Delft University of Technology: Construction Management & Engineering

Master of Science Thesis:

Considering project goal feasibility in decision-making during project execution in large industrial projects

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Summary

In this thesis report created for the MSc: Construction Management and Engineering at the Delft University of Technology, decision-making in large industrial engineering projects is evaluated. This research was conducted at Fluor Corporation; a large international engineering, procurement and construction contractor.

In current practice, the feasibility of the project goal is only assessed by project owners at the start of the project, up until the final investment decision (FID) is made. The final investment decision involves the decision of the owner to continue the project into the project execution phases. After the FID is made, the project goal feasibility is no longer assessed. Traditionally it is believed that in projects all decisions are made before the final investment decision and during the project there is no requirement for additional decisions. However, in practice during the project execution phase decisions need to be made partly because of project risks and uncertainty. During the project execution phase in which the actual engineering, procurement and construction is conducted, decision-makers only evaluate the impact of their decisions on time, cost and quality criteria (together called the iron triangle) instead of on the long-term project objective, the project goal. The project goal of industrial engineering projects is to deliver a product for sale, e.g. oil, natural gas and high-volume chemicals created by an industrial asset. The construction of the industrial asset is defined in this research as delivering the project output. The construction of the asset (project output) is thereby a means to an end (project goal). Whether the project goal is feasible or not depends on whether the benefits for the owner outweigh the associated cost.

Currently, decisions during project execution are evaluated, based on the impact of each decision alternative on the iron triangle criteria. This is done by evaluating the impact of each decision alternative on the total project duration, cost and quality. The aim is to minimize cost and project duration, and maximize quality. It is however not clear how to trade-off time and cost. It is not clear how much cost increase is allowed for a reduction in project duration and how much increase in project duration is acceptable for a reduction in project cost. In addition the decision makers only evaluate the effect up until the construction of the asset and do not consider the operational phase in which the benefits to the owner materialize. The effect of their decisions during project execution on the project goal is therefore not assessed. The research aimed to contribute to the scientific knowledge, by providing empirical evidence of the effect of decisions made during project execution on the project goal feasibility. This empirical evidence was currently missing as indicated in literature. Furthermore in current practice, because the effect on the project goal feasibility is not assessed, suboptimal decisions could be made.

In this research the effect of decisions made during project execution is therefore evaluated by looking at the effect of these decisions on the feasibility of the project goal. The feasibility of the project goal is modelled by using the net present value (NPV) allowing for a clear trade-off between time and cost. This is possible, because of the incorporated time-value of money, which allows for time to be expressed into cost. In addition, the NPV also incorporates the operational phase, allowing decision-makers to incorporate the impact of their decisions on the actual project goal. The NPV is suitable for assessing the feasibility of the project goal and is often used in current practice to make the final investment decision. However, using the NPV to evaluate decisions during the execution phase of projects instead of merely on the final investment decision requires for the NPV to be adjusted.

First of all, from a financial (theoretical) perspective, so called systematic risk is only incorporated in the discount rate of the NPV and project specific risk should be ignored. This is motivated by stating that project specific risk does not increase the required return, because project specific risks can be diversified. In other words, by investing in different types of projects, the project specific risks associated with industrial projects will on average not impact the investment portfolio of investors. However, from a project management perspective, project specific risks should be monitored, because these risks potentially impact the project.

Secondly, during the project execution an increased amount of information becomes available, that was not available when the final investment decision was made. This information needs to be integrated into the NPV in order for decision-makers to make a well-considered decision.

Lastly, to evaluate the decisions and their alternatives during project execution, the effects of those decision alternatives on the NPV need to be incorporated. The time-value of money used in the NPV does allow for a clear trade-off between time and cost, but it also requires the integration of the two criteria, namely determining the exact timing of each cost.

Project specific risk and uncertainty, the increased amount of information and the cash flows are incorporated into the NPV by creating a probabilistic NPV model using a new method called: "integrated probabilistic goal assessment" (IPGA). The IPGA method consists of six steps allowing for the integration of risk and uncertainty into the NPV model as well as incorporating the increased amount of information. In addition, the impact of the decisions made during project execution is modelled by using a resource loaded schedule. The resource loaded schedule, in which for each activity the used resources are determined, allows for the linkage of the time and cost criteria. The output of the IPGA method is a probabilistic NPV, which is represented by a probability density function. This probability density function is created for each decision alternative by using Monte Carlo simulation. Because of the impacts of risks and uncertainties on the shape of this probability density function, comparing different decision alternatives required a new decision rule. This new decision rule is derived from the "conditional net present value at risk" C-NPVaR.

In this research, the IPGA method is applied to 10 decision moments derived from two real projects. By conducting case studies the decisions were identified and for each decision the different decision alternatives were stated. The decision alternatives that were previously chosen in the case study projects were compared with the decision alternatives recommended by the IPGA method. In other words, the decision alternatives that were chosen based on the iron triangle criteria were compared to the decisions recommended based on the project goal feasibility criteria. In the research a first attempt was made to examine decisions during project execution by assessing the impacts of the associated decision alternatives on project goal feasibility. In this research it was found that in 4 of the 10 decisions, the IPGA method recommended a different decision alternative than the decision alternative that was chosen in the project. In 3 out of those 4 decisions, the risks that were introduced by the decisions had a significant effect on the distribution function of the NPV.

Based on interviews with the project managers and sponsors involved in the project, it was found the riskiness of the project was underestimated. Furthermore based on the sensitivity analysis and case studies, it was found that the risks were not fully incorporated in the decisions. Furthermore the manageability of those risks was overestimated by decision makers. It was furthermore found that certain incentives are in place for project managers to evaluate their decisions based on deterministic time and cost values and not asses the feasibility of the project goal. Based on the sensitivity analysis conducted it was found that the results from the IPGA method were not highly dependent on the exact discount rate used in the NPV formula nor on the exact magnitude of the benefits to the owner.

The research aimed to contribute to the scientific knowledge, by providing empirical evidence of the effect of decisions made during project execution on the NPV. This empirical evidence was currently missing. Although the empirical evidence provided by this research alone cannot substantiate the exact extent to which decisions during project execution change because of assessment of the project goal feasibility it is recommended to apply this method to a project in which decision-makers did incorporate risks on time and cost in their decision making. This could further reduce the research gap by knowing the exact extent to which risks caused the found differences in this research and to what extent this was caused by using different decision criteria that assessed the project goal feasibility.

In the research it was found that when using the objective IPGA method decisions should have been altered during project execution. However because project managers are evaluated based on deterministic time, cost and quality criteria, incorporating risk might be done to a lesser extent and manageability of risks might be overestimated. For further application of the IPGA method it is therefore recommended to increase the objectivity of risk identification as well as the possibility to forecast risks by combining the IPGA method with more objective forecast data such as the data derived from the current and future “WATSON project” initiated by Fluor Corp.

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1 Preface

This thesis, conducted for the Master of Science in Construction Management and Engineering at the Delft University of Technology, required not only the inputs of many experts, but also the involvement of a wide variety of stakeholders. First of all I would like to express my gratitude to my Graduation Committee Members, for allowing me to conduct this unconventional research rooted in multiple research fields. This allowed me to combine the knowledge gained during my BSc in Building Sciences with my BSc in Economics & Business Economics and to examine a topic that really grasped my interest. I want to explicitly thank the Chair of my Graduation Committee: Prof. Dr. Hans Bakker for sharing his expertise as well as his efforts and advice on involvement and management of the stakeholders associated with this research project.

Furthermore, without the expertise and involvement of the higher management of the Dutch Fluor Corp. office and the resources made available by them, this research could not have been carried out. I would therefore like to thank General Manager Tom Duzijn as well as the other "Monthly Steering Committee" members for their personal involvement in the research. My company mentor, Erik Groeneweg, has shown a rare level of dedication. By not changing his level of commitment despite the decrease in his number of working hours, caused by unfortunate events, he has allowed for this research to be finished as planned. Lastly, the involvement of the independent consultant, Oliver Wyman, has enabled for a more objective model validation and with that higher quality results.

2 Introduction

Large projects are increasingly used in a variety of sectors, such as: infrastructure, aerospace, defence, and the industrial sector. In large industrial projects, industrial assets are created that make a product for sale, e.g. oil, natural gas and high-volume chemicals. The capital investments made in large industrial projects are ever increasing and their products satisfy the world's demand for energy, chemicals, metals and minerals (Merrow, 2011).

Projects are undertaken to achieve a specific goal (Nicholas & Steyn, 2012). Currently, large industrial projects often fail to meet this initial project goal (Merrow, 2011). In the project management literature, it is more and more accepted that project success is related to the project goal and not only the traditionally used time, cost and quality criteria. While the need for successful delivery of large projects is becoming more important, success is still poor (Merrow, 2012; Sovacool, Gilbert, & Nugent, 2014).

During the execution phase of large industrial projects, in which the asset is built or constructed, significant decisions need to be made especially in large projects in which uncertainty and changes are significant (Fricke, Gebhard, Negele, & Igenbergs, 2000). The decisions should be aimed at achieving project success. In current practice these decisions are made solely based on the time, cost and quality criteria, without considering the impact of those decisions on the feasibility of the project goal. However, in the final investment decision (FID) made prior to the start of project execution the project goal feasibility is currently assessed. The application of a similar method to decisions made during project execution has not been examined in literature (Gardiner & Stewart, 2000). This research will contribute to the scientific knowledge by examining the impact of decisions during project execution on project goal feasibility. This research will furthermore evaluate whether these decisions during project execution change when the impact of those decisions on the feasibility of the project goal is considered. The main research question therefore is:

"To what extent do decisions during project execution change, compared to current practice, when their impact on the feasibility of the project goal is considered?"

The aim of this master thesis is to contribute to the decision-making knowledge in the execution phase of large industrial projects by comparing the current decision-making practice with a new approach in which project goal feasibility is considered. As the project proceeds, more information becomes available about aspects such as risks, time and cost. This information needs to be integrated into a decision making method to be able to assess the feasibility of the project goal during project execution. To integrate this information for decision making, literature on cost-schedule integration will be examined in more detail in Chapter 5.

In the next chapter, the current decision-making practice in these industrial projects will be further examined and key concepts will be defined. In Chapter 4 the methodology that is used to answer the main research question is further explained and sub-questions are introduced. In Chapter 6, 7 and 8, the analysis of the extent to which decisions during project execution change when their impact on the feasibility of the project goal is considered, is presented. The conclusions and recommendations of this research are stated in Chapter 9 of this report.

3 Literature review

Projects can be distinguished from operations, because projects are temporary and unique endeavors while operations are ongoing and repetitive (Rose, 2013). Projects are initiated to accomplish a specific goal with a specific added value (Kelly, Male, & Graham, 2014; Nicholas & Steyn, 2012).

The term project goal is used in different contradictory ways in the project management literature. The goal of construction projects is frequently defined as the realization or creation of a system or asset. This view is however contested in the papers by (Baccarini, 1999; Ridder, 2016) and (Rose, 2013) in which it is stated that the realization of a system or asset should be seen as (merely) the project output. The project goal provides the rationale behind the project and describes the projects' long-term objective.

The contradictory usage of the term project goal can be explained by looking at the involved stakeholders in industrial projects. Two main stakeholders that are involved in these projects are the owner and the contractor. The owner initiates the project and involves the contractor to realize (build) the asset (Müller & Turner, 2005). The owner specifies the project goal as well as the needed project output to realize this goal. The contractor is involved only up until the delivery of the project output. The contractor therefore only focuses on delivery of the output and no longer on the owner's underlying project goal. Project management focuses on this process of delivering the project output, and therefore defines the project goal differently. In this research the definition by Baccarini (1999) and Ridder, (2016) is used, who define the project goal as the long-term objective as stated by the owner. In industrial projects, the realization of the asset therefore is a means (project output) to an end (project goal).

Projects are unique (Merrow, 2011), which means that a project is subject to uncertainty and risk. Uncertainty is defined as a lack of certainty (Chapman & Ward, 2003). Risks are defined as uncertain future events that, it they occur have a negative or positive impact on the project goal (Hillson & Simon, 2012). At the start of the project it is therefore not known whether the project goal will be achieved. During the project, more information becomes available and uncertainty and risk decreases (Behrens & Hawranek, 1991). The feasibility of the project goal should therefore ex ante be based on expectations and estimates that comprise uncertainty and risks. Project progress as well as risks and uncertainty should therefore be monitored and controlled (Del Cano, 1992). Monitoring involves gathering information, controlling also involves acting on this information, which involves decision-making.

Projects are temporary; they are initiated by the owner with the idea to achieve the expected project goal in a specific amount of time. The project is decomposed into different phases to enable the owner to control and monitor the projects progress. Industrial projects are typically decomposed into the phases seen in Figure 1 (Merrow, 2011). The owner is involved during the whole project, while the contractor is often only involved during the FEED, engineering, procurement and construction phases in which the actual building and construction of the asset occurs. After the execution phase, the project output, the constructed asset, is delivered by the contractor to the owner. The project life cycle (PLC) and operational phase together are defined in this research as the asset life cycle (ALC) (Graham, 2010).

This is visually presented in Figure 1. Achieving the expected project goal will result in a particular benefit to the owner.

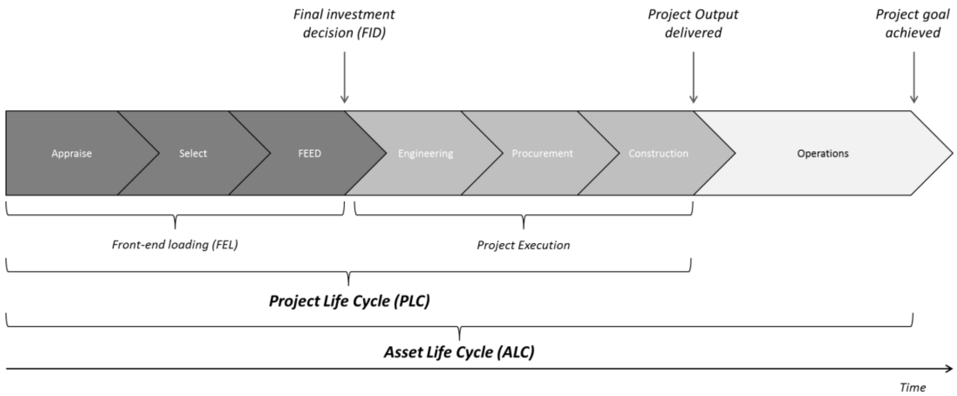


Figure 1: The phases included in industrial projects, adjusted from Merrow (2011)

Before starting a project, in current practice, a feasibility study is conducted to assess the feasibility of achieving the project goal. In industrial projects, often the cost and benefits of investing in the project are evaluated. These feasibility studies are conducted during the front-end-loading (FEL) to assess the feasibility of the project goal. At the end of the front-end-loading, the final investment decision (FID) is made in which the final decision is made whether or not to proceed with the project. The owner proceeds with the project, when the expected benefits outweigh the expected costs of achieving the project goal. Multiple methods are used to assess these cost and benefits. Ye & Tiong (2000) evaluate a large range of tools that are used for investment decisions in projects. The most common decision tools used are: the payback period, return on investment (ROI), the internal rate of return (IRR), the accounting rate of return (ARR) and the net present value (NPV) (Alkaraan & Northcott, 2006). The NPV is most widely applied in practice and emphasized as being the best alternative to other methods based on its theoretical superiority (Tziralis, Kirytopoulos, Rentizelas, & Tatsiopoulos, 2009). The NPV formula can be denoted as:

$$NPV = \sum_{t=0}^{T} \frac{FCF_t}{(1+r)^t}$$

FCF_t = Free cash flow at moment t
r = discount rate
t = time from 0-T (in years)

In this formula, both benefits (positive cash flows) and costs[1] (negative cash flows) are included. The NPV incorporates the time-value-of-money in the discount rate, which indicates that a euro today is worth more than a euro tomorrow, this allows for a clear trade-off between time and costs (Angus, Flett, & Bowers, 2005). The NPV is a one-dimensional criterion, when the net present value of a project

[1] From an accounting perspective the correct term would be expenditure. Expenditures differ from cost, because costs are recorded at the moment the cost is incurred, while expenditures represent cash outflows.

is higher than zero (NPV>0) this indicates that the project's expected benefits outweigh the costs and that the project goal is expected to be feasible.

One major cost for the owner in the cost-benefit analysis is the payment to the contractor for delivery of the project output. If these costs become too high, the expected benefit no longer outweighs the costs. The owner therefore creates constraints for the contractor for the output to be delivered. These constraints comprise: time, cost and quality requirements to which the contractor should comply (Willems & Vanhoucke, 2015). The contractor must deliver the specific output described by quality requirements, within a specific timeframe, while not exceeding the budget. The time, cost, and quality criteria together are called the iron triangle. The specific amounts of these iron triangle criteria agreed upon by owner and contractor before project execution comprise the baseline. The baseline consists of the original estimate and contingency. Contingency is a specific amount added to an estimate in order to deal with small changes. The budget consists of this baseline and additional management contingency.

The owner monitors the performance of the contractor by looking at his ability to stay within these baselines prior to advancing to a new phase. Monitoring time, cost and quality is crucial for the owner, because as long as the baselines are not exceeded, achieving the project goal is expected to be feasible. The time, cost and quality constraints can therefore be seen as a subset of the NPV (Gardiner & Stewart, 2000). They are a subset because some information is not included in the time, cost and quality requirements. These requirements only focus on the execution phase and therefore do not incorporate benefits to the owner, (realized in the operations phase). In other words, the requirements are only concerned with the project output, while the NPV is concerned with the project goal ($T, C, Q, \in NPV$). Furthermore, a clear trade-off between the different requirements is not provided within the iron triangle. The NPV is often used to make the FID (Chan & Chan, 2004). However in order to apply the NPV to decision making during project execution, some adjustments need to be made.

Because of the uncertainty and risk, caused by the uniqueness of large industrial projects, often changes occur during the project execution phase. If changes are minor, the original time, cost and quality baselines will not need to be altered (because contingency is included). In these changes, the contractor attempts to maximize quality, while minimizing time and costs (El-Rayes & Kandil, 2005). Because time, cost and quality requirements are a subset of the NPV, exceeding the baselines will affect the feasibility of the project goal. In large projects, cost and time overruns are very common and can often impact the project to such an extent that the benefits no longer outweigh the costs (Flyvbjerg, 2014). When changes occur during project execution having an impact that will result in exceeding the baselines (cost or time overruns), re-authorization by the owner is needed. To deal with these changes owners (and contractors) need to make decisions. Examples of these decisions involve speeding up the project in order to stay within the time baseline while accepting cost overruns or slowing down the project to stay within the budget while accepting time overruns.

Decision-making involves making a choice from a set of alternatives using criteria (Korhonen, Moskowitz, & Wallenius, 1992). The chosen criteria and information on which the decision is made are crucial. The steps taken in making a decision can be visualized as in Figure 2. First a problem or potential decision to be made needs to be identified, information on the decision is gathered and possible decision alternatives are identified. These decision alternatives are evaluated based on their impact on pre-defined decision criteria. Based on the impact of the decision alternatives on the decision criteria, the preferred alternative is chosen (Bazerman & Moore, 2008; Zeleny & Cochrane, 1973).

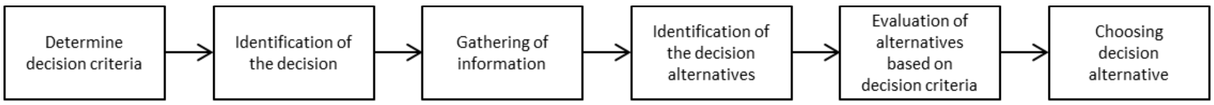


Figure 2: The decision making process, adjusted from (Bazerman & Moore, 2008)

Traditionally in projects, it was believed that by fixing the requirements, changes will no longer occur and decisions will not have to be made during project execution. Decision-making during project execution might be more expensive than making decision in prior phases. However because of the changes occurring in large projects, decisions need to be made (Ibbs, Wong, & Kwak, 2001). In current practice the feasibility study conducted before project initiation is no longer used (or even forgotten) during project execution (Del Cano, 1992).Gardiner & Stewart (2000) found that contractors make significant decisions during project execution: moving milestone dates, reducing quality of the deliverables (capacities etc.), applying additional resources and rearranging workloads, without considering the impact on the feasibility of the project goal. The effect of their decisions during project execution on the project goal is therefore not assessed and because of that suboptimal decisions from a project goal perspective could be made. Even when contractors are obligated to re-authorize their project, because time, cost and quality baselines will be exceeded, there is no obligation to assess the effect on the feasibility of the project goal, even though some contractors believe it would have been the right thing to do (Gardiner & Stewart, 2000; Shenhar, Dvir, Levy, & Maltz, 2001). A possible explanation could be the lack of an incentive to do so, because contractors are only monitored (and rewarded) based on meeting time, cost and quality baselines (Lundin & Hartman, 2012).

The iron triangle requirements allow the owner to monitor and control the project execution, because it allows the owner to break the project into controllable pieces. However, using these criteria in for significant decisions (which could influence the feasibility of the project goal because the baselines are exceeded) could cause problems. The first problem emerges from the fact that time, cost and quality is a subset of the NPV. Project success does not only depend on achieving time, cost and quality baselines (Atkinson, 1999; Ika, 2009; Westerveld, 2003). Project success has been divided by Baccarini (1999) into two distinct features: project management success and product success. Project management success focuses on the process and compliance to cost, time and quality requirements. Product success means achieving the project goal (Baccarini, 1999). This widely accepted view emphasizes that project success depends on achieving the project goal and not (as traditionally believed) only on staying within the iron triangle (Boehm, 2006; Cooke-Davies, 2002; OGC, 2009).

The second problem arises, because time and costs are not translated into a congruent unit. This two-dimensional criterion does not allow for a clear trade-off between time and costs. It is for instance not clear what increase in costs would be acceptable for a reduction in time. Often in practice, either a time-driven strategy, in which minimizing time is considered more important, or a cost-driven strategy, in which minimizing project costs is considered more important, is adopted in an attempt to deal with this problem.

Evaluating the impact of decisions on the feasibility of the project goal during project execution requires a tool which can incorporate the increased amount of available information. Furthermore, risk and uncertainty need to be incorporated because these risks and uncertainties might potentially impact the project (Smith, Merna, & Jobling, 2009). Recent advances have been made that allow for the integration of information on time and costs and their associated risks and uncertainties during project execution (Hulett & Avalon, 2017). In this integrated probabilistic analysis the increased amount of information that has become available during project execution can be incorporated. A single Monte Carlo (MC) simulation is used to integrate time, costs, risks and uncertainty (Hulett et al., 2011). Although the method allows for the incorporation of the increased amount of information about time, costs, uncertainty and risk during project execution, the feasibility of the project goal and a clear trade-off between time and costs provided by the NPV are still missing.

Because of the problems encountered when strategic decisions are evaluated only by their impact on time, cost, and quality, it is proposed that the impact of those decisions on the feasibility of the project goal is assessed. The assessment should incorporate risk and uncertainty relevant to project managers. A method that has received substantial attention is the use of a probabilistic-NPV. This approach also uses a Monte Carlo simulation to determine the probability density function of the NPV (Caron, Fumagalli, & Rigamonti, 2007; Tziralis et al., 2009; Ye & Tiong, 2000). This probabilistic-NPV method has however not yet been applied for decision-making during project execution.

In the next chapter the research methodology applied in this research to answer the main research question is further explained.

4 Research Methodology

To answer the main research question, two case studies are conducted in this research. By using case studies, the current practice in decision-making (in which the time, cost and quality decision criteria are used) could be compared to a new method in which the feasibility of the project goal was considered, represented by the NPV.

4.1 Cases study method

To answer the main research question, the extent to which decisions during project execution change when the impact of the decisions on the project goal is considered needed to be measured. To measure this change, a comparison had to be made between current practice decision making and a new approach in which the feasibility of the project goal was considered.

To measure the effect of a change, an experiment would have been well suited. However, conducting an experiment about decision-making in large engineering projects would not be feasible, because including all required context of such large projects would be impossible. Case studies do allow for this context to be considered (Verschuren, Doorewaard, Poper, & Mellion, 2010).

However, the case studies had to be conducted in a particular way. The case studies used in this research were evaluated by looking at the effect of a change within a project. The effect of the change was modelled and compared to the actual situation. This meant that in the project two things were compared. The first being the actual chosen decision alternative and the second being the decision alternative that should have been chosen based on the impact on the project goal feasibility.

First of all the decisions that were actually made were identified. These decisions did not consider the impact of the different decision alternatives on the feasibility of the project goal. For each decision the associated decision alternatives were identified as well as the actual chosen decision alternative. Secondly, the impact of each decision alternative on the project goal feasibility was modelled, based on which a recommended decision alternative was determined. The actual chosen decision alternative was then compared to the recommended decision alternative. If both alternatives were equal, this would indicate that assessing project goal feasibility would not affect decision-making during project execution. If however both alternatives differed, this would indicate that assessing project goal feasibility during project execution would influence decision-making.

As explained, the evaluated decisions had to be realistic and therefore had to take into account the relevant context. The projects on which the case studies were conducted were selected based on the following requirements. First, because the assessment of the project goal feasibility is less cumbersome when the benefits are quantifiable, the benefits of the evaluated projects had to be quantifiable. For projects in which the goal is related to environment, safety, aesthetics and health, the quantification becomes much more complicated (Ridder, 2016). In industrial projects the main goal of projects is to sell a product for sale, produced by the asset that is created during the project (Merrow, 2011). It is therefore possible to quantify the project goal as being business driven. Therefore in this research two industrial projects in which it was specifically stated that the project was business driven. The input data used for the case studies was taken from these two projects.

4.2 Conceptual model

The conceptual model that was used to compare the decisions that were determined within the case studies is presented in Figure 3. The figure describes the decision making process evaluated in this research. First of all, the identification of the decision, the gathering of information and the identification of the decision alternatives were not altered in this research. Although the case studies were already in the operational phase or at the end of the execution phase, the information that was available at the moment the decision was made was used in the research. Any additional information available after the decision was made was not included. The only step in Figure 3 that was adjusted was the used decision criteria. Instead of the iron triangle criteria, actually used in the case study project, the feasibility of the project goal (NPV) was used. It was examined what the effect was of changing these decision criteria. The impacts of the decision alternatives consisted of the impacts of the decisions on the owner.

For example, assuming that in the project a decision was made with two alternatives. In the project alternative 1 of was chosen. If based on the assessment of the feasibility of the project goal, alternative 2 was recommended, this would imply that when assessing the project goal feasibility alternative 2 should have been chosen instead of alternative 1.

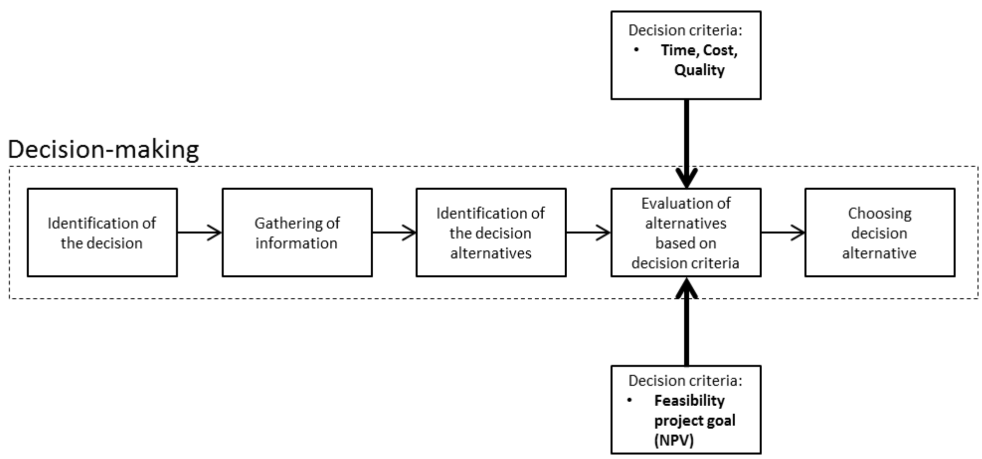


Figure 3: The decision making process, conceptual model, adjusted from (Bazerman & Moore, 2008)

4.3 Research Framework

The research framework used to answer the main research question is presented in Figure 4. In order to be able to answer the main research question, multiple sub-questions were derived.

First of all, to be able to determine the NPV during project execution, an appropriate method had to be applied. Because in current practice the feasibility of the project goal is not assessed during project execution, no clear method existed. The first sub-question therefore was:

Sub-Question 1: "Through what method can the net present value be determined during project execution of a large industrial project?"

Although the NPV is applied before project execution, for the final investment decision, the NPV needs to be adjusted when used during project execution. This is caused by the fact that the increased amount of information should be incorporated, risks and uncertainty should be incorporated and the impact of each decision alternative should be modelled. By conducting a literature study in chapter 5 a method was developed that can be applied to create a net present value model to be used during project execution.

