

Two Monte Carlo Simulation Methods for the Analysis of Cost and Schedule Risks in Oil and Gas Projects Case Study: The National Iranian Drilling Company

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The processes related to oil and gas infrastructure are costly and hazardous. So, it requires complex measures to prevent the project overflow in terms of cost and time. This paper proposes two new methods with the capability of use in oil and gas projects, namely a modified risk driver method, and an integrated risk-schedule driver approach under the pressure of probable resources. The goal of the study is to increase the use of cost and schedule risk analysis in the company under study with a focus on incidental costs calculated at the end of the development phase. Using the Primavera Risk Analysis software, we will perform the cost and schedule risk analysis of an oil project at the National Iranian Drilling Company using each one of the proposed modern methods and with the help of consulting engineers and compare their results considering the estimation of incidental costs and the recognition of high-severity risks. Then, we will perform a sensitivity analysis on the activity level in order to enhance the schedule risk analysis of the target company and identify the most significant activities in the project program through a series of measurements. Also, we will perform a numerical analysis considering the integrated cost and cost risks. © 2024 Journal of Energy Management and Technology

keywords: Cost risk analysis, schedule risk analysis, Monte Carlo Modeling, quantitative risk analysis, Primavera Risk Analysis software.

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1. INTRODUCTION

According to [1], the definition of risk can vary depending on the application domain. For instance, in the business domain, risk is defined as the likelihood of achieving successful outcomes. On the other hand, in the project domain, it is defined as the successful completion of a project within a predetermined timeframe and cost [2, 3]. The Project Management Institute Reference [4] defines risk as an uncertain event or condition that, if it occurs, can have a positive impact (opportunity) or a negative impact (threat) on project objectives. Since projects are subject to uncertainties arising from both external and internal factors, effective risk management is necessary to reduce the probability of occurrence and/or minimize the negative impact of risky events [5]. In terms of assessing uncertainties, risks are typically categorized as low, medium, or high, depending on the overall impact they may have. From a quantitative perspective, risk is addressed through the implementation of countermeasures aimed at reducing either the likelihood or the consequences of a risk, or by transferring the risk to a third party, such as an insurance company [6].

Risk management is an essential and systematic process implemented in industrial establishments, following the manufacturer's policies and industry best practices. This process plays a crucial role in understanding the cause-and-effect relationships between risks and their associated operations [7, 8]. Risk management can be proactive, employing managerial procedures to lower the probability of occurrence, or reactive, responding promptly to minimize the negative impact after a risk has manifested. It is important to note that the occurrence of risks often changes over time, necessitating continuous monitoring. The comprehensive management of risk involves the identification, control, and minimization of the impact of unpredictable or uncertain events. Four fundamental phases in the risk management process: risk identification, risk assessment, risk analysis, and risk mitigation [6]. Among these phases, the risk analysis phase holds prime importance. Its objective is to prioritize identified risks and provide data to support the evaluation and treatment of risks. During the risk analysis process, it is crucial to systematically utilize available information to determine the frequency of specified events and assess the magnitude of their consequences

[9, 10]. This process can take various forms, including qualitative, semi-qualitative, quantitative, or a combination thereof. Qualitative risk analysis involves instinct-based assessments of a situation, while quantitative risk analysis aims to assign numeric values to risks using empirical data or quantified qualitative assessments [11]. Risk analysis methods based on systems and probability are typically employed in cases where sufficient failure statistics are unavailable [12, 13].

One of the primary goals of project managers is to create a cost estimation method and a project schedule showing when the project will be completed. Considering the fact that the project risks often tend to increase rather than decrease the costs, the delayed commissioning of projects (cost and time increase) has become commonplace [14]. In oil projects, like many other projects in Iran, the time-cost balance issue is the main concern. Oil and gas development projects are compressed and high-risk investments, which make them vulnerable to cost and time overruns [15]. In addition to the balance theorem, some costs are considered as a buffer and the maximum sum of the project cost. The estimation value of this sum can help complete the project, which can cause significant damage to the contractor and the employer. If we want to make this sum realistic, we should consider finding and analyzing the risks carefully and finding relationships between them. In this research, we seek to find methods of quantitative analysis that improve the values of Cost Risk Analysis (CRA) and Schedule Risk Analysis (SRA). We will use software applications to estimate the cost at which the project will be completed. We will test the typical methods by focusing on the amount of buffers, comparing them with Quantitative Risk Analysis-Monte Carlo Simulation (QRA-MCs) and selecting the appropriate method. We will compare the method used by oil companies with the appropriate method found in the previous step. The ultimate goal of this study is to help mitigate the cost and time overruns in oil and gas projects. Additionally, this research tries to introduce a method by which oil and gas companies can estimate the additional cost of work (buffer) and update its rate at the design and planning stages, and even in the implementation stages, if needed. If it is continuously updated, it is possible to minimize the accumulation of additional capital to guarantee doing the work or to think of finding capital to guarantee doing the work. This research will be organized as follows: we will review the previous studies in the next part. In the third part, we discuss the research process, methodology and the tools used in the research to analyze the problem under study. The results will be presented and analyzed in the next part, and the fifth part will deal with the conclusion of the study and end with some suggestions for future research.

2. LITERATURE REVIEW

Here, we review the articles that have been written about risks, estimation conditions, how to use numerical methods, the Monte Carlo method, and information analysis. Reference [16] conducted a study on major oil and gas projects, finding that risks related to offshore projects tend to increase and are an important factor in doing risk analysis and evaluating reliable probabilities. The determined probabilities provide no guarantee and instead allow for the fulfillment of cost and time criteria. He stated that stakeholders in offshore projects need more than ever to be realistic and rational about the probabilities required, know about the probability of fulfillment of the approved expense and schedule, the probability of overflow of the cost and predicted schedule, and identify high-probability risks for which we should define

a reliable risk severity mitigation program. References [14] and [16] performed research on risks and concluded that they should avoid underestimating the time and cost in order to cope with the overflow problem. Reference [14] found that we should avoid underestimating the cost and time in order to eliminate the cost and time overflow problems in projects. To achieve this aim, it is very necessary to recognize and evaluate the conditions and events that can divert the cost and time of the project from the initial estimation. This method is known as risk analysis, which in turn paves the way for developing a realistic probability assessment of time and cost. It is necessary to identify and evaluate the conditions and events that may divert project costs and time from the initial estimate. Investigating various project risks and their impacts, he found that cost risk depends on the uncertain elements of the project and that cost estimation will not be reliable if planning fails. References [14] and [17] criticized Monte Carlo and non-Monte Carlo approaches and concluded that the Monte Carlo simulation always ensures that concepts and results will be consistent. Considering that Monte Carlo techniques take into account the combination of multiple risks, their results can practically enhance decision-making confidence for managers. This paper deals with the quantitative risk analysis method, which can in turn be done through different models. Reference [17] classified quantitative evaluation methods into computational methods and software methods. The computational methods were subdivided into (1) Monte Carlo simulation methods; (2) numerical approximation methods; (3) precise algebraic solutions; and (4) torque calculation methods. References [18], [19] and [14] analyzed the various methods used for quantitative evaluation. They found that Monte Carlo simulation models have been experienced and tested more than the various methods of quantitative risk analysis. They argue that the Monte Carlo simulation model is the most common and acceptable method for quantitative risk analysis. By combining various risks and their interactive impacts, the MCs technique practically leads to multiple options from which decision-makers can choose based on their potential tolerance. In addition, the above-mentioned result, which is based on probability, is one of the requirements of the association for the advancement of cost engineering regarding the probability assessment method. Therefore, the new methods of evaluation and assessment in the oil and gas industry usually use probabilistic thinking through the use of incidental simulation techniques. Reference [20] presented a novel quantitative risk analysis and assessment approach integrating AHP and Monte Carlo simulation methods. The study employed AHP to assign weights to Confidentiality, Integrity, and Availability (CIA) as information asset security attributes. To address uncertainties in vulnerabilities and threats, Monte Carlo simulation was utilized, considering multiple evaluators' perspectives. Reference [21] assessed cost estimation in construction projects using Monte Carlo simulation, examining the probability distribution of different cost elements. The authors explored correlations between project costs and simulation results, highlighting the value of Monte Carlo simulation for risk management and cost estimation. They identified an imbalanced and positively skewed cost distribution, indicating interdependencies among cost elements. In a study by [22], a fuzzy Monte Carlo simulation (MCS) approach was proposed to address the mentioned issues. The fuzzy MCS offers advantages over traditional MCS by incorporating both aleatory and epistemic uncertainty, and generating a range of probability distributions. Additionally, the paper explored the effective utilization of fuzzy MCS for uncertainty and global

sensitivity analysis. Reference [23] employed a Monte Carlo simulation-based fate model to investigate the behavior of six antibiotics in wastewater treatment. The study found that norfloxacin and ciprofloxacin exhibit higher removal rates during secondary treatment compared to other antibiotics. The total removal efficiencies were primarily influenced by the tertiary process, with reverse osmosis achieving high removal rates for all antibiotics. Ozone treatment demonstrated negative correlations between antibiotic removal and molecular weight, log octanol-water partition coefficient, and acid dissociation constant. Reverse osmosis effectively reduced antibiotic toxicity, while residual erythromycin and ciprofloxacin in effluent pose higher risks even after ozone and powder activated carbon treatments. These findings contributed to optimizing wastewater treatment and assessing antibiotic risks in the environment. Reference [24] developed a dual-interval stochastic programming method (MC-DSP) using Monte Carlo simulation to assess uncertainty impacts on crop planning and irrigation water supply. Applied to the Zhangweinan River Basin in China, the method generated solutions for crop planning and water allocation, revealing changes in system benefits and irrigation shortages due to varying surface water availabilities. Insufficient water for wheat irrigation poses a risk to food supply, and all subareas of farmland experience water deficits under different scenarios. The conflicts between economic development and agricultural sustainability necessitated adjustments to food security policies. Reference [25] conducted a study to identify the critical risk criteria in Oil and Gas Construction (OGC) projects based on data collected from expert interviews in Iran in 2016. The study utilized DEMATEL to evaluate the relative strengths of interdependencies among the risks and employs the ANP method to assess the significance of risk factors and determine an optimal risk management strategy. The research findings contributed a novel adaptation of risk assessment methodology specifically tailored to OGC projects, highlighting key risk factors influencing project success and aiding in the development of policies for reliable energy supply planning. Reference [6] focused on studying the recognition, application, and quantification of risks in project management, specifically within an oil and gas project in Oman. Qualitative data on project risks were gathered through field visits and interviews, which were then converted into numerical values based on expert opinions. Monte Carlo simulation using Risky Project Professional software predicted a potential 2-year delay and an 8% chance of exceeding the budget. The numerical analysis was validated by comparing it with qualitative analysis conducted with project managers. Reference [26] provided a comprehensive assessment of risks in the Iranian bridge construction industry through site visits, interviews, and questionnaires. Monte Carlo simulation was employed to quantitatively analyze risks on a real project, determining their impact on project time and cost. Financial risk was identified as the most critical factor affecting projects. Practical solutions for risk assessment and analysis were proposed, beneficial for contractors, project managers, and project control engineers in bridge construction companies. Reference [27] assessed the impact of delay risks on the completion time of an oil and gas project in Indonesia. Data on delay risks were collected from literature reviews, project documents, and interviews. A Monte Carlo simulation was conducted, revealing a probability of less than 1% for on-time completion and projected extensions of 10.6% (405 days) and 14.2% (418 days) with 50% and 80% probabilities, respectively. The sensitivity analysis identified tubular delivery as the most influential activity, with long-lead item

