra deck with the necessary equipment for the compression on top of other process units.

After explaining the tool purpose and working, the interviewee started by explaining the situation of the asset and of the level of up-to-date information to support the project development. For this location, it appeared that for the moment of this project development, much and good information is available that provides very good insights and knowledge of this platform. These include 3D models, platform equipment integrity information and proper buy in from operational crews. Furthermore, subsurface data is also known as it concerns an existing reservoir. Many projects have been done in recent times of this platform and information management systems are in place and are being followed. It is thus expected that this project is not subject to large uncertainties on the asset information side.

Therefore, while filling in the IV scores, it appeared that most of the start parameters that represent physical and functional platform characteristics were given low variability scores from 0 to 2. Also, high level design development was rated at an average value of approximately two. Discipline engineering parameters were valued at IV levels of 2 and 3, since
no evidence could be found in the report that site visits had been made to verify discipline specific existing design and status. On the execution planning part of the design, the lowest scores were given being 3 and 4.

Based on the scores, the outcome variability was calculated at 2.4. This is considered as a robust score for the evaluated point of time in the project cycle when compared to the required score of 2.5 at this point which is explained in chapter 6. After calculating this score, the tool was set to calculation in order to define the next steps that need to be taken to obtain the required score at DG3 being a IV value of 2. The tool mainly suggested improvements in execution planning and strategy and a few improvements on scope definition for the disciplines most related to the core scope of this project.

In Appendix A, the evaluation of the parameters per group can be found. Overall it was concluded that the model reflected the good state of platform knowledge which resulted in a good robustness score. The activities that were suggested pointed in the right direction as the interviewee indicated the importance of project execution planning and strategy. Also, the discipline activities that were indicated as important were indeed the most important disciplines for this type of project.

The overall interviewee opinion about the tool was that the tool would point in the right direction for the project team to focus on. Furthermore, the interviewee indicated that the principles behind the model are sound and that in general terms, a tool like this that helps to work out what to focus on would be quite helpful in theory.

On the other hand, the complexity is high and without proper understanding, the tool could be a blackbox where information is supplied and an answer is given without proper understanding of the process. In the experience of the interviewee, people then tend not to use the outcomes of the tool or adjust the input values such that their own opinion is substantiated instead of finding new insights. However, the interviewer acknowledged that it was possible to both understand and use the tool during a two hour session. The current way the tool is presented however would require a training before self-assessment of projects is possible.

Main applicability of the tool was thought by the interviewer to be of assistance to a process that is currently done by using human minds at which is determined what is important for the project development. Because even less time and resources exist pre-DG2 compared to DG3, the interviewee expected the tool to be even more applicable to that phase.

5-3 Conclusions on tool results

The main objectives of this chapter were to provide understanding of how the results should be interpreted and to show the outcomes of running the tool for the total activity planning use mode and the pilot sessions on Brownfield projects.

By visualizing the results in graphs showing the courses of the most important parameter IV values, it was explained why the shown parameters were the most important ones and during what phase the tool suggest a high level of activity for optimal outcome robustness. Also, by showing the output parameters variability level, better understanding was achieved how the tool works and why certain activities were suggested. The shown results, can now be used to develop guidelines on this archetype Brownfield project planning. This will be explained further in the next chapter.
The results that came out indicated the parameters most important for optimal robustness of the project outcome in different phases. These parameters were reviewed and evaluated with support of an expert which provided insights and learnings that were either incorporated or taken into account for recommendations. Overall, the shown parameters indicated correctness based on experience and logical reasoning. A few questions were raised on what parameters were more important than others on a very specific level. Furthermore, comments were made on how the model could be used and what the instructions should be to ensure proper usage by project development teams. The last step was to compare the results of the tool with learnings from applicable Brownfield projects. Comparing the results to five different themes that were identified as cost drivers, parameters that came up reflected these themes. Taking into account all both the validation and the comparison to Brownfield projects, the results reflect Brownfield specific issues for this archetype.