To be able to determine whether or not the same decision alternatives is recommended by the NPV method (as the actual decision alternative chosen in the project) specific decisions need to be assessed. Because the NPV allows for a clear trade-off between time and cost, which is absent in current decision making, decisions in which these trade-offs have been made were examined. Especially decisions in which risks were involved, impacting both time and costs were examined. Furthermore, large changes affecting the project baselines were expected to lead to the most significant results. Small changes not affecting the baseline are therefore not examined in this research. Because of the practice-oriented aspects of this research, the examined decisions should be realistic and are therefore derived from real case study projects. Especially in the complex environments in which large industrial projects take place it is essential to evaluate the decision-making process in the relevant context (Merrow, 2011). To find the decisions and the associated decision alternatives, in Chapter 6 the following sub-questions were answered:

Sub-Question 2a: “What decisions were made in the case study projects?”

Sub-Question 2b: “What decision alternatives were chosen when the impact of the decision alternatives on the currently used criteria was considered?”

After identifying the type of decisions that were made during project execution in large industrial projects, 10 decisions (and the associated decision alternatives) were evaluated against the method determined in chapter 5. To identify the 10 decisions, interviews were held with the involved project managers. Interviews were held, because it was not feasible within the given timeframe of the research, to identify all relevant decisions made in the case study projects based on desk research. It was therefore needed to engage the project managers of the contractor to be able to identify the decisions made in the case study projects. To mitigate any subjective information, the decisions and their impacts had to be documented at the particular moment in time during which the decision was made. Furthermore, because in industrial projects information asymmetries exist between owner and contractor (Müller & Turner, 2005), the contractors possess more information about the project execution phase than owners do, it was required that all decision information had also been available to the owner. If this would not have been the case, the owner could have chosen a specific decision alternative, without having the information needed to make the decision.

The following criteria were used to determine the project managers to be involved in the interviews. First, the project managers were not allowed to be involved in any other part of the research (Appendix 10). Secondly, the project managers had to be involved in the decision making process of the particular case study project. The interviews were first conducted individually to avoid unwanted consensus and after that group meetings were held.

To compare the decision alternatives that are recommended based on the project goal feasibility, derived from the NPV model, and time, cost and quality the following sub-question was in Chapter 6 the following sub-question is also answered:

Sub-Question 3: "What decision alternative is recommended when the impact of the decision alternatives on the feasibility of the project goal is considered?

This question is answered by evaluating the impact of the decision alternatives on the feasibility of the project goal, by using the method developed in chapter 6.

After answering sub-question 2 and 3, the chosen decision alternatives based on the currently used criteria can be compared to the recommended decision alternatives based on project goal feasibility. In the last sub-question, the findings of sub-questions 2 and 3 are compared by answering the following question:

Sub-Question 4: "Are the actually chosen decision alternatives in the projects equal to the decision alternatives recommended based on assessment of the feasibility of the project goal?"

This last sub-question was answered in Chapter 7 by comparing the preferred decision alternative chosen based on sub-questions 2 and 3. When the preferred decision alternatives under question 2 and 3 for a decision differ, this could indicate that the decision would have been different when the iron triangle criteria were used, compared to the feasibility of the project goal criteria.

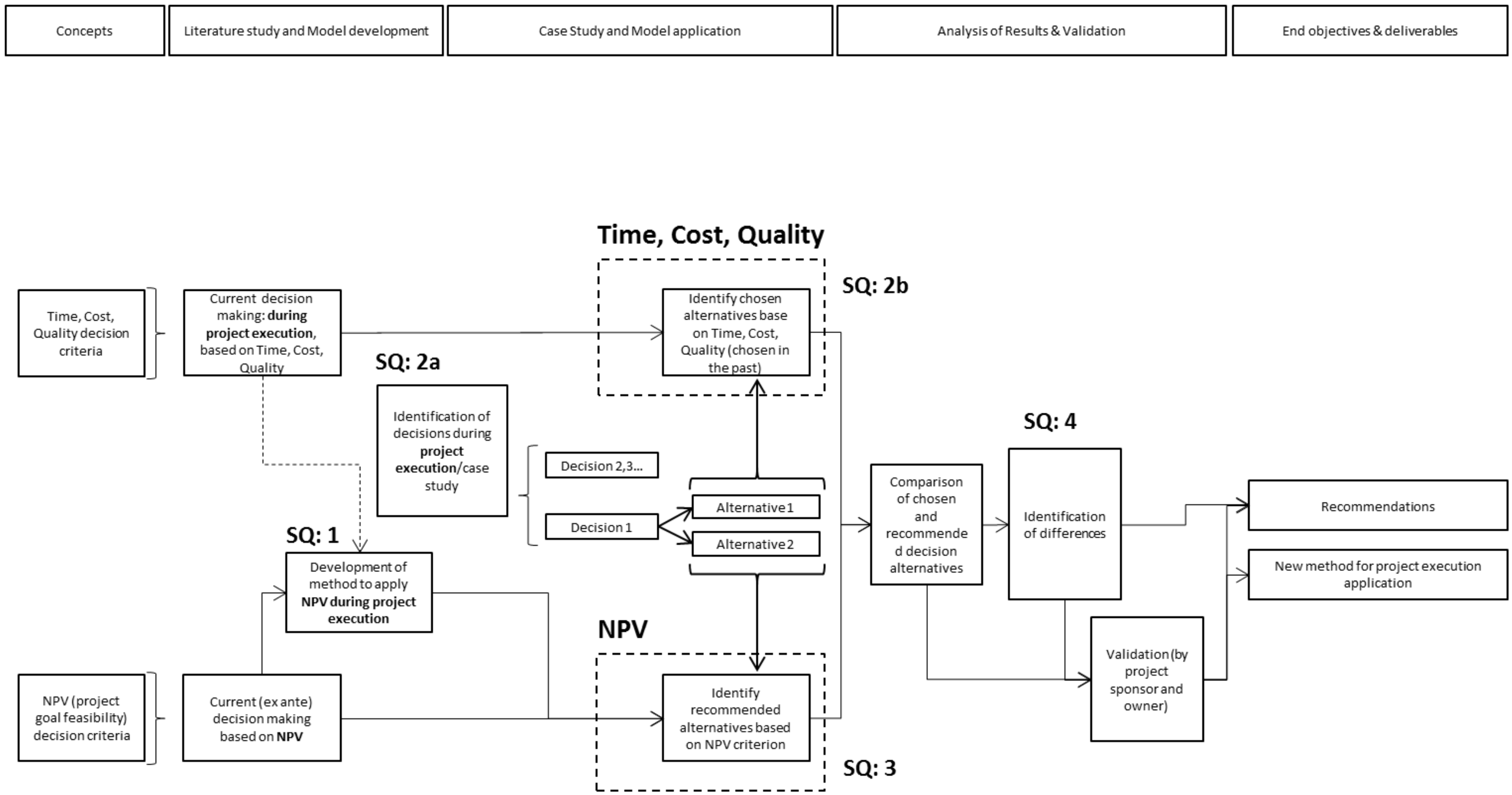


Figure 4: Research framework (own figure)

4.4 Data

As explained in the previous chapter, the assessment of the feasibility of the project goal requires the increased amount of information to be incorporated as well as risks and uncertainty. It is important to emphasize that the increased amount of information refers to all the information available at the specific moment in time at which the decision was made. This requires all information up until the moment at which the decision was made to be incorporated, however any information available after the decision (e.g actual project duration etc.) had to be excluded. The reason is that the actual chosen decision alternative was based only on information available at the moment in time. The decision alternative recommended based on the assessment of the feasibility of the project goal should therefore also only incorporate information available at the same moment. Any insights gained in hindsight would therefore compromise the research.

Because of the previous mentioned data requirements, the input data consists of estimates of time, cost and quality made at the specific moment in time at which the decision in the case study project was made. In addition inputs on risks and uncertainty were used as well as the decision impacts on time, cost and quality and risk and uncertainty. All data is provided by Fluor Corp., the contractor involved in both case study projects.

Because the input consisted of estimates which were subject to uncertainty, their variable impacts are described not by deterministic values, but by distribution functions. Different distribution functions can be. Back, Boles, and Fry (2000) and Fente, Schexnayder, and Knutson (2000) prefer the usage of beta distribution functions. Hulett et al. (2011) prefer the usage of triangular distribution because a great degree of uncertainty is conveyed and the parameters needed for the distribution can be easily collected from experts. Fluor has used triangular distribution functions in the contingency document of the case study projects to indicate uncertainty by determining a low, most likely and high value. Triangular distribution functions will therefore be used to describe uncertainty. Estimated costs are reported monthly in the monthly cost reports. Risks are represented by discrete probabilities (see Appendix 3 for further explanation). Data on these probabilities and impacts is available through the project specific risk register.

The fact that a large amount of the data consists of estimates could create the impression that the used data is very subjective and therefore no robust conclusions can be made. It is however important to note that the input data used for both the chosen decision alternatives based on time, cost and quality and the recommended decision alternative based on the project goal feasibility is equal to a large extent, as presented in Figure 5. From the figure it can be derived that the input data for assessment of the time, cost and quality criteria only differs from the data used for assessment of the feasibility of the project goal because in the latter input data about the operations is also included. It is therefore important for this research that the data about the operations phase is realistic and reliable. To achieve this, the data was validated and an external consultant was involved, who specializes in developing business cases and conducting project goal feasibility studies for owners in this sector. The fact that (subjective) estimates are used is not considered a problem, because it is evaluated whether decisions would change based on the estimates available at that specific moment in time (whether subjective or not).

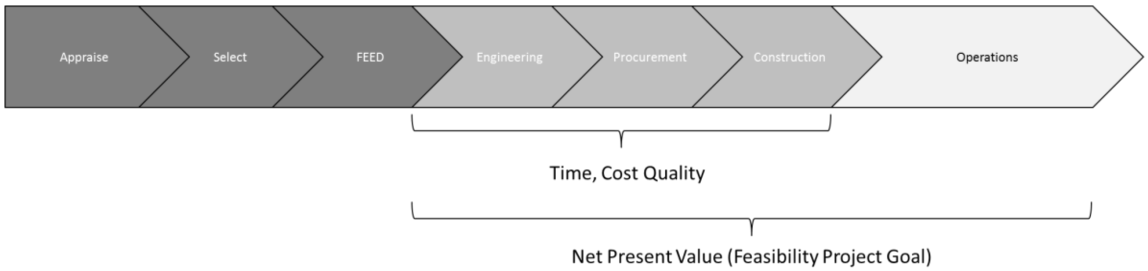


Figure 5: Data on the impact on the net present value

Even when the comparison is made as explained, there is still a possibility that although the assessment of the project goal feasibility recommends a specific alternative, decision-makers decide otherwise (Kahneman & Tversky, 1979). This would indicate that either the validity of the project goal assessment is questioned or that other aspects motivated a particular decision. To avoid making the wrong conclusion by only looking at the modelled impact of the decision alternatives on the project goal feasibility, interviews are conducted with project sponsors and project managers involved in the decision-making process of specific projects. In addition, the research is validated in multiple ways.

4.5 Validation

The validation of the research was divided into three distinct parts: method validation, model validation and decision validation.

Method validation

First of all, because of the introduction of a new method, able to assess the feasibility of the project goal during project execution, the method was validated by industry experts. This validation was conducted, because the method is applied to decisions-making and because of this practice oriented focus, the experts in practice were asked whether they agreed with the applicability of the method in practice and the soundness of the method. Because contractors and owners in the construction sector often have conflicting interests, the method was not only validated by involving the contractor, but also by project management consultants having ample experience as representatives of owners. Furthermore, the method was theoretically validated by academic experts, a list of interviewees is presented in Appendix 7.

Model validation

Secondly, the NPV model used in this research to assess the project goal feasibility could potentially suffer from multiple errors (Ye & Tiong, 2000). Estimation errors caused by an inappropriate cash flow model were only possible to a certain extent. The cash flows during project execution were all based on the estimate models used at the specific moment in time at which the decision was made. These inputs about the project execution phase were used for both the iron triangle method and for assessing the feasibility of the project goal and would therefore not induce any errors (that would compromise the research). NPV specific inputs, such as the discount rate could cause errors, since the discount rate was only used for the NPV model (and not in the iron triangle case). These inputs were therefore derived from the annual reports of the owner and in addition validated by the project sponsor, owner and the earlier mentioned independent consultant. In the first case study project this part of the validation was done with the responsible project sponsor and an independent consultant. In the second case study project the project manager of the owner was also involved. A list of interviewees is presented in Appendix 7. However, to further assess the impact of the made assumptions, a scenario analysis was conducted (in Chapter 7) to determine the effect of changing these assumptions on the results found in the research.

Decision validation

Lastly, the found preferred alternatives that were developed were validated by involving the project sponsors of the specific case study projects. In the first case study project the project sponsor was involved to validate whether or not de decision would have actually changed when assessed from a project goal perspective. In the second case study the project sponsor and project manager of the owner were both involved to assess whether they agreed with the recommended decision alternatives.

5 Method to determine the feasibility of the project goal during project execution

In this chapter the first sub-question is answered: “Through what method can the net present value be determined during project execution of a large industrial project?” by conducting a literature study into the net present value and its application in engineering projects. First the net present value is explained in further detail, after which the newly developed method is motivated and explained. At the end of this chapter the newly developed method is illustrated by an example calculation, to further explain the exact implications of the method.

5.1 The Net Present Value (NPV)

In current practice, the NPV is only used up until the FID to assess the feasibility of the project goal. Because of the incorporated time-value of money, the NPV provides a clear trade-off between time and cost. In addition, the NPV also incorporates the operational phase, allowing decision-makers to incorporate the impact of their decisions on the actual project goal (Gardiner & Stewart, 2000). However, applying the NPV to decisions during the execution phase of projects instead of merely on the final investment decision requires for the NPV to be adjusted.

The Net Present Value (NPV) is used to discount future cash flows by using an appropriate discount rate. Different discount rates can be used, but the weighted average cost of capital (WACC) is often used in practice. The formula of the WACC can be described by:

$$WACC(adj.tax) = r_D * \frac{D}{V}(1 - T_c) + r_E * \frac{E}{V}$$

WACC = weighted average cost of capital (adjusted for tax)
r_D = cost of debt capital
r_E = cost of equity capital
E = company equity value
D = company debt value
V = company value = D+E
T_c = Corporate tax rate

The WACC uses the cost of capital of both equity holders and debt holders. These providers of capital require a specific return from the owner company, the cost of capital, to be compensated for providing either equity or debt. Because of the tax deductibility of interest, the tax shield is included in the formula (Miles & Ezzell, 1980). Because the WACC is adjusted for taxes, the cash flows used in the NPV formula should also be adjusted for taxes (Berk et al., 2013). It is important to note that the WACC reflects the systematic risk of an investment (Berk et al., 2013). The concept of systematic risk will be explained in the following text. The earlier introduced NPV formula can be rewritten as:

$$NPV = \sum_{t=0}^{T} \frac{FCF(after\ tax)_t}{(1 + WACC(adj.tax))^t}$$

$FCF(after\ tax)_t$ = Free cash flow after tax at moment t
WACC = weighted average cost of capital (adjusted for tax)
t = time from 0-T (in years)

The NPV uses cash flows as inputs. Cash flows are distinct from cost, since cash flows resemble the actual cash flow on the moment a payment is made (negative cash flow) or received (positive cash flow). Costs are in contrast to cash flow accounted for on the moment the costs are incurred and are not dependent on the actual payments. To determine the cash flows needed for the NPV calculation, the following formula can be used:

$$FCF = Net\ income + Depreciation - \Delta\ NWC - CAPEX - T_c$$

FCF = Free cash flow (after tax)
CAPEX = Capital expenditures (paid by the owner)
ΔNWC = the difference in net working capital
T_c = Corporate tax rate

When applying this formula to engineering projects, in general the following main cash flows can be distinguished (Espinoza & Morris, 2013). At the start of the project the owner incurs a negative cash flow consisting of capital expenditures (CAPEX) paid to the (main) contractor. When the project output is delivered, these capital expenditures indicate the value of the asset to be depreciated. During the operations phase, the owner receives net income from the operations of the asset adjusted for the earlier mentioned depreciation.

5.2 Incorporating project specific risk into the NPV

Decision making during project execution, requires risk and uncertainty to be incorporated (Smith et al., 2009). It is important to note that risk is defined differently in the finance and business literature in which the NPV was developed, compared to the project management literature. In the finance and business literature risk can be defined as:

"The probability that an investment's actual return will be different than expected. This includes the possibility of losing some or all of the original investment (Kungwani, 2014)."

In project management risk is defined as:

"An uncertain, future event, that, if it occurs has a negative or positive impact on project promises (Hillson & Simon, 2012)."

Both definitions acknowledge that risks comprise both positive and negative effects. However, in project management risks are seen as events that either happen or not (discrete probability). In finance risks are seen as any variation of the return and not merely as events. In this research the definition of risk from the project management literature is adopted. Furthermore, the variation will be defined as uncertainty and uncertainty will be treated as distinct from risk.

Furthermore, risk in the finance literature is divided into systematic and unsystematic risk (Farid, Boyer, & Kangari, 1989). Unsystematic risk or project specific risk can be diversified and does not require a higher return by providers of capital (Sharpe, 1970). In other words, systematic risk increases the WACC, while project specific risk does not (Berk et al., 2013). A visualization of the different risk definitions used in this research is presented in Figure 6. Examples of systematic risks for the construction industry include unanticipated increases in inflation or interest rates, labor shortages, and economic downturn or recession (Farid et al., 1989).

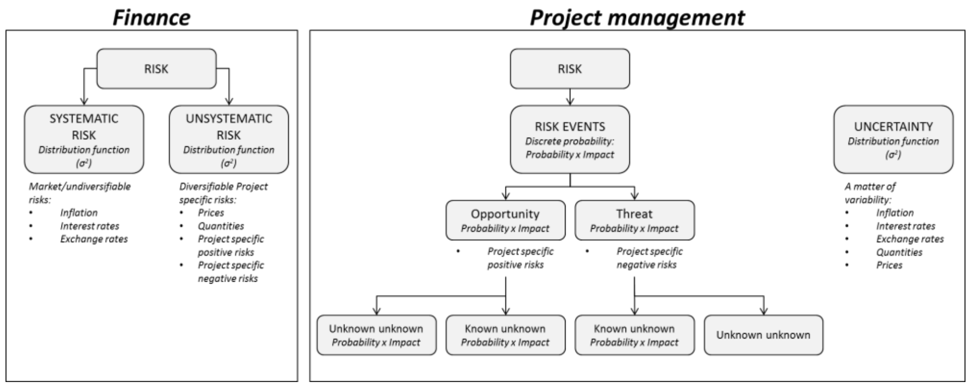


Figure 6: Risk & uncertainty defined in finance and project management

However, from a project management perspective, the project specific risk is important, since these project specific risks influence the performance of the project and diversification is not always desirable (Kim, Hwang, & Burgers, 1993). Project specific risk can be incorporated into the NPV in two distinct ways: either a risk-adjusted discount rate is used, or the risks can be reflected by the cash flows. Using a risk-adjusted discount rate often leads to a constant discount rate, which assumes that the risk profile of the entire project that is being discounted (incl. operations) is equal. However, projects become less risky and uncertain when they become closer to delivery, because more information becomes available and estimates materialize (Farid et al., 1989). Also operations are subject to different types of risks compared to the preceding phases. To be able to incorporate the reduced risks, methods that use a variable discount rate are often used, for example the decreasing discount rate (DDR). In these methods it is however still unclear how to determine the discount rate.

The second method in which uncertainty and risk is incorporated into the cash flows, requires more sophisticated calculations. Traditionally scenario analyses were used to find the impacts of uncertainties and risks. More recently, Monte Carlo (MC) simulations are used to simulate a very large amount of scenarios (10.000+) automatically (see Appendix 3 for explanation of the MC method) (Agarwal & Virine, 2016). By simulating a large amount of scenarios, a distribution function of the NPV can be determined and visually represented by a distribution function. A simplified visualization of an arbitrary NPV distribution derived from a Monte Carlo simulation is presented in Figure 7.

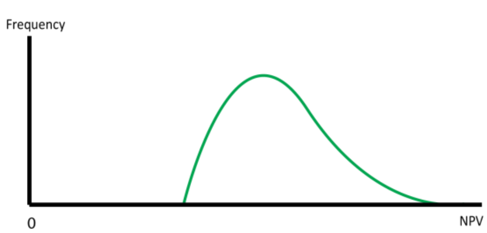


Figure 7: Probability density function of the NPV, derived from the DNPV method

Using Monte Carlo simulation to incorporate the project specific risk into the distribution function of the NPV has been recently been studied in literature. The decoupled-net present value (DNPV) is applied by Espinoza and Morris (2013) to the FID on infrastructure projects. This method uses the WACC as the discount rate while incorporating the project specific risk into the distribution function of the NPV. The similar NPV-at-risk method presented in the paper by Ye and Tiong (2000) also uses the WACC as the appropriate discount rate. A similar method is used by Tziralis et al. (2009). However, these probabilistic-NPV methods have so far only been used for the final investment decision (Espinoza & Morris, 2013; Tziralis et al., 2009; Ye & Tiong, 2000). To be able to use the probabilistic-NPV during project execution, the information about time and costs, available during project execution, needs to be integrated in order to assess the impacts of decisions made during project execution.

5.3 Integration of time and costs information during project execution

Time and cost are traditionally estimated in a deterministic way (Vrijling, 2009). In these types of methods deterministic estimated values are used that do not incorporating uncertainty and risk. More sophisticated methods do incorporate uncertainty and risk, impacting both time and cost, but often use separate Monte Carlo simulations to determine the distribution function of time and the distribution function of cost. These methods therefore do not consider the timing of cost, which is required in order to calculate the probability density function of the NPV.

The further integration of time and cost data, or cost-schedule integration has been studied by multiple authors (Le Isidore, Edward Back, & Fry, 2001). Cost-schedule integration is defined by Le Isidore et al. (2001) as: “the pre-established planning structure used to combine range estimating and probabilistic scheduling such that the simultaneous analysis of the results of these planning tools can be performed.” The earliest methods proposed linking the cost breakdown structure (CBS) used in the cost reports with the work breakdown structure (WBS) used to schedule activities. More recently a method was developed, that relies on mapping the WBS in a network and based on that subdivide the cost of a project. A limitation of this method is the bookkeeping burden that it requires (Le Isidore et al., 2001). However this limitation is primarily an issue when the method is used for controlling purposes. For risk analysis purposes this method has evolved towards the “Integrated cost and schedule risk analysis” (ICSRA) presented by Hulett and Avalon (2017). The “Integrated cost and schedule risk analysis” method consists (amongst others) of the following components: the resource loaded project schedule, applying uncertainty to different types of activities, determining and assigning risks to activities and conducting a Monte Carlo Simulation on both time and cost.

5.4 The Integrated Probabilistic Goal Assessment (IPGA) method

The integrated cost and schedule risk analysis method provides the possibility to combine the uncertainties and risks associated with both time and cost into one single Monte Carlo simulation. By combining the ICSRA method and a probabilistic NPV calculation, the feasibility of the project goal can be evaluated incorporating uncertainty and risk as well as the increase amount of information that has become available during the project execution phase (Hulett & Avalon, 2017). The new method developed by combining the integrated cost and schedule risk analysis and the probabilistic NPV, will be called the “Integrated Probabilistic Goal Assessment” (IPGA) method. The integration of the previously mentioned methods in the IPGA method can be further illustrated by dividing the IPGA method into six steps. These six steps derived from the ICSRA method described by Hulett and Avalon (2017) and the probabilistic NPV methods by Ye and Tiong (2000), Tziralis et al. (2009) and Espinoza and Morris (2013) are presented in further detail below. In paragraph 5.5 the six steps comprising the IPGA method are explained in more detail by an example calculation.

5.4.1 Step 1: Create an integrated resource loaded schedule:

The resource loaded schedule is created in a similar way as described by Hulett and Avalon (2017). From the cost estimated, the contingency is removed, since contingency was added to the estimate to account for uncertainty and risk, which will now be modelled by the distribution function of the NPV. The work breakdown structure is used as the basis for the resource loaded schedule. From this work breakdown structure the project activities are derived. The activities are linked through a schedule network and resources (required for the specific activity) and their associated cost are added to each activity. The schedule should be detailed enough to represent both the interconnection of activities and the risks and uncertainties impacting the specific activities. The level of detail of the model is thus dependent on the specific decisions that will be evaluated.

In this research, this granularity or level of detail, of the model was determined by conducting semi-structured face-to-face interviews with three experts. These experts were selected based on a number of criteria. First of all, these experts had to have substantial experience in industrial projects and scheduling and cost controlling (20+ years). Secondly, these experts were not allowed to be involved in the further thesis research. The resulting schedule networks used for the case study projects are presented in Appendix 1b and Appendix 2b.

5.4.2 Step 2: Determine the expected monthly cash flows:

The NPV formula requires cash flows as input, as well as the exact timing of these cash flows. It is therefore required that the cost estimates recorded in the cost reports are transformed into cash flows. As explained earlier, for cash flows the exact timing of the payment is essential, therefore payment delays are added and the total cost of activities are distributed over the duration of the associated activities.

5.4.3 Step 3: Incorporate data about uncertainty and risk:

Risks are assigned to the specific activities and both their impact on the activity duration and the cash flow of each activity is modelled. The risks are modelled by discrete distribution functions. Uncertainty is represented by triangular distribution functions (Appendix 1). In this research report Palisade @Risk is used to model these distributions.

5.4.4 Step 4: Add data on decision alternatives for a particular decision moment in time:

The previous steps have simulated the project as if no decision alternatives exist. Decision alternatives are added to the model by incorporating their expected impacts on time and costs as well as any risks related to the decision alternatives. Furthermore, it should be emphasized that cost and time estimates are used (and not realized values). Because estimates of cost and time are used, for each decision alternative these inputs must be updated accordingly. Any risks impacting already completed activities should not be included in the model and any cash flow already realized should be considered sunk (Gardiner & Stewart, 2000).

5.4.5 Step 5: Model the NPV distribution function through Monte Carlo simulation for each decision alternative

The IPGA method uses a single Monte Carlo simulation to determine the probability density function of the NPV. Because of the uncertainties and project risks, impacting project durations and cash flows, an analytical approach becomes cumbersome as explained in Appendix 6. A Monte Carlo simulation can offer a solution in those circumstances (Appendix 3). A single Monte Carlo simulation is used to determine the uncertainty and risks of the resource-loaded schedule. The output of this simulation is a distribution function for the NPV for each decision alternative. To perform the Monte Carlo (MC) simulation used in the probabilistic NPV method, Palisade @Risk for Excel is used. Monte Carlo simulation is explained in Appendix 3. Although incorporating the schedule network could have been more easy in scheduling software, such as Primavera (Hulett & Avalon, 2017), the cash flow and NPV functions make spreadsheet software such as Palisade @Risk for Excel a more suitable software tool for the analysis (Gilmer & Druker, 2014). An example of the output obtained when the IPGA method is applied to two decision alternatives is presented in Figure 8.

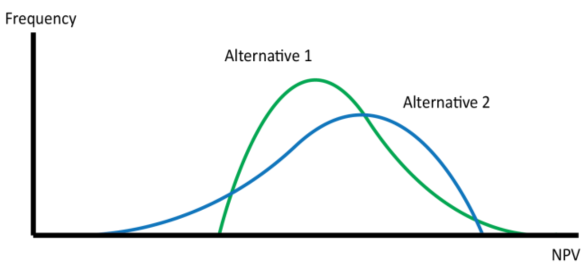


Figure 8: The distribution functions determined through Monte Carlo simulation for the decision alternatives

5.4.6 Step 6: Determine the preferred alternative by using an appropriate decision rule to compare the NPV probability density functions of the used alternatives:

In the previous step, for each decision alternative a distribution function for the NPV was determined. In this last step the distribution functions of the NPVs are compared based on a pre-specified decision rule. The decision rule applied to a deterministic NPV used for investment appraisal is straight forward. The decision rule is to take an investment opportunity as long as the NPV is higher than zero. When applying a probabilistic NPV, this decision rule is no longer applicable and must therefore be adjusted (Ye & Tiong, 2000), (Tziralis et al., 2009). When the probabilistic-NPV is used to evaluate whether or not to invest in a project, a variation of the NPV>0 rule can be applied (Ye & Tiong, 2000). However, when the probabilistic NPV is used to compare two or more decision alternatives another decision rule must be applied. The IPGA method therefore requires another decision rule to compare the NPV distribution functions.

When comparing two mutually exclusive projects, the project should be chosen with the highest NPV (Ross, 1995). This decision rule is straight forward when two deterministic NPVs are compared. However, to determine the highest NPV of two distribution functions this decision rule cannot be readily applied as explained by Figure 8. From the figure it becomes clear that because the distribution functions overlap and the shapes of the distribution functions are unequal, determining which alternative has the highest NPV becomes cumbersome. This example is relevant, because the risks and uncertainties introduced by specific decision alternatives influence the shape of the distribution functions of the NPV (Ye & Tiong, 2000).

The risks impact the tail of the distribution functions (as explained in Figure 6), the NPV distribution functions will therefore potentially be subject to skewness and excess kurtosis (compared to normally distributed data). Because of this the NPV distributions cannot be assumed to be normally distributed. Determining the distribution with the highest NPV value can therefore not be based on parametric statistical testing, since parametric testing requires the assumption of normally distributed distribution functions (Hodges Jr & Lehmann, 1956). Non-parametric testing can be applied when the assumption of normally is violated, however non-parametric statistical tests (e.g. Mann-Whitney U-test, Kolmogorov-Smirnov) require the additional assumption that the variance of both distributions is equal, or that the compared distributions of the NPV (although not normally distributed) are equal (Brooks, 2014). Furthermore, non-parametric tests often do not specify the exact difference between the distribution functions and the required calculations are often extensive and not transparent. Lastly, other methods were found, that overcome the earlier described problems, while not requiring the additional assumptions.