delivery being the risk with the greatest impact on project delays. The findings informed stakeholders in developing effective risk mitigation strategies. Reference [28] examined risk management challenges in Public-Private-Partnership (PPP) project implementation. Through decomposition analysis, government risk, market risk, and project risk were identified as key risks in PPP projects. A list of PPP project risks was established, and an improved matter element model was proposed for risk assessment. Reference [29] presented a novel consulting process to address the previously mentioned challenges in the triangular FAHP. This process included an innovative questionnaire design and an approach for determining fuzzy numbers based on experts' responses. The effectiveness of the proposed method was demonstrated through its application in the Jinan metro tunnel construction case study, where the new questionnaire outperforms the traditional one in terms of convenience and time efficiency for collecting experts' opinions, resulting in the establishment of consistent judgment matrices using triangular fuzzy numbers. Reference [30] presented an original risk assessment approach using Monte Carlo simulation that addresses the co-occurrence of risks. They utilized extended and classic simulations to prioritize risks through Co-Occurrence-based Risk Assessment (CORA) and determines uncertainty levels for each risk source. The proposed model not only identified and analyzed risks but also explored relationships between them, distinguishing between resonance and reduction effects. The authors incorporated a system dynamic model to visualize risk relationships and was successfully applied to a petrochemical project. The results highlighted the significance of considering risk co-occurrence, emphasizing the value of CORA in comprehensive decision-making for managers. Reference [31] analyzed 46 infant formulas from the Chinese market to determine the levels of 3-MCPDEs and GE. By combining occurrence and consumption data, a Monte Carlo simulation-based model was developed to assess the risk of these contaminants in Chinese infant formulas. The results showed that 3-MCPDEs posed minimal health risks to most populations aged 0-36 months, while GE may pose potential risks to 10% of the 0-12 month's age group. The study highlighted the importance of considering uncertainties in the assessment and provides insights for regulatory limits in China. Reference [32] measured the concentration of diazinon, chlorpyrifos, and malathion in cantaloupe and soil samples from Kashan and Aran-Bidgol, Iran. Monte Carlo simulation was used to estimate the oral and dermal health risks associated with these pesticides. The results indicated that the concentrations of these pesticides in cantaloupe and soil were within acceptable limits. However, continuous exposure to these pesticides may still pose potential harm. The study emphasized the importance of understanding the health consequences of pesticide contamination and implementing remedial strategies to mitigate environmental concerns. Reference [33] examined the distribution, sources, and environmental risks of potentially toxic elements (PTEs) in cultivated soils in Lishui City, China. The results highlighted Pb and Cd as the main pollutants with higher ecological risks. Analysis identified natural, mining, traffic, and agricultural sources contributing to PTE accumulation. Mining activities were found to significantly impact human health risks, especially for children. This research provided valuable insights for managing PTE pollution and controlling health risks in cultivated soils. Reference [34] evaluated the economic risks of district heating (DH) networks considering uncertainties in energy prices and waste heat availability. A case study of an inter-regional heat transfer network in Austria was conducted

using Monte Carlo simulations. The results demonstrated that DH networks, by optimizing the utilization of waste heat and integrating various heat sources, can mitigate the economic risks associated with fluctuating energy prices compared to individual heating systems.

The inability of the existing models to integrate systemic risks is one of the most noticeable inherent deficiencies. This inefficiency is a chronic problem that affects all MC-based models. Instead of considering the project as a whole, it focuses on linear elements and thus can only focus on the project-specific risks. This paper initially proposes a modified hybrid model, which, unlike the model presented by [35], extracts the results of both models separately and then integrates them in a separate step. Due to the need for an extra step, this will add to the complexity of the task. In addition, the common risk analysis software applications are not able to simultaneously control both integrated methods, which, as a result, limits the applicability of the combined model in the industry. To solve this problem, we present an integrated risk driver approach with Probabilistic Resource Loaded Schedule (PRLS), the use of which will lead to a better prioritization of the noticeable risks involved in the costs of this project. In this regard, based on the gathered data, "uncertainty of duration" has the most critical impact. Therefore, improving the accuracy of the input data for the program can increase the accuracy of the estimated final cost. The main differences between this paper and other studies that have been conducted in this area are presented as follows:

- Simultaneous consideration of cost and time risks directly,
- Considering the correlation of risks,
- High iterations of risk variables that reduce the probability of not considering the important risks,
- The decision maker's freedom to balance time and cost
- Introducing two new Monte Carlo simulation methods, the modified risk driver method and the integrated risk schedule method, under the pressure of probable resources with the ability to be used in oil and gas projects,
- Possibility of changing the analyses at the start of the project stages and reducing uncertainty,
- Implementation of cost risk analysis and schedule risk analysis of an oil project in Iran's National Drilling Company using the proposed methods.

3. METHODOLOGY

A. Research Stages

This research aims to enhance the performance of CRA and SRA methods by focusing on probable costs at the end of the development phase. Different methods of ascertaining probable costs have been investigated by different studies, among which the quantitative risk analysis methods based on Monte Carlo simulation models for cost and schedule have been subjected to more in-depth studies. The steps involved in this article are as follows:

1. Investigating the CRA and SRA techniques with a focus on probabilistic estimation using QRA-MCS-based models to find a new solution usable in oil and gas projects in Decision Gate 3 (DG3).

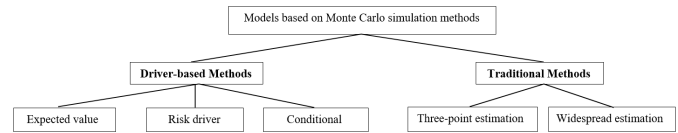


Fig. 1. Classification of Monte Carlo simulation methods [14].

2. Comparing the theory of the current approach in a sample company in terms of CRA, SRA, and probability estimates in DG3 with recommended procedures in order to find possible contradictions and cases of incorrect use and their impact on final results.
3. Implementing the new CRA and SRA methods identified in the sample company and comparing the results with current procedures in order to improve the sample company's status in terms of estimation of probable costs and identification of significant risks.
4. Doing a practical comparison between the Monte Carlo simulation methods for estimation of probabilistic costs and the corresponding non-MC models in the sample company in order to find the inconsistency in their results.

B. Examining Typical MCs-Based Models for the QRA

All the methods presented hereafter make use of the simulation process. These methods combine expert judgment with the analytic model and then obtain probabilistic outputs using simulation. Figure 1 presents a classification of Monte Carlo simulation methods.

B.1. Traditional Methods

Traditional models are those that use probability density functions (PDFs) to provide uncertainty in the values of elements due to the impact of existing risks. In other words, these techniques focus on the level of activity rather than the risk. The three-point estimation method is the simplest type of MC-based model that confirms the risks by taking uncertainty and associated risks into account for each project. The larger the distribution width, the greater the uncertainty of income. Some criticisms of the 3-point estimate method are presented below:

- In this method, the risk probability is ignored completely, and risks are presented merely due to their unknown impacts.
- It is not possible to distinguish the impact of each risk on the cost of the entire project. In other words, this model does not play a role in determining the most serious risks and planning to reduce them.
- Focusing on the element of each project cost leads to a loss of the impact of the risk on other cost elements.
- The mental evaluation of the collective impact of multiple risks on the elements of each cost is difficult for experts. This plays a role in the uncertainty of the input data.

The widespread estimation method was developed based on the Pareto principle (also known as the 80/20 rule, the law of the vital few, or the principle of factor sparsity). This method can be assumed as an advancement to a 3-point estimate model focusing merely on vital activities, which, according to Humphreys (2008), impedes the final probable underestimation caused by

the 3-point method. This method determines the risks of the project cost by focusing on a few vital elements, classifying the vital opportunities and risks, and using the Monte Carlo simulation technique. The key to using this method is to identify the vital elements of the project and apply the spectrum of estimates to those elements. A common misconception is that very large cost elements are vital due to their scope, while an item must be considered vital if it can be sufficiently changed to impose a significant impact on the profit or cost of the project. The main critique of the widespread estimation method is that it neglects the impact of uncertainty associated with non-vital elements by assigning algebraic values for them and ignores their collective impacts. In rare cases, highly correlated non-vital elements have collective impacts even beyond the impact of the vital item, but this impact cannot be taken into account with this method due to the exclusive focus on vital elements.

B.2. Driver-based Methods

According to the Association for the Advancement of Cost Engineering (AACE), the key concept in risk management is that a probabilistic estimate should reflect the causes or drivers of the risk. By contrast, traditional methods (3-point estimate or widespread estimate models) do not bind the calculated probabilistic estimate to the root causes of uncertainty. In order to overcome this deficiency, driver-based approaches that focus particularly on risks have been gradually developed. In other words, [36] argue that baseline estimates should be competitive, that is, they should require increased pricing and excessive prescription for general unknowns. As shown in Figure 1, driver-based models include three methods: the risk driver, the conditional method, and the expected value method. We study an oil project at the National Drilling Company. A comparison of the process of cost and time analysis in this company (Appendix 3) with the researched methods shows that the National Drilling Company currently uses the risk driver method. Accordingly, it is assumed that these analyses are not affected by the inefficiency of traditional methods. Therefore, this paper proposes two new methods based on the risk driver method in order to analyze the cost and schedule risks in oil and gas projects. In the following, we will introduce the risk driver method and these new methods.

Method 1: The Risk Driver Method

This method was introduced by [14]. Let's provide a brief explanation of this method.

- Risks are derived from the risk register form.
- Risks are assigned to project element costs (more than one risk is assigned to an element).
- The probability of each risk is estimated (algebraic).
- The impacts of each risk regarding estimation of the corresponding base of cost elements in incremental terms are specified explicitly, that is, the incremental coefficients of "L, M, H" for the impact on the element of each cost and the type of probabilistic distribution for it are specified.
- Implementation of MCs, meaning that in each iteration, if multiple risks affect one activity, their incremental factors (random selection from probabilistic distributions of impacts) are multiplied by one another and are applied by estimating the baseline cost (algebraic value) of the project

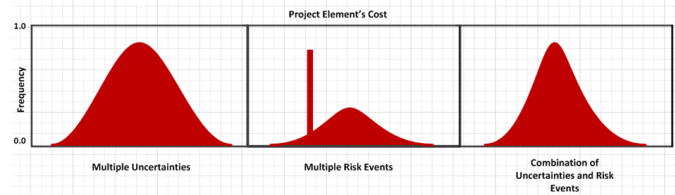


Fig. 2. The impact of risk uncertainties and events on the form of the probability density function based of Reference [14].

element for determining the cost of that particular activity during that iteration. If a risk does not occur during the iterations, value 1 is assigned as its incremental impact to neutralize its impact in the increment (multiplication).

- Risk events may or may not occur (with a probability of less than 100%) and have uncertain impacts. The absence of key, high-quality personnel is an example of this. The probabilities of risky events are specified with an algebraic value.

Figure 2 shows the impacts of the assignment of multiple monopoly uncertainties and risk events and their combination with the distribution of project cost elements. It is necessary to emphasize that the probability distribution will change if a completely risky event occurs. Because the element of each risk is 100% definite, the cost of many iterations of MCs will be equal to the baseline estimate. The mutation in the combination mode tends to fade. Reference [14] shows that correlations between line elements are due to risks, and risks are assigned to project elements in this model. Because conclusions are inferred from the incremental factors of risks, the cost elements are correlated with the progression of the simulation. These risks must be independent of one another and integrated into each term. Therefore, there is no need to determine the correlation between risk elements.

Method 2: Modified Risk Driver Method

Regardless of the correlation between non-deterministic elements, one of the inaccurate uses is inaccuracy in the results of MC-based models. In order to avoid the participation of correlation coefficients in non-deterministic elements, we used independent risk factors in the risk driver method. This approach is quite consistent with [14] approach to the selection of risk factors. By using this method, Reference [14] claimed that by choosing strategic level risks, we do not need to estimate the correlation coefficients between uncertain factors of risk. In addition, due to the use of the risk driver method, the correlations between the lines in the cumulative distribution function (CDF) are modeled in practice, and consequently, there will be no need to estimate the correlation coefficients through them. However, as [37] asserts, entering risks only from the strategic level causes us to ignore the impacts of some of the precise technical risks and acts as a deterrent, causing the correlation between the curve lines of the CDF not to be fully accounted. This indicates that if we involve only risks at strategic levels that are closely interrelated, we will still need to use the correlation coefficients between them in order to precisely determine the residual correlation due to the impact of ignoring the precise technical risks.

Method 3: An integrated risk-schedule driver approach under the pressure of probable sources

The integrated cost-schedule risk driver method has been selected as the latest technology for implementation in the CRA domain and compared with the current risk driver method. This choice is justified for the following reasons: Considering the fact that the Eavar field development project is one of the major projects in the oil and gas industry, it is assumed that a large amount of the cost of this project is supplied through time-dependent resources. Accordingly, as an impact of sensitivity analysis on the cost of the Eavar project, the "schedule impact", which is the impact of the fluctuations of the schedule on project cost, has been posed as the most significant risk in the CRA. This confirms the above-mentioned assumption regarding the size of time-dependent resources in the project, and thus emphasizes the degree of effective involvement of schedule risks and uncertainties in cost-risk analysis. In contrast, this impact is only estimated approximately in the risk driver method for the CRA in the target project (Method 1) by adding a single risk item called the "schedule impact" (Appendix 5). This type of analysis is performed outside the framework of the project schedule and, as a deterrent factor, considers only one single-purpose impact of schedule risks on the project cost. According to this principle, the effective involvement of the schedule impact in the project cost is described as a benefit of integrated analysis in the risk driver method through the direct modeling of the relationship between cost and schedule. Modeling is done by applying the integrated risk driver method using the project schedule as a platform.