The second part of this chapter consists of the outcomes of two piloting sessions where the tool was used to assess the robustness quality of two projects in pre-DG3 phase and to define what project elements to focus on from the point evaluated onwards. A conclusion following from both sessions was that the tool calculated a robustness score that reflected the actual situation of the projects according to the experts participating in the sessions. The steps forward suggested by the tool for the historic project pilot indicated strong resemblance with the issues that came up when the project was developed further onwards. Both interviewees acknowledged the idea and rationale behind the tool to be sound and identified potential additional value when using the tool. Feedback mostly consisted of providing insights of the tool working to the user and developing a good functional layout.
Chapter 6

Decision support by use of tool

In the previous chapters the development, validation and results of the tool were outlined. The reason for developing this tool was explained in the first two chapters. Main purpose that was specified is to improve decision making by optimizing the scope definition based on project and site specifics. This chapter will describe the last step to achieve this main purpose which is how the tool can actually be used in the project development process and how this will impact the decision making in the early phases of Brownfield projects.

This chapter objectives are therefore aimed on this last step. Based on the tool working and capabilities, in the first section it is explained how the tool can be used in practice and how it can be implemented in the process. It is then demonstrated when and how in the process the tool use can assist and improve decision making.

The second section will present a reflection on the tool requirements set out at the beginning of the method development in section 3-1-2 and on the tool purpose in general. After this section, the wider implications of the tool use and outcomes is explained, as proper incorporation should impact other areas of project development than only the technical scope definition too. The fourth section will then discuss the general working of the tool and to what extent the tool and its wider implication will contribute to the main objective of this research. The last section will provide the conclusions from this chapter.

6-1 Incorporating the tool in the project development process

This section contains three subsections that describe three different aspects of the incorporation of the tool in the project development. First, it is described how the tool can be used in practice. Second an implementation strategy is outlined to ensure best use and maintenance of the tool. Third, it is explained how and when the tool is applicable during the project development process. This last section will also explain how the tool can improve decision making during the project phases it can be used.
6-1-1 Tool practical use

In Appendix B, it is explained how the model can be used for the two different use modes. This explanation is supported by screenshots. Using the tool for obtaining results of important parameters or assessing the quality of the project robustness is not a complex process. During the piloting sessions described in the previous chapter, the interviewees indicated that the session with a two hours duration was sufficient and enough to combine a short introduction and filling in the variability scores. However, as explained in the Appendix, more extensive tool use sessions with multiple participants can improve the quality of the outcome as the variability levels can be filled in more consistent with reality.

The people that could provide the input should be persons that are involved in the project from a position where they have overview of the progress and quality of the project development elements. These persons would conventionally be Front-End Development Managers or maybe Concept Engineers. Furthermore, Project Managers that will focus more on the execution planning can also provide useful contributions to the process.

6-1-2 Implementation strategy

This section provides a strategy how the tool can be implemented in the project organization. Most importantly for implementation of this tool is to ensure an entity or person within the organization will be the owner of the tool. The latest version of the tool will be stored at this entity and supplied when applicable projects can be supported. Main responsibilities of the owner should be:

- Communicate within the project development community to show the added value of the tool and the tool results
- Provide guidance with tool use and how to develop the project with the lessons learned coming from the tool
- Provide facilitators to guide tool use sessions
- Develop set of tools tailored to other archetype projects by organizing dependency identification sessions

Another important aspect of the implementation is to ensure the model is updated according to project learnings and new insights. After each applicable project, the learnings should be captured to verify or adapt the dependencies in the tool. A yearly session could be organized where experts can provide input in order to let the model represent the combined experience from different project and people learnings. Another idea is to develop an open source type of tool where people involved in projects could indicate insights and learnings on parameters and dependencies. Based on input in this open source model, the tool owner can decide to change the tool at certain points.
6-1-3 Applicability during project development

This section will describe the applicability of the tool during the early project development phases. Important aspect is to understand what the function of the tool can be at different stages. The tool will not provide clear and fully correct answers but can rather be used as starting point for discussions on potential risks and choices in activity planning. Furthermore, it is very important for tool users to understand the purpose of the tool. It will assist in front end development activity planning and decision making based on technical aspects of the projects for developed concepts. It will thus not provide ideas or insights how to optimize a certain concept. This difference is very important and should be communicated at all times when the tool is used.

The applicability of the tool described in this section is divided into pre- and post-DG2. For both phases, the contribution to improving decision making is explained.

Pre-DG2 tool applicability

At very early phases of project development, main events that will lead to opportunity realization options and subsequent concept ideas are opportunity framing and concept identification. Because no concepts are yet developed at this early point, the robustness check use mode is not yet applicable. However, learnings from the tool results about the most important parameters can be used as starting point for the opportunity framing and concept identification. These learnings could either be presented at these sessions, or pre-work could be done to foresee potential risks or issues that the project can potentially encounter in later stages.