The method described by Caron et al. (2007) as the "net present value at risk" (NPVaR) can overcome the problems associated with statistic testing, since the NPVaR does not require the distribution functions to be normally distributed nor that the distributions or variances are equal (Ye & Tiong, 2000). The net present value at risk ($NPVaR_{\alpha\%}$) is derived from the value at risk ($VaR_{\alpha\%}$) metric, commonly used to evaluate distribution functions of returns (Caron et al., 2007). The $VaR_{\alpha\%}$ is described as:

Given the probability distribution of the return on a given investment, the VaR at level α ($VaR_{\alpha\%}$)for the return is the value, x, for which the probability of obtaining a return less than x is α (Holton, 2003).

In other words, the VaR describes the probability that a return of an investment is less than a specific value. The $NPVaR_{\alpha\%}$ can be described as:

"Given the probability distribution of the NPV, on a given investment, the NPVaR at level α ($NPVaR_{\alpha\%}$)for the NPV is the value, x, for which the probability of obtaining a NPV less than x is α (Caron et al., 2007)."

The $NPVaR_{\alpha\%}$ thus describes the probability (α) that the NPV is less than a specific value (x). In Figure 9 this concept is explained. In the figure, there is a 10% probability (α) that the NPV will be lower than 100 (x). Using the concept of the NPVaR allows for decision alternatives to be evaluated when the distribution of the NPV of those decision alternatives are unequal (and non-normally distributed).

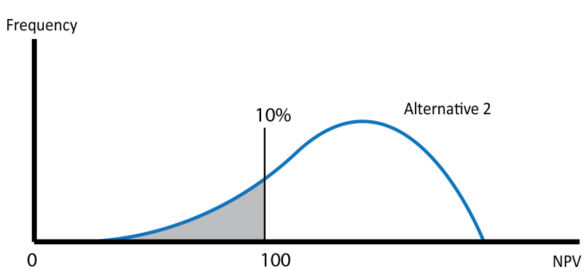


Figure 9: The concept of the NPVaR

The application of the NPVaR to compare decision alternatives is further explained in Figure 10. In the graph on the left side of Figure 10, the NPV distribution functions of alternative 1 and alternative 2 of an arbitrary decision are compared based on the NPVaR. In the left figure, the $NPVaR_{5\%}$ is used to evaluate both alternatives. The $NPVaR_{5\%}$ indicates that there is a 5% probability that the NPV value is lower than a specific value (x). From the figure it can be derived that the $NPVaR_{5\%\ alt1.}$ attains a higher value (x_1) than the $NPVaR_{5\%\ alt2}$ (x_2). This means that there is a 5% probability that the NPV of alternative 1 will be less than x_1, and that there is a 5% probability that the NPV of alternative 2 will be less than x_2. It is therefore recommended based on the $NPVaR_{5\%}$ to choose decision alternative 1.

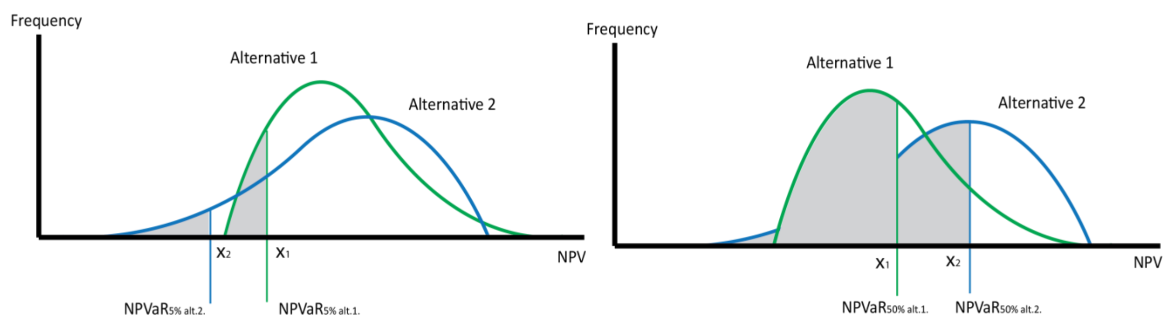


Figure 10: The NPVaR applied to two decision alternatives

However, when comparing the distribution functions of the NPV based on a different value for α in the $NPVaR_{\alpha\%}$, for example the 50% percentile a different outcome is found. Based on the $NPVaR_{50\%}$ found in the right figure, the $NPVaR_{50\%\ alt2}$ value (x_2) is higher than the $NPVaR_{50\%\ alt1}$ value (x_1). The graph on the right side of the figure thus indicates that there is a 50% probability that the NPV of alternative 1 will be less than x_1 and that there is a 50% probability that the NPV of alternative 2 will be less than x_2. It is therefore recommended based on the $NPVaR_{50\%}$ to choose alternative 2.

The previous visualization illustrates the importance of the value of α in the $NPVaR_{\alpha\%}$ metric. The level of α indicates the level of risk aversion of the decision-maker (Ye & Tiong, 2000). A risk averse decision-maker would choose a low value of α (5%), since the probability that the NPV value is lower than the NPVaR is only 5%, in other words the level of certainty is equal to 95%. A less risk averse or risk seeking decision-maker would choose a higher value of α, for example 50%, since the probability that the NPV value is lower than the NPVaR is 50%.

Similarly to the $VaR_{\alpha\%}$, the $NPVaR_{\alpha\%}$ suffers from the limitation that it underestimates tail probabilities or the exact shape of the tails of distributions (Rockafellar & Uryasev, 2002). As presented in Figure 6, the impacts of risks influence the tail of the NPV distribution. These risks impact both the length of the tail as well as the exact shape of the tail. The "conditional value at risk" (C-VaR) was introduced in order to overcome this limiation of the VaR. Similarly to the C-VaR, the ":conditional net present value at risk" (C-NPVaR) overcomes this limitation (Caron et al., 2007).The C-NPVaR metric can be described as:

"The conditional expectation of the NPV given that the NPV is beyond the $NPVaR_{\alpha\%}$ *level (Caron et al., 2007)"*

The added conditionality indicates that the tail of the distribution function of the NPV is evaluated by looking at the average of that tail, given that the NPV value is less than the $NPVaR_{\alpha\%}$ level. The application of the C-NPVaR to compare two decision alternatives is explained in Figure 11.

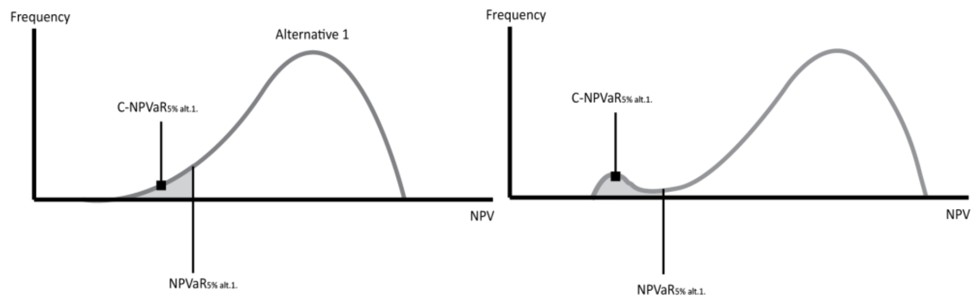


Figure 11: Comparison of impact of the shape of the tail of an NPV distribution function on both the C-$NPVaR_{5\%}$ and $NPVaR_{5\%}$

In Figure 11 the effect of the tail of the NPV distribution on both the NPVaR and C-NPVaR are compared. Because the $NPVaR_{5\%}$ only evaluates the 5% percentile of the NPV distribution, the exact shape of the tail of the NPV distribution does not influence the value of the NPVaR. The negative effect the tail has on the NPV distribution is therefore underestimated. Because the C-NPVaR evaluates the average NPV value given that the NPV value is lower than the $NPVaR_{5\%}$, the C-NPVaR does incorporate these negative effects caused by the exact shape of the tail of the NPV distribution. The C-$NPVaR_{a\%}$ will therefore always indicate a lower NPV value then the $NPVaR_{5\%}$ (Caron et al., 2007).

Similar to the NPVaR, the C-NPVaR does require the decision maker to determine the value α. The value α is dependent on the level of risk aversion of the decision maker. Although it can be justified that owners in the industrial construction sector behave risk averse (Walls & Dyer, 1996), this assumption is not made in the research.

To further explain the concepts introduced so far in this chapter, and the details of the IPGA method, an example calculation is presented in the follow paragraph.

5.5 Example calculation

The 6 steps taken in the integrated probabilistic goal assessment (IPGA) method, explained in the previous paragraph, are explained in more detail in the following example. In the example the distribution functions of two decision alternative are determined through the IPGA method. The decisions are derived from a fictitious project for consisting of only 7 activities. The first 6 activities comprise the activities needed to realize the project output (derived from the WBS). The seventh activity represents the operational phase of the asset, in which commodities (e.g. oil) are produced by the asset and sold.

Step 1: Create an integrated resource loaded schedule:

The first step is to integrate the activity durations and the resources associated with each activity. Each activity requires a specific resource type and duration. Because the first 6 activities comprise the activities needed to realize the project output, these are negative cash flows for the owner. In the operational phase, the owner expects to realize positive cash flows by selling the commodities produced by the asset.

In Table 1 the seven activities are presented as well as the resource types needed to realize the activity. The following resource types, derived from the report by Hulett and Avalon (2017) are distinguished in this report: labor, material, equipment, sub-contracts and indirect. Profit is added to distinguish the operational phase from the previous phases. Labor consists of services provided to the owner for which the payment is based on the needed man-hours. Material consists of bulk materials which are bought in large quantities. Equipment differs from materials it requires development and cannot be bought in bulk quantities. Sub-contracts consist of both a material and a labor part. The indirect resource type is either a combination of the earlier resource types or a variety of other resources (e.g. the rental of facilities).

Activity	Resource type	Activity cost (MEUR)	Start date	Finish date	Activity duration (days)
Activity 1	Material	-30.00M	30-Jun-17	29-Oct-17	123
Activity 2	Labor	-20.00M	29-Oct-17	24-Jan-18	40
Activity 3	Sub-contract	-6.00M	8-Dec-17	24-Apr-18	90
Activity 4	Material	-6.00M	8-Dec-17	25-May-18	121
Activity 5	Material	-5.00M	8-Dec-17	24-Jun-18	151
Activity 6	Material	-5.00M	8-Apr-18	2-Oct-18	130
Activity 7	Profit	82,000,000	14-Nov-18	2-Jun-19	200
Grand Total		10.00M			

Table 1: Resource type per activity, example calculation

The 7 activities are to be conducted in a particular sequence. This sequence can be represented by a schedule network, in which the logical relations of the different activities are visualized. Four logical relations are distinguished: finish-to-start (FS), finish-to-finish (FF), start-to-start (SS) and start-to-finish (SF). For these 7 activities a schedule network has been created as presented in Figure 12.

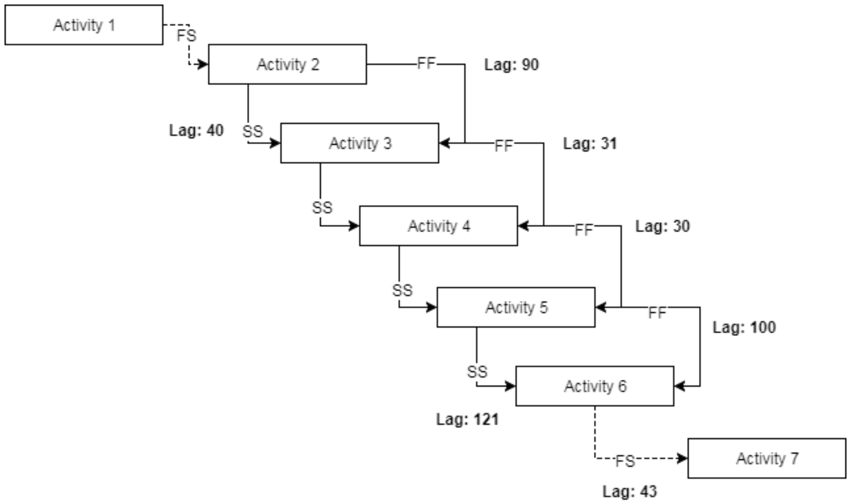


Figure 12: Schedule network, example calculation

The logical relations are enhanced by so called lags. The lags indicated a delay between subsequent activities. For example, from Figure 12 it can be derived that, activity 3 can only start 40 days after activity 2 has started (SS) and activity 3 can only finish 90 days after activity 2 has finished (FF). The granularity of the network included in the resource loaded schedule should not only incorporate the essential activities and logic, but should also allow for the essential risks to be assigned to the activities as well as decision impacts to be modelled.

Step 2: Determine the expected monthly cash flows:

Because in the IPGA method, the net present value is calculated, the cost determined per activity in the previous step, need to be expressed as cash flows. Because the first six activities comprise the (CAPEX) to the owner and the last activity represents profits, the first six activities result in negative cash flows for the owner, while the last activity results in a positive cash flow for the owner. As explained previously, since the weighted average cost of capital (WACC) adjusted for tax is used, the cash flows is also adjusted for taxes (Berk et al., 2013). The created asset is assumed to be linearly depreciated during the operational phase over its lifetime.

To further specify the cash flows, payment delays and advance payments are incorporated in the model. Payment delays consist of the amount of days it takes for the invoice to be paid after receiving the invoice (cost are recorded at invoice date). Advance payments consist of a percentage payment of the total cost, prior to starting an activity. Furthermore, when determining the cash flows per activity, the exact distribution of the total cost over the total duration of each activity must be determined.

The distribution of these cash flows over the duration of an activity is referred to as “cash flow loading”. For example, the monthly rent paid for a temporary facility in a particular project would result in a uniform cash flow loading, since every month the cash flow is equal. However, the payment for man-hours provided in services is dependent on the staffing plan, the actual man-hours spent or forecasted, for the service. The cash flow loadings for each resource type are derived from beta-distributions. These beta-distributions were not derived by the researcher, but were already specified in each case study project and used during the project to make monthly cash flow forecasts. The beta-distribution uses two parameters: α and β. The cash flow loading of each resource type is determined by these parameters. For further explanation on this distribution, see Appendix 3.

The specific resource type assigned to an activity also determines the cost of an activity is time dependent or time independent. An overview of the resource types and the associated, cash flow loadings, time dependencies and beta-distributions used in this research is presented in Table 2.

Resource type	**Cash flow loading**	**Time dependency**	**Beta-distribution**	
			α	**β**
Labor/Services	Staffing plan	Time dependent	2.5	3
Sub-contracts	Contract specific (pre-payment)	Contract specific	Contract specific	Contract specific
Material (Bulk)	Payment at delivery	Time independent	2.5	3
Equipment	Payment through milestone dates	Time independent	16	17
Profit	Uniform (with ramp-up time)	-	-	-
Indirect	Type specific (uniform, or any other)	Time dependent/independent	16	17

Table 2: Resource types and associated cash flow loading, time dependency and beta-distributions.

From Table 2 it can be derived that the costs of activities using labor as resource type are time dependent. Material and equipment are considered time independent, since a delay in material or equipment delivery will not increase the price to be paid for the material or equipment (Hulett & Avalon, 2017). Because sub-contracts consist of both time dependent labor and time independent materials, the ratio of these two resources is important to determine the time dependency of the sub-contract[2], which will be illustrated later on in this example. The indirect type is type specific, since it can comprise a variety of resource types. The beta distributions are visually represented in Figure 13.

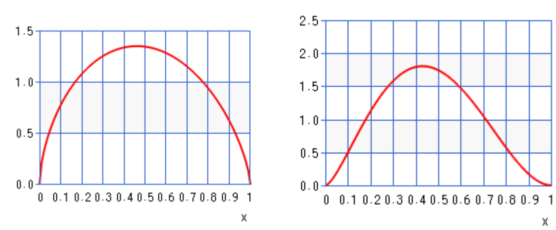


Figure 13: Cash flow loading curves for each distribution type. Left: α=1.6, β=1.7. Right: =2.5, β=3

For each activity the advance payment, payment delay, time dependency and resource type used are presented in Table 3.

[2] The case study projects consisted of reimbursable contracts, in which sub-contracts consisted of both a variable (time dependent) and fixed part.

Activity	Advance payment (%)	Resource type	Variable cost (%)	TD/TI	Start date	Finish date	Payment delay (days)	Start date + Payment delay	Finish date + Payment delay	Duration (days)	Beta-distribution α	β
Activity 1	0.0%	Material	0%	TI	30-Jun-17	31-Oct-17	45	14-Aug-17	15-Dec-17	123	1.6	1.7
Activity 2	0.0%	Labor	100%	TD	31-Oct-17	10-Dec-17	45	15-Dec-17	24-Jan-18	40	2.5	3.0
Activity 3	0.0%	Sub-contract	60%	TD	10-Dec-17	10-Mar-18	45	24-Jan-18	24-Apr-18	90	2.5	3.0
Activity 4	0.0%	Material	0%	TI	10-Dec-17	10-Apr-18	45	24-Jan-18	25-May-18	121	1.6	1.7
Activity 5	0.0%	Material	0%	TI	10-Dec-17	10-May-18	45	24-Jan-18	24-Jun-18	151	1.6	1.7
Activity 6	10.0%	Material	0%	TI	10-Apr-18	18-Aug-18	45	25-May-18	2-Oct-18	130	1.6	1.7
Activity 7	0.0%	Profit			30-Sep-18	18-Apr-19	0	30-Sep-18	18-Apr-19	200		

Table 3: Cash flow distribution inputs

From Table 3 it can be derived that Activity 2 and 3 are the only time dependent (TD) activities included in this example and the sub-contract associated with activity 3 is 60% variable. This means that only 60% of the costs of the sub-contract are time dependent. By combining the information from the schedule network about the sequence of activities and their logical relations with the characteristics of each activity derived from the resource types used, the resource loaded schedule can be determined. This resource loaded schedule is visually represented by a Gantt chart seen in Figure 14.

	31-Jul-17	31-Aug-17	30-Sep-17	31-Oct-17	30-Nov-17	31-Dec-17	31-Jan-18	28-Feb-18	31-Mar-18	30-Apr-18	31-May-18	30-Jun-18	31-Jul-18
Activity	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12
Activity 1		-2.45M	-8.55M	-9.99M	-7.45M	-1.55M							
Activity 2						-8.25M	-11.75M						
Activity 3							-0.07M	-2.28M	-3.11M	-0.54M			
Activity 4							-0.13M	-1.36M	-2.03M	-1.75M	-0.73M		
Activity 5							-0.07M	-0.82M	-1.31M	-1.31M	-1.09M	-0.40M	
Activity 6								-0.50M			-0.07M	-0.98M	-1.41M
Activity 7													
CAPEX		-2.45M	-8.55M	-9.99M	-7.45M	-9.80M	-12.02M	-4.96M	-6.45M	-3.59M	-1.89M	-1.38M	-1.41M
Depreciation													
Corporate Tax													
Free Cash flow (After tax)	0.00M	-2.45M	-8.55M	-9.99M	-7.45M	-9.80M	-12.02M	-4.96M	-6.45M	-3.59M	-1.89M	-1.38M	-1.41M
NPV	2.34M												
Discount rate (yearly)	6%												

	31-Aug-18	30-Sep-18	31-Oct-18	30-Nov-18	31-Dec-18	31-Jan-19	28-Feb-19	31-Mar-19	30-Apr-19	31-May-19	30-Jun-19	31-Jul-19	31-Aug-19
Activity	t=13	t=14	t=15	t=16	t=17	t=18	t=19	t=20	t=21	t=22	t=23	t=24	t=25
Activity 1													
Activity 2													
Activity 3													
Activity 4													
Activity 5													
Activity 6	-1.32M	-0.72M	-0.01M										
Activity 7			12.71M	12.30M	12.71M	12.71M	11.48M	12.71M	7.38M				
CAPEX	-1.32M	-0.72M	-0.01M										
Depreciation			-10.29M	-10.29M	-10.29M	-10.29M	-10.29M	-10.29M	-10.29M				
Corporate Tax			0.73M	0.60M	0.73M	0.73M	0.36M	0.73M	-0.87M				
Free Cash flow (After tax)	-1.32M	-0.72M	11.98M	11.70M	11.98M	11.98M	11.12M	11.98M	8.25M	0.00M	0.00M	0.00M	0.00M

Figure 14: Gantt chart, example calculation

In this example, the corporate tax rate is assumed to be 30% and the yearly WACC adjusted for tax is assumed to be 6%. The monthly cash flows are presented in Figure 14. By discounting the free cash flows (after tax) by the WACC adjusted for tax, a net present value of 2.54 million is found. The cash flows are presented monthly; since monthly payments are made in the projects to be assessed. However, the activity durations are described in days. This enables the model to take into account activity delays to a very detailed level.

To illustrate the effect of resource loading on the distribution of the cash flows over an activity, the cash flow curve of activity 6 is plotted in Figure 15.

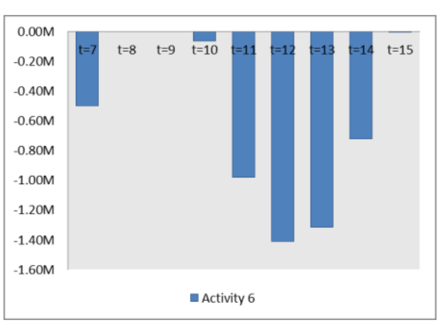


Figure 15: Cash flow curve, activity 6, example calculation

In Figure 15, the cash flow curve of activity 6 is shown. The prepayment of 10% indicated in Table 3 is responsible for the high negative cash flow at t=7. The rest of the cash flow is distributed over t=10 until t=15, based on the beta-distribution (α=1.6, β=1.7). Activity 6 finishes at 18 august 2018, incorporating the payment delay, resulting in a finish date at 2 October 2018. Only 2 days of the activity occur in October 2018, thus leading to the low negative cash flow at t=15. By adding all cash flow distributions as presented in Figure 14, a total free cash flow curve (after tax) of all activities is created. This free cash flow curve is presented in Figure 16.

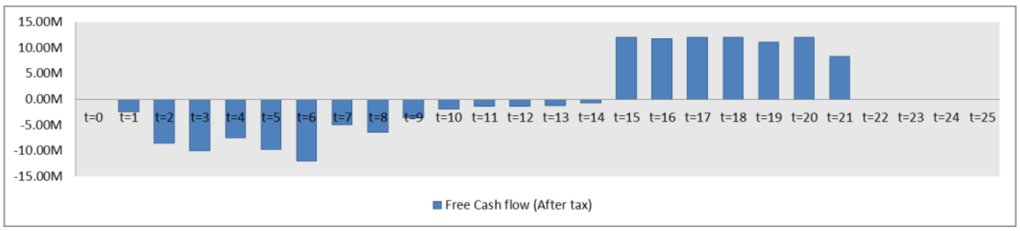


Figure 16: Total free cash flow curve (after tax), example calculation

The cash flow curve (after tax) presented in Figure 16, is a deterministic cash flow curve. In the next step, this deterministic cash flow curve is transformed into a probabilistic cash flow curve by incorporating uncertainty and risk.

Step 3: Incorporate data about uncertainty and risk:

Both the estimated activity duration and the estimated cash flow of each activity are uncertain. The uncertainty about the duration and cost of each activity is indicated in Table 4 by using low and high values in addition to the most-likely values presented in Table 1.

	Activity cost (MEUR)			Activity duration (days)		
	low	most-likely	high	low	most likely	high
Activity 1	-35.00M	-30.00M	-25.00M	100	123	150
Activity 2	-22.50M	-20.00M	-17.50M	30	40	50
Activity 3	-6.50M	-6.00M	-5.50M	60	90	120
Activity 4	-6.50M	-6.00M	-5.50M	100	121	140
Activity 5	-5.03M	-5.00M	-4.98M	100	151	180
Activity 6	-5.03M	-5.00M	-4.98M	110	130	150
Activity 7	82,000,000	82,000,000	82,000,000	200	200	200
Grand Total	1.45M	10.00M	18.55M			

Table 4: Inputs describing the uncertainty of the example

Similarly to the Gantt chart and cash flow curve created for the most-likely values (Figure 13 and Figure 15), Gantt charts and cash flow curves for the other values can be determined. To illustrate the effect of the uncertainty, two extreme Gantt charts are created. The first extreme scenario, presented in Figure 17, consists of the longest durations (high duration) and most negative amount of cost (low cost). The second extreme scenario, presented in Figure 18 consists of the shortest duration (low duration) and least negative amount of cost (high cost).

Activity	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12	t=13	t=14	t=15	t=16	t=17	t=18	t=19	t=20	t=21	t=22	t=23	t=24	t=25
	31-Jul-17	31-Aug-17	30-Sep-17	31-Oct-17	30-Nov-17	31-Dec-17	31-Jan-18	28-Feb-18	31-Mar-18	30-Apr-18	31-May-18	30-Jun-18	31-Jul-18	31-Aug-18	30-Sep-18	31-Oct-18	30-Nov-18	31-Dec-18	31-Jan-19	28-Feb-19	31-Mar-19	30-Apr-19	31-May-19	30-Jun-19	31-Jul-19	31-Aug-19
Activity 1		-2.11M	-7.60M	-9.60M	-8.74M	-6.17M	-0.78M																			
Activity 2							-9.28M	-13.21M	-0.01M																	
Activity 3								-0.05M	-1.78M	-2.82M	-1.69M	-0.16M														
Activity 4								-0.12M	-1.24M	-1.67M	-1.74M	-1.31M	-0.42M													
Activity 5								-0.07M	-0.74M	-1.03M	-1.15M	-1.03M	-0.79M	-0.22M												
Activity 6									-0.50M			-0.09M	-0.81M	-1.13M	-1.12M	-0.95M	-0.42M									
Activity 7																	1.64M	12.71M	12.71M	11.48M	12.71M	12.30M	12.71M	5.74M		
CAPEX		-2.11M	-7.60M	-9.60M	-8.74M	-6.17M	-10.06M	-13.45M	-4.27M	-5.52M	-4.58M	-2.59M	-2.02M	-1.35M	-1.12M	-0.95M	-0.42M									
Depreciation																	-11.51M	-11.51M	-11.51M	-11.51M	-11.51M	-11.51M	-11.51M			
Corporate Tax																	-2.96M	0.36M	0.36M	-0.01M	0.36M	0.24M	0.36M	1.72M		
Free Cash flow (After tax)	0.00M	-2.11M	-7.60M	-9.60M	-8.74M	-6.17M	-10.06M	-13.45M	-4.27M	-5.52M	-4.58M	-2.59M	-2.02M	-1.35M	-1.12M	-0.95M	4.18M	12.35M	12.35M	11.49M	12.35M	12.06M	12.35M	4.02M	0.00M	0.00M
NPV	-3.95M																									
Discount rate (yearly)	6%																									

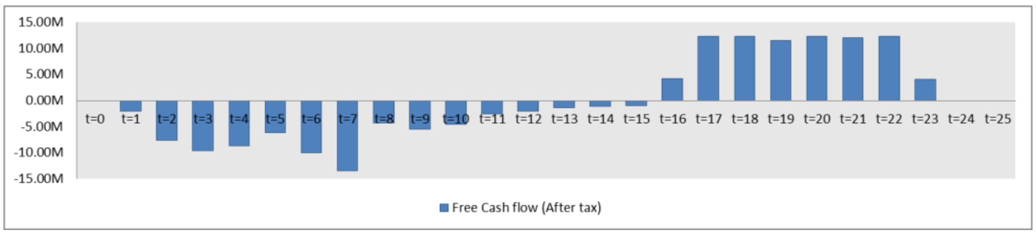


Figure 17: Gantt chart and cash flow curve, longest duration, most negative amount of cost, example calculation

From the Gantt chart and cash flow curve in Figure 17 a NPV of -3.95 M was found. The increased duration and increased cost logically reduced the NPV of the project.