Sensitivity analysis in driver-based methods

Better and more reliable sensitivity analysis is regarded as a major advantage of driver-based methods over traditional methods because sensitivity analysis can be done on risk drivers rather than activities. Now it is good to find the risks that are more serious at a certain level of confidence and subsequently provide reliable inputs for the discount plan. The impact of each risk on the cost of the whole project and its prioritization by sensitivity analysis depend on the following:

- Its probability of occurrence,
- The scope of its impact on the project cost elements,
- The number and size of the cost elements assigned,
- The predetermined confidence level at which the sensitivity analysis is performed, given that the resulting Tornado diagrams are based on correlation concepts that are themselves determined by input and output distributions (A risk significant at the P-70 level may not be significant at another level).

4. CONCLUSIONS AND THEIR INTERPRETATIONS

In this part, we will implement the methods presented on an oil project at the Iranian National Drilling Company. It should be noted that the Consulting Engineers Company performs the cost and schedule risk analysis for the target project based on the process of cost and schedule risk analysis of the National Iranian Drilling Company at DG3. To analyze the results, instead of the @Risk software, we used the trial version of the Primavera Risk Analysis (PRA) software for the following reasons:

- Free access to the trial version of the PRA was available only for one month.
- In comparison with @Risk, the PRA software has a combination of more terminal equipment and computer programs.
- Unlike @Risk, there is no need to write the formula in Excel to describe the system's specifications in the PRA software. Therefore, it is quite possible to learn how to use the PRA skillfully in a short period of time.

The PRA software is a powerful tool for project risk analysis. It enables the user to apply it for the following purposes: schedule risk analysis, cost risk analysis, and combined cost/schedule risk analysis for projects. In addition, the PRA software includes various types of reports: distribution charts, Tornado diagrams, dispersal charts, and possible liquidity assessments. It should be noted that this software was, in some cases, able to control and test the reliability of the collected data. For example, to eliminate the deficiencies in the calculated coefficients (Appendix 11), the risk correlation table was controlled and corrected by means of this software.

A. Results of the risk driver method

The risk driver method is the current approach of the target company in the use of CRA and SRA. To implement the risk driver method and analyze the results, the researchers collected the input cost and schedule data related to the project. They collected the schedule data from the existing report and collected the cost data with the collaboration of specialists from the National Iranian Drilling Company. This project was implemented through the use of the Primavera Risk Analysis software. Table 1 presents the input data collected from the project as well as the elements considered in this analysis. It should be noted that all uncertain elements in the input data are presented using triangular distributions.

In this method, all simulations were performed with the risk analysis module of the PRA software. The total cost and the duration of the project were 180562340000 Rials and 1494 days, respectively. Based on the type of the input risk data, all the risks were defined in the software as quantitative risks, except for "schedule accuracy", which was defined for activities as "activity duration Uncertainty". The Latin-Hypercube Sampling (LHS) method, which is an acceptable sampling method superior to MC sampling, was used in the software during simulation. In order to implement CRA and SRA separately, we started two "hidden risk plans", one by considering the schedule risk and the other by considering the cost risks. After 1000 iterations of simulations, we extracted the CDF and PDF for the cost and activity duration of the target project.

A.1. Analysis of the CRA results

Figure 3 shows the PDF and CDF obtained from the CRA for the Eavar Lavan project, in which the risk driver method is based on the current approach of the drilling company. It is possible to calculate risk probability based on different confidence levels. Appendix 1 shows that the National Iranian Drilling Company uses the confidence level of 50% here in the following ways:

Probability of cost = P50 value/the final cost

As Figure 3 shows, the probability of the cost of this project is 24306326730 trillion Rials, which is 13.4% of the estimated final cost of the project. It is noteworthy that, as shown in Figure 3, there is only a 1% probability of reaching a definite value. In addition, the standard deviation indicating the amount of

Table 1. The input data of CRA and SRA for the project (Method 1).

Input data		Description
CRA input data	Baseline cost (Appendix 1)	This includes estimated costs for all project activities. The cost elements were considered just like the schedule elements.
	Cost Risks (Appendix 2)	These data were prepared with the help of the specialists at the NIDC . This document includes both the risks and the uncertainties associated with the baseline cost of all costs. Risk also includes the probability of risk and its impact, Risk-related elements are extracted from a company’s report, and related are obtained with the help of specialists from the National Iranian Drilling Company.
SRA input data	Baseline schedule (Appendix 3)	This document includes both the risks and uncertainties associated with the preliminary estimation of the duration of activities. The risks also include their probability and impacts.
	Schedule risks (Appendix 4)	These data were extracted from an existing report within the company

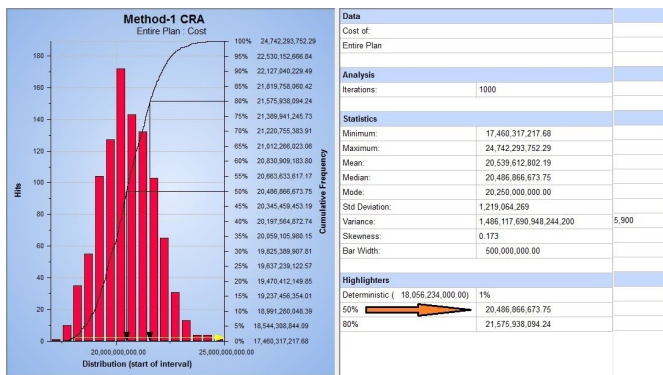


Fig. 3. PDF and CDF for the CRA of the project (Method 1).

uncertainty in the final result is equal to 1219064269 units. In order to reduce the probability of a risk, we should mitigate the specified risks. In this regard, sensitivity analysis is considered one of the main benefits of driver-based methods over the old methods. Figure 4 shows the impacts of sensitivity analysis on the project cost, which includes the impact of each risk on the total cost of the project and subsequently its priority

As presented in Figure 4, the "schedule impact", which is the impact of the fluctuation of the schedule on the cost, will be the most significant risk to the project cost. This shows the specific impact of the schedule risks and uncertainties on the project cost. In addition, the concept mentioned in the previous section emphasizes that the most important cost risks in large projects are, in fact, schedule risks.

A.2. Results of the SRA results

Figure 5 shows the PDF and CDF obtained from the SRA for the Eavar project, which are based on the current approach of the National Iranian Drilling Company using the risk driver method. As the above figure shows, the estimated final cost of the project activity duration is 1494 days, and its probability of success is only 1%. The confidence levels of 50% and 80% for the project activity duration are 1555 and 1687 days, respectively. Figure

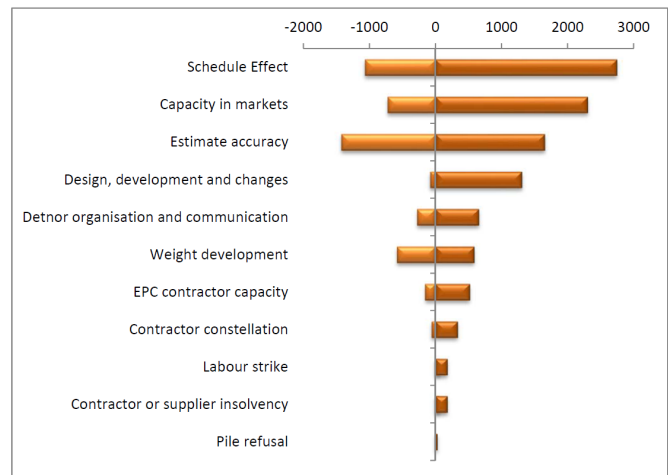


Fig. 4. Tornado diagram of the cost risk of the target project (Method 1).

5 shows a significant deviation in the PDF of the time obtained for the project from the normal distribution. This deviation, the extension of the right-hand side of the graph, is extracted by activity 43 (Appendix 3). This is a probabilistic branching with the greatest impact on the project’s completion date because it is always on a critical path. In simple terms, the part of the ongoing activity is postponed, and the subsequent parts should be carried out in less time and under pressure until the finish date.

Cost results

From the CDF of the cost, the cost probability of the target project was calculated based on the confidence level of 50% to be 2430632673, which is 13.4% of the estimated baseline final cost. In addition, the sensitivity analysis showed that the "schedule impact", which is the impact of the schedule fluctuations on the cost, is the most significant risk to the project cost. This finding

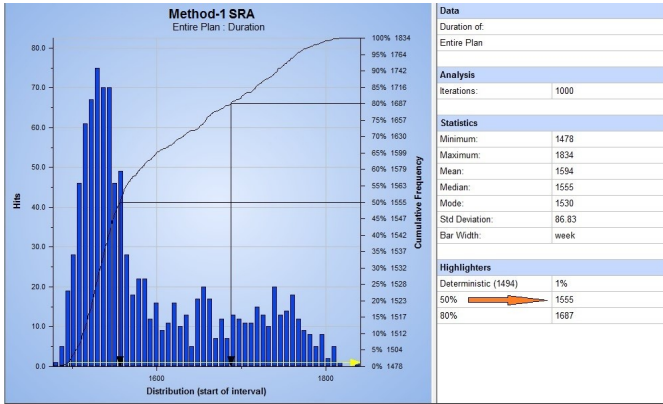


Fig. 5. PDF and CDF related to the SRA of the project (Method 1).

reveals the specific impacts of the schedule risks on the cost of the major projects.

Schedule results

From the CDF, the activity duration of the project was calculated at a confidence level of 50% to be 1555 days, which is 40% higher than the project’s preliminary design. In addition, the PDF also shows a significant deviation from the normal distribution, which is shown in the form of a deviation at the end of the graph. This deviation, which is a positive point, is based on the concept of probabilistic branching, which is used in the schedule design, has a probability of occurrence, and will have serious consequences for the project’s activity duration.

B. Results of the modified risk driver method

Method 2 is a modified version of Method 1, in which the inconsistencies identified with the corresponding theory have been corrected. It has been emphasized that the entry of strategic-level risks in Method 1 helps ignore the impacts of some of the available technical risks. The result is that we ignore the residual correlation between the project line elements. To eliminate this inefficiency, the correlation coefficients of 0.3 are only adjusted and set up between the activities of each work package due to the overall technical risks affecting the components of each work package. For the implementation of Method 2, in addition to considering the correlation coefficients, we should consider the input data and the process the same as Method 1.

All cost and schedule inputs presented in Method 1 are also used here. To consider the residual correlation and correlation coefficients between the activities of each work package, we select and set up the overall technical risks that affect the components of each work package. Extracting the correlation coefficients from experts is not so promising. Therefore, considering that the residual correlation is not a significant value, we consider the hypothetical value of 0.3, which has been proposed by [38], for all correlation coefficients. To apply this concept in the CRA through the PRA software, we apply correlation coefficients of 0.3 between the estimated uncertainties of the activity duration. The same procedure is followed for SRAs by applying these correlations between the estimated uncertainties of the activity duration. Finally, as in Method 1, two "compact risk plans" are created, and the results of 1000 iterations of simulation are shown in two different forms for the CRA and SRA.

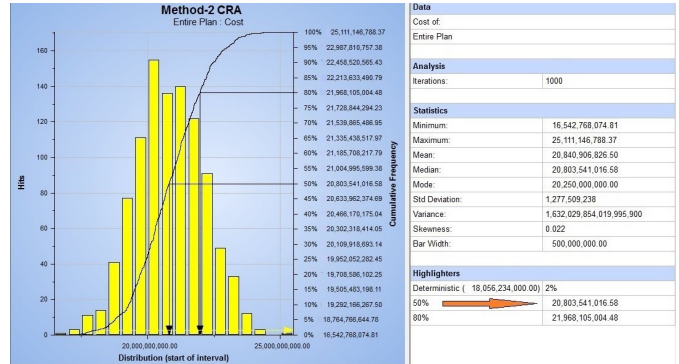


Fig. 6. PDF and CDF related to the CRA of the target project (Method 2).