At this point, early decisions can be improved since input from the project results can point the involved persons into directions where potential risks can be identified. The main added value here is that these learnings are based on combined experience and previous project information captured in the tool instead of the experience of the persons present at the meetings. By taking the approach with the model, also a more reproducible process can be established.

From the moment when concepts are identified, the total project activity planning use mode can be put into work to define the design activity sequence. This way, project elements that exclude concepts from further development because of major predicted issues can be identified earlier. The tool ensures a more consistent approach and at feasibility gate or DG2, the robustness check mode can both check if the outcome robustness is sufficient and if several concepts can be compared because they have similar levels of definition. The decision making at this decision gate will thus be improved by the tool in two different ways. It assist in terms of helping to use the appropriate information for the decision making by providing guidance on what to focus at. It also supports the decision process by aiming the decision on comparable alternatives with good quality since the tool assists in identifying early showstoppers and comparing robustness of different concepts.

Post-DG2 tool applicability

In the select phase, often two or three concepts are worked up to make a good decision at concept select. These concepts are the ones that were identified as feasible at DG2. At the
start of this phase, the tool could be used to establish a design planning for the Brownfield concepts based on the variability levels at that moment in time. This will show where the team need to focus on but also which other units outside the project team should be consulted to acquire the necessary information. Furthermore, based on output of the tool, a planning could be made which site visits should be performed and what information should be collected during these visits.

By optimizing the definition and thus having the right information, the tool contributes to improvement of the decision making at concept select. Similar to the DG2 moment, the tool can also be used to assess the robustness of the evaluated concepts at concept select to decide whether all concept definitions are mature enough and if the concepts can be compared evenly.

After the concept has been selected, activities can be determined using the tool to work towards DG3. These activities can either be done or put aside for resource or time reasons resulting in a suboptimal scope definition. However, at the decision making moment at DG3, the project team can indicate the risks that still exist according to the tool and take them into account when making the decision to proceed to the next phase. Again, the decision quality is improved by the model since not only the right information should be available based on the suggested activity sequence, also information that is not available can be identified and taken into account.

6-2 Reflection on requirements and purpose

This section provides a reflection on the requirements for the tool that were defined in section 3-1-2. After this reflection, an general evaluation is described to what extent the purpose of the tool has been met.

First, the functional requirements are evaluated:

- **Representing Brownfield projects in terms of project and site specifics**
  By developing a model that simulates a project with a network of parameter dependencies, an innovative method was developed to meet this requirement. This means that the requirement is met, however some concessions had to be made regarding the level of detail of the project representation. In addition to that, time limits on this study only allowed a limited amount of input from various sources resulting in a product with a certain level of subjectivity. To mitigate this issue, methods were suggested to keep improving the tool and the tool quality.

- **Relating these specifics to potential risks on change in project outcome values**
  This requirement was met by the way the tool is developed and works. The relation between the project and site specifics and the project outcome is captured in the weight based dependencies and the variability levels of the activity parameters. The quality of these dependencies and weight levels is similar to the issue described for the previous requirement and is suggested to be improved through incorporation of new insights and learnings.
• **Identifying the most important relations and largest risks**  
The tool is capable of identifying these two elements by the way it was developed. Based on outcomes from validation sessions and project piloting sessions, it was concluded that the tool does indicate the appropriate project elements that show large risk to the outcome.

• **Providing output based on these risks that can be incorporated into the project development process**  
The tool provides output expressed in variability values based on the risks that are captured in the model. This output is validated by experts and according to them the outcomes will put the user focus in the right direction. The indicated added value of the tool is not that it points out very surprising project elements, but that it explicitly states where the project development team should put their efforts to which is something that does not exist yet. Furthermore, it was indicated how and when the tool is applicable in the project development process. This requirement was thus met but the quality of the tool results could be improved further.

Second, the non-functional requirements are evaluated:

• **Workable and functional visual layout**  
The interface presented to the tool user are functional and can be handled with little or no explanation. Functionality is added to highlight important features and results. The interface that a tool moderator must understand to make adjustments or additions is more complex since the moderator should be able to understand the matrices. This is definitely doable with a proper explanation. Also, according to literature this is suggested to be the most efficient way to record and visualize a large network of dependencies.

• **Tool should be understandable for users**  
During validation this topic was discussed. The outcome was that a risk exists that the tool is too complex which could result into less understanding or application of the results. Functionality in the tool and manuals are developed to be supplied with the tool to mitigate this issue. However, this is one of the largest obstacles for the tool to be actually used in the process. When put in perspective to other tools that are used however, sufficient trainings could be provided when the added value of the tool proves to be sufficient.