Activity	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12	t=13	t=14	t=15	t=16	t=17	t=18	t=19	t=20	t=21	t=22	t=23	t=24	t=25
	31-Jul-17	31-Aug-17	30-Sep-17	31-Oct-17	30-Nov-17	31-Dec-17	31-Jan-18	28-Feb-18	31-Mar-18	30-Apr-18	31-May-18	30-Jun-18	31-Jul-18	31-Aug-18	30-Sep-18	31-Oct-18	30-Nov-18	31-Dec-18	31-Jan-19	28-Feb-19	31-Mar-19	30-Apr-19	31-May-19	30-Jun-19	31-Jul-19	31-Aug-19
Activity 1		-2.81M	-9.31M	-9.50M	-3.39M																					
Activity 2					-3.33M	-14.17M																				
Activity 3							-2.43M	-3.53M	-0.64M																	
Activity 4							-1.23M	-1.82M	-1.82M	-0.63M																
Activity 5							-0.78M	-1.24M	-1.45M	-1.13M	-0.39M															
Activity 6								-0.50M			-0.85M	-1.45M	-1.43M	-0.74M												
Activity 7														1.23M	12.30M	12.71M	12.30M	12.71M	12.71M	11.48M	6.56M					
CAPEX		-2.81M	-9.31M	-9.50M	-6.72M	-14.17M	-4.44M	-7.09M	-3.90M	-1.76M	-1.24M	-1.45M	-1.43M	-0.74M												
Depreciation														-9.22M	-9.22M	-9.22M	-9.22M	-9.22M	-9.22M	-9.22M						
Corporate Tax														-2.40M	0.92M	1.05M	0.92M	1.05M	1.05M	0.68M	1.97M					
Free Cash flow (After tax)	0.00M	-2.81M	-9.31M	-9.50M	-6.72M	-14.17M	-4.44M	-7.09M	-3.90M	-1.76M	-1.24M	-1.45M	-1.43M	2.88M	11.38M	11.66M	11.38M	11.66M	11.66M	10.80M	4.59M	0.00M	0.00M	0.00M	0.00M	0.00M
NPV	7.86M																									
Discount rate (yearly)	6%																									

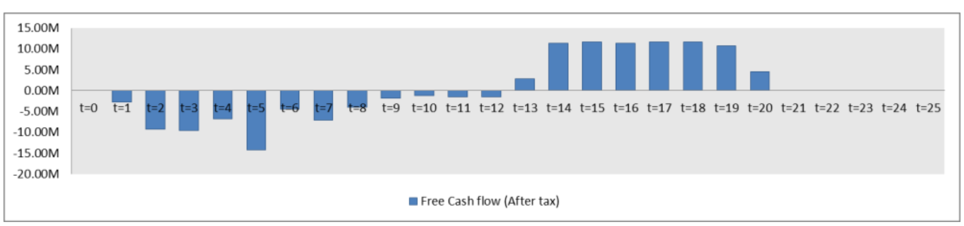


Figure 18: Gantt chart and cash flow curve, shortest duration, least negative amount of cost, example calculation

From the Gantt chart and cash flow curve in Figure 18 a NPV of 7.86M was found. The decreased duration and decreased cost logically increased the NPV of the project.

In addition to uncertainty represented by low, most-likely and high values, risks need to be incorporated in the model. Risks are represented as discrete risks (and are distinct from uncertainty). In the example two discrete risks: risk A and risk B are identified as seen in Table 5.

Risk #	Category	Probability	Impacted Activities	Impact	
				Cost (MEUR)	Time (days)
Risk#A	Discrete	60%	Activity 2	-2.50M	50
Risk#B	Discrete	30%	Activity 5	-2.50M	70

Table 5: Inputs describing the risk of the example

The identified risks in Table 5, both have an impact on activity cost and activity duration. Both risks impact different activities. For simplicity it can be stated that in 60 out of a 100 times, risk A will increase the activity duration of activity 2 by 50 days and will increase the cost of activity 2 by 2.5MEUR. In 30 of 100 times, risk B will increase the duration of activity 5 by 70 days and increase the cost of activity 5 by 2.5MEUR. The risks are assumed to be independent, since in both case studies to be assessed, the risks were also assumed to be independent. It is however acknowledged that valuable insights can be obtained when the potential dependencies of risks are identified (Kwan & Leung, 2011).

In addition to the impacts of each risk on the activities presented in Table 5, the sequence of activities and logical relations creates additional impacts of the risks. These impacts, caused by the time dependencies of the activities and their mutual relationships are illustrated in Table 6.

	Duration (months) (excl. risk events)	Duration estimate (incl. risk events)	Cost estimate (excl. risk events)	Cost estimate (incl. risk events)	TI/TD	Variable costs (%)	Cost estimate (Adjusted)	Difference in cost (cascading/indirect FF effects)	Duration estimate incl. risks and schedule logic	Difference in duration (cascading/indirect FF effects)
Activity 1	**123**	**123**	-30,000,000	-30,000,000	**TI**	**0%**	-30,000,000	0	**123**	**0**
Activity 2	**40**	**90**	**-20,000,000**	**-22,500,000**	**TD**	**100%**	**-22,500,000**	0	**90**	**0**
Activity 3	**90**	**90**	-6,000,000	-6,000,000	**TD**	**60%**	**-8,000,000**	**2,000,000**	**140**	**50**
Activity 4	**121**	**121**	-6,000,000	-6,000,000	**TI**	**0%**	-6,000,000	0	**171**	**50**
Activity 5	**151**	**151**	-5,000,000	-5,000,000	**TI**	**0%**	-5,000,000	0	**201**	**50**
Activity 6	**130**	**130**	-5,000,000	-5,000,000	**TI**	**0%**	-5,000,000	0	**180**	**50**
Activity 7	**200**	**200**	82,000,000	82,000,000	**TI**	**0%**	82,000,000	0	**200**	**0**
		Grand Total	10,000,000	7,500,000			5,500,000			

$$Cost\ TD\ Activity\ 3 = \left(\frac{6{,}000{,}000}{90\ days} * 60\% * 50\right) = 2{,}000{,}000$$

Table 6: Risk effects caused by time dependency and schedule logic

In Table 6 the impact of risk A on the duration and cost of activity 2 is shown. In this table the scenario in which risk A has occurred is illustrated[3]. The duration of activity 2 has increased (with 50 days) from 40 to 90 days. Also the cost of activity 2 has increased (with 2.5MEUR) from 20MEUR to 22.5MEUR. Although activity 2 is a time dependent activity, increasing the duration of activity 2 does not increase the cost of activity 2 apart from the impact of risk A. This effect is incorporated in the model, since the risk impacts are already expressed in both time and cost, and increasing the activity cost based on time dependency would result in erroneously double counting. However, another effect of risk A is illustrated

[3] The most-likely values are used in the first and fourth column, to enable a better understanding of the risk impact.

in Table 6. Because, based on the schedule network from Figure 12, an increase in the duration of activity 2, would result in a later finish date of activity 3 and because of the time dependency of activity 3, the cost of activity 3 increase by 2M. The exact calculation is presented in Table 6. The durations of activity 4, 5, 6 and 7 are also influenced, but because these activities are not time dependent, there is no cost effect[4].

Step 4: Add data on decision alternatives for a particular decision moment in time:

The model is used to evaluate decision making at a particular moment in time during project execution. In this example, a decision is to be made at t=0. For this decision, three decision alternatives are identified, each with their specific impacts.

Decision	Description	Impact cost (MEUR)	Impact duration (days)	Linked to activity*
Alternative 1		0.00M	0	

Table 7: Decision impact example calculation, alternative 1

The first decision alternative has no specific effect on the activities in the example, as presented in Table 7, while the second alternative, presented in Table 8, involves a cost reduction[5] against a longer duration of activity 6.

Decision	Description	Impact cost (MEUR)	Impact duration (days)	Linked to activity*
Alternative 2	Reduce costs while increasing project duration	3.00M	90	Activity 6

Table 8: Decision impact example calculation, alternative 2

In the third activity, a cost reduciton is realized, but a risk is introduced with a probability of 10% and an impact on both the duration and cost of activity 6 as presented in Table 9.

Decision	Description	Impact cost (MEUR)	Impact duration (days)	Linked to activity*
Alternative 3		1.00M		Activity 6

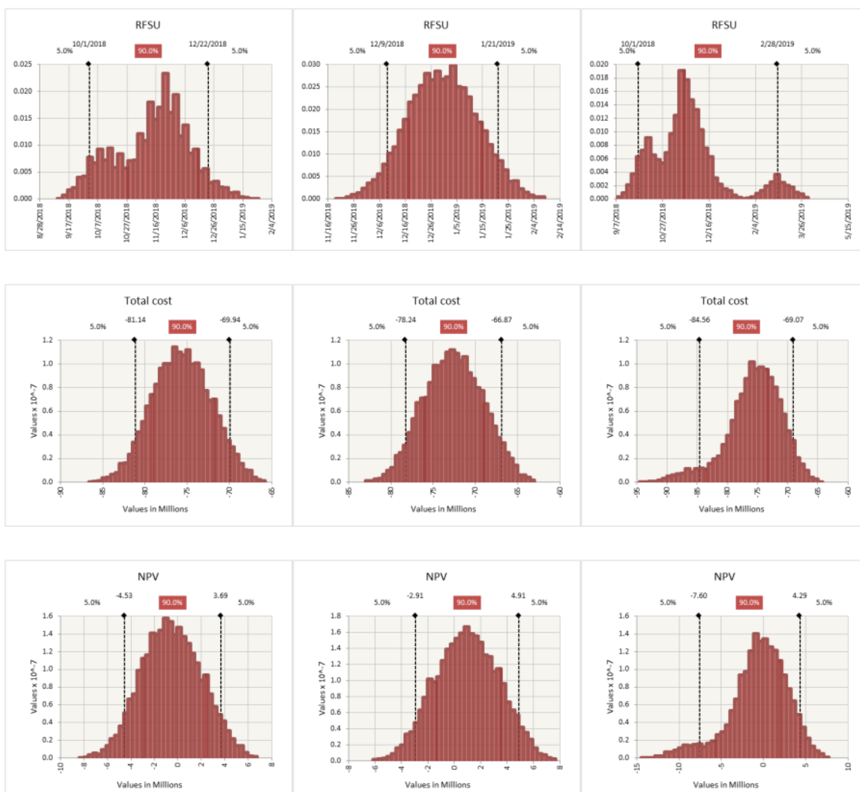
Risk#	Category	Description	Probability	Impact Cost (MEUR) most-likely	Expected Impact Time (days) most-likely	Linked to activity*
Dec 13	Bernoulli		10%	-10.00M	150	Activity 6

Table 9: Decision impact example calculation, alternative 3

[4] This is a very specific situation, but it is included to increase the reader's comprehension of the model.
[5] Cost reductions are represented by positive values while increased costs are represented by negative values.

Step 5: Model the NPV distribution function through Monte Carlo simulation for each decision alternative

In step 2 and 3, three scenarios, with different values for the durations and costs of the activities were evaluated. Instead of merely 3 scenarios, an infinite amount of scenarios can be evaluated, because the values of Table 1 are represented not by 3 extreme values, but by continuous triangular distributions, able to attain any value between the low and high value. Instead of calculating 3 scenarios, 10.000 simulations are calculated by using Monte Carlo simulation. For each decision alternative 10.000 simulations are run, resulting in a distribution function of the NPV for each decision alternative. However to increase the transparency of the model, the determined distribution functions for the total project cash flow (activity 1-6) and the "ready for start-up time" (RFSU) (start date of activity 7) are also included. These distribution functions are presented in Figure 19.



Alternative 1 *Alternative 2* *Alternative 3*

Figure 19: Distribution function of RFSU, Total cost and NPV, alternative 1,2 and 3, example calculation

The distribution functions represented in Figure 19 indicate the effect of risks and uncertainty on the probability density functions of the total cost, RFSU date and NPV. Uncertainty has an effect on the width of the probability density function, while risks influence the tail of the curves. A risk will increase the RFSU date (right tail), will make the total cost more negative (left tail) and would lower the NPV (left tail). Important to note is the RFSU distribution function of alternative 2. The tail of this distribution function is less extreme compared to the tails of alternative 1 and 3. This can be explained by looking at the schedule network in Figure 12.

In alternative 2, the duration of activity 6 is increased by 90 days. From the schedule network in Figure 12 and Table 6 it can be derived that risk A and risk B impacting the duration of activity 2 and 5 and having a cascading effect on the subsequent activities are influenced by alternative 2. Impact of the risks on the duration of activity 2 and 5 will no longer influence activity 6, because the duration of activity 6 has already increased by 90 days. The increase in duration of activity 6 proposed in alternative 2 therefore mitigates Risk A and Risk B.

Step 6: Determine the preferred alternative by using an appropriate decision rule to compare the NPV probability density functions of the used alternatives:

The preferred decision alternative, following the IPGA method, will be determined by comparing the C-$NPVaR_{\alpha\%}$ values of each alternative. First, derived from the NPV distribution functions in Figure 19, NPV values are visually compared in Figure 20.

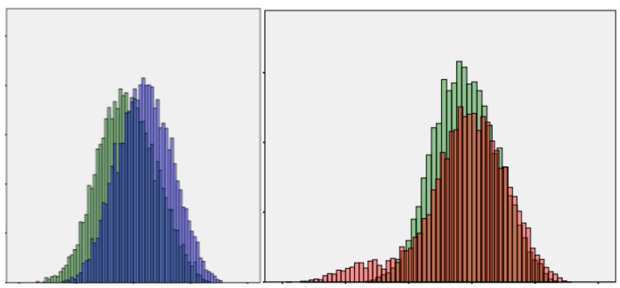


Figure 20: Comparison of NPV distribution functions. Left: alternative 1 and 2, right: alternative 1 and 3.

The $NPVaR_{\alpha\%}$ and C-$NPVaR_{\alpha\%}$ values for the decision alternative derived from the distribution functions of the NPV are presented in Table 10.

Example calculation

$NPVaR_{\alpha\%}$	Alternative 1.1	Alternative 1.2	Alternative 1.3	C-$NPVaR_{\alpha}$	Alternative 1.1	Alternative 1.2	Alternative 1.3
5%	-4.529M	-2.915M	-7.595M	5%	-5.459M	-3.743M	-9.486M
10%	-3.705M	-2.126M	-4.897M	10%	-4.770M	-3.115M	-7.752M
15%	-3.145M	-1.602M	-3.614M	15%	-4.315M	-2.693M	-6.564M
20%	-2.707M	-1.101M	-2.827M	20%	-3.966M	-2.358M	-5.744M
25%	-2.294M	-0.680M	-2.299M	25%	-3.669M	-2.064M	-5.123M
30%	-1.929M	-0.323M	-1.784M	30%	-3.410M	-1.803M	-4.620M
35%	-1.574M	0.025M	-1.359M	35%	-3.173M	-1.567M	-4.197M
40%	-1.226M	0.349M	-0.962M	40%	-2.951M	-1.348M	-3.831M
50%	**-0.592M**	**0.974M**	**-0.245M**	50%	**-2.543M**	**-0.945M**	**-3.205M**
60%	0.100M	1.593M	0.505M	60%	-2.159M	-0.573M	-2.668M
65%	0.451M	1.931M	0.909M	65%	-1.972M	-0.394M	-2.417M
70%	0.822M	2.273M	1.302M	70%	-1.786M	-0.215M	-2.172M
75%	1.224M	2.669M	1.722M	75%	-1.598M	-0.036M	-1.931M
80%	1.674M	3.079M	2.200M	80%	-1.408M	0.146M	-1.692M
85%	2.210M	3.530M	2.733M	85%	-1.211M	0.331M	-1.451M
90%	2.793M	4.112M	3.367M	90%	-1.006M	0.524M	-1.205M

Table 10: $NPVaR_{\alpha\%}$ and C-$NPVaR_{\alpha\%}$ values alternative 1, 2 and 3, example calculation

For illustrative purposes, the $NPVaR_{50\%}$, the median value, of the three alternatives is compared. Based on the $NPVaR_{50\%}$, alternative 2 is preferred over 1 and 3. Furthermore, alternative 3 is preferred over alternative 1. However, the C-$NPVaR_{50\%}$ value should be used as explained in the previous chapter. Based on the C-$NPVaR_{50\%}$ it is concluded that decision alternative 1 is preferred over decision alternative 3. This illustrates the effect of using the C-$NPVaR_{\alpha\%}$ compared to using the $NPVaR_{\alpha\%}$.

The highest contributions of risks and uncertainties are presented in Table 11. This table lists the most important uncertainties and risks and the contribution of these risks and uncertainties to the value of the NPV, the RFSU and total cost of the project. The RFSU (ready for start-up time) indicates the duration of the project up until the project output is ready for operation. The contribution of the specific risks and uncertainties to the variance of the NPV indicates the contribution of the risks and uncertainties to the width of the distribution curves presented in Figure 19.

	Alternative 1			Alternative 2			Alternative 3		
	Change in Output Statistic for NPV			Change in Output Statistic for NPV			Change in Output Statistic for NPV		
Rank	Description	Low	High	Description	Low	High	Description	Low	High
1	Unc.Activity 1	€ (3,001,440)	€ 1,921,949	Unc.Activity 1	€ (1,569,543)	€ 3,599,229	Dec 1.3	€ (7,378,663)	€ 187,969
2	Risk#A	€ (1,764,925)	€ 1,358,311	Risk#A	€ (206,691)	€ 2,721,086	Unc.Activity 1	€ (2,934,672)	€ 1,980,411
3	Unc.Activity 2	€ (1,814,110)	€ 743,520	Unc.Activity 2	€ (257,448)	€ 2,262,801	Risk#A	€ (1,810,552)	€ 1,351,825
4	Risk#B	€ (1,953,823)	€ 121,943	Risk#B	€ (311,078)	€ 1,552,920	Unc.Activity 2	€ (1,957,063)	€ 732,993
5	Unc.Activity 3	€ (1,503,145)	€ 45,904	Unc.Activity 3	€ 135,394	€ 1,510,773	Risk#B	€ (2,029,120)	€ 38,875

	Alternative 1		Alternative 2		Alternative 3	
	Contribution to Variance NPV		Contribution to Variance NPV		Contribution to Variance NPV	
Rank	Description	Contribution to Variance	Description	Contribution to Variance	Description	Contribution to Variance
1	Risk#A	38.2%	Unc.Activity 1	39.3%	Dec 1.3	45.3%
2	Unc.Activity 1	34.7%	Risk#A	36.1%	Risk#A	21.5%
3	Risk#B	13.8%	Risk#B	10.7%	Unc.Activity 1	19.1%
4	Unc.Activity 2	8.6%	Unc.Activity 2	8.9%	Risk#B	7.1%
5	Unc.Activity 3	2.7%	Unc.Activity 3	3.1%	Unc.Activity 2	4.5%

	Alternative 1			Alternative 2			Alternative 3		
	Change in Output Statistic for RFSU			Change in Output Statistic for RFSU			Change in Output Statistic for RFSU		
Rank	Description	Low	High	Description	Low	High	Description	Low	High
1	Unc.Activity 1	26-Oct-18	1-Dec-18	Unc.Activity 1	12-Dec-18	17-Jan-19	Dec 1.3	13-Nov-18	27-Feb-19
2	Risk#B	4-Nov-18	4-Dec-18	Unc.Activity 6	16-Dec-18	13-Jan-19	Unc.Activity 1	5-Nov-18	10-Dec-18
3	Risk#A	28-Oct-18	24-Nov-18	Unc.Activity 1	29-Dec-18	31-Dec-18	Risk#B	15-Nov-18	12-Dec-18
4	Unc.Activity 5	6-Nov-18	24-Nov-18	Unc.Activity 4	29-Dec-18	31-Dec-18	Risk#A	7-Nov-18	3-Dec-18
5	Unc.Activity 2	11-Nov-18	16-Nov-18	Unc.Activity 3	29-Dec-18	31-Dec-18	Unc.Activity 5	18-Nov-18	1-Dec-18

	Alternative 1		Alternative 2		Alternative 3	
	Contribution to Variance RFSU		Contribution to Variance RFSU		Contribution to Variance RFSU	
Rank	Description	Contribution to Variance	Description	Contribution to Variance	Description	Contribution to Variance
1	Risk#B	30.0%	**Unc.Activity 1**	**61.6%**	Dec 1.3	63.6%
2	Risk#A	29.5%	**Unc.Activity 6**	**37.9%**	Risk#A	10.4%
3	Unc.Activity 1	16.6%			Risk#B	8.9%
4	Unc.Activity 5	3.8%			Unc.Activity 1	6.2%
5	Unc.Activity 2	0.5%			Unc.Activity 5	1.1%

	Alternative 1			Alternative 2			Alternative 3		
	Change in Output Statistic for Total cost			Change in Output Statistic for Total cost			Change in Output Statistic for Total cost		
Rank	Description	Low	High	Description	Low	High	Description	Low	High
1	Unc.Activity 1	€ (79,115,490)	€ (72,199,468)	Unc.Activity 1	€ (76,162,841)	€ (68,910,678)	Dec 1.3	€ (84,317,685)	€ (74,582,918)
2	Risk#A	€ (77,322,062)	€ (73,088,325)	Risk#A	€ (74,377,234)	€ (69,980,413)	Unc.Activity 1	€ (78,892,501)	€ (71,973,651)
3	Unc.Activity 2	€ (77,500,788)	€ (73,826,635)	Unc.Activity 2	€ (74,350,007)	€ (70,752,100)	Risk#A	€ (77,253,884)	€ (72,933,154)
4	Risk#B	€ (77,407,190)	€ (74,840,767)	Risk#B	€ (74,489,222)	€ (71,754,547)	Unc.Activity 2	€ (77,526,375)	€ (73,695,192)
5	Unc.Activity 3	€ (77,072,554)	€ (74,765,332)	Unc.Activity 3	€ (73,814,228)	€ (71,830,557)	Risk#B	€ (77,389,104)	€ (74,793,364)

	Alternative 1		Alternative 2		Alternative 2	
	Contribution to Variance Total cost		Contribution to Variance Total cost		Contribution to Variance Total cost	
Rank	Description	Contribution to Variance	Description	Contribution to Variance	Description	Contribution to Variance
1	Risk#A	37.6%	Risk#A	39.3%	Dec 1.3	42.2%
2	Unc.Activity 1	36.7%	Unc.Activity 1	36.1%	Risk#A	22.5%
3	Risk#B	11.2%	Risk#B	11.0%	Unc.Activity 1	21.1%
4	Unc.Activity 2	9.5%	Unc.Activity 2	8.6%	Risk#B	6.2%
5	Unc.Activity 3	3.2%	Unc.Activity 3	3.1%	Unc.Activity 2	5.1%

Table 11: Contribution to change in variance of output values of NPV, RFSU, and total cost, example calculation

The change in the output statistic indicates to what extent the NPV, RFSU and total cost of the project are impacted by the identified risks and uncertainties. The low values indicate the lowest output median found, while the high value indicates the highest output median found. The range thus indicates the impact of the particular risk or uncertainty. For example, the output median of the NPV of alternative 1 affected by Risk A varies between 1,358,311, when the risk does not occur and -1,764,925 when the risk does occur. These low and high values are used, because many risks impact both time and cost (simultaneously), indicating an average impact on the median NPV output would therefore misrepresent the impact of the risks. Furthermore it would only provide information on the average effect (deterministic approach) of the risk on the median value of the NPV and not incorporate any information about the effect on the tails of the distribution functions or the distribution functions in general. It is important to note that a risk decreases the NPV value, increases the RFSU date and decreases the total project cost (since cost are indicated by negative values).

From Figure 12 and Table 6 it can be derived that risk A and risk B impacting the duration of activity 2 and 5 and having a cascading effect on the subsequent activities are mitigated by alternative 2 (as was concluded in the previous text). This is also clear from Table 11, Risk A and Risk B do no longer contribute to the variance or value of the RFSU in alternative 2.

In the next chapter the IPGA method demonstrated in this chapter is applied to two real projects.

6 Case study Application: Project 1 & Project 2

In this chapter, the results from the application of the IPGA method to two case studies are described. For the two case study projects, an answer is provided to sub-question 2a, 2b and 3 regarding: what decisions were identified, which alternatives were chosen during the project and what decision alternatives were recommended by the IPGA method.

6.1 Input data

The input data used in the case study applications to determine the impact of the decision alternatives on the project goal feasibility consisted was similar to the input data presented in the example calculation in Figure 12, Table 3, Table 4 and Table 5 in Chapter 5. The confidential input data used for the case study projects was made available to the committee members. The input data used for the first case study project is presented in Appendix 1, while the input data used for the second case study project is presented in Appendix 2.

Similarly to the tables from the previous chapter, the input data consisted of: the schedule network, cash flow distribution inputs, inputs describing the uncertainty of the project, inputs describing the risks of the project and inputs and assumptions describing the operational phase of the project.

The schedule networks used in the models was based on the typical schedule network used by the contractor in industrial projects (see Appendix 1b and 2b) and the actual used schedule network found in the used Primavera P6 software. These networks were validated by schedule experts. The networks had to enable modelling of the decision impacts, the essential cash flows and the project risks. The schedule networks for both projects were more extensive than the networks used in the example. The schedule network of the first case study project comprised 474 activities. These 474 activities were divided into 4 distinct subprojects as seen in Appendix 1b. The schedule network of the second case study project incorporated 119 activities. In both case study projects the engineering, procurement and construction phases were not sequentially conducted, but overlapped. This was also reflected by the used schedule logic presented in Appendix 1b and 2b.

The cash flows were derived from the cost estimates documented in the monthly cost reports. Payment delays and pre-payments were taken from the invoice register and the specific sub-contracts involved in the project. The beta distributions were derived from the cash flow forecast models. Data on time dependency of activities was provided by the used escalation models. The resulting cash flow distributions are presented in Appendix 1a and 2a.

The uncertainty of the cost estimates consisted of triangular distribution functions documented in the cost contingency models. Inputs on uncertainty of activity durations were not used in the projects. Instead of triangular distribution functions, discrete risks with a triangular impact were documented in the projects. For this reason the risks presented in Appendix 1d and 2d are separated into two distinct categories: discrete and triangular distributed risks. The triangular distributed risks are not exactly the same as uncertainty as defined in this research. However, adjusting the input data would compromise the research, since it is essential that the information available at the moment on which the decision was made is used. Also, adding uncertainty to the project on top of the already identified triangular distributed risks could result in double counting the project uncertainty. The risks were derived from the internal and external risk registers and schedule risk analyses. A total of 146 risks were incorporated in the first case study project (Appendix 1d). In the second case study project a total of 32 risks were incorporated (Appendix 2d). These numbers only include the risks not assigned to specific decision alternatives.

The input data about the operational phase was derived from the information provided by the owner and was assessed by an independent consultant. This also involved the used weighted average cost of capital (adjusted for taxes) and the corporate tax rate. The magnitudes of the operational cash flow, WACC and corporate tax rate are presented in Appendix 1e and Appendix 2e.

Based on the described input data a model was created for each case study project. These models were developed in a similar way as the model presented in the example calculation. However, because of the increased amount of input data, the models developed for the case study projects were more extensive than the model presented in the example. In the next paragraph the first case study project is introduced, after which the decisions made in that particular project are described in more detail.

6.2 Case Study Project 1: Description

The first case study project is an industrial project in Western Europe, which required a significant investment (of approximately one billion EUR). At the start of the project it was clearly stated that the success of the project was dependent on both staying within budget as well as delivering the project output within the estimated project duration. The asset was developed to create a product for sale and the expected lifespan of the asset was 20 years.

Project Summary	Costs (%CAPEX)	Duration (%)	Duration (Months)
FEL	0.15%	1.06%	3
FEED	2.92%	2.82%	8
EPC	96.93%	11.62%	33
Operations		84.51%	240
Total	100%	100%	284

Table 12: General overview case study project 1

The descriptive data presented in Table 12 provides an overview of the durations of the different project phases. The FEED phase as well as the EPC phase of the project was assigned to the same main contractor. For the EPC phase a reimbursable contract between owner and the contractor was used. During the research, the project was already in the operations phase. In Figure 21 the most likely monthly cash flows (after tax), estimated when the FID was made are plotted. This cash flow curve provides insight in the ratio between the estimated CAPEX (and the positive cash flows expected during the operational phase.

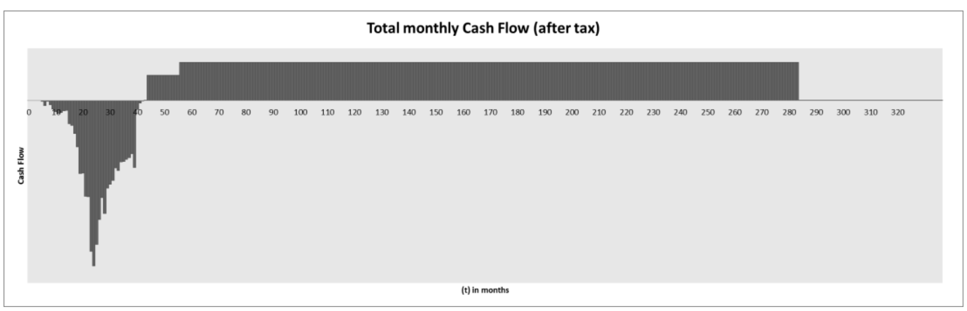


Figure 21: Project 1: Total monthly cash flow (after tax) , most likely values, excluding risks and uncertainty

It is important to note that the actual duration of the project and the actual project cost increased the budget significantly. When the probabilistic distribution functions of the RFSU date and total project cost were used, even in the estimated worst case scenario (highest project cost and highest project duration) the actual value could not have been realized. In other words even when all risks affecting the schedule and cost were included, the estimated project duration and actual project cost were lower than the realized cost. This indicates clearly that in this project the project risks were underestimated. This statement was validated and acknowledged by both project sponsor and project manager involved.

6.3 Case Study Project 1: Decisions

As explained in chapter 4, interviews were conducted with the project managers of the case study project individually, after which a workshop was held. A total of five project managers, representing all relevant disciplines in the project, were involved for this particular project. Each decision involved a trade-off between time and cost between the associated alternatives or an increased amount of risks. For each decision alternative the exact timing on which the decision occurred (relatively to the start of the FEL) is presented. The 6 decisions derived from the interviews are presented in Table 13.