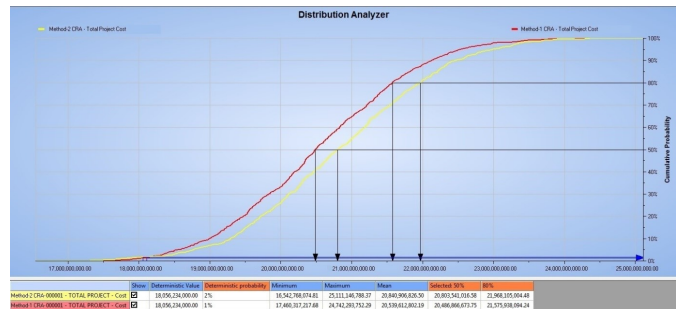


Fig. 7. The CDFs of target project’s cost obtained from the CRA of Method 1 and Method 2

B.1. Results of CRA analysis

The CDF chart extension shows the final cost of the project and consequently increases the uncertainty in the final result (Figure 6). Also, considering the impact of the existing technical risks can lead to a correlation between the yellow and red lines (Figure 7).

B.2. Results of SRA analysis

Like what was mentioned in the CRA, Figure 8 shows the PDF and SDF related to the SRA using the modified risk driver method, in which the residual correlations among the lines are considered. Figure 9 shows a comparison between the CDFs of the total activity duration of the project obtained from Method 1 (blue line) and Method 2 (green line). Considering the continuation of the diagram of the obtained CDFs, like what was described in the CRA results and as expected, the inclusion of correlation into the analysis would extend the CDF chart of the activity duration, thereby increasing the uncertainty in the final result (Figure 9). Of course, this impact is smaller than the corresponding result about the cost. Regarding the changes in the P50 and P80 values, the results of Figure 9 suggest that the inclusion of correlation through the modified method only has a small and insignificant impact on the final result. This insignificant impact can be partially justified for the following reasons:

Two contradictory positions were previously described about the changes in the final activity duration of the project at the P-50 level, if there exist parallel paths. On the one hand, the inclusion of correlations only in the activities of each path will exacerbate the impact of integration errors due to integration and consequently increase the project’s activity duration in the P50. On the other hand, the inclusion of correlations between

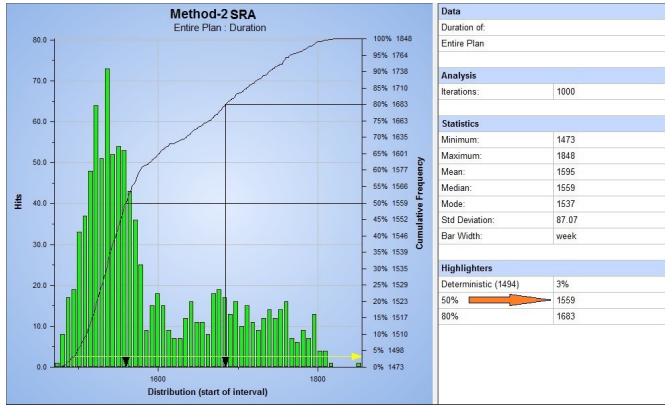


Fig. 8. PDF and CDF related to the SRA of the target project (Method 2).

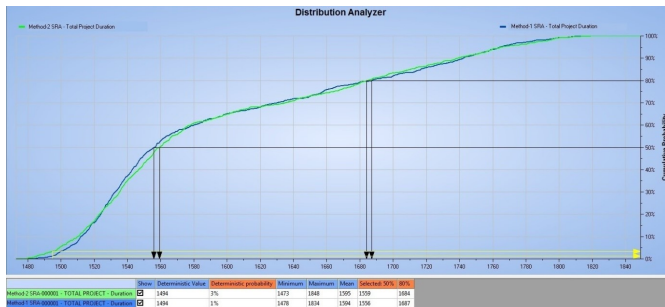


Fig. 9. The CDFs of the target project's cost, obtained from the SRA of Method 1 and Method 2

parallel paths acts differently than the impact of the integration error, and as a deterrent factor, it will mitigate the project's activity duration at the P-50 level. Now, considering the schedule of the Eavar project (Appendix 3), the inclusion of the correlation between the activities of each work package in Method 2 leads to the combination of the conflicting situations mentioned above, which neutralize each other. Therefore, the project activity duration at the P-50 level or even P80 remains roughly equal to the value obtained from Method 1.

Table 3 shows that the inclusion of the residual correlation between line elements in the risk driver method has had no more significant impacts on the final results of the SRA than on the CRA, which is shown in Table 2. As explained previously, this is due to the greater complexity of the SRA due to the impact of the series and parallel paths on the final results. In order to summarize the whole topic, we do not recommend counting the residual correlations in the risk driver method in projects in which time plays a crucial role and which have a complex schedule, i.e., where the cost has no determining role.

Cost results

Table 2. Impact of considering the residual correlation on the CRA results (Method 2).

Std.Deviation	P50	P80	Contingency at P50
+4.7 %	+1.5 %	+1.8 %	+13 %

Table 3. Impact of considering the residual correlation on the SRA results (Method 2).

Std.Deviation	P50	P80
+0.2 %	+0.2 %	-0.2 %

The extension of the CDF chart shows the final cost of the project and consequently increases the uncertainty in the final result (an increase of 4.7% in the pre-calculated standard deviation). On the other hand, unlike the theory, the pre-estimated cost of the project has increased to a level of confidence of 50%, resulting in a 13% increase in probability of occurrence. Therefore, it seems that taking into account the impact of the existing precise technical risks that can result in a correlation between the CDF lines can be useful for a contractor company and help it achieve a more accurate probability of occurrence.

Schedule results

The inclusion of the residual correlation in the analysis has a significant impact on the final SRA results in comparison with the CRA impact, and the final CDF of the schedule remains almost the same as that in Method 1. This is due to the logic of the schedule of the target project, in which the parallel and series paths that exist simultaneously will have a contradictory impact on the final schedule of the projects. As a general suggestion, it does not appear useful to consider the residual correlation in the risk driver method in time-based projects with a complex schedule where the cost is not important.

C. Results of the integrated risk-schedule method under the pressure of probable resources

The integrated risk driver method is one of the newest methods that directly models the impact of schedule fluctuations on project costs by integrating the SRA with the CRA. To implement this method, we have used the same schedule data as the previous ones. On the other hand, we separated the time-dependent and time-independent sources in the case of cost and included in the model the risks associated with them. The residual correlation between line elements is similar to Method 2. In addition, due to the integration of schedule risks and uncertainty with the CRA, we have also considered the correlation between the cost risk and the schedule risk. The procedure was followed based on the process presented by the PRA software. Table 4 presents the data required to impose costs and risks on the schedule and production in the PRLS.

An additional step is also taken to confirm the identified risks. After identifying the risks, we evaluate them to see whether they cover the main uncertainties. The evaluation table is presented in Appendix 10. This step helps us ensure that the risk areas identified by the previous studies in the oil and gas industry are included in our analysis.

In PRLS, all simulations are performed through the PRA. As stated in Method 1, the final cost and activity duration of the project are 18056234000 and 1494 days, respectively. The main difference here is the set-up of a schedule under the pressure of resources. Cost and uncertainty risks are implemented in the plan in two ways: 1) the cost risks assigned to the activities; and 2) the uncertainty of the Burn Rate, which is assigned to the compensation rate of resources. For the schedule risks, the

first group (uncertainty) is assigned as the uncertainty of the activity durations, and the rest are considered quantitative risks and assigned to activities. Regarding the correlation between non-deterministic elements, except for the correlation between borderline elements (similar to Method 2), correlations between cost risk and time risk are also taken into consideration. This additional consideration is due to the integration of schedule risk with the CRA. Therefore, both types of correlations are covered when the integrated approach is used: the correlation between the cost risks separately, the correlation between schedule risks separately, and the correlation between the cost and schedule elements.

Similar to what was mentioned in the risk driver method to describe the uncertain impact of each risk on the cost and duration of activities, the triangular distribution is also used here, and LHS sampling is used in simulations. By executing simulations for 5000 elements, the CDF, PDF, and scatter diagram are extracted for the cost and activity duration of the target project. It is noteworthy that the results of the integrated method for activity duration are similar to the results obtained in Method 2, presented in Figure 8, since both the activity duration and the risks are considered on a similar schedule. Therefore, only its results on the project cost are analyzed in the following:

Challenges and Defects

As explained previously, schedules usually develop at a lower level than risk and cost data. This causes problems in building a schedule under the pressure of resources. We face a similar challenge in deciding about the number of resources and levels of work breakdown structure (WBS) to be assigned to them. On the one hand, the mere selection of WBS for the allocation of resources leads to the neglect of the impact of schedule risks associated with time-dependent resources in lower-level activities. On the other hand, the definition and allocation of precise and specific resources to each activity (cost elements are similar to the schedule activities) make the processes of data collection and analysis more difficult. To overcome this challenge, we have defined specific resources for each work package to be assigned to the activities within that work package. Therefore, resources are defined neither briefly nor at a detailed level, and a strategy has been adopted among the options mentioned above. Considering the fact that the integrated risk model of PRLS is a kind of MC-based model, the correlation coefficients considered in this case have been obtained with a very approximate estimation and are not completely accurate.

3.1. Analysis of the CRA results

Figure 10 shows the PDF and CDF of the target project's cost using the integrated risk driver method of PRLS (Method 3). Figure 11 also makes a comparison between the CDFs of the total cost of the project obtained by this method (green line), Method 1 (red line), and Method 2 (yellow line). Figure 11 shows that the application of the integrated approach, on the one hand, extends the CDF chart of the final cost of the project and thus increases uncertainty in the final result. On the other hand, it estimates the project cost at the P50 and P80 levels of confidence and, as a deterrent, increases the required cost probability value. The difference between Method 3 and Method 2 lies only in their background attitudes toward involving the impact of schedule risks in the CRA. In Method 3, a relationship is directly modeled between cost and schedule by using the

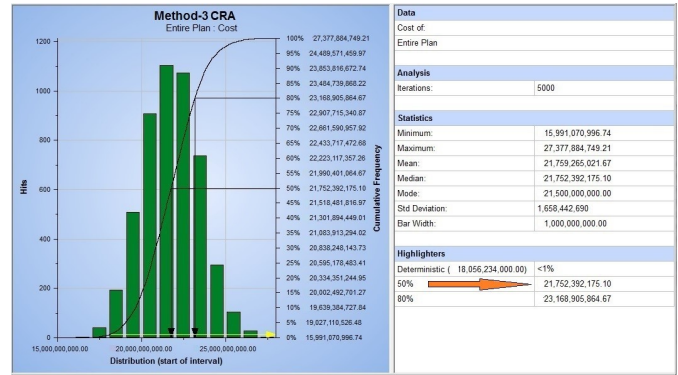


Fig. 10. PDF and CDF associated with the CRA of the target project (Method 3).

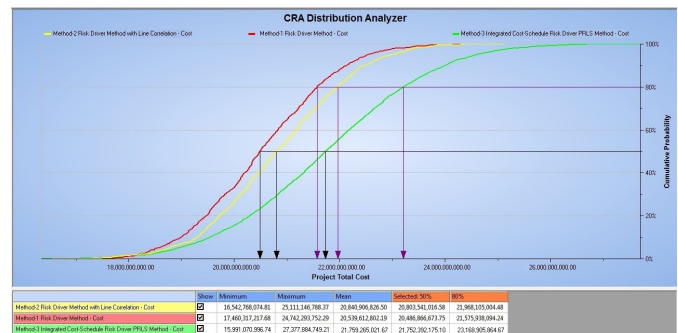


Fig. 11. CDFs of the target project's cost based on the CRA of methods 1, 2 and 3

schedule under the pressure of resources, whereas in Method 2, this relationship is estimated quite approximately by adding a specific risk to the cost (the schedule impact). Therefore, it seems that the estimated impact of schedule on the cost is not exact in the risk driver method (as applied in Methods 1 and 2), and, consequently, the results are not as reliable as those in Method 3. For example, the probability of occurrence required at the 50% confidence level in Method 3 is equal to:

P50 value- the final cost = 3,696,158,175

This value is much higher than that obtained in the current approach of the target company in Method 1. This result shows that independent risk analysis is one of the reasons for unpredictability and lower actual estimates of cost and schedule in the projects. Table 5 summarizes the results of Figures 3, 6, and 10 and highlights the impact of the use of the integrated cost-time risk analysis on the estimated costs of the project in comparison with the independent cost risk analysis. These impacts are shown as the percentage of changes in the final results in ratio to the results obtained from Methods 1 and 2.

Table 5 shows that PRLS actions increase the expected probability of occurrence at the P-50 level by 52% and 34%, respectively, in comparison with methods 1 and 2. This comparison shows that Method 1, which is the current approach of the target company in which not only the correlation between line elements is ignored, but also the schedule risks are not considered in the CRA, may face considerable costs.