• **Incorporation of tool outcomes should be feasible**  
The overall course of the different parameters show logical correct order of getting more definition for individual parameter. This is also incorporated in the tool modeling by introducing the actualIV value. During validation sessions, the sequence and course of the design activities was also found to be feasible. However, looking at identified non-technical aspects of projects, higher management should be convinced in certain cases to do the activities as suggested by the tool. To achieve this, results from the tool itself could potentially help to demonstrate the importance of certain activities in early phases.
• **Adjustment of tool settings should be possible**

With proper explanation and using the built-in functionality, the tool can be changed and adjusted to the needs of the user. However care must be taken at deciding who can change the settings and to what extent, since a part of the added value of this tool comes from the fact that the project is evaluated using a fixed framework which improves reproducibility and consistent approaches in the development process.

The purpose of the method was defined as to optimize the scope definition of a certain Brown-field project on a certain moment of time in the project cycle based on its project specifics and site conditions. When looking at every element of this purpose definition, the tool appears to at least serve all of these elements to a certain extent. The scope definition is optimized by the suggested activities of the tool. This functionality can be done for every moment in the project design cycle. Furthermore, the suggestions and thus the scope definition optimization are based on parameters that define the project specifics and site conditions. Extra functionality that comes with these features is the ability of the model to assess the robustness of the project with respect to a certain outcome parameter.

### 6-3 Wider implication of research outcomes

In the previous chapters the development and outcomes of the tool were provided and in the previous sections in this chapter it was explained how the tool can be used and implemented to serve the main purpose of this study. The tool however is a proposed framework that provides a solution to deal with the identified need for the project development process to be more tailored to specific project risks. Outcomes and use of the tool can support other aspects of the development process too such as management decisions, human behaviour and team capabilities and cooperation and interface management between different involved teams. These wider applications are discussed in this section.

Decisions of higher management to pressure the speed of early project development or to assign insufficient resources to the process can result into suboptimal project performance. This was already identified during the research done on the decision process described in chapter 2. This study suggests to improve the decision process by tailoring the front-end development process to project and site specific risks. The results and use of the tool can support other aspects of the development process too such as management decisions, human behaviour and team capabilities and cooperation and interface management between different involved teams. These wider applications are discussed in this section.

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Tailoring a project development process to project and site specifics can be translated into optimization of team composition and cooperation between different involved units and teams. The team composition can be more focused on the specific risks that are common to a certain project or archetype project as indicated by the outcomes of the tool. For compression related projects for example, efforts can be made to include persons in the development team with capabilities in the direction of discipline specific elements or typical execution related challenges for the project. Furthermore, the tool suggest explicit levels of buy in from units
or teams outside the core development team that, if adhered to, will result into improved cooperation and more effective collection of the necessary information. For example, if a site survey would be organized in an early development phase, the tool outcomes can be used to define what persons should be present and what type of information should be gathered to what level of definition.

The adjustment of the development process based on project specific risks is in this study translated to a large set of parameters and dependencies. Better understanding of these dependencies itself can improve project outcomes. A problem that was often identified during interviews in the early phase of this research was the gap between the project development team and the project execution team. If the impact of certain design decisions on the execution possibilities would be understood and involved earlier and better in decisions, undesired outcomes can be avoided. The tool can assist in this process by showing the steps why certain design activities should be done. Also, the process of tailoring the tool to a certain project itself could provide much insight into all these relations within the project.

The approach developed in this study was focused on Brownfield projects and even more specific focused on offshore, compression related projects. The rationale behind the way how to make choices in front-end planning could be used in a much wider range of project. In this dissertation, it was explained how the method can be tailored to other Brownfield projects or what the implications would be when fitting the tool to onshore instead of offshore. The mindset of tailoring the front-end process more explicitly towards the risks that come with certain projects could however be used for Greenfield developments as well. Greenfield projects for example, are often much more subjected to non-technical risks because new environments are entered. Tailoring the tool with parameters and dependencies that account for that type of risks could also provide new insights and more effective development processes.

6-4 Discussion of research and framework use for decision making and project development

The previous section described the wider impact of this study and the developed framework, making the picture of this research complete. This section provides a final discussion of the added value and the new elements this study outcomes suggest. It describes how the tool is different from existing tools and processes, what the added value is and also the limitations and implementation challenges.