Overview decisions

Decision	**Description**	**Decision moment (months from FEL start date)**
1	Adopt concurrency of FEED and EPC	t=8
2	Acceleration of the engineering schedule	t=10
3	Procure against low cost	t=10
4	Start construction while engineering progress is lacking	t=14
5	Sub-contract discount	t=20
6	Schedule mitigation proposed by sub-contractor	t=22
	Final investment decision (FID)	t=6

Table 13: Decisions made during project execution in case study project 1

The decisions presented in Table 13 are described in more detail in the following paragraphs. For each decision the decision alternatives are introduced as well as the impact of each decision alternative on time, cost and risk. For each decision the alternative that was actually chosen in the project is described. After that the IPGA method is applied to the decision in order to determine what decision alternative is recommended when the feasibility of the project goal is assessed. In other words, for which decision alternative a higher $C\text{-}NPVaR_{\alpha\%}$ value is found.

6.3.1 Decision 1: Adopt concurrency of FEED and EPC 8 months after FEL

In the case study, the first identified decision commenced 8 months after starting the FEL phase. At that particular moment in time, the project was in the FEED phase, and 2 months prior to the decision, the final investment decision was made by the owner to continue with the project with the specified budget and schedule.

The decision was made to start early EPC, which involved already carrying out engineering, procurement and construction tasks, while the FEED phase was not completed. These tasks involved procurement of long lead items and earlier release of information to other sub-contractors and vendors. The FEED was originally planned to last 8 months. To adjust the budget of the FEED phase and EPC phase accordingly, man-hour budgets were shifted from the EPC budget to the early EPC budget.

By already carrying out these tasks prior to finishing the FEED phase, it was expected that the baseline schedule could be met and any schedule delays would be prevented. It was however also indicated that the increased concurrency (overlap of activities) of the FEED and EPC tasks that was introduced by starting early EPC, introduced a risk of rework and potential loss of productivity caused by immaturity of the design, lack of resources and undefined scope of work. These risks, potentially impacting both time and costs were added to the risk register. The two decision alternatives are explained in more detailed.

6.3.1.1 Alternative 1: Adopt concurrency of FEED and EPC up to 3.5 months

The first alternative involved starting early EPC 3.5 months prior to finishing the FEED phase. The risks introduced by this decision alternative are presented in Table 14. A delay in the FEED phase would have a cascading effect on the subsequent phases, impacting design of piling, civil, structural steel and piping activities through the schedule logic as presented in Appendix 1a. The specific risks introduced by this decision and the activities these risks impact upon are presented in Table 14.

Alternative 1.1

Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 1.1. BRMF 4	Discrete	Construction Management resources to support Early Engineering is lacking	90%		-0.25M			15		GEN FEED
Dec 1.1. BRMF 5	Discrete	Construction HSE resources to support Early Engineering is Lacking	90%		-0.50M			20		GEN FEED
Dec 1.1. SRA1 BRMF17,18	Triangular	Design Immaturity, Incomplete Conceptual Basis, Continuing FEED into EPC, causing inefficiencies and potentially impact schedule	60%	-1.200M	-0.90M	-0.90M	30	35	40	GEN FEED
Dec 1.1. SRA17	Triangular	CSA Design Immaturity vs early Contract Awards causing rework and potential schedule impact (Congestion in CSA Engineering causing limited to no flexibility in the design)	30%	-1.200M	-0.90M	-0.90M	5	10	15	TDIK005 Civil Works
Dec 1.1. SRA21	Triangular	Feed punch list items hampering 30% model review and purchasing process	40%	-1.200M	-0.90M	-0.90M	10	15	20	30% Model Review Subproject 1
Dec 1.1. BRMF 1	Discrete	Early contracts to support EPCM phase. Immaturity of SOW impacting baseline and result in scope creep	90%		-0.25M			15		GEN FEED
Dec 1.1. BRMF 33	Discrete	Change on equipment after PO placement, causing escalation on PO pricing and late deliveries – impacting schedule	75%		-0.50M			20		GEN FEED
Dec 1.1. SRA2	Triangular	Subproject 2 IFD	30%	0.000M	0.00M	0.00M	0	5	10	P&IDs IFD Subproject 2

Table 14: Decision impacts project 1, decision 1, alternative 1

6.3.1.2 Alternative 2: Adopt concurrency of FEED and EPC up to 2 months

In the second alternative the early EPC would only commence after the release for design of the data sheets and piping and instrumentation diagrams (P&IDs). This release for design involves the start of engineering activities based on these drawings. The second alternative involved accepting concurrency up to 2 months, which would delay the start of the EPC phase with 1.5 months. This delay would however not require the additional allowances and would not introduce the same amount of risks as was introduced in alternative 1.

Alternative 1.2

Description	Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Dec 1.2. Direct	Delay the start of the EPC phase with 1.5 months		45	GEN FEED
Dec 1.2. Direct	Do not shift manhours from the EPC budget to the Early EPC budget	-6.80M	0	GEN Engineering
Dec 1.2. Direct	Do not shift manhours from the EPC budget to the Early EPC budget	6.80M	0	GEN FEED
Dec 1.2. External BRMF	Avoid Detailed engineering rework Subproject 1	0.16M	-5	60% Model Review Subproject 1
Dec 1.2. External BRMF	Avoid Detailed engineering rework Subproject 2	0.22M	-5	60% Model Review Subproject 2
Dec 1.2. External BRMF	Avoid Detailed engineering rework Subproject 3	0.21M	-5	60% Model Review Subproject 3
Dec 1.2. External BRMF	Avoid Detailed engineering rework Subproject 4	0.49M	-5	60% Model Review Subproject 4

Table 15: Decision impacts project 1, decision 1, alternative 2

6.3.1.3 Results Decision 1

In this decision a trade-off was made between increasing the riskiness of the project (alternative 1.1) and delaying the project while reducing project costs (alternative 1.2). The increased riskiness is reflected in decision alternative 1.1 by the increased width of the probability density function of the NPV. In the case study project, alternative 1 was chosen in this particular decision. For both alternatives the C-NPVaR$_{\alpha\%}$ values were calculated based on the input values presented in Appendix 1. The distribution functions of the NPVs of both decision alternatives are plotted in Figure 22.

NPVaR$_{\alpha\%}$	Alternative 1.1	Alternative 1.2
5%	283.204M	291.173M
10%	288.537M	296.689M
15%	292.097M	300.393M
20%	294.714M	303.187M
25%	297.073M	305.641M
30%	299.413M	307.830M
35%	301.649M	310.116M
40%	303.882M	312.054M
50%	307.925M	315.754M
60%	311.632M	319.614M
65%	313.680M	321.503M
70%	315.694M	323.552M
75%	318.147M	325.953M
80%	320.707M	328.322M
85%	323.577M	331.194M
90%	327.290M	334.452M

C-NPVaR$_{\alpha\%}$	Alternative 1.1	Alternative 1.2
5%	277.520M	285.696M
10%	281.790M	289.907M
15%	284.666M	292.822M
20%	286.867M	295.074M
25%	288.682M	296.950M
30%	290.279M	298.581M
35%	291.745M	300.066M
40%	293.121M	301.448M
50%	295.686M	303.945M
60%	298.033M	306.225M
65%	299.157M	307.330M
70%	300.267M	308.412M
75%	301.376M	309.502M
80%	302.506M	310.602M
85%	303.654M	311.729M
90%	304.861M	312.897M

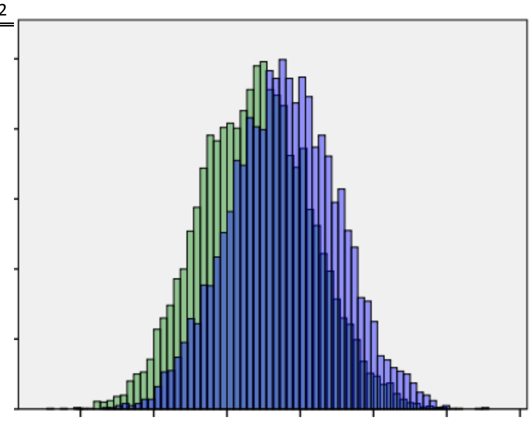


Figure 22: NPVaR and C-NPVaR values, project 1, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

From Table 16 it can be derived that the risks introduced by the first decision alternative (as presented in Table 14) did not contribute to a large extent to the output value of the NPV. Furthermore, the impact of decision alternative 1 did only contribute 2% to the variance of the NPV of decision alternative 1 through both the variance of cost (1.4%) and the variance of the project end date (2.5%), as presented in Appendix 8.

Alternative 1 Change in Output Statistic for NPV				**Alternative 2** Change in Output Statistic for NPV		
Rank	**Name**	**Lower**	**Upper**	**Name**	**Lower**	**Upper**
1	Risk #10	€ 302,907,269	€ 313,366,637	Risk #10	€ 310,694,793	€ 320,663,463
2	Risk #64	€ 302,893,894	€ 313,036,522	Risk #65	€ 310,896,136	€ 320,858,905
3	Risk #65	€ 302,891,040	€ 312,606,767	Risk #64	€ 310,963,994	€ 320,777,821
4	Risk #72	€ 304,174,653	€ 311,597,294	Risk #61	€ 312,258,811	€ 319,392,646
5	Risk #66	€ 304,143,068	€ 311,266,354	Risk #72	€ 312,395,582	€ 319,239,281
6	Risk #61	€ 304,309,772	€ 311,405,236	Risk #66	€ 312,469,762	€ 319,035,157
7	Risk #64	€ 304,904,150	€ 310,474,960	Risk #10	€ 313,276,106	€ 318,170,835
8	Risk #65	€ 305,409,268	€ 310,837,676	Risk #64	€ 313,321,890	€ 318,209,374
9	Risk #10	€ 305,291,853	€ 310,532,862	Risk #64	€ 313,293,020	€ 318,139,144
10	Risk #64	€ 305,094,008	€ 310,276,015	Risk #65	€ 313,422,916	€ 318,215,928

Alternative 1 Contribution to Variance NPV			**Alternative 2** Contribution to Variance NPV	
Rank	**Name**	**Contribution to Variance**	**Name**	**Contribution to Variance**
1	Risk #10	11%	Risk #64	11%
2	Risk #72	11%	Risk #72	11%
3	Risk #61	10%	Risk #61	11%
4	Risk #66	6%	Risk #66	5%
5	Risk #10	5%	Risk #64	5%
6	Risk #64	5%	Risk #10	5%
7	Risk #64	3%	Risk #65	3%
8	Risk #65	3%	Risk #64	3%
9	Risk #10	3%	Risk #65	3%
10	Risk #65	3%	Risk #37	2%
11	Risk #37	3%	Risk #10	2%
12	Dec 1.1. SRA1 BRMF17,18	2%	Risk #14	2%
13	Risk #51	2%	Risk #11	2%
14	Risk #11	2%	Risk #53	2%

Table 16: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 1, decision 1

Although the impact on the NPV was small, the third risk, caused by "design immaturity and an incomplete conceptual basis", was found to impact the RFSU date (Appendix 8). Also the second risk, caused by "a lack of construction resources" was found to impact the project completion date. This indicates that the increased riskiness (alternative 1.1), impacting the duration of the project, was more severe than the direct delay accepted in alternative 1.2. Based on the C-NPVaR values presented in Figure 22, decision alternative 2 was recommended, although the difference in the C-NPVaR values between the two alternatives was small. It was therefore recommended to only adopt concurrency of the FEED and EPC phase up until 2 months.

6.3.2 Decision 2: Acceleration of the Engineering schedule 10 months after FEL

Ten months after the start of the FEL, to shorten the duration of the engineering activities from 18 months to 15 months, the decision was made to reduce the duration of activities, resulting in potential risks impacting both cost and time.

6.3.2.1 Alternative 1: Decrease the schedule duration by altering the customary sequence of activities

In the first alternative the normal duration was altered. The normal procedure involved releasing work packages for sub-contractors and reviewing the 3D model (60% model review) only after information from vendors about purchase orders had become available (Appendix 1a). It was however decided to release the work packages prior to receiving the required vendor information and to plan the 60% model review prior to receiving all vendor information. Because work packages were releases prior to receiving vendor information, revisions of the work packages might be necessary, resulting in rework, impacting both cost and schedule. Because the 60% model review was planned before all vendor data would be available, not all items can be included in the model on time, resulting in delays on downstream activities.

Furthermore, structural steel models were normally released a specific amount of working days after the efficient 60% model review was held. The decision was made to issue the steel model 22 days earlier (at latest). Because of this decrease in working days, the cascading effect of delays in the 60% model review would increase, impacting steel model releases, steel deliveries to site and potentially site activities.

Lastly, isometrics are normally issues after the 90% model review. However, because of the schedule pressure it was decided to start isometrics production before the 90% model review. Also the total duration of the isometrics issue activity was reduced by 1.5 months assuming higher production rate (from 100 to 125 isometrics per week). Because the issuing of isometrics was started earlier, the quality of the drawing might be too low, leading to revisions impacting both time (installation activities) and cost. The potential risks and their impacts, resulting from these activities are presented in Table 17.

Alternative 2.1

Risk#	**Category**	**Description**	**Probability**	**Impact Cost (MEUR)**			**Expected Impact Time (days)**			**Linked to activity***
				low	most-likely	high	low	most-likely	high	
Dec 2.1. SRA 4 BMRF 22	Triangular	Late availability of vendor data causing rework/ longer cycles	30%				5	10	15	15 Activities in total: incl. Mechanical Equipment (Subproject 4) 4-0211
Dec 2.1. SRA 1	Triangular	Late Vendor Data for civil design	30%				5	10	15	60% Model Reviews of all subprojects
Dec 2.1. SRA 010	Triangular	Iso rework due to early Iso Production/Issue	20%	-1.200M	-0.90M	-0.60M	10	15	20	K010 of all subprojects
Dec 2.1. SRA 27	Triangular	Early Iso issue	90%				0	0	10	Isometrics (small bore)
Dec 2.1. SRA 012	Triangular	Changes made to steel models due to late vendor data	50%				0	5	10	K008 Structural steel

Table 17: Decision impacts project 1, decision 2, alternative 1

6.3.2.2 Alternative 2: Do not decrease the schedule duration

In the second alternative, engineering activities would last 3 months longer. The risks, impacting both time and cost would however not be introduced in this alternative. The impacts of this decision alternative are presented in Table 18.

Alternative 2.2

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Release steel models 50 days (instead of 28 days) after 60% model review		22	Subproject 2K008 Structural Steel
Release steel models 50 days (instead of 28 days) after 60% model review		22	Subproject 4 K008 Structural Steel
Release steel models 50 days (instead of 28 days) after 60% model review		22	Subproject 3 K008 Structural Steel
Normal isometrics production rate (125 instead of 100 per week)		45	Isometrics (small bore) Subproject 2
Normal isometrics production rate (125 instead of 100 per week)		45	Isometrics (small bore) Subproject 4
Normal isometrics production rate (125 instead of 100 per week)		45	Isometrics (small bore) Subproject 3

Table 18: Decision impacts project 1, decision 2, alternative 2

6.3.2.3 Results Decision 2

In this decision a trade-off was made between increasing the project riskiness (alternative 2.1) and delaying the project (alternative 2.2). The introduced risks in the first alternative impacted most heavily upon the duration of the activities. This indicates that the delay accepted in the second alternative had a higher impact on the duration of the project (decreasing the NPV) compared to the impact of the risks introduced by the first alternative on the duration of the project.

$NPVaR_{\alpha\%}$	Alternative 2.1	Alternative 2.2	$C\text{-}NPVaR_{\alpha}$	Alternative 2.1	Alternative 2.2
5%	295.074M	290.060M	5%	289.147M	283.789M
10%	300.818M	295.245M	10%	293.632M	288.256M
15%	304.209M	298.957M	15%	296.609M	291.258M
20%	307.161M	301.736M	20%	298.879M	293.541M
25%	309.612M	304.193M	25%	300.792M	295.441M
30%	311.721M	306.423M	30%	302.435M	297.088M
35%	313.705M	308.573M	35%	303.905M	298.582M
40%	315.732M	310.589M	40%	305.256M	299.957M
50%	319.628M	314.125M	50%	307.748M	302.454M
60%	323.600M	318.067M	60%	310.048M	304.730M
65%	325.733M	320.245M	65%	311.170M	305.840M
70%	327.973M	322.389M	70%	312.289M	306.948M
75%	330.332M	324.639M	75%	313.411M	308.051M
80%	332.903M	327.282M	80%	314.548M	309.166M
85%	335.996M	330.119M	85%	315.715M	310.308M
90%	339.777M	333.678M	90%	316.938M	311.503M

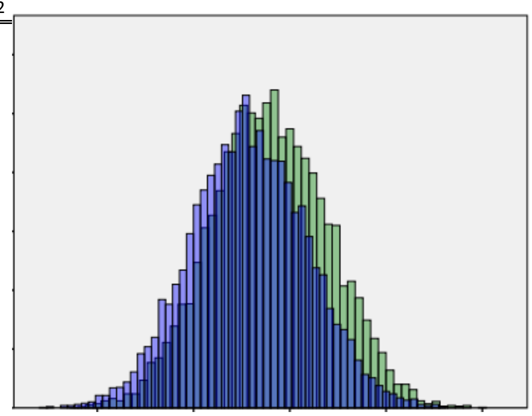


Figure 23: NPVaR and C-NPVaR values, project 1, decision 2, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR values found in Figure 23, decision alternative 1 was also recommended.

6.3.3 Decision 3: Procure against low cost 10 months after FEL

At the start of the procurement activities, the decision was made to reduce the total cost of mechanical equipment. This price reduction of the equipment would be realized by procuring the equipment in a low cost country (LCC), increasing the delivery times of the activities as well as introducing risks.

6.3.3.1 Alternative 1: Procure mechanical equipment in a low cost country, decreasing the purchase price, while increasing the delivery duration and introducing risks

In this alternative, the materials would be procured in an LCC, resulting in a reduced target price of 30% on mechanical equipment compared to the current budget. The decision was made to procure all mechanical equipment in a low cost country (LCC), which would increase the delivery duration by 2 months. In addition the riskiness about the actual delivery dates and the quality of the materials was increased. The risks are presented in Table 19, the direct impacts are presented in Table 20.

Alternative 3.1

Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 3.1. SRA011	Triangular	Longer Deliveries, Materials/Equipment	10%	-1.200M	-0.90M	-0.60M		15		43 Activities in total: incl. Equipment 4-0211
Dec 3.1. SRA3, BRMF6	Discrete	Technical requirements Low Cost Country (LCC) sourcing causing schedule and cost pressure	80%					15		19 Activities in total: incl. Equipment 4-0211
Dec 3.1. SRA 2	Triangular	Late arrival of 20% of the Equipment	30%				10	15	20	2 Activities in total: incl. Equipment 4-0211
Dec 3.1. BRMF12	Discrete	Low cost country sourcing, impacting project TIC, schedule and quality	75%		-0.50M			14		Precommissioning Subproject 4

Table 19: Decision impacts project 1, decision 3, alternative 1

Alternative 3.1

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Low cost country sourcing, cost reductions but procurement increase	8.00M		Equipment (all subprojects)

Table 20: Direct decision impacts project 1, decision 3, alternative 1

6.3.3.2 Alternative 2: Procure mechanical equipment closer to site and pay a higher price

In the second alternative, the materials would not be procured in an LCC, resulting in higher prices, but shorter delivery dates. The impact is presented in Table 21.

Alternative 3.2

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
No late delivery		-75	Mechancial Completion (Total)

Table 21: Decision impacts project 1, decision 3, alternative 2

6.3.3.3 Results Decision 3

In the decision a trade-off was made between increasing the project riskiness while decreasing project cost (alternative 3.1) and decreasing the project duration (alternative 3.2).

$NPVaR_{\alpha\%}$	Alternative 3.1	Alternative 3.2	$C\text{-}NPVaR_{\alpha}$	Alternative 3.1	Alternative 3.2
5%	283.927M	301.257M	5%	274.091M	295.256M
10%	292.929M	306.567M	10%	281.388M	299.671M
15%	298.225M	310.014M	15%	286.189M	302.545M
20%	302.205M	313.090M	20%	289.699M	304.787M
25%	305.390M	315.667M	25%	292.528M	306.709M
30%	308.079M	317.911M	30%	294.909M	308.400M
35%	310.331M	319.953M	35%	296.954M	309.908M
40%	312.759M	321.990M	40%	298.774M	311.291M
50%	317.255M	326.076M	50%	302.032M	313.850M
60%	321.541M	330.046M	60%	304.919M	316.211M
65%	323.639M	332.153M	65%	306.278M	317.357M
70%	325.691M	334.433M	70%	307.590M	318.494M
75%	328.309M	336.784M	75%	308.885M	319.633M
80%	331.084M	339.517M	80%	310.182M	320.789M
85%	334.150M	342.654M	85%	311.497M	321.980M
90%	338.132M	346.221M	90%	312.860M	323.224M

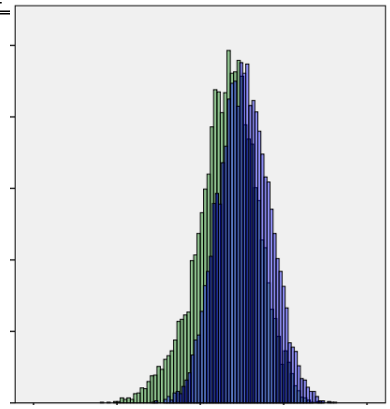


Figure 24: NPVaR and C-NPVaR values, project 1, decision 3, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

From Table 22 it can be derived that risks introduced by decision alternative 3.1 significantly contributed to the output value of the NPV. Furthermore, from Appendix 8 it was derived that the risk introduced by decision alternative 3.1 significantly contributed to the total project cost. It was also found that the impact of decision alternative 1.1, chosen in one of the previously made decisions, impacted both the NPV of decision alternative 3.1 and 3.2.

Alternative 1 — Change in Output Statistic for NPV | **Alternative 2** — Change in Output Statistic for NPV

Rank	Name	Lower	Upper	Name	Lower	Upper
1	Dec 3.1. SRA011	€ 286,991,028	€ 319,479,852	Risk #10	€ 321,052,696	€ 331,492,822
2	Risk #10	€ 310,974,237	€ 321,123,431	Risk #65	€ 321,201,758	€ 331,328,580
3	Risk #64	€ 311,162,422	€ 321,207,962	Risk #64	€ 321,303,688	€ 331,163,755
4	Risk #65	€ 311,552,854	€ 320,814,072	Risk #72	€ 322,441,878	€ 330,191,870
5	Risk #72	€ 312,539,431	€ 319,881,299	Risk #61	€ 322,720,975	€ 329,940,826
6	Risk #66	€ 312,453,656	€ 319,746,810	Risk #66	€ 322,746,434	€ 329,877,529
7	Risk #61	€ 312,750,179	€ 319,306,458	Risk #10	€ 323,490,050	€ 328,895,384
8	Risk #64	€ 313,516,894	€ 318,865,343	Risk #10	€ 323,320,665	€ 328,724,399
9	Risk #10	€ 313,478,247	€ 318,707,172	Risk #64	€ 323,711,479	€ 328,681,546
10	Risk #10	€ 313,566,892	€ 318,614,371	Risk #65	€ 324,075,825	€ 328,839,140

Alternative 1 — Contribution to Variance NPV | **Alternative 2** — Contribution to Variance NPV

Rank	Name	Contribution to Variance	Name	Contribution to Variance
1	**Risk #10**	30%	**Risk #64**	11%
2	Risk #65	8%	Risk #72	11%
3	Risk #72	7%	Risk #61	10%
4	Risk #61	7%	Risk #66	6%
5	Risk #66	4%	Risk #64	5%
6	Risk #64	4%	Risk #10	5%
7	Risk #10	3%	Risk #65	3%
8	Risk #10	2%	Risk #10	3%
9	Risk #64	2%	Risk #64	3%
10	Risk #65	2%	Risk #65 (AA149)	2%
11	Risk #65	2%	Dec 1.1. SRA1 BRMF17,18	2%
12	Dec 1.1. SRA1 BRMF	2%	Risk #37	2%
13	Risk #37	1%	Risk #53	2%
14	Risk #11	1%	Risk #14	2%

Table 22: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 1, decision 3

In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR values presented in Figure 24, decision alternative 2 was recommended. Schedule reduction (3.2) was recommended over cost reduction (3.1). It was therefore recommended based on the IPGA method to procure mechanical equipment from a location closer to site.

6.3.4 Decision 4: Start construction while engineering progress is lacking 14 months after FEL

It was proposed to postpone construction to avoid potential reworks caused by the very tight front end of the EPC phase. Construction was however started as planned in the EPC L2 Schedule with only 17% engineering completion. Normally construction was started with (on average) 50% engineering completion. Site mobilization caused increased costs because of the needed site facilities and staff. Two alternatives were identified in this decision.

6.3.4.1 Alternative 1: Mobilize site with 17% engineering completion

In the first alternative, construction was started as planned in current schedule with only 17% engineering completion. In addition to the risks presented in Table 23, direct costs were introduced, because of the facilities and staff required for the site mobilization.

Alternative 4.1										
Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 4.1. External	Discrete	Additional costs during procurement and construction due to lacking maturity of engineering increased field changes +10% field changes	80%		-0.40M			35		Civil Works Subproject 2
Dec 4.1. External	Discrete	Additional costs during construction due to lacking maturity of engineering increased field changes +10% field changes	20%		-1.00M			35		Civil Works Subproject 4
Dec 4.1. External	Discrete	Additional costs during construction due to lacking maturity of engineering increased field changes +10% field changes	80%		-0.50M			35		Civil Works Subproject 3
Dec 4.1. External	Discrete	Additional costs during construction due to lacking maturity of engineering increased field changes +10% field changes	20%		-1.10M			35		Civil Works Subproject 1

Alternative 4.1			
Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Construction Rework due to early realeaso fo planning documents to support schedule	-1.52M	15	K005 Civil Works (all subprojects)
Civil overdesign due to early release of planning documents to support schedule	-1.49M	15	K005 Civil Works (all subprojects)
2 months extra mobilization (out of 24 months)	-9.57M		

Table 23: Decision impacts project 1, decision 4, alternative 1

6.3.4.2 Alternative 2: Postpone construction until larger percentage of engineering completion is attained

In the second alternative the start of construction was postponed, to avoid potential reworks caused by the very tight front end of the EPC phase. The direct impact is presented in Table 24.

Alternative 4.2			
Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Increased schedule duration		30	K005 Civil Works (all subprojects)

Table 24: Decision impacts project 1, decision 4, alternative 2

6.3.4.3 Results Decision 4

In the decision a trade-off was made between increasing the project riskiness while also increasing project cost (alternative 4.1) or increasing the project duration (alternative 4.2).

$NPVaR_{\alpha\%}$	Alternative 4.1	Alternative 4.2
5%	270.319M	297.614M
10%	279.589M	306.394M
15%	284.633M	311.680M
20%	288.834M	315.490M
25%	292.499M	318.601M
30%	295.647M	321.588M
35%	298.256M	323.992M
40%	300.874M	326.411M
50%	305.874M	330.937M
60%	310.556M	335.322M
65%	313.183M	337.774M
70%	315.677M	339.894M
75%	318.196M	342.424M
80%	321.087M	345.358M
85%	324.415M	348.663M
90%	328.579M	352.785M

$C\text{-}NPVaR_{\alpha}$	Alternative 4.1	Alternative 4.2
5%	259.650M	286.945M
10%	267.721M	294.526M
15%	272.389M	299.436M
20%	276.337M	302.993M
25%	279.703M	305.804M
30%	282.260M	308.201M
35%	284.549M	310.284M
40%	286.610M	312.147M
50%	290.385M	315.449M
60%	293.620M	318.386M
65%	295.189M	319.780M
70%	296.921M	321.139M
75%	298.244M	322.472M
80%	299.543M	323.814M
85%	300.927M	325.175M
90%	302.381M	326.586M

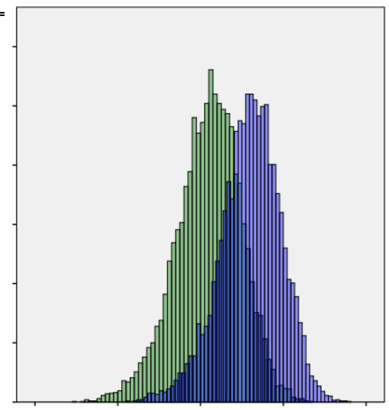


Figure 25: NPVaR and C-NPVaR values, project 1, decision 4, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

Based on Table 25 it was found that the risks introduced by decision alternative 4.1 significantly contributed to both the variance as well as the output of the NPV. Furthermore it was noted that the impact of decision alternative 3.1 made in the previous decision had an impact on both decision alternative 4.1 and 4.2.