Another benefit of the integrated risk analysis over the risk driver method is that the former provides a more comprehensive

Table 5. Impact of the integrated cost- schedule analysis on CRA Results

Comparing to	Std.Deviation	P50	P80	Contingency at P50
Method1	+36 %	+6.2 %	+7.3%	+52%
Method2	+29%	+4.5%	+5.4%	+34%

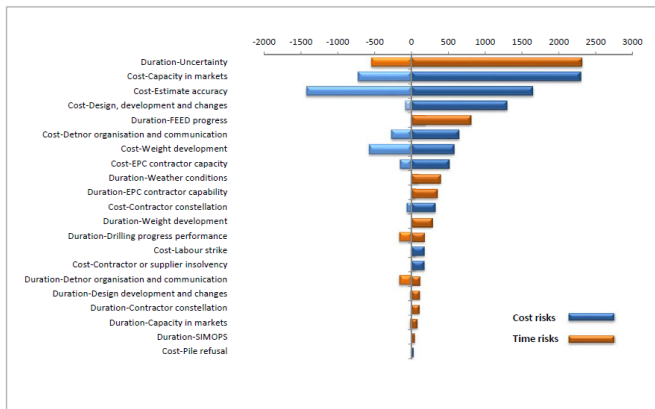


Fig. 12. Tornado diagram of the risks of the target project (Method 3).

criterion for differentiating and prioritizing the risks. Figure 12 shows the results of performing sensitivity analysis through the PRLS on the cost of the Eavar project. Different points can be obtained from the results discussed below.

First, the "schedule impact" is identified as the most significant cost risk of the project in the sensitivity analysis performed using Method 1. As mentioned previously, this risk shows an estimate of the accumulated impact of all schedule risks and uncertainties on project costs. Although this highlights the impact of the schedule risks and uncertainties on project costs, it does not determine which of them is more serious and more important. Figure 12 shows this distinction, indicating that the "activity duration uncertainty" that results from the schedule will be the most significant cost risk of the project. Accordingly, the fifth schedule risk is "activity duration progress". Second, Figure 12 shows that although the "schedule impact" has been divided into different elements showing all the schedule risks and uncertainties, again one of these components, that is, "activity duration- uncertainty" will have the first place in sensitivity analysis. This issue shows the potential impact of schedule on the project cost. In addition, as the results show, the first and third positions of the uncertainty in the input data belong to the activities of activity duration and cost estimation, respectively. This finding also shows the importance of achieving accurate input data. As described for estimating the cost of undersea structures, data that are based on estimation usually attract the most attention and the most concern, and the results of Figure 12 confirm this.

C.2. Analysis of the Scatter diagram

The following results are presented and evaluated for both project cost and project time: The scatter diagram is the unique output of the integrated cost-schedule risk analysis. We first analyze the correlation between the cost and time of the target

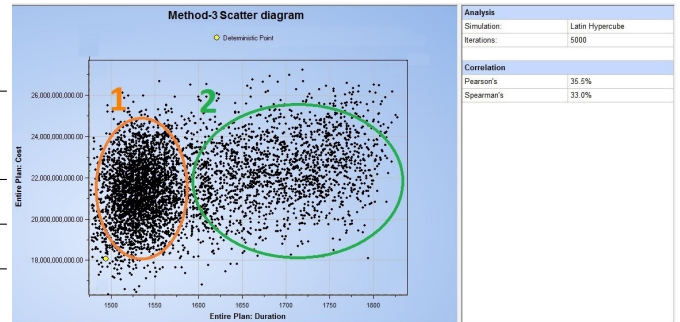


Fig. 13. The impact of schedule on the density of the scatter diagram

project and then evaluate the achievement of the joint confidence level (JCL) in the target project.

Correlation between the cost and time of the project

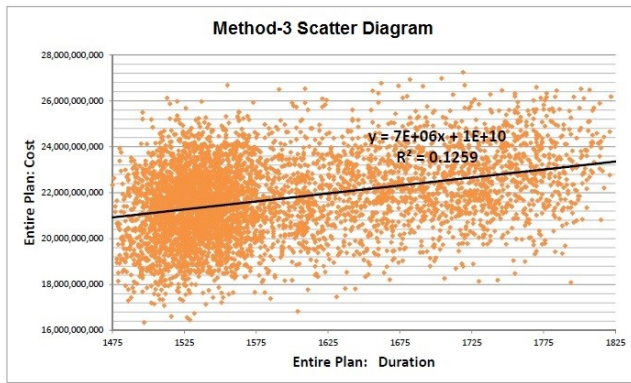
By analyzing 5,000 replicates, we obtained Figure 13 with 5,000 points, each one representing the completion point of the project and the cost associated with it during a replication process, which is calculated during an iteration process from within the schedule under the pressure of resources. As shown in Figure 13, the scatter diagram can be divided into two distinct parts based on the density of the points. This is due to the impact of the probabilistic branching (Activity 43, Appendix 3) considered in the design of the project schedule. This factor can significantly affect the duration of the project (extension of the right-hand side of the PDF of the project activity duration in Figure 5), but this impact will not be similar to the project cost (roughly the normal distribution of the project cost in Figure 3). Therefore, Region 1, with a greater density of its points in Figure 13, represents the cost and probable activity duration of the project without the impact of probabilistic branching on the schedule. Accordingly, Region 2 with fewer points indicates the cost and probable activity duration in those iterations, which probabilistic branching has affected. The important point is that modeling the probabilistic branching of the project cost is considered one of the capabilities of integrated cost-schedule analysis. Figure 13 shows a positive correlation between the cost and time of the target project, which is based on two different methods of correlation measurement. The correlation is 33% and 35.5%, respectively. To clearly determine this correlation, we formulated the line related to linear regression by transferring the data of project cost and activity duration from the PRA to Microsoft Excel software. Figure 14 shows the results of this analysis.

As shown in the figure, we can find the relationship between the cost risks and schedule risks by determining the slope of the regression line, and consequently, the impact of the schedule is diminished due to delays in the project. Now, considering the high regression line, we can calculate the impact of a one-day delay in the schedule on the project cost using the following formula:

$$Badconsequencesofone - daydelay = (7 * 10^6) * 1 = 7 * 10^6 \quad (1)$$

Obtaining the Joint Confidence Level (JCL)

We provide an analysis in the following to obtain the joint



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.354821212
R Square	0.125898092
Adjusted R Square	0.125723202
Standard Error	1600911279
Observations	5000

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	1.84496E+21	1.84496E+21	719.8687704	2.9209E-148
Residual	4998	1.23095E+22	2.56292E+18		
Total	4999	1.46544E+22			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	10660241078	414274476.1	25.73231443	3.1062E-137	9848081345	11472400811	9848081345	11472400811
X Variable 1	6958391.026	259347.5583	26.8303703	2.9209E-148	6449956.025	7466826.027	6449956.025	7466826.027

Fig. 14. Correlation between the cost and activity duration of the target project

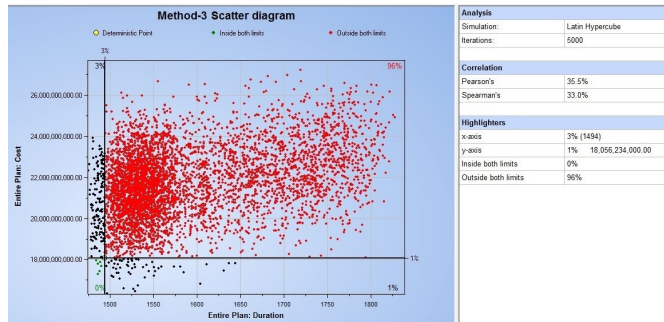


Fig. 15. Obtaining the estimated values of time and final cost

confidence level about the cost and time of the target project. In Figure 15, the transverse lines are adjusted based on the estimates of the final cost and project time. The green points in the lower part of its left side show some repetitions among 5000 repetitions in which both goals have been achieved, whereas the red points show the loss of both goals. The figure shows that simultaneous achievement of both definite goals is very improbable (approximately 0%), and the goals are missed in 96% of the cases. Figure 16 shows a situation in which the goals for the project cost and time in the P50 have been set separately. Although the cost and time values are determined with a probability of 50% here, there is a far lower probability of achieving both goals simultaneously. Green points, as shown in Figure 16, constitute 30% of the total points, indicating that the JCL, which is the possibility of simultaneous achievement of both goals at the P-50 level, will be 30%. This is consistent with the equations presented in the study section:

$$F(x)F(y) < F(x, y) = Pr(x < x_1, y < y_1)F(x) \quad (2)$$

$$F(x)F(y) < F(x, y) = Pr(x < x_1, y < y_1)F(y) \quad (3)$$

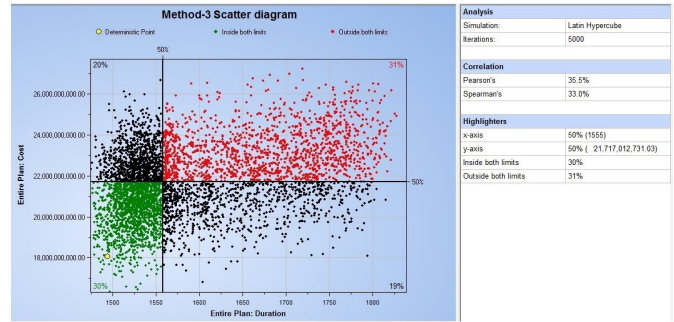


Fig. 16. The borderline level of confidence for project cost and time at the P-50 level.

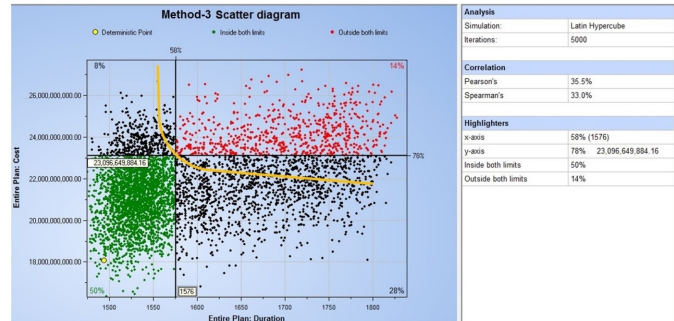


Fig. 17. The JCL for cost and time at the P-50 level

The joint confidence level of cost and time is limited by the multiplication of their borderline confidence levels, but none of them will be higher. The hypothetical lower limit is such that the cost and schedule grow independently, and the upper limit is also 100% correlation. Accordingly, for the target project in Figure 16, where the borderline confidence level for cost and time has been set at 50%, the above equation is written as follows:

$$25% < JCL = 30% < 50% \quad (4)$$

In the search for cost and time goals (borderline confidence level) for the JCL of, say, 50%, the inverse process of what was stated above is taken. Here, the intersection points of the lines are locked so that 50% of the points will be in the quarter of the south-west of the graph. Figure 17 shows the results of this position for the target project.

As previously mentioned, Figure 17 shows that satisfying the JCL of 50% requires determining a higher level of confidence for each borderline confidence level of cost and time. In this situation, the cost and time goals are set to 78% and 58%, respectively, so that a JCL of 50% can be achieved. In this situation, the cost probability is calculated as follows:

$$Cost\ probability = P78\ value - final\ cost = 5040415884 \quad (5)$$

This cost probability is equal to 27.9% of the final cost of the project, which is much lower in comparison with the 13.4 percent calculated by the company's current method (Method 1) (it is almost doubled by Method 1). Therefore, the implementation of an integrated cost-schedule analysis may lead to the identification of cost probabilities that may not be feasible for companies. Figure 17 also shows the boundary line, which represents the other pairs of cost and time goals that will lead to a JCL to 50%. In order to reduce the probability of occurrence required in the JCL of 50%, we have to move down and to the

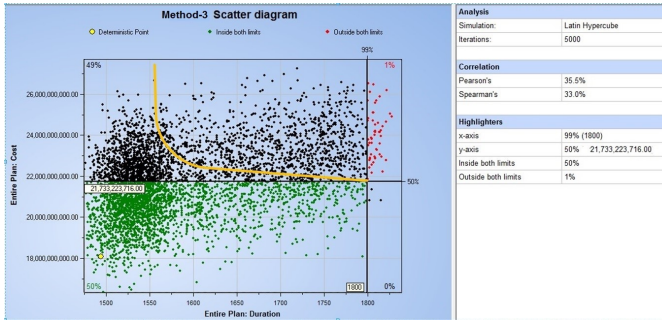


Fig. 18. Hypothetical movement to the right and bottom of the borderline.

right of the borderline. However, as we emphasized in the previous section, such a transfer along the JCL contour will not be associated with the same probability since the part must have a density of many points, which has a very low probability. In other words, by knowing the current plan and quantifying the risks, we may complete the project at a time-cost point along the left-down to right-up extension, that is, a point where there are the most points of the cost-time pair. However, this very improbable movement is presented in the results of Figure 18. In such a situation, to achieve a JCL of 50%, the borderline confidence level for the project cost must be set at least at the P50 level, which leads to a prolongation of the projects' activity duration till 224 days (1800 days in Figure 18, minus 1576 days in Figure 17). Based on the calculated loss for each delayed day, this movement along the borderline will have an approximate cost equal to the following:

$$Loss = 10^6 * 224 * 7 = 1560000000 \quad (6)$$

Again, it is noteworthy that this move towards the extreme left and bottom of the borderline is very improbable.