The tool distincts itself from existing processes because of the rationale behind the development of the tool that was developed in the first phase of this study. Determining choices in project development based on quantitative interdependencies between project elements with regards to the outcome risk adds a new method of project development. When comparing the tool to existing systems and tools, it is therefore that element that distinguishes the method. Instead of assessing the quality of the front-end design process over the entire technical and non-technical spectrum, the method proposed in this study focuses more on important parameters for the specific process, enhancing the effectiveness.

The framework developed provides an opportunity to capture experience and expertise into a model. This way, a very complex process with a large number of dependencies that change
with different project and site specifics is captured to support the development process, assisting something that is currently done by using human brain power. Outcomes of the tool provide explicit guidance on where to focus on enabling a more consistent and reproducible process. Also, by using the outcomes, allocating project development efforts can be done more effectively with respect to risk minimization.

The contribution to the decision making process aimed for in this study is directed to a specific part which gives certain limitations to the use of the outcomes of this study. Most importantly, it must be understood well how the framework supports project development. It optimizes the scope definition level with respect to the project specific risks. It does however not optimize the scope itself. When developing a project, teams should always aim to improve the concept design and execution methods in order to achieve cost-effective, high quality and safe solutions. The tool will only assist in what data and information is necessary to improve the robustness of the outcome of these developed concepts.

The largest implementation challenge that needs to be discussed here is the effort required to tailor the tool to other archetypes. Estimated time to tailor the tool to another archetype would be one or two days and would require the involvement of multiple persons from different perspectives on the project that is evaluated. The added value coming out of this investment in resources and time should have enough potential to make the decision to organize the sessions. Based on the evidence provided in this study, such a decision is difficult to support. However, only the sessions itself could already add value to the wider understanding of the evaluated projects. This understanding should be present in every project development process, but time and resource limits almost always prevent the teams from taking this effort. The framework developed provides an opportunity to do an investment outside of a project and use the lessons and tool within multiple applicable projects.

6-5 Conclusions on decision support

This chapter described the translation from the developed theoretical tool to application in practice of project development. This was done by explaining how the tool is used and what the strategy can be to implement it into the current organization and project development. Most importantly, it was described when and how the tool could be used in the project development process and how the decision quality can be improved by the tool. Both the use modes of the tool appeared to have distinctive functionality in the process potentially leading to better decision making. The decision quality can potentially be improved by the model in terms of better information and higher quality of alternatives and comparison. This reflects the intended improvement areas to decision making as identified at the end of chapter two.

With all steps of the method development now completed, reflections to the requirements and main purpose were provided. The tool was evaluated to have the intended capabilities and outputs as set out in the method requirements. Critical notes were identified at usability, mainly because of the high complexity of the tool. For this issue, some mitigation measures were given that were either incorporated at the end of this study or written down for further recommendations and research steps.

With the tool development explained and the translation to practical use made, the third section of this chapter provided a more high level view of the implications of the research.
outcomes. It was identified that the tool was developed to fit the purpose of a more risk based approach where multiple project elements are connected to define this risk. When the suggested outcomes are followed, this could impact higher management decisions in terms of investment in early development phases, team compositions and cooperations between different units and teams and it could decrease the gap between front-end development and its impact on execution. Furthermore, the question was asked whether this approach would be applicable to Brownfield only or if a wider use with respect to for example non-technical risk assessment in Greenfield development is feasible too.

Finally, a discussion of the tool value, difference from other systems and limitations was added in this chapter. The dependencies within the model distinct it from other tools. Also, the capability to capture experience and expertise of a complex system is an innovative element. Limitations of the framework consist of the fact that the tool does not optimize the scope itself and that a significant effort is required to tailor the tool for other archetypes which need to add enough value to make the decision to organize sessions to obtain the other archetype tailored tools.
This chapter contains the conclusions and recommendations with respect to the study reported in this dissertation. Subject of this study was Brownfield project development and the initial high level motivation behind the initiation of the study was the poor project performance in terms of cost and schedule predictability when compared to Greenfield projects. At the end of this chapter, areas of interest that were identified for further research are provided.

7-1 Conclusions

The main objective of this study was specified in the introduction part as to improve the quality of decision making in early phases of Brownfield project design. Three main parts can be identified in this thesis that explain the steps used to fulfill the main purpose. Chapter 2 provided an analysis of the current decision making process in order to scope this research to a specific objective. Chapters 3, 4 and 5 describe the development of the method framework, the contentual building and the results of the tool. In chapter 6, different aspects of using the developed framework in project development were explained together with an overview of the wider implications and a discussion of the developed framework with regards to the decision making process.