Alternative 1 — Change in Output Statistic for NPV | **Alternative 2** — Change in Output Statistic for NPV

Rank	Name	Lower	Upper	Name	Lower	Upper
1	Dec 3.1. SRA011	€ 275,512,274	€ 308,075,898	Dec 3.1. SRA011	€ 301,378,389	€ 333,122,918
2	Risk #64	€ 299,101,295	€ 310,335,370	Risk #10	€ 324,826,520	€ 335,280,736
3	Risk #65	€ 299,218,335	€ 310,319,677	Risk #65	€ 324,795,028	€ 335,197,551
4	Risk #10	€ 299,014,021	€ 310,100,002	Risk #64	€ 324,676,522	€ 334,993,013
5	Dec 4.1. External	€ 302,822,527	€ 311,517,003	Risk #72	€ 326,124,744	€ 333,985,841
6	Risk #72	€ 300,763,611	€ 308,801,190	Risk #61	€ 326,206,225	€ 333,589,260
7	Risk #61	€ 300,684,433	€ 308,680,206	Risk #66	€ 326,158,930	€ 333,529,502
8	Risk #66	€ 300,982,653	€ 308,593,788	Risk #64	€ 327,315,069	€ 332,947,820
9	Risk #47	€ 299,787,011	€ 305,600,753	Risk #65	€ 327,126,301	€ 332,748,784
10	Risk #37	€ 301,951,348	€ 307,564,047	Risk #64	€ 327,249,842	€ 332,818,309

Alternative 1 — Contribution to Variance NPV | **Alternative 2** — Contribution to Variance NPV

Rank	Name	Contribution to Variance	Name	Contribution to Variance
1	Risk #10	25%	Risk #64	27%
2	Risk #64	8%	Risk #65	8%
3	Risk #61	8%	Risk #61	8%
4	Risk #66	8%	Risk #72	8%
5	Risk #72	4%	Risk #66	4%
6	Dec 4.1. External	4%	Risk #65	4%
7	Risk #37	4%	Risk #10	3%
8	Risk #64	3%	Risk #10	2%
9	Risk #65	2%	Risk #64	2%
10	Risk #10	2%	Risk #64	2%
11	Risk #64	2%	Risk #65	2%
12	Risk #65	2%	Risk #37	2%
13	Risk #10	1%	Dec 1.1. SRA1 BRMF17,18	2%
14	Dec 1.1. SRA1 BRM	1%	Risk #53	2%

Table 25: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 1, decision 4

In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR values presented in Figure 25, decision alternative 2 was recommended. However, based on the validation interviews with the sponsor it was found that the choice for alternative 1 was motivated by other reasons. It was explained that the site was mobilized earlier, because it allowed the owner to signal to its shareholders that the project was on schedule. Because of this motivation it is assumed that the IPGA decision alternative chosen in the project will not change based on the assessment of the feasibility of the project goal.

6.3.5 Decision 5: Sub-contract discount 20 months after FEL

During the mechanical and piping contract award (the largest contract in the project) it was agreed to allow for the sub-contractor to start with the installation of mechanical and piping equipment and materials only when all needed information and materials were available.

6.3.5.1 Alternative 1: Accept the clause against a price reduction

In the first alternative, the clause was added to the contract, resulting in a price reduction. The inclusion of the clause would delay the start of the mechanical and piping installation. Furthermore, late delivery of materials, equipment or information would cause the sub-contract not to start the mechanical and piping installation. For this clause a price reduction was given by the sub-contractor to the owner as presented in Table 26.

Alternative 5.1

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
	7.50M	75	K010 All subprojects

Table 26: Decision impacts project 1, decision 5, alternative 1

6.3.5.2 Alternative 2: Pay a higher price to the sub-contractor

In the second alternative, the price reduction was not provided by the sub-contractor and therefore a higher price would have been paid by the owner. This would however exclude the contract clause, resulting in an earlier start date of the mechanical and piping installation.

6.3.5.3 Results Decision 5

In the decision a trade-off was made between a cost reduction while allowing a delay (alternative 5.1) or not allowing the delay and therefore not receiving the cost reduction (alternative 5.2).

$NPVaR_{\alpha\%}$	Alternative 5.1	Alternative 5.2
5%	293.696M	313.707M
10%	302.338M	322.443M
15%	307.344M	328.547M
20%	311.687M	332.775M
25%	315.458M	336.579M
30%	318.591M	339.913M
35%	321.576M	342.709M
40%	324.256M	345.455M
50%	329.374M	350.909M
60%	334.817M	355.765M
65%	337.484M	358.675M
70%	340.256M	361.665M
75%	343.385M	364.601M
80%	346.911M	367.981M
85%	350.949M	372.085M
90%	356.143M	377.022M

$C\text{-}NPVaR_{\alpha}$	Alternative 5.1	Alternative 5.2
5%	283.748M	303.760M
10%	291.059M	311.185M
15%	295.670M	316.042M
20%	299.149M	319.715M
25%	302.052M	322.728M
30%	304.549M	325.325M
35%	306.764M	327.613M
40%	308.796M	329.678M
50%	312.394M	333.378M
60%	315.681M	336.703M
65%	317.256M	338.281M
70%	318.800M	339.847M
75%	320.334M	341.397M
80%	321.884M	342.949M
85%	323.467M	344.536M
90%	325.136M	346.199M

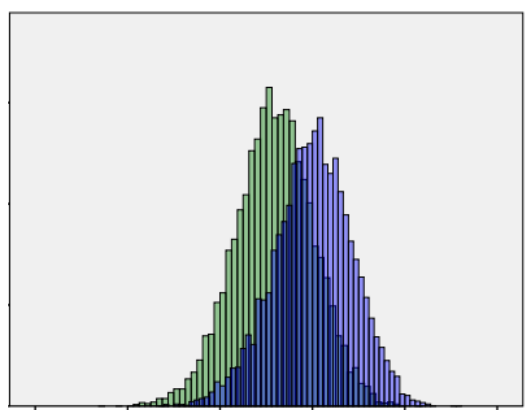


Figure 26: NPVaR and C-NPVaR values, project 1, decision 5, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

In this decision no risks were introduced, therefore the contributions of those risks to the NPV are not presented. In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR values found in Figure 26, decision alternative 2 was recommended. This indicated that schedule reduction (5.2) was recommended over a cost reduction (5.1).

6.3.6 Decision 6: Schedule mitigation proposed by sub-contractor 22 months after FEL

During construction, a proposal to mitigate schedule delay by 5 weeks on the construction of the offices was made by a sub-contractor. The sub-contractor required additional payments for this acceleration, resulting in extra costs for the owner.

6.3.6.1 Alternative 1: Reject the proposed schedule delay mitigation

In the first alternative the acceleration was accepted, resulting in additional acceleration cost for the owner, while decreasing the duration of the control building construction. The direct impacts are presented in Table 27. No immediate risks were indicated or documented.

Alternative 6.1 Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
	-0.50M	-35	Subproject 2 K001 Control Building

Table 27: Decision impacts project 1, decision 6, alternative 1

6.3.6.2 Alternative 2: Accept the proposed schedule delay mitigation, increasing cost

In the second decision alternative, the schedule delay mitigation, proposed by the sub-contractor was rejected by the owner. The impact of this alternative was that the schedule mitigation was not conducted and acceleration costs were not paid.

6.3.6.3 Results Decision 6

In the decision a trade-off was made between increasing the project cost while decreasing the project duration (alternative 6.1) not interfering. No risks were introduced in this decision.

$NPVaR_{\alpha\%}$	Alternative 6.1	Alternative 6.2
5%	286.145M	286.330M
10%	294.326M	294.217M
15%	300.035M	299.795M
20%	304.339M	304.348M
25%	308.386M	308.176M
30%	311.781M	312.080M
35%	314.897M	315.339M
40%	317.874M	318.391M
50%	324.426M	324.192M
60%	330.696M	330.272M
65%	333.871M	333.486M
70%	337.422M	336.857M
75%	341.099M	340.371M
80%	345.458M	344.462M
85%	350.285M	349.530M
90%	355.889M	355.783M

$C\text{-}NPVaR_{\alpha}$	Alternative 6.1	Alternative 6.2
5%	277.399M	276.242M
10%	283.939M	283.401M
15%	288.449M	287.989M
20%	291.885M	291.552M
25%	294.787M	294.495M
30%	297.332M	297.117M
35%	299.607M	299.496M
40%	301.705M	301.665M
50%	305.618M	305.601M
60%	309.274M	309.195M
65%	311.044M	310.939M
70%	312.804M	312.668M
75%	314.566M	314.396M
80%	316.360M	316.143M
85%	318.204M	317.952M
90%	320.133M	319.869M

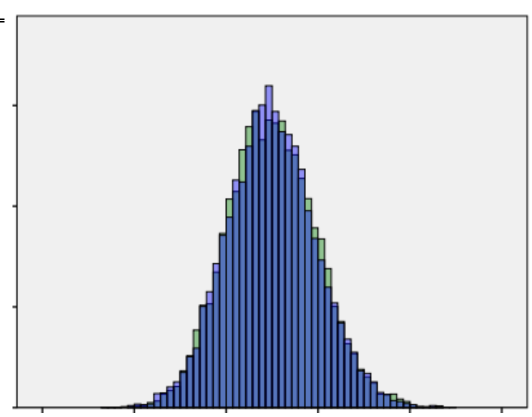


Figure 27: NPVaR and C-NPVaR values, project 1, decision 6, and distribution functions of the NPV (green =alternative 1, blue = alternative 2)

In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR value, no decision alternative was recommended, since no significant[6] differences between the C-NPVaR values presented in Figure 27 were found.

[6] Non-parametric tests were conducted to evaluate whether the distribution functions of the NPVs of both alternatives differed.

6.4 Case Study Project 2: Description

The second case study project is an industrial project in Western Europe, which required an investment (of under a half billion EUR). The project is currently being executed, and is therefore still in the EPC phase. The FEED phase as well as the EPC phase of the project was assigned to the same main contractor. A reimbursable contract with incentive fee was decided upon for the EPC between the owner and the contractor. The project comprised the construction of multiple modules at a yard outside of Europe. The descriptive data presented in Table 28 provides an overview of the durations of the different project phases.

Project Summary	Costs (%CAPEX)	Duration (%)	Duration (Months)
FEL	0.14%	1.15%	3
FEED	2.07%	3.46%	9
EPC	97.80%	10.77%	28
Operations		84.62%	240
Total	100%	100%	280

Table 28: General overview case study project 2

In Figure 21 the most likely monthly cash flow (after tax), estimated when the FID was made is plotted. This cash flow curve provides insight in the ratio between the CAPEX (negative cash flow at the start of the project) and the positive cash flows expected during the operational phase.

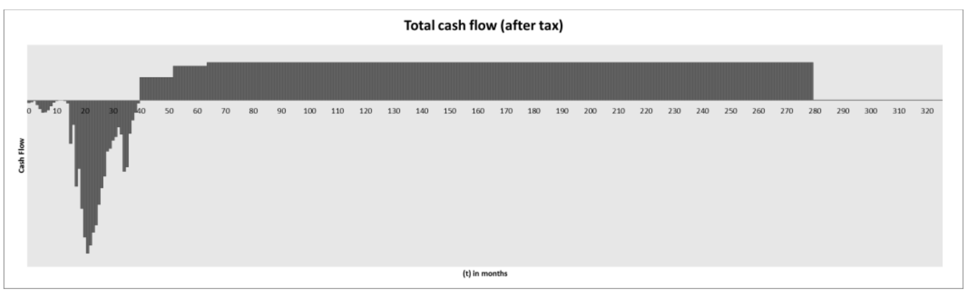


Figure 28: Project 2: Total monthly cash flow (after tax) , most likely values, excluding risks and uncertainty

Also in this project the actual duration of and the actual project cost increased the budget significantly. When the probabilistic distribution functions of the RFSU date and total project cost were used, even in the estimated worst case scenario (highest project cost and highest project duration) the actual value could not have been realized. In other words even when all risks affecting the schedule and cost were included, the estimated project duration and actual project cost were lower than the realized cost. This indicates clearly that in this project the project risks were underestimated. This statement was validated and acknowledged by both project sponsor and project manager involved.

6.5 Case Study Project 2: Decisions

As explained in chapter 4, interviews were conducted with the project managers of the case study project individually, after which a workshop was held. Two project managers were involved for this particular project. Each decision involved a trade-off between time and cost between the associated alternatives or an increased amount of risks. For each decision alternative the exact timing on which the decision occurred (relatively to the start of the FEL) is presented.

In this particular project a total of 4 decisions were identified and examined. For each decision alternative the exact timing on which the decision occurred (relatively to the start of the FEL) is presented in Table 29.

Decision	Description	Decision moment (months from FEL start date)
1	Schedule Acceleration	t=9
2	Adopt concurrency of FEED and EPC	t=9
3	Accelerate module delivery	t=16
4	Accept the absence of float between EP&C	t=18
	Final investment decision (FID)	t=7

Table 29: Decision list case study project 2

In the case study project, for all decisions, the first decision alternative was chosen. The decisions impacted the budget as well as the schedule.

6.5.1 Decision 1: Schedule Acceleration 9 months after FEL

Nine months after the start of the FEL and after the final investment decision was made the decision was made to reduce the current schedule by 2 months.

6.5.1.1 Alternative 1: Accelerate the schedule, reducing the project duration, while increasing risks and potential costs

In the first decision alternative, the schedule was accelerated. This acceleration involved a reduction of the duration of deliveries of multiple equipment items. For the acceleration of deliveries, acceleration costs were paid. However there was still a risk included in the risk register, concerning late deliveries. These late deliveries could potentially be caused by revisions, because steel models had to be issued before 60% model review, increasing the chance of rework/revisions after the 60% model review. Furthermore over/under procurement would also increase. The impact of the costs associated with these risks would impact subsequent activities at site and the module yard, not being able to start with the module assembly. The risks introduced by this alternative are presented in Table 30.

Alternative 1.1

Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 1.1 BRMF 5a	Triangular	Schedule delay due to equipment, steel and piping deliveries too late	60%	-0.075M	-0.10M	-0.15M	10	15	20	10 Activities in total: incl. Mechanical Equipment (Field) 4-0501, Electrical (Field) 6-0100
Dec 1.1 BRMF 5b	Triangular	Schedule delay due to equipment, steel and piping deliveries too late	85%	-0.075M	-0.10M	-0.15M	10	24	32	3 Activities in total: incl. Mechanical Equipment (Modules) 4-0405
Dec 1.1. BRMF 6	Triangular	Schedule delay / cost impact if Instrument, electrical and materials late	85%	-0.075M	-0.10M	-0.15M	10	12	14	4 Activities in total: incl. Instrumentation (Modules) 7-0013
Dec 1.1 BRMF 7	Discrete	Schedule delay / cost impact if EHT materials late	85%		-0.50M			20		Electrical (Modules) 6-0015
Dec 1.1. BRMF 8	Discrete	Schedule delay / cost increase if shop workload exceeds capacity	85%		-0.50M			32		Mechanical completion date

*For impacts on purchase order activities, only the most critical acitvities are presented here

Table 30: Decision impacts project 2, decision 1, alternative 1

6.5.1.2 Alternative 2: Do not decrease the schedule duration

In the second alternative, the schedule acceleration was not introduced, leading to an increased duration (compared to alternative 1) of multiple activities.

Alternative 1.2

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Increased delivery duration including transport to yard (no acceleration cost)	1.46M	15	10 Activities in total: incl. Mechanical Equipment (Field) 4-0501, Electrical (Field) 6-0100
Increased delivery duration including transport to yard (no acceleration cost)	1.11M	25	3 Activities in total: incl. Mechanical Equipment (Modules) 4-0405
Increased delivery duration including transport to yard (no acceleration cost)	1.50M	25	4 Activities in total: incl. Instrumentation (Modules) 7-0013
Increased delivery duration including transport to yard (no acceleration cost)		25	Electrical (Modules) 6-0015
Increased delivery duration including transport to yard (no acceleration cost)	1.20M	0	Mechanical completion date

Table 31: Decision impacts project 2, decision 1, alternative 2

6.5.1.3 Results Decision 1

In the decision a trade-off was made between increasing the project riskiness (alternative 1.1) and decreasing the project cost, while increasing the duration (alternative 1.2).

$NPVaR_{\alpha\%}$	Alternative 1.1	Alternative 1.2
5%	189.939M	195.958M
10%	190.837M	196.859M
15%	191.467M	197.447M
20%	191.980M	197.910M
25%	192.415M	198.321M
30%	192.800M	198.702M
35%	193.156M	199.044M
40%	193.504M	199.357M
50%	194.176M	199.998M
60%	194.845M	200.688M
65%	195.199M	201.041M
70%	195.552M	201.398M
75%	195.975M	201.785M
80%	196.450M	202.240M
85%	196.988M	202.729M
90%	197.665M	203.414M

$C\text{-}NPVaR_{\alpha\%}$	Alternative 1.1	Alternative 1.2
5%	188.843M	194.984M
10%	189.628M	195.710M
15%	190.147M	196.198M
20%	190.540M	196.570M
25%	190.871M	196.879M
30%	191.161M	197.151M
35%	191.421M	197.397M
40%	191.659M	197.623M
50%	192.097M	198.036M
60%	192.500M	198.421M
65%	192.694M	198.608M
70%	192.885M	198.795M
75%	193.077M	198.981M
80%	193.272M	199.170M
85%	193.474M	199.365M
90%	193.688M	199.570M

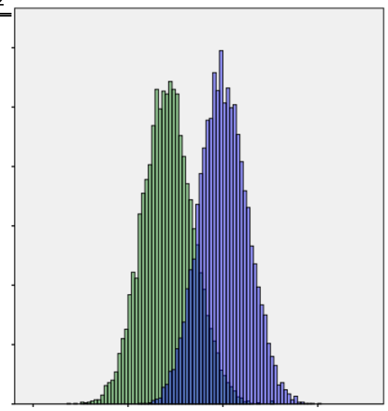


Figure 29: NPVaR and C-NPVaR values, project 2, decision 1

It was found that risks introduced by alternative 1.1, involving shop workload exceedance (BRMF 8) as well as schedule delays due to late deliveries of steel and piping materials (BRMF 5a) influenced both the NPV value and its variance. Furthermore, from Appendix 9 it is derived that the risks impacted both the RFSU and total project cost.

Alternative 1 — Change in Output Statistic for NPV | **Alternative 2** — Change in Output Statistic for NPV

Rank	Name	Lower	Upper	Name	Lower	Upper
1	Unc. K001 MODULE FABRICATION & ASSEMBLY	€ 191,731,538	€ 196,720,605	Unc. K001 MODULE FABRICATION & ASSEMBLY	€ 197,509,177	€ 202,613,547
2	Unc. 0-0020 EPCM HO	€ 193,127,529	€ 195,319,005	Unc. 0-0020 EPCM HO	€ 198,932,462	€ 201,067,710
3	Risk#34	€ 193,691,053	€ 195,859,178	Risk#34	€ 199,614,414	€ 201,528,666
4	Dec 1.1. BRMF 8	€ 193,935,717	€ 195,818,678	Unc. K010a MODULE TRANSPORT (AGILITY)	€ 199,136,076	€ 201,009,703
5	Unc. K010a MODULE TRANSPORT (AGILITY)	€ 193,345,175	€ 195,219,292	Unc. K003 CIVIL WORKS & U/G WORKS	€ 199,287,136	€ 200,856,775
6	Risk#32	€ 193,491,130	€ 194,939,517	Risk#32	€ 199,371,755	€ 200,865,627
7	Unc. K003 CIVIL WORKS & U/G WORKS	€ 193,665,023	€ 194,876,765	Risk#23	€ 199,730,958	€ 201,176,347
8	Risk#23	€ 193,965,510	€ 195,076,756	Risk#26	€ 199,972,182	€ 201,005,905
9	Risk#26	€ 194,133,358	€ 194,990,660	Unc. K005 ISBL MECHANICAL & PIPING	€ 199,628,211	€ 200,502,604
10	Dec 1.1 BRMF 5a	€ 193,898,282	€ 194,740,022	Risk#33	€ 199,643,442	€ 200,432,857

Alternative 1 — Contribution to Variance NPV | **Alternative 2** — Contribution to Variance NPV

Rank	Name	Contribution to Variance	Name	Contribution to Variance
1	Risk#32	30%	Risk#32	34%
2	Dec 1.1. BRMF 8	12%	Risk#23	11%
3	Unc. 0-0020 EPCM HO	7%	Unc. 0-0020 EPCM HO	8%
4	Unc. K010a MODULE TRANSPORT (AGILITY)	6%	Unc. K010a MODULE TRANSPORT (AGILITY)	6%
5	Risk#23	5%	Risk#26	5%
6	Unc. K003 CIVIL WORKS & U/G WORKS	4%	Unc. K003 CIVIL WORKS & U/G WORKS	4%
7	Risk#26	3%	Risk#33	3%
8	Dec 1.1 BRMF 5a	2%	Risk#40	2%
9	Risk#25	2%	Risk#30	2%
10	Risk#40	2%	Risk#25	2%
11	Risk#30	2%	Unc. K005 ISBL MECHANICAL & PIPING	2%
12	Risk#33	1%	Risk#43	2%
13	Unc. K005 ISBL MECHANICAL & PIPING	1%	Risk#35	1%
14	Unc. K006 ELECTRICAL & INSTRUMENTATION	1%	Risk#36	1%

Table 32: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 2, decision 1

In the actual case study project, decision alternative 1 was chosen. Based on the C-NPVaR values presented in Figure 29, decision alternative 2 was recommended. The direct schedule delay (1.2) was therefore recommended over increased schedule and cost risk (1.1). Especially the risks impacts on the duration were found to be significant and these risks were found to have a larger effect on the schedule duration than the proposed delay.

From the sponsor validation it became clear that ,the supplier and sub-contractors activities were accelerated, while the engineering, procurement and construction activities managed by the main contractor (and because of reimbursable contract, owner) were not able to provide the needed information. The sponsor indicated that the main contractor should have not accepted this acceleration, since the risks associated with decision alternative 1 were not manageable by the main contractor. The owner indicated that, although aware of the risks, the risks were linked to competitive capabilities of the main contractor. Accelerating the project, although the needed information was not available, should be managed by the main contractor. From the results found in this decision, and the validation, it can be concluded that although aware of the risks, the manageability of these risks is potentially overestimated.

6.5.2 Decision 2: Adopt concurrency of FEED and EPC 9 months after FEL

During the FEED phase, the decision was made to start early EPC. Some risks were identified concerning rework and late design changes.

6.5.2.1 Alternative 1: Accept 3 months concurrency between FEED and early EPC

The FEED was not completed, thus resulting in 3 months concurrency between FEED and early EPC. This introduced the risks presented in Table 33.

Alternative 2.1										
Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 2.1 BRMF 3	Discrete	Rework due to Design Freeze at end of FEED not effective	50%		-0.500M			30		FEED Services
Dec 2.1 BRMF 4	Triangular	Rework due to late engineering deliverables or late revisions	40%	-0.030M	-0.060M	-0.075M	16	24	32	FEED Services

Table 33: Decision impacts project 2, decision 2, alternative 1

6.5.2.2 Alternative 2: Delay the EPC phase while completing the FEED phase

In the second alternative, the risks would not have been introduced and the Early EPC activities would have been delayed compared to the FEED phase.

Alternative 2.2.			
Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Delay the EPC phase		20	FEED Services

Table 34: Decision impacts project 2, decision 2, alternative 2

6.5.2.3 Results Decision 2

In the decision a trade-off was made between increasing the project riskiness (alternative 2.1) and delaying the project (alternative 2.2).

$NPVaR_{\alpha\%}$	Alternative 2.1	Alternative 2.2
5%	192.542M	192.984M
10%	193.399M	193.819M
15%	194.045M	194.468M
20%	194.550M	194.939M
25%	194.994M	195.384M
30%	195.406M	195.779M
35%	195.794M	196.157M
40%	196.179M	196.525M
50%	196.890M	197.221M
60%	197.600M	197.941M
65%	198.003M	198.321M
70%	198.420M	198.736M
75%	198.899M	199.188M
80%	199.423M	199.691M
85%	200.073M	200.273M
90%	200.785M	201.076M

$C\text{-}NPVaR_{\alpha}$	Alternative 2.1	Alternative 2.2
5%	191.560M	192.001M
10%	192.285M	192.723M
15%	192.771M	193.199M
20%	193.153M	193.578M
25%	193.479M	193.897M
30%	193.766M	194.179M
35%	194.028M	194.435M
40%	194.273M	194.673M
50%	194.726M	195.115M
60%	195.145M	195.524M
65%	195.349M	195.724M
70%	195.554M	195.924M
75%	195.760M	196.126M
80%	195.972M	196.332M
85%	196.194M	196.546M
90%	196.429M	196.775M

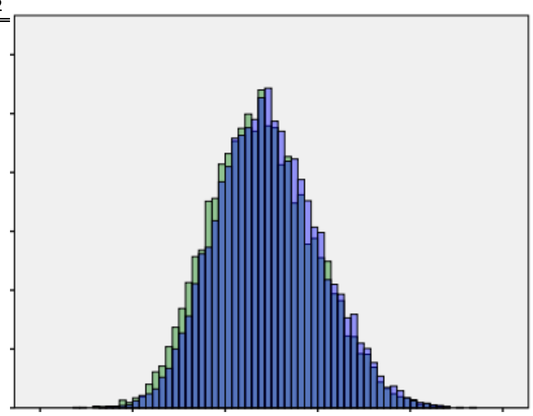


Figure 30: NPVaR and C-NPVaR values, project 2, decision 2

The risks involved with alternative 2.1, did contribute to the value of the NPV, however the increased duration in decision alternative 2 had a similar effect on the NPV distribution. Therefore no decision alternative was preferred based on the C-NPVaR$_{\alpha\%}$ values presented in Figure 30[7].

Alternative 1 / **Alternative 2**

Change in Output Statistic for NPV

Rank	Name (Alt. 1)	Lower	Upper	Name (Alt. 2)	Lower	Upper
1	Unc. K001 MODULE FABRICATION & ASSEMBLY	€ 194,424,430	€ 199,570,767	Unc. K001 MODULE FABRICATION & ASSEMBLY	€ 194,918,206	€ 199,787,551
2	Risk#34	€ 196,217,950	€ 199,481,812	Risk#34	€ 196,567,194	€ 199,779,584
3	Unc. 0-0020 EPCM HO	€ 195,812,697	€ 197,961,460	Unc. 0-0020 EPCM HO	€ 196,362,006	€ 198,301,736
4	Unc. K010a MODULE TRANSPORT (AGILITY)	€ 196,115,877	€ 197,858,473	Unc. K010a MODULE TRANSPORT (AGILITY)	€ 196,370,948	€ 198,102,360
5	Risk#32	€ 196,202,731	€ 197,903,595	Risk#32	€ 196,580,944	€ 198,120,336
6	Unc. K003 CIVIL WORKS & U/G WORKS	€ 196,309,099	€ 197,654,362	Unc. K003 CIVIL WORKS & U/G WORKS	€ 196,617,358	€ 198,149,282
7	Risk#23	€ 196,772,011	€ 197,716,139	Risk#23	€ 197,058,404	€ 198,235,415
8	Dec 2.1 BRMF 4	€ 196,501,758	€ 197,347,013	Unc. K005 ISBL MECHANICAL & PIPING	€ 196,745,049	€ 197,842,820
9	Unc. K005 ISBL MECHANICAL & PIPING	€ 196,603,785	€ 197,375,501	Risk#26	€ 197,244,636	€ 198,238,170
10	Risk#30	€ 196,580,685	€ 197,342,392	Risk#25	€ 196,973,552	€ 197,896,810

Alternative 1 / **Alternative 2**

Contribution to Variance NPV

Rank	Name (Alt. 1)	Contribution to Variance	Name (Alt. 2)	Contribution to Variance
1	Risk#32	27%	Risk#32	26%
2	Unc. 0-0020 EPCM HO	23%	Unc. 0-0020 EPCM HO	26%
3	Unc. K010a MODULE TRANSPORT (AGILITY)	8%	Risk#23	8%
4	Unc. K003 CIVIL WORKS & U/G WORKS	5%	Unc. K010a MODULE TRANSPORT (AGILITY)	5%
5	Dec 2.1 BRMF 4	3%	Unc. K003 CIVIL WORKS & U/G WORKS	4%
6	Risk#23	2%	Risk#26	3%
7	Risk#33	2%	Risk#40	2%
8	Risk#40	2%	Risk#33	2%
9	Dec 2.1 BRMF 3	2%	Risk#25	1%
10	Risk#30	2%	Risk#30	1%
11	Risk#25	1%	Unc. K005 ISBL MECHANICAL & PIPING	1%
12	Risk#26	1%	Risk#43	1%
13	Unc. K005 ISBL MECHANICAL & PIPING	1%	Risk#15	1%
14	Risk#43	1%	Risk#14	1%

Table 35: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 2, decision 2

In the actual case study project, decision alternative 2.1 was chosen. Based on the C-NPVaR value, no decision alternative was recommended, since no significant difference was found between the alternatives.

[7] Non-parametric tests were conducted to evaluate whether the distribution functions of the NPVs of both alternatives differed.

6.5.3 Decision 3: Accelerate module delivery 16 months after FEL

The decision was made to accelerate the delivery of the modules from the yard to the construction site. The acceleration was to be realized by creating two separate shipments instead of a single shipment, speeding up the schedule against increased cost.

6.5.3.1 Alternative 1: Accelerate module delivery

The first alternative involved using two shipments. Using two shipments increased the total transportation cost. The earlier delivery of part of the modules, caused by the usage of two shipments would not reduce the total module delivery duration, but would allow construction at site to start earlier.

6.5.3.2 Alternative 2: Do not accelerate the module delivery

In this alternative the module delivery would not be accelerated, thus resulting in later start of the construction activities that could commence after part of the modules would have been delivered to site. This would have resulted in a schedule delay (compared to alternative 1) and a cost reduction (compared to alternative 1).