Cost Results

Implementation of the integrated cost-schedule risk analysis has dramatically extended the CDF chart of the final cost of the project, thereby increasing uncertainty in the final outcome (36% and 29% growth in the calculated standard deviation for Method 1 and Method 2, respectively). In addition, the estimated cost of the project has increased at all levels of confidence, leading to an increased probability of occurrence of the calculated cost (52% and 34% growth in the pre-calculated probability for Method 1 and Method 2, respectively). Therefore, it is probable that the current method for the company will lead to a waste of time and cost in the project by estimating a lower degree of probability. The results also confirm the assumption that the typical independent risk analysis is a hidden cause of the waste of time and cost in the project. The results of sensitivity analysis, like those obtained from previous methods, have emphasized the importance of schedule but suggested a better prioritization by breaking down the "schedule impact" into its components. It has been shown that "uncertainty of activity duration" caused by activity duration will have the greatest impact on the project cost. The following results were obtained from the analysis of the scatter diagram, which is the unique outcome of Method 3:

- The time and cost of the project have a correlation of 35%.

- Each day of delay will impose a cost of approximately 70 billion Rials on the project.

In order to achieve a JCL of 50%, we must consider the borderline confidence level at 78%, which would lead to a cost probability twice as high as that of Method 1. In following, in Table 6, a comparison of the results of the proposed approach with a deterministic approach (no uncertainty and no risk considerations) is given. The results show that a reduction in the final cost of the project and a reduction in the duration of the project as expected. This due to the fact that by removing uncertainty and risk considerations, many limitations of the problem will be reduced and will lead to a reduction in the final cost of the project and a reduction in the duration of the project. The proposed approach can provide more accurate results against the changes and uncertainties in the data and environment. Also, the proposed approach pays attention to risk considerations such as limitations, unknown external factors and other possible factors in calculations and decisions. These risk considerations can help improve confidence in the results and reduce the chance of larger errors compared to a deterministic approach.

5. CONCLUSION AND SUGGESTIONS

We dealt in this research with an estimate of the cost of project completion for oil and gas projects, considering the risks using Monte Carlo simulation methods. For this purpose, we first analyzed the typical methods of cost and schedule risk analysis with a focus on probabilistic estimation using the Monte Carlo simulation model. Subsequently, we proposed a modern approach with the capability of being used in oil and gas projects. Using the PRA software, we implemented the modern methods of cost and schedule risk analysis for an oil project at the National Iranian Drilling Company with the help of the Consulting Engineers Company and compared their results based on the estimation of incidental costs and the recognition of high-severity risks. Next, we performed a sensitivity analysis on the activity level in order to improve the SRA approach in the target company and identified the most significant activities in the project plan through a series of measurements. Finally, we presented a theoretically reasonable model to improve probability estimation in the project, which can be used for major projects in the oil and gas industry at the end of the development phase. We also performed a numerical analysis considering the schedule and cost risks in an integrated way, which led to good results and analyses taking into account the correlation of risks. The research shows that the impact of resource pressure in the risk driver analysis method helps increase the project's probability estimation in terms of time and cost, and the direct impact of both cost risk and schedule risk in the integrated risk driver method ensures that the level of correlation is estimated accurately. As a future research work, providing a practical approach to a better estimation of correlation can be beneficial. This can enhance the reliability of the results obtained from independent driver-based models as well as the integrated risk driver model of PRLS. Besides, providing a practical solution for separating systemic and project-specific risks from one another by avoiding iterations of the latter's impact can also be suggested for future research. This can enhance the practicality of the proposed integrated model.

Table 6. a comparison of the results of the proposed approach with a deterministic approach.

	With a deterministic approach	With the proposed approach
The final cost of the project	16,772,568,348	18,056,234,000
the duration of the project	1,357	1,494

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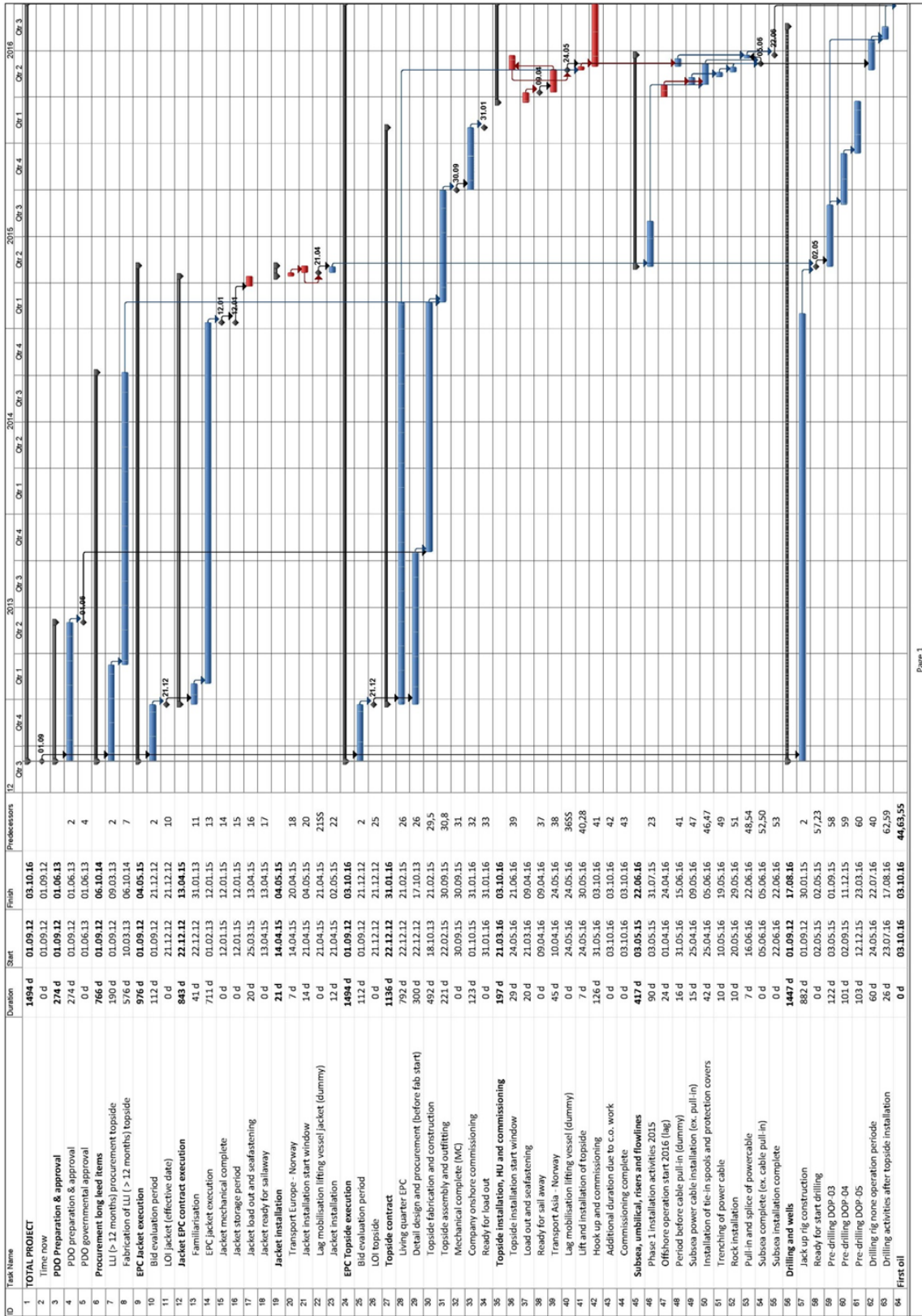
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ID	Level	Desc.	Duration	Total cost
1	1	TOTAL PROJECT	1494	18,056,234,000
2	2	Project management		2,686,212,000
3	2	PDO Preparation & approval	274	0
4	3	PDO preparation & approval	274	
5	3	PDO governmental approval	0	
6	2	Procurement long lead items	766	1,722,350,000
7	3	LLI (> 12 months) procurement topside	190	1,722,350,000
8	3	Fabrication of LLI (> 12 months) topside	576	
9	2	EPC Jacket execution	976	867,644,000
10	3	Bid evaluation period	112	
11	3	LOI jacket (effective date)	0	
12	3	Jacket EPC contract execution	843	767,624,000
13	4	Familiarisation	41	
14	4	EPC jacket execution	711	728,064,000
15	4	Jacket mechanical complete	0	
16	4	Jacket storage period	0	
17	4	Jacket load out and seafastening	20	39,560,000
18	4	Jacket ready for sailaway	0	
19	3	Jacket installation	21	100,020,000
20	4	Transport Europe	7	49,980,000
21	4	Jacket installation start window	14	
22	4	Lag mobilisation lifting vessel jacket (dummy)	0	
23	4	Jacket installation	12	50,040,000
24	2	EPC Topside execution	1494	4,892,721,000
25	3	Bid evaluation period	112	
26	3	LOI topside	0	
27	3	Topside contract	1136	3,620,761,000
28	4	Living quarter EPC	792	489,456,000
29	4	Detail design and procurement (before fab start)	300	1,648,200,000
30	4	Topside fabrication and construction	492	575,148,000
31	4	Topside assembly and outfitting	221	872,287,000
32	4	Mechanical complete (MC)	0	
33	4	Company onshore commissioning	123	35,670,000
34	4	Ready for load out	0	
35	3	Topside installation, HU and commissioning	197	1,271,960,000
36	4	Topside installation start window	29	
37	4	Load out and seafastening	20	73,660,000
38	4	Ready for sail away	0	
39	4	Transport Asia	45	105,300,000
40	4	Lag mobilisation lifting vessel (dummy)	0	
41	4	Lift and installation of topside	7	105,280,000
42	4	Hook up and commissioning	126	987,720,000
43	4	Additional duration due to c.o. work	0	
44	4	Commissioning complete	0	
45	2	Subsea, umbilical, risers and flowlines	417	1,180,067,000
46	3	Phase 1 installation activities 2015	90	35,100,000
47	3	Offshore operation start 2016 (lag)	24	837,168,000
48	3	Period before cable pull-in (dummy)	16	61,760,000
49	3	Subsea power cable installation (ex. pull-in)	15	42,000,000
50	3	Installation of tie-in spools and protection covers	42	61,488,000
51	3	Trenching of power cable	10	62,600,000
52	3	Rock installation	10	53,400,000
53	3	Pull-in and splice of powercable	7	26,551,000
54	3	Subsea complete (ex. cable pull-in)	0	
55	3	Subsea installation complete	0	
56	2	Drilling and wells	1447	6,707,240,000
57	3	Jack up rig construction	882	829,080,000
58	3	Ready for start drilling	0	
59	3	Pre-drilling DOP-03	122	624,640,000
60	3	Pre-drilling DOP-04	101	564,590,000
61	3	Pre-drilling DOP-05	103	579,890,000
62	3	Drilling rig none operation periode	60	
63	3	Drilling activities after topside installation	26	4,109,040,000
64	1	First oil	0	