For all three main thesis parts, conclusions drawn are provided below. Section 7-1-4 presents the final conclusions with regards to the main research question.

7-1-1 Conclusions with respect to the decision making analysis

The high level main objective of this study needed to be specified based on an analysis of the situation within Shell and the industry regarding Brownfield project development with specific focus on the decision making in the process. This analysis was done by reviewing documents and literature on current systems and processes in place, the way decisions are assessed on quality and identification of the root causes of Brownfield project underperformance. Findings
Conclusions and recommendations

from this study were supplemented and verified by a survey study on historic Brownfield projects and expert views from a range of different angles to the situation.

Main conclusions on existing processes and systems were that typical Brownfield project elements are not or not enough present in the current tools and standards. Many of these supporting systems are more tailored to Greenfield project development resulting from many years of experience how to gradually develop a project. Brownfield projects have a more unique nature that require focus on the right elements of the project based on risks involved. Measures that were historically put in place to account for Brownfield issues such as factors in cost estimation did not result into intended improvements. However, in recent times, more work is done in certain areas that does include the Brownfield specific elements.

Studies that were done on root cause analysis of Brownfield project performance issues provide similar results that are mainly directed towards scope growth due to underestimated site specifics in terms of design and execution constraints. This finding was supported by an analysis of five comparable Brownfield projects on Shell offshore platforms.

Based on the findings, several areas of improvement were identified on technical and non-technical aspects. For this study, these areas combined with the findings from the decision process analysis were the basis of this study its specific objective. This objective was defined as to optimize the scope definition of a certain Brownfield project on a certain moment in the project design cycle based on its project specifics and site conditions.

7-1-2 Conclusions with respect to the developed method and results

To fulfill the specific objective, a method was developed and the decision was made to develop a tool that could be used in the project development to improve decision making in the end. Because the objective stated that the project outcome should be linked to project and site specifics, a choice was made to develop a network of parameters and dependencies in order to simulate a project. The framework developed for this purpose should be capable of capturing a process of identifying risks that is currently done by combined experience and expertise of persons involved in the project development.

The conclusions that can be drawn with respect to the development of this method is at first that the developed method offers Shell a framework that captures the intended complex process and offers support in the project development process. In terms of functionality, the capabilities of the model are as requested upon start of the method development.

The content captured in the tool was tailored to offshore compression projects. Four different parameter categories were identified and approximately fifty activities were captured to develop the technical scope of an applicable concept. The parameters and dependencies were identified during sessions with experts with different perspectives on the projects. Upon completion of the tool, verification and high level validation steps were performed to demonstrate the working of the tool and the reflection of a project development process.

The model working and results were validated by expert interviews and historic and current project evaluation by the tool. Based on these sessions, it was concluded that the model serves the intended purpose of project development optimization that supports the front-end development process. For the offshore compression project archetype, the tool suggested a strong focus in the pre-DG2 phase on functional and physical design of the platform.
on core scope discipline focus being mechanical static and dynamic scope. Secondly, certain execution constraints and execution planning itself were suggested to be focused on in the early phase of the project development.

Piloting sessions indicated a correct reflection of the robustness quality of the project outcomes at the evaluated point in time. Furthermore, the interviewed experts indicated that the outcomes of the tool add value to the process which could lead to better project performance. The interviewees acknowledged the added value of the tool compared to existing ones.

7-1-3 Conclusions with respect to the decision support using the developed framework

The tool can be used during the entire early project phase and can be used to serve different purposes that all offer improvement of the decision quality in terms of using appropriate information and the quality of the alternatives. Because of the more specific nature of Brownfield projects scope this study suggest that using the appropriate information for making decisions is crucial for improving project performance.

Besides the direct purpose of the tool to identify the technical project elements to focus on, wider implications of the framework exist that can benefit the project development process. The rationale behind the framework development of focusing more on project specific risks and the subsequent outcomes of the tool can provide support to higher management decisions about how much time and effort should be invested in early development phases. By determining the optimal level of definition of certain project elements, the amount of effort can be obtained to allocate time and money in the most effective way. Furthermore, based on the developed outcomes, team compositions can be tailored to a specific project and cooperation between units and teams can be optimized to decrease the risk of project outcome change as effective as possible.