Alternative 3.2.

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Cost reduction	2.40M		K010a MODULE TRANSPORT (AGILITY)
Schedule delay		28	K005 ISBL MECHANICAL & PIPING

Table 36: Decision impacts project 2, decision 3, alternative 2

6.5.3.3 Results Decision 3

In this decision a trade-off was made between accepting the acceleration (alternative 3.1) and delaying the project while not paying acceleration cost (alternative 3.2).

Based on the C-NPVaR$_{\alpha\%}$ decision alternative 1 was preferred.

NPVaR$_{\alpha\%}$	Alternative 3.1	Alternative 3.2
5%	199.756M	198.361M
10%	200.666M	199.317M
15%	201.351M	199.995M
20%	201.914M	200.595M
25%	202.446M	201.129M
30%	202.894M	201.683M
35%	203.341M	202.211M
40%	203.749M	202.689M
50%	204.633M	203.623M
60%	205.560M	204.495M
65%	206.043M	204.937M
70%	206.576M	205.383M
75%	207.151M	205.893M
80%	207.708M	206.481M
85%	208.347M	207.349M
90%	209.108M	208.311M

C-NPVaR$_{\alpha}$	Alternative 3.1	Alternative 3.2
5%	198.823M	197.369M
10%	199.529M	198.128M
15%	200.027M	198.637M
20%	200.432M	199.051M
25%	200.784M	199.413M
30%	201.098M	199.744M
35%	201.387M	200.060M
40%	201.657M	200.360M
50%	202.164M	200.918M
60%	202.652M	201.441M
65%	202.894M	201.693M
70%	203.137M	201.941M
75%	203.385M	202.187M
80%	203.637M	202.436M
85%	203.895M	202.699M
90%	204.162M	202.983M

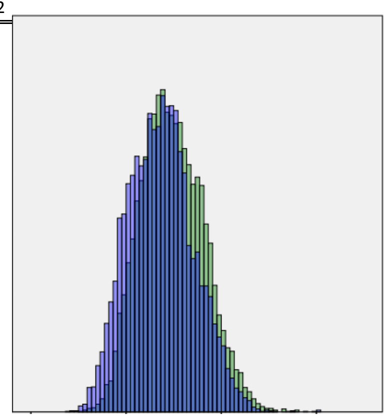


Figure 31: NPVaR and C-NPVaR values, project 2, decision 3

In the actual case study project, decision alternative 3.1 was chosen. Based on the C-NPVaR values presented in Figure 31, decision alternative 3.1 was also recommended. This indicates that both the IPGA method and the iron triangle preferred the alternative to accept the schedule acceleration.

6.5.4 Decision 4: Accept the absence of float between EP&C 18 months after FEL

In this project multiple modules were fabricated at a module yard outside of Europe (the site location). Between the delivery of materials and equipment and the construction of the modules at the yard, no slack (or float) was incorporated. A delay in material or equipment deliveries would therefore have a cascading effect on the module fabrication activity. During the project delays were incurred resulting in even negative float between the delivery of materials and equipment and module fabrication. This schedule pressure introduced a number of risks involving late delivery of materials, inefficiencies and potential low quality products on top of risks already indicated in previous decisions and the risk register.

6.5.4.1 Alternative 1: Accept the absence of float between EP&C

In the first alternative, the previously mentioned absence of float was accepted and 4 risks were added to the risk register. In addition these risks/concerns were communicated between owner and the main contractor.

Alternative 4.1

Risk#	Category	Description	Probability	Impact Cost (MEUR)			Expected Impact Time (days)			Linked to activity*
				low	most-likely	high	low	most-likely	high	
Dec 4.1 BRMF 17	Triangular	Late material availability at Yard	85%	-0.250M	-0.500M	-0.750M	30	30	30	K010a MODULE TRANSPORT (AGILITY)
Dec 4.1 BRMF 38	Discrete	Increased schedule risk due to elimination of float, increased EP&C concurrency, leading to inefficiencies and quality issues	50%		-2.000M			20		K010a MODULE TRANSPORT (AGILITY)
Dec 4.1 BRMF 37	Discrete	Receiving sub-standard materials/equipment at site / module yard	50%		-0.500M			20		K010a MODULE TRANSPORT (AGILITY)
Dec 4.1 BRMF 44	Discrete	Loss of personnel availability due to project pressure 0 float schedule and compressed execution.	25%		-0.500M			15		K010a MODULE TRANSPORT (AGILITY)

Table 37: Decision impacts project 2, decision 4, alternative 1

6.5.4.2 Alternative 2: Delay the module fabrication by 3 weeks

Because of the schedule pressure, it was proposed to delay the start of the module fabrication (construction) by 3 weeks, in order to allow for the delays to be mitigated.

Alternative 4.2.

Description	Impact Cost (MEUR)	Expected Impact Time (days)	Linked to activity*
Increased schedule duration		21	K010a MODULE TRANSPORT (AGILITY)

Table 38: Decision impacts project 2, decision 4, alternative 2

6.5.4.3 Results Decision 4

In this decision a trade-off was made between increasing the project riskiness (alternative 4.1) and increasing the schedule duration (alternative 4.2).

$NPVaR_{\alpha\%}$	Alternative 4.1	Alternative 4.2
5%	192.464M	195.935M
10%	194.229M	197.569M
15%	195.212M	198.671M
20%	196.008M	199.417M
25%	196.716M	199.971M
30%	197.372M	200.471M
35%	197.969M	200.976M
40%	198.480M	201.491M
50%	199.441M	202.555M
60%	200.518M	203.625M
65%	201.100M	204.143M
70%	201.734M	204.700M
75%	202.370M	205.381M
80%	203.138M	206.212M
85%	204.151M	207.319M
90%	205.658M	208.912M

$C\text{-}NPVaR_{\alpha}$	Alternative 4.1	Alternative 4.2
5%	190.610M	194.044M
10%	191.932M	195.391M
15%	192.788M	196.284M
20%	193.428M	196.970M
25%	193.956M	197.514M
30%	194.412M	197.964M
35%	194.822M	198.356M
40%	195.198M	198.714M
50%	195.881M	199.363M
60%	196.510M	199.970M
65%	196.811M	200.266M
70%	197.111M	200.562M
75%	197.417M	200.860M
80%	197.731M	201.170M
85%	198.058M	201.499M
90%	198.415M	201.869M

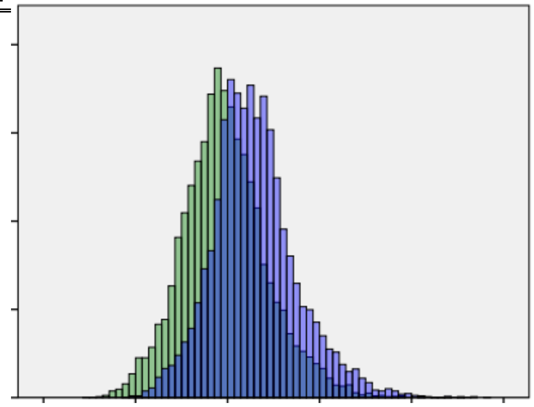


Figure 32: NPVaR and C-NPVaR values, project 2, decision 4

Alternative 1 / **Alternative 2**

Change in Output Statistic for NPV

Rank	Name	Lower	Upper	Name	Lower	Upper
1	Risk#23	€ 198,897,120	€ 202,376,842	**Risk#34**	€ 201,922,844	€ 206,177,203
2	Dec 2.1 BRMF 3	€ 198,072,340	€ 201,343,139	Risk#23	€ 202,048,923	€ 205,687,652
3	Dec 4.1 BRMF 38	€ 198,120,551	€ 201,307,113	Dec 2.1 BRMF 3	€ 201,282,713	€ 204,730,724
4	Dec 2.1 BRMF 4	€ 197,958,605	€ 200,872,262	Dec 2.1 BRMF 4	€ 201,127,753	€ 204,110,783
5	Dec 4.1 BRMF 17	€ 199,362,774	€ 201,967,394	**Risk#32**	€ 201,725,761	€ 204,179,964
6	Risk#26	€ 199,507,704	€ 201,760,450	Risk#26	€ 202,697,250	€ 204,999,059
7	Dec 4.1 BRMF 37	€ 198,692,383	€ 200,747,877	Unc. 0-0020 EPCM HO	€ 202,066,951	€ 203,835,891
8	Unc. 0-0020 EPCM HO	€ 198,654,841	€ 200,543,102	Unc. K001 MODULE FABRICATION & ASSEMBLY	€ 202,052,860	€ 203,671,819
9	Dec 4.1 BRMF 44	€ 198,528,039	€ 200,133,213	Risk#25	€ 202,378,663	€ 203,514,512
10	Risk#34	€ 199,370,982	€ 200,967,569	Risk#40	€ 202,382,336	€ 203,513,814

Alternative 1 / **Alternative 2**

Contribution to Variance NPV

Rank	Name	Contribution to Variance	Name	Contribution to Variance
1	Risk#23	12%	Risk#23	16%
2	Dec 2.1 BRMF 4	12%	Dec 2.1 BRMF 4	13%
3	Dec 4.1 BRMF 37	11%	**Risk#32**	12%
4	Risk#26	9%	Risk#26	10%
5	Dec 4.1 BRMF 17	5%	Risk#25	7%
6	Risk#34	5%	Risk#33	4%
7	Dec 4.1 BRMF 44	4%	Unc. 0-0020 EPCM HO	1%
8	Unc. 0-0020 EPCM HO	2%	Risk#40	1%
9	Risk#25	2%	Risk#1	1%
10	Risk#40	1%	Risk#30	1%
11	Risk#33	1%	Unc. K001 MODULE FABRICATION & ASSEMBLY	1%
12	Risk#30	1%	Risk#2	1%
13	Risk#32	1%	Risk#43	1%
14	Risk#1	1%	Dec 2.1 BRMF 4	1%

Table 39: Contribution to variance and output value of the NPV caused by risks and decision impacts, project 2, decision 4

In Table 39 it is found that the risk impacts of decision alternative 4.1 had a significant contribution to both the variance and output value of the NPV. Furthermore based on Appendix 9 it was found that there were significant risk impacts on the project duration. Apparently the impact of these risks outweighed the proposed delay.

In the actual case study project, decision alternative 4.1 was chosen. Based on the C-NPVaR value, decision alternative 4.2 was recommended. This indicates that using the IPGA method, the direct schedule delay (4.2) was recommended over increased schedule risk (4.1). This was substantiated by the data provided in Appendix 9.

The project manager of the owner indicated that the project manager is assessed based on its capabilities to stay within budget and schedule baselines. Choosing decision alternative 2, thus delaying the project with certainty would be unacceptable. It was furthermore acknowledged by the project manager that the decisions were therefore based on deterministic values and risks were not completely included in the decision making process. Risks were seen as manageable, while deterministic values were not. It was however found in this decision that the risks introduced by alternative 1 would result in an even longer schedule duration.

7 Comparison of preferred alternatives

In the previous chapter the decision alternatives chosen in the case study project and the decision alternatives recommended based on their impact on the feasibility of the project goal (found through the IPGA method) were presented. In this chapter the following research question is answered: "Are the actually chosen decision alternatives in the projects equal to the decision alternatives recommended based on assessment of the feasibility of the project goal?"

7.1 Summary of chosen and recommended decision alternatives

In Table 40 the chosen decision alternatives are compared to the recommended decision alternatives determined in the previous chapter. The impact and trade-offs for each decision alternative, determined in the previous chapter are summarized. Furthermore the decision alternative that was actually chosen in the project is presented in the table as well as the decision alternative recommended (based on the IPGA method). For decision 1 of project 1 only a small effect was found, indicating that the differences between the NPV distribution functions of the alternatives were not substantial. Because in decision 6 in the first project and decision 2 in the second project no significant differences were found between the distribution functions of the NPV, it is stated that "none" of the two alternatives was recommended by the IPGA method. For decision 4 of project 1 it was found that the choice for decision alternative 4.1 was motivated by another reason, namely the signaling to shareholders. These described decisions will therefore not be used to answer the main research question. However based on the remaining decisions, conclusions can be made.

Project 1

	Alternative 1	**Alternative 2**	**Chosen decision alternative**	**Recommended decision alternative**	**Note**
Decision 1	Increased project riskiness, impacting both time and cost	Increase the project duration while decreasing project cost	alternative 1	alternative 2	only a small effect was found
Decision 2	Increased project riskiness, impacting both time and cost	Increase the project duration	alternative 1	alternative 1	
Decision 3	Increased project riskiness, impacting both time and cost. Decrease project cost	Decrease the project duration	alternative 1	alternative 2	
Decision 4	Increased project riskiness, impacting both time and cost. Increase project cost	Increase the project duration	alternative 1	alternative 2	Motivated by other reasons
Decision 5	Increasing project duration, while decreasing project cost		alternative 1	alternative 2	
Decision 6	Increase project cost, while decreasing project duration		alternative 1	none	

Project 2

	Decision alternative 1	**Decision alternative 2**	**Chosen decision alternative**	**Recommended decision alternative**	**Note**
Decision 1	Increased project riskiness, impacting both time and cost	Decrease project cost while increasing project duration	alternative 1	alternative 2	
Decision 2	Increased project riskiness, impacting both time and cost	Increase the project duration	alternative 1	none	
Decision 3	Accept acceleration	Increase the project duration, while decreasing project cost	alternative 1	Alternative 1	
Decision 4	Increased project riskiness, impacting both time and cost	Increase the project duration	alternative 1	alternative 2	

Table 40: Comparison of chosen decision alternatives, and recommended alternatives based on the C-NPVaR

From Table 40 it can be concluded that in 4 out of the remaining 6 decisions, the IPGA method recommended a different decision alternative than the decision alternative that was actually chosen in the project. These decisions are decision 3 and 5 of project 1 and decision 1 and 4 of project 2.. The results for these decisions as found in Chapter 6 are summarized in Figure 33.

Project 1

- Dec 3: A schedule reduction was recommended over a cost reduction
- Dec 5: A schedule reduction was recommended over a cost reduction

Project 2

- Dec 1: A schedule delay was recommended over increased schedule risk and cost risk
- Dec 4: A schedule delay was recommended over increased schedule risk

Figure 33: summary of decisions for which the IPGA method recommended a different decision alternative than the chosen decision alternative

From Figure 33 it can be concluded that in all four decisions the recommended decision alternative had a shorter schedule duration compared to the other involved decision alternative. This conclusion is most clear in decision 3 and 5 in project 1, since the schedule reduction was recommended over a cost reduction. In Chapter 6, it was also found that in decision 5 (project 1), 1 and 4 (project 2) the risks introduced by the decision alternative had a significant impact on the NPV. In decision 1 and 4 the introduced risks resulted on average in an increased schedule duration compared to the schedule duration of the other alternative. These risks were known to the decision-makers. It was furthermore found in decision 1 and 4 that for the project manager accepting a delay with certainty would be unacceptable and therefore the project manager had chosen alternative 1. This indicates that although the risks impacting the schedule would increase the schedule duration on average to a larger extent than the proposed delay, it was still not chosen by the project manager.

In the next paragraph a scenario analysis is conducted to evaluate the effect of changing two of the main assumptions made in this research on the found differences between the chosen and recommended decision alternatives.

7.2 Scenario Analysis

A scenario analysis was conducted to examine the effect of the assumptions made in both case study projects. The main assumptions examined in this scenario analysis are the magnitude of the operational cash flow and the used WACC. Both values were validated by the project sponsor (and owner) as well as an independent consultant. However the impact on the model of changing these assumptions can provide valuable insights into the robustness of the found differences and derived results. The results of the scenario analysis are presented in Table 41.

Project 1

	Operational cash flow (after tax)								
	-50%			**Current**			**+50%**		
$NPVaR_{\alpha\%}$	5%	50%	90%	5%	50%	90%	5%	50%	90%
Alternative 1.1	-32.41M	-12.32M	7.86M	381.61M	406.62M	432.39M	794.66M	825.99M	857.37M
Alternative 1.2	-26.04M	-6.68M	13.46M	390.38M	414.96M	441.20M	807.31M	836.87M	868.83M
Difference	6.37M	5.64M	5.60M	8.77M	8.34M	8.81M	12.65M	10.88M	11.46M
Alternative 2.1	-30.55M	-10.14M	10.00M	387.27M	413.45M	439.23M	805.50M	837.13M	868.29M
Alternative 2.2	-34.31M	-14.67M	5.41M	383.41M	408.59M	434.31M	800.94M	832.09M	863.46M
Difference	-3.77M	-4.53M	-4.58M	-3.86M	-4.86M	-4.92M	-4.56M	-5.04M	-4.83M
Alternative 3.1	-41.66M	-6.11M	15.06M	379.57M	416.79M	442.63M	797.88M	839.60M	871.52M
Alternative 3.2	-24.21M	-3.71M	16.96M	399.42M	424.43M	450.37M	821.05M	852.70M	885.08M
Difference	17.44M	2.40M	1.90M	19.85M	7.64M	7.74M	23.17M	13.10M	13.57M
Alternative 4.1	-66.30M	-32.06M	-6.24M	349.32M	387.79M	419.05M	785.05M	826.61M	864.13M
Alternative 4.2	-41.69M	-7.32M	15.14M	377.85M	413.64M	441.58M	812.95M	854.99M	888.35M
Difference	24.61M	24.73M	21.38M	28.53M	25.85M	22.53M	27.90M	28.38M	24.22M
Alternative 5.1	-57.55M	-21.62M	1.98M	371.23M	410.87M	440.85M	801.53M	843.34M	879.43M
Alternative 5.2	-36.30M	-1.49M	23.48M	394.71M	434.19M	465.02M	827.57M	869.86M	906.33M
Difference	21.25M	20.13M	21.51M	23.48M	23.32M	24.17M	26.04M	26.52M	26.90M
Alternative 6.1	-134.44M	-101.46M	-74.45M	364.74M	400.07M	433.34M	735.90M	775.67M	817.38M
Alternative 6.2	-133.93M	-100.95M	-73.94M	365.26M	400.58M	433.85M	736.41M	776.18M	817.90M
Difference	0.51M	0.51M	0.51M	0.51M	0.51M	0.51M	0.51M	0.51M	0.51M

Project 2

	Operational cash flow (after tax)								
	-50%			**Current**			**+50%**		
$NPVaR_{\alpha\%}$	5%	50%	90%	5%	50%	90%	5%	50%	90%
Alternative 1.1	30.82M	35.20M	40.00M	189.76M	194.42M	199.80M	348.38M	353.74M	359.80M
Alternative 1.2	37.27M	41.64M	46.08M	196.85M	201.48M	206.54M	356.25M	361.31M	367.28M
Difference	6.45M	6.44M	6.08M	7.09M	7.06M	6.74M	7.87M	7.57M	7.48M
Alternative 2.1	33.28M	37.90M	43.25M	192.68M	197.60M	203.63M	351.83M	357.29M	364.40M
Alternative 2.2	33.45M	38.05M	43.32M	193.03M	197.91M	204.03M	352.46M	357.81M	364.90M
Difference	0.17M	0.15M	0.08M	0.35M	0.31M	0.40M	0.63M	0.51M	0.50M
Alternative 3.1	32.74M	36.20M	41.05M	197.38M	201.39M	207.32M	361.75M	366.70M	373.69M
Alternative 3.2	32.20M	35.75M	40.91M	196.54M	200.70M	207.06M	360.44M	365.70M	373.41M
Difference	-0.54M	-0.45M	-0.14M	-0.84M	-0.69M	-0.26M	-1.31M	-1.00M	-0.27M
Alternative 4.1	19.88M	26.28M	34.37M	194.26M	199.85M	205.42M	355.23M	364.74M	375.03M
Alternative 4.2	22.71M	28.81M	37.11M	198.21M	203.16M	209.88M	360.84M	369.51M	379.90M
Difference	2.83M	2.53M	2.73M	3.95M	3.31M	4.46M	5.62M	4.77M	4.87M

Table 41: Scenario analysis project 1 and 2: Operational cash flow (after tax)1.000 iterations

The scenario analysis presented in Table 41 indicates the effect of changing the operational cash flow (after tax) on the NPV distribution function. To describe the NPV distribution function, the $NPVaR_{5\%}$, $NPVaR_{50\%}$ and $NPVaR_{90\%}$ are included in the table. The scenario analysis used the same inputs derived from 1000 MC iterations while varying only the operational cash flow and discount rate. For the operational cash flow (after tax) the used value was decreased by 50% in the first scenario, while the value was increased by 50% in the last scenario. For the WACC values of 3%, 6% and 9% were evaluated.

An increase in the operational cash flow (after tax) increases the NPV value, since the benefits to the owner, consisting of the operational cash flow, increase. Similarly, a decrease in the operational cash flow (after tax) decreases the NPV value, since these benefits decrease. Based on the presented differences between the decision alternatives, increasing or decreasing the operational cash flow did not have an effect on the recommended decision alternative based on the IPGA method. This means that changing the used operational cash flow by 50% does not influence the results from this research. It was however found that changing the operational cash flow does influence the magnitude of the difference found between the decision alternatives.

Project 1

	WACC (adj. for tax)								
	3%			**6%**			**9%**		
NPVaR$_{\alpha\%}$	5%	50%	90%	5%	50%	90%	5%	50%	90%
Alternative 1.1	716.75M	739.71M	763.63M	381.61M	406.62M	432.39M	172.71M	197.31M	222.69M
Alternative 1.2	725.53M	748.21M	771.97M	390.38M	414.96M	441.20M	180.55M	204.87M	230.96M
Difference	8.78M	8.50M	8.34M	8.77M	8.34M	8.81M	7.84M	7.56M	8.27M
Alternative 2.1	722.25M	746.07M	769.89M	387.27M	413.45M	439.23M	177.83M	203.23M	228.51M
Alternative 2.2	718.55M	741.26M	765.23M	383.41M	408.59M	434.31M	173.11M	198.08M	223.60M
Difference	-3.69M	-4.81M	-4.66M	-3.86M	-4.86M	-4.92M	-4.72M	-5.15M	-4.91M
Alternative 3.1	712.89M	749.71M	773.88M	379.57M	416.79M	442.63M	170.22M	206.11M	232.01M
Alternative 3.2	731.43M	754.72M	778.67M	399.42M	424.43M	450.37M	189.59M	214.56M	240.57M
Difference	18.54M	5.00M	4.80M	19.85M	7.64M	7.74M	19.37M	8.45M	8.56M
Alternative 4.1	692.25M	729.27M	758.92M	349.32M	387.79M	419.05M	147.99M	185.57M	216.78M
Alternative 4.2	719.56M	755.94M	782.10M	377.85M	413.64M	441.58M	175.44M	210.98M	239.16M
Difference	27.31M	26.67M	23.17M	28.53M	25.85M	22.53M	27.45M	25.40M	22.39M
Alternative 5.1	706.84M	745.64M	773.36M	371.23M	410.87M	440.85M	154.32M	193.99M	224.07M
Alternative 5.2	729.06M	767.10M	795.52M	394.71M	434.19M	465.02M	180.35M	219.18M	250.23M
Difference	22.22M	21.46M	22.16M	23.48M	23.32M	24.17M	26.03M	25.19M	26.16M
Alternative 6.1	633.34M	668.10M	698.22M	364.74M	400.07M	433.34M	86.56M	123.15M	157.15M
Alternative 6.2	633.85M	668.61M	698.73M	365.26M	400.58M	433.85M	87.08M	123.66M	157.67M
Difference	0.51M	0.51M	0.51M	0.51M	0.51M	0.51M	0.52M	0.52M	0.52M

Project 2

	WACC (adj. for tax)								
	3%			**6%**			**9%**		
NPVaR$_{\alpha\%}$	5%	50%	90%	5%	50%	90%	5%	50%	90%
Alternative 1.1	311.72M	316.49M	321.74M	189.76M	194.42M	199.80M	111.27M	115.81M	121.09M
Alternative 1.2	318.67M	323.34M	328.34M	196.85M	201.48M	206.54M	118.47M	122.87M	127.83M
Difference	6.94M	6.85M	6.60M	7.09M	7.06M	6.74M	7.20M	7.06M	6.74M
Alternative 2.1	314.33M	319.40M	325.34M	192.68M	197.60M	203.63M	114.38M	119.10M	124.98M
Alternative 2.2	314.73M	319.62M	325.59M	193.03M	197.91M	204.03M	114.74M	119.36M	125.28M
Difference	0.40M	0.22M	0.25M	0.35M	0.31M	0.40M	0.36M	0.26M	0.30M
Alternative 3.1	317.79M	321.78M	327.41M	197.38M	201.39M	207.32M	118.49M	122.33M	128.26M
Alternative 3.2	317.38M	321.37M	327.37M	196.54M	200.70M	207.06M	117.29M	121.47M	127.80M
Difference	-0.41M	-0.41M	-0.04M	-0.84M	-0.69M	-0.26M	-1.21M	-0.87M	-0.46M
Alternative 4.1	306.60M	313.91M	323.07M	194.26M	199.85M	205.42M	109.28M	117.05M	126.17M
Alternative 4.2	309.92M	317.00M	326.21M	198.21M	203.16M	209.88M	113.43M	120.82M	130.00M
Difference	3.32M	3.10M	3.14M	3.95M	3.31M	4.46M	4.15M	3.77M	3.82M

Table 42: Scenario analysis project 1 and 2: WACC (adj. for tax)

The scenario analysis presented in Table 42 indicates the effect of changing the WACC (adj. for tax) on the NPV distribution function. It is concluded that there is a negative relationship between the value of the WACC and the NPV. Increasing the WACC decreases the NPV. It was found that the recommended decision alternatives did not depend on the value of the WACC. However, the magnitude of the differences in NPVaR values between the decision alternatives was impacted by the change in WACC value.

The results from the scenario analysis for the decisions, for which the chosen decision alternative was different from the recommended decision, will be further examined. These decisions include decision 3 and 5 (project 1) and decision 1 and 4 (project 2). The differences found between the chosen decision alternatives of decision 1 and 4 (project 2) and decision 3 (project 1) increased when the operational cash flow or the WACC increased. This can be explained by looking at Figure 33. In all four decisions the difference was caused by the recommended decision alternative having on average a shorter schedule duration. The difference between the two decision alternatives was thus caused by the recommended alternative having on average a shorter schedule duration than the chosen alternative. Based on this conclusion, the effects found in the scenario analysis can be explained.

This is explained, because an increase in the WACC (caused by the time-value of money) or operational cash flow makes a delay more costly. By making a delay more costly, the second alternative would only become more attractive, since the delay in that alternative was smaller. It can therefore be explained why the difference between the two alternatives increased when the operational cash flow or WACC increased. Alongside the assumptions about the magnitude of the operational cash flow and the WACC, additional assumptions motivated the usage of the IPGA method. These are evaluated in the following texts.

7.3 Non-normality assumption

The usage of the $NPVaR_{\alpha\%}$ metric was motivated by the fact that the distribution functions of the NPV were non-normally distributed. Using IBM SPSS the normality of the distribution functions was assessed. In Table 43 the Kolmogorov-Smirnov test is used to assess the non-normality of the found NPV distributions of the alternatives of all evaluated decisions.

Project 1	Kolmogorov-Smirnov		**Project 2**	Kolmogorov-Smirnov	
	stat.	Sig.		stat.	Sig.
Alternative 1.1	0.013	0.001	*Alternative 1.1*	0.009	0.054*
Alternative 1.2	0.006	0.200*	*Alternative 1.2*	0.013	0.001
Alternative 2.1	0.010	0.024	*Alternative 2.1*	0.019	0.000
Alternative 2.2	0.009	0.052*	*Alternative 2.2*	0.021	0.000
Alternative 3.1	0.029	0.000	*Alternative 3.1*	0.03	0.000
Alternative 3.2	0.010	0.039	*Alternative 3.2*	0.024	0.000
Alternative 4.1	0.026	0.000	*Alternative 4.1*	0.036	0.000
Alternative 4.2	0.027	0.000	*Alternative 4.2*	0.052	0.000
Alternative 5.1	0.012	0.002			
Alternative 5.2	0.015	0.000			
Alternative 6.1	0.016	0.000			
Alternative 6.2	0.011	0.010			

* In these alterantives, the null hypothesis cannot be rejected, therefore no indication for non-normality (α = 5%)

Table 43: Kolmogorov-Smirnov test for non-normality

Based on Table 43 it can be concluded that the NPV distributions were non-normally distributed, since the null hypothesis of the Kolmogorov Smirnov test was rejected in most cases. For alternative 1.2, 2.2 of project 1 the null hypothesis could not be rejected and there was therefore no reason to assume that those NPV distributions were non-normally distributed. Also, alternative 1.1. in project 2 was normally distributed. However all the normally distributed NPV distributions found in this research had a non-normally distributed alternative (1.1 and 2.1 in project 1 and 1.2 in project 2). The usage of the $NPVaR_{\alpha\%}$ metric is therefore justified.

7.4 C- $NPVaR_{\alpha\%}$ vs. $NPVaR_{\alpha\%}$

The C- $NPVaR_{\alpha\%}$ metric was used, because it was expected that the impact of discrete risks on the tail distribution of the NPV would make the usage of the $NPVaR_{\alpha\%}$ metric unsuitable. In all decision alternatives it was however found that there was no difference in recommended decision alternative when the $NPVaR_{\alpha\%}$ metric was used, compared to the C- $NPVaR_{\alpha\%}$ metric. This could indicate that the usage of the C- $NPVaR_{\alpha\%}$ metric would only induce more calculative work. However, based on interviews with the project sponsor, it was found that the amount of risks identified and the impacts assigned to those risks in both case study projects were underestimated. It is therefore recommended to use the C-$NPVaR_{\alpha\%}$ metric for future applications of the IPGA method.