ID	Activities	Risk name:	Estimate accuracy			Capacity in markets			EPC contractor capacity			Design, development and changes			Contractor constellation		
		Probability:	100 %			100 %			100 %			100 %			100 %		
		Cost	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX
1	TOTAL PROJECT																
2	Project management	2,686,212,000	-154,301,620	0	154,301,620	-154,301,620	0	268,603,639									
3	PDO Preparation & approval																
4	PDO preparation & approval																
5	Procurement long lead items																
6	LLI (> 12 months) procurement topside	1,722,350,000	-86,129,327	0	172,256,654	-103,355,192	103,355,192	206,710,385	-34,451,731	0	120,581,058	0	43,064,663	120,581,058	-17,225,865	0	86,129,327
7	Fabrication of LLI (> 12 months) topside																
8	EPC Jacket execution																
9	Bid evaluation period																
10	Jacket EPC contract execution																
11	Familiarization																
12	EPC jacket execution	728,064,000	0	29,097,807	58,195,613							0	0	72,744,517			
13	Jacket load out and sealastening	39,560,000	0	1,582,194	3,164,387							0	0	3,355,484			
14	Jacket installation																
15	Transport Europe - Norway	49,980,000							0	500,000	1,000,000	0	3,000,000	6,000,000			
16	Jacket installation start window																
17	Jacket installation	50,040,000							0	500,000	1,000,000	0	3,000,000	6,000,000			
18	EPC Topside execution																
19	Bid evaluation period																
20	Topside contract																
21	Living quarter EPC	489,456,000	-24,482,292	0	48,964,583	-25,378,750	25,378,750	58,157,500	-9,792,917	0	34,275,208	0	12,241,146	34,275,208	-4,896,458	0	24,482,292
22	Detail design and procurement (before fab start)	1,648,200,000	-82,417,406	0	164,834,912	-95,300,887	95,300,887	197,801,174	-32,366,362	0	115,384,368	0	41,206,703	115,384,368	-16,483,481	0	82,417,406
23	Topside fabrication and construction	575,148,000	-28,745,535	0	57,491,070	-34,434,642	34,434,642	68,989,284	-11,438,214	0	40,243,749	0	14,372,767	40,243,749	-5,743,907	0	28,745,535
24	Topside assembly and outfitting	872,287,000	-43,610,313	0	87,220,625	-52,332,375	52,332,375	104,664,750	-17,444,125	0	61,054,438	0	21,805,196	61,054,438	-8,722,063	0	43,610,313
25	Company onshore commissioning	35,670,000	-1,782,280	0	3,564,559	-2,138,736	2,138,736	4,277,471	-712,912	0	2,495,192	0	891,140	2,495,192	-356,456	0	1,782,280
26	Topside installation, HU and commissioning																
27	Topside installation start window																
28	Load out and sealastening	73,660,000							0	736,570	1,473,139	0	4,418,418	8,836,836			
29	Transport Asia - Norway	105,300,000							0	1,052,840	2,105,680	0	6,317,040	12,634,080			
30	Lift and installation of topside	105,200,000							0	1,052,840	2,105,680	0	6,317,040	12,634,080			
31	Hook up and commissioning	987,720,000	-4,440,000	16,640,000	17,230,000	-23,950,000	65,230,000	145,250,000	-11,975,000	0	38,320,000	-23,950,000	47,900,000	85,800,000			
32	Subsea, umbilical, risers and flowlines																
33	Phase 1 installation activities 2016	35,100,000	-6,390,400	0	4,195,200				-1,048,800	0	2,796,800	-1,748,000	3,496,000	6,392,000	-343,600	0	1,748,000
34	Offshore operation start 2016 (lag)	837,168,000	-200,341,672		100,470,836				-25,117,709	0	66,380,537	-41,862,848	83,725,637	167,451,333	-8,372,570	0	41,862,848
35	Period before cable pull-in (dumpling)	61,760,000	-14,823,600	0	1,414,400				-1,853,700	0	4,343,200	-3,083,500	6,173,000	12,358,000	-617,300	0	3,083,500
36	Subsea power cable installation (ex. pull-in)	42,000,000	-10,080,000	0	5,040,000				-1,260,000	0	3,360,000	-2,100,000	4,200,000	8,400,000	-420,000	0	2,100,000
37	Installation of tie-in spools and protection covers	61,488,000	-14,755,928		1,377,364				-1,844,491	0	4,319,643	-3,074,152	6,149,303	12,298,607	-614,830	0	3,074,152
38	Trenching of power cable	62,600,000	-15,096,800	0	1,508,400				-1,877,100	0	5,005,600	-3,128,500	6,257,000	12,514,000	-625,700	0	3,128,500
39	Rock installation	53,400,000	-12,813,600	0	6,406,800				-1,601,700	0	4,271,200	-2,663,500	5,333,000	10,678,000	-533,900	0	2,663,500
40	Pull-in and splice of power cable	26,550,000	-6,372,000	0	3,186,000				-786,500	0	2,124,000	-1,327,500	2,655,000	5,310,000	-265,500	0	1,327,500
41	Drilling and wells																
42	Jack up rig construction	829,080,000	-124,500,000	0	124,500,000	-41,500,000	83,000,000	207,500,000				0	41,500,000	58,100,000			
43	Pre-drilling DCP-03	624,640,000										0	24,962,640	43,684,620			
44	Pre-drilling DCP-04	564,590,000										0	22,582,560	33,519,840			
45	Pre-drilling DCP-05	579,890,000										0	23,198,448	40,597,284			
46	Drilling rig none operation periode																
47	Drilling activities after topside installation	4,109,040,000	-616,361,760	0	616,361,760	-205,453,320	410,907,840	1,027,269,600				0	205,453,320	287,635,488			
	Total	18,056,234,000	-1,429,370,711	107,320,000	1,189,647,693	-785,806,321	879,739,422	2,233,824,403	-194,041,061	3,849,250	914,438,512	-82,350,000	640,834,648	1,288,117,831	-55,233,430		326,167,192

Appendix 2 - Cost Risks (Part 1)

ID	Activities	Risk name:	Detnor organization and communication			Weight development			Pile refusal			Labour strike			Contractor or supplier insolvency			Contractor or supplier insolvency		
		Probability:	100 %			100 %			10 %			20 %			10 %			10 %		
		Cost	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX
1	TOTAL PROJECT																			
2	Project management	2,686,212,000	-60,581,032	0	154,301,620															
3	PDO Preparation & approval																			
4	PDO preparation & approval																			
5	Procurement long lead items																			
6	LLI (> 12 months) procurement topside	1,722,350,000	-34,451,731	0	86,129,327	-172,256,654	0	172,256,654				17,225,865	34,451,731	51,617,596	17,225,865	34,451,731	51,617,596			
7	Fabrication of LLI (> 12 months) topside																			
8	EPC Jacket execution																			
9	Bid evaluation period																			
10	Jacket EPC contract execution																			
11	Familiarization																			
12	EPC jacket execution	728,064,000	-14,548,303	0	36,372,259				1,214,452	14,548,303	21,823,355	501,956	1,163,312	1,745,868						
13	Jacket load out and sealastening	39,560,000	-791,097	0	1,971,742				395,548	791,097	1,186,645	31,644	63,288	94,332						
14	Jacket installation																			
15	Transport Europe - Norway	49,980,000	0	500,000	1,500,000				0	0	0	500,000								
16	Jacket installation start window																			
17	Jacket installation	50,040,000	0	500,000	1,500,000				0	0	0	500,000								
18	EPC Topside execution																			
19	Bid evaluation period																			
20	Topside contract																			
21	Living quarter EPC	489,456,000	-3,792,917	0	24,482,292	-48,964,583	0	48,964,583				4,896,458	9,792,917	14,689,375	4,896,458	9,792,917	14,689,375			
22	Detail design and procurement (before fab start)	1,648,200,000	-32,366,362	0	82,417,406	-164,834,912	0	164,834,912				16,483,481	32,366,362	48,550,444	16,483,481	32,366,362	48,550,444			
23	Topside fabrication and construction	575,148,000	-11,438,214	0	28,745,535	-57,491,070	0	57,491,070												



Page 1

Appendix 3- Schedule

Uncertainty Element	Prob	Consequence		Detnor project cost			P40 topside		Jacket		DBW - Services		DBW - Fog rate		T&I		Offshore hook-up and commissioning		Fictal and other logistics		SURF		E. Orleg tie-in cost		Hanz		Net total Consequence			Expected Value		Std Dev	
		P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	P10	ML	P90	Valance (sum-VarrCovar)				
		1.00	-0.15	0.00	0.15	-167	0	167	-271	0	271	-32	-64	-592	0	592	-175	75	173	-282	-140	-360	0	360	-1140	-33	1170	15	813	883	902		
Capacity in markets	1.00	-0.05	0.05	0.15	-167	0	167	-271	0	271	-32	-64	-592	0	592	-175	75	173	-282	-140	-360	0	360	-1140	-33	1170	15	813 <td>883 <td>902</td> </td>	883 <td>902</td>	902			
EPC contractor capacity	1.00	-0.03	0.00	0.08																													
Design Development and change	1.00	-0.05	0.10	0.20																													
Contractor constellation	1.00	-0.01	0.00	0.05																													
Detnor organisation and communication	1.00	-0.03	0.00	0.05	-83	0	83	-135	0	135	-19	0	19	-50	0	50	-100	0	100	-12	0	12	-24	0	24	-30	0	30	-60	0	60	178	
Weight development	1.00	-0.10	0.00	0.10																													
Schedule effect	1.00				75	0	250	-542	0	542																							
Pile refusal	0.10	0.01	0.02	0.03																													
Labour strike	0.20	0.01	0.02	0.03																													
Contractor or supplier insolvency	0.10	0.01	0.02	0.03																													
Totall per cost element		Exp. Vaue	Uncertainty		357.3		6196		853.8		4540		2874		544.8		672.9		709.3		1256		569		2690		13.10%	7 493 637	2 852	7 493 637			
					+/- 285		842		50		940		355		28		450		295		200		45		492		11.1%	2 737		11.1%	125		
					9%		14%		6%		21%		12%		5%		52%		42%		16%		8%		18%	1.00							
					Base =		21 817		P15 =		21 832		Mean =		24 679		P85 =		27 525														
					Base =		21 817		P10 =		21 175		Mean =		24 679		P90 =		28 182														

Appendix 5 - Schedule Impacts on Cost Risks

Activity ID	Activity name	Identified shortcoming
17	Jacket load out and sea fastening	Constraint: As late As Possible
21	Jacket Installation start windows	Constraint: Must Start On Specific Date
23	Jacket Installation	Constraint: Start No Later than Specific date
34	Ready for load out	Without successor activity
36	Topside installation start windows	Constraint: Must Start On Specific Date
37	Load out and sea fastening	Constraint: As late As Possible Without predecessor activity
39	Transport Asia	Constraint: Must Finish On Specific Date
41	Lift and installation of topside	Constraint: Start No Later than Specific date
47	Offshore operation start 2016 (lag)	Constraint: Must Start On Specific Date Without predecessor activity
61	Pre-drilling DOP-05	Without successor activity

Appendix 6. Problems with schedule

		Cause of overrun												
		Too optimistic estimates	Optimistic interpolation of previous project assumption	Unclear project assumption in early phase	Material procurement process	Changes in specification	Delayed payment	Increase of price in primary construction materials	Poorly defined work scope	Lack of planning	Insufficient operational robustness and maintainability of engineering technology	The implementation of new technology without qualification	The Placing of orders before engineering is completed	
Schedule Risk	Capacity in markets					✓								
	EPC Contractor capability											✓		
	Design development and changes					✓						✓		
	Drilling progress performance									✓				
	Contractor constellation										✓			
	FEED progress											✓		
	Detnor organization and communication												✓	
	Weather conditions													✓
	Weight development												✓	
	SIMOPS												✓	