7-1-4 Final conclusions regarding the main research question

Referring back to the main objective of this thesis, to contribute to improving Brownfield project performance by improving the decision quality for the front-end development phase, the following can be concluded based on this study:

- Project development in Brownfield projects needs more specific focus on project elements compared to Greenfield development.
- This study developed a risk based approach where choices in development planning are optimized based on project and site specifics.
- Identifying these risks is a complex procedure since many project elements are interrelated and relative importance varies with project nature and site challenges.
- The tool developed for this purpose provides a framework to identify common risks in archetype Brownfield projects and can be used to assess outcome robustness quality and improve effectiveness of early phase development.
• The tool results and use provide a basis for better informed decision making resulting in lower probability of rework or recycles or cost growth.

• Besides improvement to technical scope definition, the framework and results can also be interpreted to have implications for higher management decisions and development team compositions and cooperation in the front-end development phase in order to improve the quality of the process.

The rationale and framework developed based on the findings above serve the purpose of improving the decision quality. Based on evaluation of results and expert opinions, it can be concluded that the outcomes of this study contribute to the decision quality of Brownfield projects if properly incorporated into the development process. With an improved decision quality, the projects are less likely to result in undesired project outcomes or in rework or results, which in the end contributes to overall Brownfield project performance.

7-2 Recommendations

The following recommendations follow from the research conducted and reported in this dissertation:

• Most important recommendation following from this study is to incorporate the rationale of tailoring project development in early phases more to specific project and site risks than the way it is currently done. The development process appears to have evolved too much into a standard, gradual process that is based on experience from decades of project development. Especially for Brownfield projects, it appears that the right focus can result into improvement of project performance and a more efficient development process.

• The previous recommendation needs guidance and support on how to actually achieve it. Therefore, the framework in this research was developed. It is recommended that the framework or the results are incorporated into the process. However, since the tool was not tested on a large number of projects and improvement areas for the tool can be identified, it must be decided by Shell at what level it should be incorporated with potential increase in the future. The amount of effort should thereby be less compared to the expected added value of embedding the findings. Incorporation of the framework is recommended at the following levels of use from the lowest amount of effort investment to the highest:

  1. Only the result outcomes for compression related projects are incorporated into projects that fit that archetype. Most important outcomes are summarized in the previous section and explained extensively in the results chapter. The findings are communicated in the project development community and possibly incorporated into standards and guidelines. If positive results appear, other archetype main findings can be identified as well by using the tool and incorporated in the same way.
2. In addition to the implementation of the tool outcomes, the tool itself is implemented and used too. This can also be done starting for compression related projects and potentially be extended to other types when positive results are found.

3. The most rigorous recommended way of implementation of this study is to develop the tool for multiple archetypes and communicate the existence in order to promote use for applicable projects.

- As indicated in the previous recommendation, areas of improvement within the developed framework were identified. It is therefore recommended to investigate these areas in order to achieve maximal value from the tool. The two most important areas of development are:
  
  - An increased level of definition of what design activities correspond to the 5 levels of definition for activity parameters. This has not been studied intensively in this research although for each parameter an indication is given in the tool. If more specified levels of definition can be obtained, for example by input from the corresponding disciplines or teams, even more explicit guidance is provided by the tool what level of definition is required at what moment in time.
  
  - Where possible, quantitative sources were used to quantify the weights of dependencies between parameters. If more project data would be captured, averages could be used to assign even more substantiated weights on dependencies which will increase the quality of the outcome. This recommendation can be interpreted in a wider context. Capturing project data to find out even more specific where the cost drivers are in order to mitigate these early one is an opportunity that is worth to investigate.

- The findings that impact elements of project development outside the technical scope in this research are recommended to be incorporated as well. Especially the way higher management makes choices and assigns time and resources to Brownfield projects should be evaluated since this was also one of the main areas of improvement that came out of the first part of this research.

- The incorporation of a more risk based approach to project development is recommended to be researched in a wider project development context. Onshore and Greenfield projects for example deal with different risks than the ones researched in this study, but the rationale behind the framework can be applicable in those fields as well.

- Final recommendation is to identify other areas the framework can be used for. For example, traditional risk identification and HSSE risks assessment can benefit from the properties of the tool. Traditionally, individual risks on project outcome are identified and taken into account when making decisions. The added value of the developed tool can be that coupled risks and dependencies between risks can be taken into account too. This can be beneficial since often many of these risks are connected.