8 Conclusions, Recommendations and Discussion

In this chapter the answer to the main research question is presented. Conclusions about the contribution of this research to the currently existing research gap are made, the practical relevance of the research is assessed, limitations are presented and the chapter ends with a reflection. Based on the presented conclusions, recommendations for further research and recommendations to practice are made.

The research aimed to contribute to the scientific knowledge, by providing empirical evidence of the effect of decisions made during project execution on the NPV. This empirical evidence was currently missing as indicated in the literature. The main research question in this research therefore was: *"To what extent do decisions during project execution change, compared to current practice, when their impact on the feasibility of the project goal is considered?"* This question was answered by comparing choices made in real projects and reevaluating those decisions based on the impact of the decisions on the feasibility of the project goal.

In this research a first attempt was made to assess the project goal represented by the NPV during the project execution as well as the effect of the decisions made during project execution on the NPV. In this research it was found that through the usage of the integrated probabilistic goal assessment (IPGA) method, the impact of decisions on a probabilistic NPV of an industrial project can be evaluated during the project execution phase. The IPGA method incorporates the newly available information on time, costs, risks and uncertainty into a probabilistic NPV. In addition, decision impacts during project execution can be modelled and through the usage of the $\text{C-NPVaR}_{\alpha\%}$ the different impacts of decision alternatives can be assessed.

In four out of the ten decisions evaluated by the IPGA method a different decision alternative was recommended, when evaluating the impact of those decisions on the project goal. These results were validated by involving project sponsors and project managers of the owner. It was first of all found that by looking at the developed distribution functions of the net present value, that the riskiness of the projects was underestimated. This was substantiated by the actual time and cost overruns that occurred in both projects. It was furthermore found that in three of the four decisions, there was a significant impact of risks on the project goal feasibility. It was acknowledged that these risks, although known by the project owner and contractor, were not sufficiently incorporated in the decisions or the manageability was overestimated. It was furthermore admitted that the decisions made in both case study project were based on deterministic values of time, cost and quality. These deterministic values do not incorporate the risks and uncertainties.

It can therefore not be concluded that the recommendations to choose different decision alternatives were necessarily caused by the assessment of the project goal feasibility. The reason for this is that the differences found were also significantly impacted by the risks associated with the decision alternatives. The difference could therefore also be caused by a lack of incorporation of risks into the decision-making or an overestimation of the manageability of these risks. It was also found that the involved project managers were not evaluated based on the riskiness of their decisions, but merely on the effect of their decisions on the project budget and schedule. In addition, it was concluded that in some decisions other motivations might influence the decision making of the involved stakeholders causing decision-makers not to base their decision on the feasibility of the project goal.

8.1.1 Limitations

The main limitation of this research was caused by the limited time and resources available, which resulted in examination of only two case study projects in one specific construction sector (the industrial sector), furthermore in both projects reimbursable contracts between the main contractor and owner were used. Because of the limited amount of time available, the evaluated decisions were based on interviews with the involved project managers instead of merely on desk research. It could be the case that the decisions that were remembered by the project managers were only the bad decisions with negative outcomes. This could have resulted in the chosen alternatives already being bad decisions (Kahneman & Tversky, 1979).

The available resources and more specifically the available data resulted in uncertainty in activity durations being reflected by triangular distributions with a discrete probability and not by triangular distributions itself. Furthermore, in the project all risks were expressed in time and cost. Although some factors such as safety are not recommended to be expressed in time and cost, because of ethical aspects, because of the incentive fee used in the reimbursable contract the input data did express safety in time and cost.

The attempt to integrate the increased amount of information that becomes available during project execution required assumptions and a specific level of granularity. Independency of risks was assumed. Also, although the granularity of the model and the network used in the model was validated by experts, it is expected that increasing the level of detail would create more robust outputs and would enable the evaluation of decisions with smaller impacts.

8.1.1.1 Internal validity of the research

By explicitly using only the information that was available at the specific moment in time at which the decisions were made, the possibility for a causal relationship between project goal feasibility and decisions is strengthened. However this temporal precedence is simulated in this research. Although it was explicitly mentioned (see Appendix 10), the interviewees could be biased because of their current knowledge. For example knowledge about the actual outcome of the project or decision might be an omitted variable that influences the preparedness to change the decision. It is however important to note that when owners (and contractors) acknowledge that a decision would have changed, this is similar to admitting that the previously chosen decision alternative was not focused on the feasibility of the project goal and that the choice made in the project should have been altered. The owners (and contractor) therefore have no incentive to confirm the research and rather have an incentive to stay with their previous decision (and not admit their mistakes). Because of this, absolute anonymity was provided in this research.

8.1.1.2 External validity of the research

In this research a first attempt was made to examine whether decisions during project execution change when the feasibility of the project goal is considered. This research specifically focused on a particular subset of large projects, namely industrial projects. Generalizing the conclusions to large projects in general, should be done with caution, because the exact decision-making process and project goal in for instance governmental projects differ. The industrial sector was chosen, because the benefits associated with achieving the project goal are easier to quantify, which makes the used NPV calculation more robust. In other sectors it is harder to quantify the project goal and benefits (Freeman & Beale, 1992).

8.1.2 Recommendations for future research

The C-NPVaR$_{\alpha\%}$ can be used to assess the different impacts of decision alternatives; however this metric depends on the risk appetite of the decision maker. A risk averse decision maker will require a higher significance level and would therefore evaluate decision alternatives using a lower α value. Especially in decisions in which the different impacts between decision impacts are small, the chosen α value could impact the choice of the decision maker. It is therefore recommended to do further research into the risk aversion of decision makers especially in decisions made during project execution.

In this research large decisions impacting both time and cost were selected, because it was expected that a significant impact would be found when those decision would be evaluated using the IPGA method. It is however recommended to also evaluate smaller decisions as well and to assess whether the efforts needed for the IPGA method outweigh the potential added value caused by the changed decisions.

More and more quantitative feasibility analysis methods are used in large projects in other sectors (e.g. social cost benefit analysis)(Pearce, Atkinson, & Mourato, 2006). In these sectors the project goal feasibility is also currently not assessed during project execution when strategic decisions are made. The method and NPV model developed in this research could therefore possibly be applied to other sectors and projects. This could also strengthen the current research and applied NPV model.

Although the empirical evidence provided by this research alone cannot substantiate the exact extent to which decisions during project execution change because of assessment of the project goal feasibility it is recommended to apply this method to a project in which decision-makers did incorporate risks on time and cost in their decision making. This could further reduce the research gap by knowing the exact extent to which risks caused the found differences in this research and to what extent this was caused by using different decision criteria that assessed the project goal feasibility.

8.1.3 Recommendations to practice

The input data used for the decision making at the specific moment in time was used. However, this input data was suboptimal in some cases. For instance triangular distributions were used to assess the uncertainty of time and cost, however other distribution functions are more theoretically sound (Wing Chau, 1995). This was not a limitation of the research, but it is a limitation of the developed model. Furthermore the expression of safety into time and cost was not optimal. It is therefore recommended to express safety risks in terms of safety impacts. It is however expected that variables such as safety can be added to the IPGA method, by assigning additional distribution functions to these variables with their own risk aversion level (level of α).

In the research it was found that when using the objective IPGA method decisions should have been altered during project execution. However because project managers are evaluated based on deterministic time, cost and quality criteria, incorporating risk might be done to a lesser extent and manageability of risks might be overestimated. For further application of the IPGA method it is therefore recommended to increase the objectivity of risk identification as well as the possibility to forecast risks by combining the IPGA method with more objective forecast data such as the data derived from the current and future “WATSON project” initiated by Fluor Corp.

8.1.4 Reflection

A valuable insight gained in this research was the fact that it was found to be possible to integrate academic concepts derived from the finance literature such as the C-NPVaR with concepts found in the project management literature to create something new. Currently these different fields are not completely aligned as experienced in this research. The MSc in Construction Management and Engineering has allowed me to find this link and to make a first attempt to integrate some concepts of these fields.

However, besides the integration of academic aspects, practice oriented research was a large part of this thesis. Although the academic literature used was rooted in management studies it was found that it was sometimes cumbersome to actually apply some concepts to practice. For instance the integration of the input data used for the model. Theoretically it was determined that this data could be integrated in the NPV. However in practice as experienced during this research, the integration of the information was more complex than expected, even though 6 months of work were used to accomplish this integration. This was mainly caused by the need to integrate different information streams between departments in project organizations.

Not only data within the contractor company needed to be integrated, data between stakeholders also had to be combined. In this thesis research therefore a large part of the research consisted of managing and bringing the stakeholders together. Stakeholders had to be informed, leading to the arrangement of many meetings and separate presentation in order to explain concepts and integrate information needed for the IPGA method. It was clearly apparent that the 10 decisions evaluated during these six months required a lot of effort. The information sharing between stakeholders was often hard and the different stakeholders involved in the industry were clearly not always willing to cooperate. This cooperation was however required for this research and will be required for future application of the IPGA method.

9 Bibliography

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Appendix 1: Confidential

Appendix 2: Confidential

Appendix 3: Distribution functions

Random variables are variables that are subject to variation which may be described by a probability distribution function. Random variables can be divided into discrete and continuous random variables.

Discrete random variables can take on values on a finite outcome space. The probability that a discrete random variable takes on a particular value is described by the probability mass function. The probability mass function (pmf) of a discrete random variable is denoted as in the equation below:

$$f_X(x) = P(X = x)$$

The Cumulative distribution function is the function that describes the probability that a random variable takes value less than or equal to a particular value. The Cumulative distribution function (cdf) of a discrete random variable is denoted as in the equation below:

$$F_X(x) = P(X \leq x) = \sum_{x \in (x_1 \leq X \leq x_{2)}} f_X(x)$$

Probability density function (pdf) for continuous random variables:

$$P(a \leq X \leq b)$$

The Cumulative distribution function of a continuous random variable:

$$F_X(x) = P(X \leq x)$$

The Triangular distribution

The triangular distribution describes a continuous random variable. The distribution of this random variable can be described by three parameters: *a*, c, and b. The three parameters can be derived from an optimistic (*a*), a probable or realistic (c) and a pessimistic (b) estimate of the random variable.

$Triang(a, b, c)$

$$\begin{aligned} &a: a \in (-\infty, \infty) \\ &b: a < b \\ &c: a \leq c \leq b \end{aligned}$$

Plots of the probability density function (pdf) and cumulative distribution function (cdf) of an arbitrary triangular random variable are presented in Figure 34.

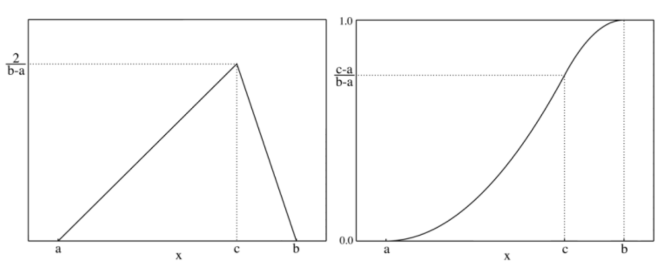

Figure 34: triangular probability density and cumulative distribution function

The probability density function on the interval [a,c] is given by:

$$f_X(x) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)}, & a \le x \le c \\ \dfrac{2(b-x)}{(b-a)(b-c)}, & c < x \le b \\ 0 \quad , & otherwise \end{cases}$$

The cumulative distribution function on interval [a,c] is given by:

$$F_X(x) = \begin{cases} 0, & x < a \\ \dfrac{(x-a)^2}{(b-a)(c-a)}, & a \le x \le c \\ \dfrac{(b-x)^2}{(b-a)(b-c)}, & c < x \le b \\ 1 \quad , & x > b \end{cases}$$

$$E(X) = \frac{a+b+c}{3}$$

$$Var(X) = \frac{a^2 + b^2 + c^2 - ab - ac - bc}{18}$$

The Uniform distribution

The uniform distribution describes a continuous random variable. The distribution of this random variable can be described by two parameters: a and b.

$U(a,b)$

$$-\infty < a < b < \infty$$

The probability density function on the interval [a,b] is given by:

$$g_X(x) = \begin{cases} \dfrac{1}{b-a}, & a \le x \le b \\ 0 \quad , & otherwise \end{cases}$$

The cumulative distribution function on interval [a,b] is given by:

$$G_X(x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a < x < b \\ 1, & x \ge b \end{cases}$$

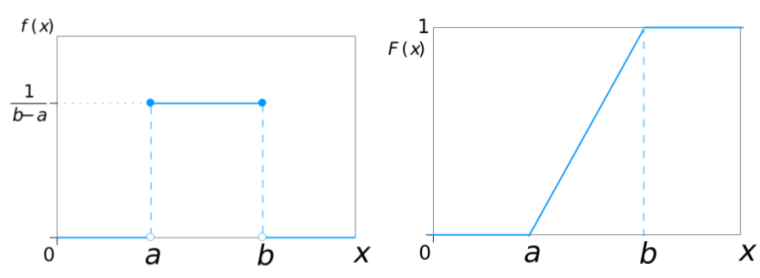

Figure 35: uniform probability density and cumulative distribution function

The Beta distribution

The Beta distribution describes a continuous random variable. The distribution of this random variable can be described by two parameters: α and β.

$Beta(\alpha, \beta)$

$\alpha > 0$
$\beta > 0$

The Bernoulli distribution

The Bernoulli distribution is a special case of the binomial distribution with only one trial (n=1) [source]. The Bernoulli distribution is a discrete distribution having two possible outcomes, 0 and 1.

Bern(p)

$$0 < p < 1, p \in [R]$$

The probability mass function on the interval [0,1] is given by:

$$f_X(x) = \begin{cases} 1 - p, & x = 0 \\ p, & x = 1 \end{cases}$$

The cumulative probability density function on the interval [0,1] is given by:

$$F_X(x) = P(X \leq x) = \begin{cases} 0, & x < 0 \\ 1 - p, & 0 \leq x < 1 \\ 1, & x \geq 1 \end{cases}$$

Appendix 4: Discrete risk probability calculation

Risks are events with a probability of occurring and an associated impact.

$risk = probability * impact$

The probability of occurring x_1 is modelled by a Bernoulli distribution $Bern(p)$:

$$f_{X_1}(x_1) = \begin{cases} 1-p, & x_1 = 0 \\ p, & x_1 = 1 \end{cases}$$

The impact x_2 is modelled by a Triangular distribution $Triang(a, c, b)$:

$$g_{X_2}(x_2) = \begin{cases} \dfrac{2(x_2 - a)}{(b-a)(c-a)}, & a \le x_2 \le c \\ \dfrac{2(b - x_2)}{(b-a)(b-c)}, & c < x_2 \le b \\ 0, & otherwise \end{cases}$$

Appendix 5: Monte Carlo simulation

As shown in the previous main text, the calculation of the probability density function of the NPV through numerical integration is rather difficult because of the large amount of random variables and their associated probability distributions.

A Monte Carlo method uses the possibility of drawing random numbers from a uniform probability density function F_U between 0 and 1. This method generates a random number NPV from a distribution by drawing a number NPV_u from the uniform cumulative distribution function between 0 and 1.

The Cumulative distribution function of a continuous random variable is:

$$F_X(x) = P(X \leq x)$$

The Cumulative distribution function of a continuous uniform random variable is:

$$G_X(x) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a < x < b \\ 1, & x \geq b \end{cases}$$

When the uniform distribution is between 0 and 1, (a=0, b=1) this becomes:

$$F_U(x) = \begin{cases} 0 \quad, & x \leq 0 \\ x, & 0 < x < 1 \\ 1 \quad, & x \geq 1 \end{cases}$$

Let $F_{NPV}(NPV)$ be an arbitrary cumulative distribution function of the NPV variable, and ${F_{NPV}}^{-1}(NPV)$ its inverse. Let NPV_U denote a realization of $F_U(x)$.

$$x = F_X^{-1}(x_u)$$

For distributions for which the inverse probability distribution $F_X^{-1}(x_u)$ is not known analytically, this method can lead to a lot of iterative calculations.

Appendix 6: Derivation to motivate usage of Monte Carlo simulation in the IPGA method

Take the NPV formula as presented in the report

$$NPV = \sum_{t=0}^{T} \frac{FCFE_t}{(1+r)^t} = \frac{FCFE_0}{(1+r)^0} + \frac{FCFE_1}{(1+r)^1} + \frac{FCFE_2}{(1+r)^2} + \cdots + \frac{FCFE_T}{(1+r)^T}$$

FCFE = Free cash flow to equity
r = discount rate
t = time from 0-T (in months)

Activities related to the project, comprise free cash flows to equity on multiple time intervals. The total amount of months an activity takes and the associated **uncertainty**, are described by a continuous random variable and distribution of this random variable is described by a Triangular distribution.

$$Duration_{Activity\ A}: d_A \sim Triang(a, c, b)$$

$$Start\ date = sd = 0 + duration\ previous\ activities\ (dependent\ on\ schedule\ network\ logic)$$

$$End\ date = ed = sd + d_A$$

The total FCFE related to an activity and the associated **uncertainty** is described by:

$$FCFE_A \sim Triang(e, g, f)$$

Depending on the activity "type", the total FCFE is distributed over the associated months (comprising the total duration of the activity) in which the activity occurs based on a uniform or beta distribution.

$$g_X(t) = U(sd, ed)$$

$$k(x) = Beta(\alpha, \beta)$$

To determine the free cash flow to equity on time t of a uniformly distributed cash flow, the following formula is used:

$$FCFE_t = g_x(t) * g(x)$$

$$g_X(t) = \begin{cases} \frac{1}{ed - sd}, & sd \leq t < ed \\ 0\ , & otherwise \end{cases}$$

$$FCFE_A \sim Triang(e, f, g)$$

To determine the free cash flow to equity on time t of a Beta distributed cash flow, the following formula is used:

$$FCFE_t = \begin{cases} sd \leq t\ \leq ed: & \int_{t-1}^{t} k(x) * g(x) * \frac{t}{f(x)} \\ t > ed: & 0 \\ t < sd: & 0 \end{cases}$$

Example calculation: Activity A (uniformly distributed cash flow)

In this example the whole project will consist of only 1 activity, Activity A. In the model a random number from the distribution function of the duration, Triang (2,3,4), is taken and rounded to the nearest integer.

$$Duration_{Activity\ A}: d_A \sim Triang(2{,}3{,}4)$$

$$Duration_{Activity\ A}: f(x) = d_A = 4$$

$sd_{Acitivity\ A} = 0 + 2 = 2$

$ed_{Activity\ A} = 2 + 4 = 6$

The discount rate is assumed to be 7%.

$r = 7\%$

$Total\ FCFE_{Activity\ A}: FCFE_A \sim Triang(100,110,120)$

$Total\ FCFE_{Activity\ X}: g(x) = 100$

Iteration of a uniformly distributed cash flow:
Assuming that the cash flows are divided in a uniform way over the months in which the activity takes places (duration).

$FCFE_t = g_x(t) * FCFE_A$

$$g_X(t) = \begin{cases} \frac{1}{ed - sd}, & sd \leq t < ed \\ 0 \quad, & otherwise \end{cases}$$

$FCFE_0$: Because $0 < sd\ (0 < 2)$, the FCFE caused by Activity X at time 0 is equal to 0.

$$FCFE_0 = 0$$

$FCFE_1$: Because $1 < sd\ (1 < 2)$, the FCFE caused by Activity X at time 0 is equal to 0.

$$FCFE_1 = 0$$

$FCFE_2 = g_x(t) * FCFE_A = 0.25 * 100 = 25$

$$g_X(2) = \begin{cases} \frac{1}{6 - 2}, & 2 \leq 2 \leq 6 \\ 0 \quad, & otherwise \end{cases}$$

$FCFE_2 = FCFE_3 = FCFE_4 = FCFE_5 = 25$

$$NPV = \frac{0}{(1.07)^0} + \frac{0}{(1.07)^1} + \frac{25}{(1.07)^2} + \frac{25}{(1.07)^3} + \frac{25}{(1.07)^4} + \frac{25}{(1.07)^5} + \frac{0}{(1.07)^6}$$

$NPV = 79.14045$

To calculate the probability density function of the NPV formula, multiple probability density functions of random variables need to be used.

$$NPV = \frac{FCFE_0}{(1.07)^0} + \frac{FCFE_1}{(1.07)^1} + \frac{FCFE_2}{(1.07)^2} + \frac{FCFE_3}{(1.07)^3} + \frac{FCFE_4}{(1.07)^4} + \frac{FCFE_5}{(1.07)^5} + \frac{FCFE_6}{(1.07)^6}$$

$FCFE_t = g_x(t) * FCFE_A$

$$g_X(t) = \begin{cases} \frac{1}{ed - sd}, & sd \leq t < ed \\ 0 \quad, & otherwise \end{cases}$$

$ed = sd + d_A$

$$g_X(t) = \begin{cases} \frac{1}{d_A}, & sd \leq t < ed \\ 0\ , & otherwise \end{cases}$$

$$d_A \sim Triang(a, b, c)$$

$$\frac{1}{d_A} \sim \frac{1}{Triang(a, c, b)}$$

$$FCFE_A \sim Triang(e, f, g)$$

The formulas above indicate that d_A and $FCFE_A$ are random variables. The formula for the NPV can then be rewritten as: The NPV formula from the uniformly distributed cash flow can be rewritten as:

$$P(p \leq NPV \leq q) = \frac{g_x(0) * FCFE_A}{(1.07)^0} + \frac{g_x(1) * FCFE_A}{(1.07)^1} + \frac{g_x(2) * FCFE_A}{(1.07)^2} + \frac{g_x(3) * FCFE_A}{(1.07)^3} + \frac{g_x(4) * FCFE_A}{(1.07)^4} + \frac{g_x(5) * FCFE_A}{(1.07)^5} + \frac{g_x(6) * FCFE_A}{(1.07)^6}$$

$$P(p \leq NPV \leq q) = \sum_{t=0}^{T} \frac{g_x(t) * FCFE_A}{(1.07)^t}$$

Given that:

$$g_X(t) = \begin{cases} \frac{1}{d_A}, & sd \leq t < ed \\ 0\ , & otherwise \end{cases}$$

There are three distribution functions incorporated in this new NPV formula, this is graphically shown in Figure 36.

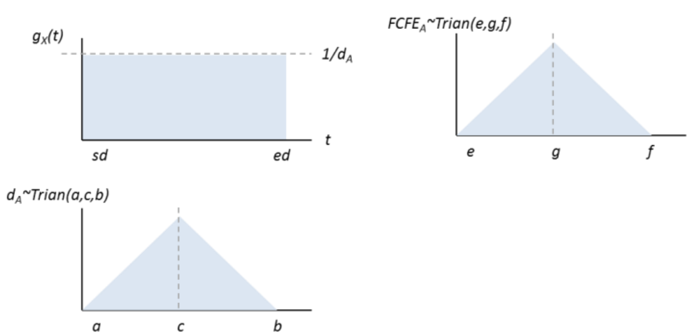

Figure 36: Visualization of the uncertainties associated with each FCFE

Because $d_A = ed - sd$, the graph of the uniform distribution $g_X(t)$ varies with the value of d_A, this influences the distribution function as shown in figure 16.

Note that in this example only 1 activity ($activity_A$) was considered. The amount of activities will normally lie between 50-100 activites. From this example it can therefore be concluded that using a Monte Carlo simulation instead of an analytical approach to determine the distribution function of the NPV can save a lot of time and effort and is therefore preffered.

Appendix 7: Interviewees

Interviewees Fluor Corporation (Confidential)

Step 1-4 of the IPGA method (six-step method) involve determining the data input. The input data for the IPGA method is equal to the input data currently used in decision-making, except for the first step[8]. In step 1, the resource-loaded schedule is determined. To determine the granularity of this resource-loaded schedule, experts are interviewed.

Granularity Resource-Loaded Schedule/network

To determine the granularity, the level of detail, semi-structured face-to-face interviews with experts will be conducted. The interviews will be semi-structured, because the lack of expertise could cause the interviewer to omit essential questions. The interviews are conducted face-to-face, to allow for trust (these types of expertise are often subject to confidentiality agreements) and control (Galletta, 2013). Three experts are selected based on a number of criteria. First of all, these experts have to have substantial experience in industrial projects and scheduling (20+ years). Secondly, these experts are not allowed to be involved in the further thesis research. Furthermore, the questions will be asked individually to each expert and not in group deliberations to avoid unwanted consensus. The following question will be asked:

- Q1: "Can you indicate a schedule, comprising a minimal amount of activities, while still incorporating the necessary schedule logic (network) and cash flows for a large industrial project?"

	Current position	**Expertise**	**Years of experience**
(confidential)	Department manager project controls & estimating at Fluor Corporation	Scheduling	33
(confidential)	Project controls director at Fluor Corporation	Scheduling, cost estimating and project controls	26
(confidential)	Global estimating technology leader at Fluor Corporation	Cost estimation and project controls	21

Table 44: Experts involved in determining granularity of resource loaded schedule Fluor (contractor)

Strategic decisions

To determine what strategic decisions will be examined in the case study report, the involved managers and staff are interviewed by using a structured interview. The involved project managers will be asked the following question:

- Q1: "Please indicate five strategic decisions in the case study project"

Interviewees Case Study Project 1

	Current position	**Position at that time**	**Years of experience in the industrial sector**
(confidential)	Commercial specialist, supply chain at Fluor Corporation	Procurement	25
(confidential)	Project manager at Fluor Corporation	Project manager	19
(confidential)	Project Director at Fluor Corporation	Project manager	29
(confidential)	Project Controller at Fluor Corporation	Lead Cost	25
(confidential)	Engineering manager at Fluor Corporation	Engineering manager	22

Table 45: Interviewees case study project 1

[8] In the other three steps, expert elicitation is used to determine the probabilistic distribution functions; however the data is not created in this research, but was already determined prior to the research. These distributions are used in both the NPV and the traditional time, cost and quality approach.

Interviewees Case Study Project 2

	Current position	Position at that time	Years of experience in the industrial sector
(confidential)	Project manager at Fluor Corporation	Procurement	25
(confidential)	Project manager at Fluor Corporation	Project manager	19

Table 46: Interviewees case study project 2

Validation of Case Study Project 1

To validate the results, semi-structured interviews with project managers and higher management of both owner and contractor will be held.

For each decision, answer the following 5 questions: (Only consider the information that was available at the particular moment in time at which the decision was made).

- Q1: "Do you agree with the impact on the feasibility of the project goal indicated by the NPV model?"
- Q2: "Do you agree with the data and assumptions about the operations phase?" (two answers needed)
- Q3: "Do you agree with the data and assumptions about the entire project?" (two answers needed)
- Q4: "Do you agree with the presented decision alternatives?" (complete/correct?)
- Q5: "Would your decision during the project execution have changed based on the found impact of that decision on the feasibility of the project goal (NPV)?"

At the end of the interview answer this question:

- Q6: "Could you indicate any other reasons why your decisions during the project execution would have changed (omitted-variable bias)?"

	Current position	Position at that time	Years of experience in the industrial sector
(confidential)	Manager of Projects at Fluor Corporation	Project Sponsor	30
(confidential)	Department manager project controls & estimating at Fluor Corporation	Project manager	29
(confidential)	E&C Global leader project controls & estimating at Fluor Corporation	E&C Global leader project controls & estimating at Fluor Corporation	30
(confidential)	Manager of Proposals at Fluor Corporation	Manager of Proposals	29

Table 47: Project management and higher management of Fluor (contractor)

	Current position	Position at that time	Years of experience in the industrial sector
(confidential)	General Manager at Fluor Corporation	Project Sponsor	30

Table 48: Project management and higher management of owner

Validation of Case Study Project 2

To validate the results, interviews with project managers and higher management of both owner and contractor will be held.

For the decision, answer the following 5 questions: (Only consider the information that was available at the particular moment in time at which the decision was made).

- Q1: "Do you agree with the impact on the feasibility of the project goal indicated by the NPV model?"
- Q2: "Do you agree with the data and assumptions about the operations phase?" (two answers needed)

- Q3: “Do you agree with the data and assumptions about the entire project?” (two answers needed)
- Q4: “Do you agree with the presented decision alternatives?” (complete/correct?)
- Q5: “Would your decision during the project execution have changed based on the found impact of that decision on the feasibility of the project goal (NPV)?”

At the end of the interview answer this question:

- Q6: “Could you indicate any other reasons why your decisions during the project execution would have changed (omitted-variable bias)?”

	Current position	**Position at that time**	**Years of experience in the industrial sector**
(confidential)	General manager Engineering at Fluor Corporation	Project manager	25
(confidential)	Project Controls manager at Fluor Corporation	Project controls manager	29

Table 49: Project management and higher management of Fluor (contractor)

	Current position	**Position at that time**	**Years of experience in the industrial sector**
(confidential)	Project Sponsor	Project Sponsor	
(confidential)	Project manager (owner)	Project manager (owner)	

Table 50: Project management and higher management of owner

Appendix 8: Confidential

Appendix 9: Confidential