7-3 Suggestions for further research

During the course of the study, several areas of interest were identified for further research.
• With Brownfield projects on different facility types such as upstream and downstream facilities, section 2-2-3 indicated a potential opportunity to do an effort to compare the way projects are done and what the outcomes are. Results from this study can lead to better understanding of cost growth drivers, since similar projects can be compared with different circumstances.

• Data capturing and management from assets appears to be a key practice that could be beneficial for project development. With a very large number of assets over the entire globe, it is a major challenge for an organization like Shell to install and maintain a consistent system that is used in a proper way. A study on what data should be captured and maintained at least and how this data can be collected and stored can be of interest.

• When interviewing persons on an offshore platform, it appeared that major miscommunications exists between office and field. For example, when buy-in was requested from operational personnel for a project, a complex report was sent which made it impossible for them to reply. A study on improving the communication style between various crews and teams could therefor be of interest.
Appendix A

Validation session transcript summaries

[this Appendix is not shown in this report version for confidentiality reasons]
Appendix B

Tool use manual

[this Appendix is not shown in this report version for confidentiality reasons]


[7] “From Brown to Green, [project name] Project Concept Selection Evaluation [internal Shell presentation].”


[15] “VAR 2 Close Out [project name] [internal Shell VAR 2 / ESAR presentation].”

[16] “[project name] After Action Review [internal Shell report].”

Master of Science Thesis G.J.P. van Berckel
[17] “Project Close Out Report Compression Projects [3 project names] [internal Shell report].”


[27] “[project name] Technical Feasibility Report [internal Shell report].”

[28] “[project name] Concept Selection and Concept Development Report [internal Shell report].”
# Glossary

## List of Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>TU Delft</strong></td>
<td>Delft University of Technology</td>
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<tr>
<td><strong>CAPEX</strong></td>
<td>Capital Expenditure</td>
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<tr>
<td><strong>ORP</strong></td>
<td>Opportunity Realisation Process</td>
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<tr>
<td><strong>DG</strong></td>
<td>Decision Gate</td>
</tr>
<tr>
<td><strong>TECOP</strong></td>
<td>Technical, Economic, Commercial, Organizational and Political</td>
</tr>
<tr>
<td><strong>FID</strong></td>
<td>Final Investment Decision</td>
</tr>
<tr>
<td><strong>ORS</strong></td>
<td>Opportunity Realisation Standards</td>
</tr>
<tr>
<td><strong>DRB</strong></td>
<td>Decision Review Board</td>
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<tr>
<td><strong>VAR</strong></td>
<td>Value Assurance Review</td>
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<tr>
<td><strong>FEL</strong></td>
<td>Front End Loading</td>
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<tr>
<td><strong>DCAF</strong></td>
<td>Discipline Controls and Assurance Framework</td>
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<tr>
<td><strong>PCAP</strong></td>
<td>Project Controls and Assurance Plan</td>
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<tr>
<td><strong>OF</strong></td>
<td>Opportunity Framing</td>
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<tr>
<td><strong>HSSE</strong></td>
<td>Health, Safety, Security and Environment</td>
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<tr>
<td><strong>WHP</strong></td>
<td>Well Head Platform</td>
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<tr>
<td><strong>IPA</strong></td>
<td>Independent Project Analysis</td>
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<tr>
<td><strong>DSM</strong></td>
<td>Design Structure Matrix</td>
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<tr>
<td><strong>IV</strong></td>
<td>Information Variability</td>
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<tr>
<td><strong>PS</strong></td>
<td>Parameter Sensitivity</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>CII</td>
<td>Construction Industry Institute</td>
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<tr>
<td>HLV</td>
<td>Heavy Lift Vessel</td>
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<tr>
<td>PoB</td>
<td>Personnel on Board</td>
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<tr>
<td>MMI</td>
<td>Mechanical, Materials and Integrity</td>
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<tr>
<td>REQ</td>
<td>Rotating Equipment</td>
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<tr>
<td>UHT</td>
<td>Utilities, Water, Energy and Heat Transfer</td>
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<tr>
<td>ELEC</td>
<td>Electrical</td>
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<tr>
<td>PACO</td>
<td>Process Automation, Control and Optimization</td>
</tr>
<tr>
<td>PFAS</td>
<td>Pipelines, Flow Assurance and Subsea</td>
</tr>
<tr>
<td>CSO</td>
<td>Civil, Structures and Offshore</td>
</tr>
<tr>
<td>VBA</td>
<td>Visual Basic for Applications</td>
</tr>
<tr>
<td>FPSO</td>
<td>Floating Production, Storage and Offloading</td>
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