Appendix 7 - Schedule Risk Assessment

ID	Level	Desc.	Duration	Total cost	Human resource	Material	Other costs	
							Name/type	cost
1	1	TOTAL PROJECT	1494	18,056,234,000				
2	2	Project management		2,686,212,000	2,686,212,000			
3	2	PDO Preparation & approval	274	0				
4	3	PDO preparation & approval	274					
5	3	PDO governmental approval	0					
6	2	Procurement long lead items	766	1,722,350,000				
7	3	LLI (> 12 months) procurement topside	190	1,722,350,000			Equipment	1,722,350,000
8	3	Fabrication of LLI (> 12 months) topside	576					
9	2	EPC Jacket execution	976	867,644,000				
10	3	Bid evaluation period	112					
11	3	LOI jacket (effective date)	0					
12	3	Jacket EPC contract execution	843	767,624,000				
13	4	Familiarisation	41					
14	4	EPC jacket execution	711	728,064,000	375,408,000	352,656,000		
15	4	Jacket mechanical complete	0					
16	4	Jacket storage period	0					
17	4	Jacket load out and seafastening	20	39,560,000	35,600,000	3,960,000		
18	4	Jacket ready for sailaway	0					
19	3	Jacket installation	21	100,020,000				
20	4	Transport Europe - Norway	7	49,980,000			Vessel	49,980,000
21	4	Jacket installation start window	14					
22	4	Lag mobilisation lifting vessel jacket (dummy)	0					
23	4	Jacket installation	12	50,040,000			Vessel	50,040,000
24	2	EPC Topside execution	1494	4,892,721,000				
25	3	Bid evaluation period	112					
26	3	LOI topside	0					
27	3	Topside contract	1136	3,620,761,000				
28	4	Living quarter EPC	792	489,456,000	289,080,000	200,376,000		
29	4	Detail design and procurement (before fab start)	300	1,648,200,000	1,648,200,000			
30	4	Topside fabrication and construction	492	575,148,000	138,744,000	436,404,000		
31	4	Topside assembly and outfitting	221	872,287,000	610,623,000	261,664,000		
32	4	Mechanical complete (MC)	0					
33	4	Company onshore commissioning	123	35,670,000	35,670,000			
34	4	Ready for load out	0					
35	3	Topside installation, HU and commissioning	197	1,271,960,000				
36	4	Topside installation start window	29					
37	4	Load out and seafastening	20	73,660,000	66,300,000	7,360,000		
38	4	Ready for sail away	0					
39	4	Transport Asia - Norway	45	105,300,000			Vessel	105,300,000
40	4	Lag mobilisation lifting vessel (dummy)	0					
41	4	Lift and installation of topside	7	105,280,000			Vessel	105,280,000
42	4	Hook up and commissioning	126	987,720,000	463,250,000	11,970,000	Rigger and installation	512,500,000
43	4	Additional duration due to c.o. work	0					
44	4	Commissioning complete	0					
45	2	Subsea, umbilical, risers and flowlines	417	1,180,067,000				
46	3	Phase 1 installation activities 2015	90	35,100,000			Vessel	35,100,000
47	3	Offshore operation start 2016 (lag)	24	837,168,000	224,328,000	489,960,000	Vessel	122,880,000
48	3	Period before cable pull-in (dummy)	16	61,760,000			Vessel	61,760,000
49	3	Subsea power cable installation (ex. pull-in)	15	42,000,000			Vessel	42,000,000
50	3	Installation of tie-in spools and protection covers	42	61,488,000	61,488,000			
51	3	Trenching of power cable	10	62,600,000			Vessel	62,600,000
52	3	Rock installation	10	53,400,000			Vessel	53,400,000
53	3	Pull-in and splice of powercable	7	26,551,000	26,551,000			
54	3	Subsea complete (ex. cable pull-in)	0					
55	3	Subsea installation complete	0					
56	2	Drilling and wells	1447	6,707,240,000				
57	3	Jack up rig construction	882	829,080,000			Rig testing, seabed prep.	829,080,000
58	3	Ready for start drilling	0					
59	3	Pre-drilling DOP-03	122	624,640,000			Rig hire cost	624,640,000
60	3	Pre-drilling DOP-04	101	564,590,000			Rig hire cost	564,590,000
61	3	Pre-drilling DOP-05	103	579,890,000			Rig hire cost	579,890,000
62	3	Drilling rig none operation periode	60					
63	3	Drilling activities after topside installation	26	4,109,040,000			Rig hire cost	4,109,040,000
64	1	First oil	0					

Appendix 8 - Resources section

ID	PR	Level	Activities	Resources name	Duration	Risk name:			Estimate accuracy			Capacity in markets			EPC contractor capacity			Design, development and changes			Contractor constellation			
						Probability	Base cost		MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	
1	1	1	TOTAL PROJECT		1494																			
2	2	2	Project management	Human resource	274	2686212000	-134301820	0	134301820	-134301820	0	268603639												
3	3	3			766																			
4	3	2	PDD Preparation & approval		190																			
5	6	2	Procurement long lead items		1722350000	-86123327	0	172228854	-103355192	206710395	-34451731	0	120581058	0	43084663	120581058	-17222885	0	86123327					
6	7	3	LLI (> 12 months) procurement topside	Equipment	576																			
7	4	3	Fabrication of LLI (> 12 months) topside		976																			
8	8	3	EPC Jacket execution		112																			
9	9	2	EPC Jacket execution		41																			
10	10	3	Bid evaluation period		711																			
11	12	3	Jacket EPC contract execution		20																			
12	13	4	Familiarisation		21																			
13	9	4	EPC jacket execution	Human resource	7	375408000	0	15004560	3000919															
14	5	5		Material	14	352656000	0	14093247	28186494															
15	5	5			20																			
16	17	4	Jacket load out and seafastening	Human resource	5	35600000	0	1423974	2847948															
17	5	5		Material	18	3960000	0	158219	316439															
18	5	5			21																			
19	19	3	Jacket installation		7																			
20	20	4	Transport Europe - Norway	Equipment	14	49980000																		
21	5	5			12																			
22	21	4	Jacket installation start window		24																			
23	19	4	Jacket installation	Equipment	25	5040000																		
24	5	5			1136																			
25	24	2	EPC Topside execution		792																			
26	10	3	Bid evaluation period		29	269080000	-1446287	0	28924373	-17354624	17354624	34703248	-5784875	0	20247061	0	7231093	20247061	-2692437	0	1446287			
27	27	3	Topside contract		300	200376000	-19020105	0	20040210	-12024126	12024126	24048252	-4008042	0	14028147	0	5010053	14028147	-2004021	0	19020105			
28	28	4	Living quarter EPC	Human resource	482	1648200000	-82417406	0	164834812	-38900887	38900887	197801774	-32366362	0	1165384368	0	41208703	1165384368	-16483481	0	82417406			
29	5	5			34																			
30	5	5			35																			
31	29	4	Detail design and procurement (before fab start)	Human resource	221	138744000	-6940379	0	13880757	-8328454	8328454	16856909	-2776161	0	3716530	0	3470189	3716530	-1388076	0	6940379			
32	5	5			36	436404000	-21805166	0	43610313	-26166188	26166188	523332375	-8722063	0	30627219	0	10902578	30627219	-4361031	0	21805166			
33	30	4	Topside fabrication and construction	Human resource	37	610623000	-30527219	0	61054438	-36632663	36632663	73263525	-1210888	0	42738106	0	15263609	42738106	-6105444	0	30527219			
34	5	5			38	261664000	-13063094	0	26166188	-15693713	15693713	31399425	-5233238	0	18316331	0	8541547	18316331	-2616619	0	13063094			
35	5	5																						
36	31	4	Topside assembly and outfitting	Human resource																				
37	5	5																						
38	5	5																						

Appendix 9 - Uncertainty compensation rate (Part 1)

ID	PRA	Level	Activities	Resources name	Duration	Risk name: Probability			Detour organisation and communication			Weight development			Pile refusal			Labour strike			Contractor or supplier insolvency		
						Base cost	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML
1	1	1	TOTAL PROJECT		1494																		
2	2	2	Project management	Human resource																			
3	3	3																					
4	3	2	PDD Preparation & approval	Human resource	274																		
5	6	2	Procurement long lead items		766																		
6	7	3	Procurement long lead items		190																		
7	4	4	Procurement long lead items																				
8	8	3	Fabrication of LU (> 12 months) topside	Equipment																			
9	9	2	EPC Jacket execution	Human resource	576																		
10	10	3	EPC Jacket execution		976																		
11	12	3	Jacket EPC contract execution		843																		
12	13	4	Familiarisation		41																		
13	3	4	EPC jacket execution		711																		
14	5	5	Jacket load out and seafastening	Human resource																			
15	5	5	Jacket load out and seafastening	Material	20																		
16	17	4	Jacket load out and seafastening																				
17	5	5	Jacket load out and seafastening																				
18	5	5	Jacket load out and seafastening																				
19	19	3	Jacket installation	Human resource	21																		
20	20	4	Jacket installation		7																		
21	5	5	Jacket installation																				
22	21	4	Jacket installation start window		14																		
23	19	4	Jacket installation		12																		
24	5	5	Jacket installation																				
25	24	2	EPC Topside execution	Equipment	1494																		
26	10	3	EPC Topside execution		112																		
27	27	3	Topside contract	Human resource	1136																		
28	28	4	Topside contract		732																		
29	5	5	Topside contract																				
30	5	5	Topside contract																				
31	29	4	Detail design and procurement (before fab start)	Human resource	300																		
32	30	5	Detail design and procurement (before fab start)																				
33	30	4	Topside fabrication and construction	Human resource	432																		
34	5	5	Topside fabrication and construction																				
35	5	5	Topside fabrication and construction																				
36	31	4	Topside assembly and outfitting	Human resource	221																		
37	5	5	Topside assembly and outfitting																				
38	5	5	Topside assembly and outfitting																				

Appendix 9 - Uncertainty compensation rate (Part 2)

ID	PRA ID	Level	Activities	Resources name	Duration	Risk name: Probability			Demor organisation and communication			Weight development			Pile refusal			Labour strike			Contractor or supplier insolvency		
						Base cost	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML	MAX	MIN	ML
33	23	4	Company onshore commissioning	Human resource	123	39570000	0	0	1782280	-3954959	0	3954959											
40	5	4	Ready for load out	Human resource	0																		
41	24	4	Topside installation, HU and commissioning	Human resource	197																		
42	35	3	Topside installation start window		23																		
43	36	4	Load out and seafastening		20																		
44	37	4																					
45	5	5	Human resource	Human resource		63300000	0	68293	1988738														
46	5	5	Material	Material		7380000	0	73857	220971														
47	39	4	Transport Asia - Norway		45																		
48	5	5	Equipment	Equipment		195300000	0	1052840	3168520														
49	41	4	Lift and installation of topside		7																		
50	5	5	Equipment	Equipment		105280000	0	1052840	3168520														
51	42	4	Hook up and commissioning		126																		
52	5	5	Human resource	Human resource		463260000	-14100000	0	23350000	-46700000	0	46700000											
53	5	5	Equipment	Equipment		512500000	-12900000	0	25900000														
54	5	5	Material	Material		11870000	-360000	0	600000	-1200000	0	1200000											
55	45	2	Subsea, umbilical, risers and flowlines		417																		
56	46	3	Phase 1 installation activities 2015		90																		
57	4	4	Equipment	Equipment		351000000																	
58	47	3	Offshore operation start 2016 (1kg)		24																		
59	4	4	Human resource	Human resource		224320000																	
60	4	4	Equipment	Equipment		122800000																	
61	4	4	Material	Material		493960000																	
62	48	3	Period before cable pull-in (dummy)		18																		
63	4	4	Equipment	Equipment		61760000																	
64	49	3	Subsea power cable installation (ec pull-in)		15																		
65	4	4	Equipment	Equipment		42000000																	
66	50	3	Installation of tie-in spools and protection covers		42																		
67	4	4	Human resource	Human resource		61480000																	
68	51	3	Trenching of power cable		10																		
69	4	4	Equipment	Equipment		62600000																	
70	52	3	Pock installation		10																		
71	4	4	Equipment	Equipment		53400000																	
72	53	3	Pull-in and splice of power cable		7																		
73	4	4	Human resource	Human resource		26951000																	
74	56	2	Drilling and wells		1447																		
75	57	3	Jack up rig construction		882																		
76	4	4	Equipment	Equipment		823080000	-8300000	0	24900000														
77	59	3	Pre-drilling DQP-03		122																		
78	4	4	Equipment	Equipment		624640000																	
79	60	3	Pre-drilling DQP-04		101																		
80	4	4	Equipment	Equipment		584590000																	
81	61	3	Pre-drilling DQP-05		103																		
82	4	4	Equipment	Equipment		578890000																	
83	62	3	Drilling rig none operation periods		60																		
84	63	3	Drilling activities after topside installation		26																		
85	4	4	Equipment	Equipment		410940000	-4190784	0	15327252														

Appendix 9 - Uncertainty compensation rate (Part 4)

ID	Desc.		Estimate accuracy		
			MIN	ML	MAX
1	Procurement long	Human resource			
3	Lead items	Equipment	-5 %	0	20 %
4	EPC Jacket execution	Human resource	0	0	20 %
5		Equipment (Other)			
6		Material	0	0	20 %
7	EPC Topside execution	Human resource	-5 %	0	20 %
8		Equipment (Other)			
9		Material	-5 %	0	20 %
10	Subsea, umbilical, Risers and flowlines	Human resource	0	0	20 %
11		Equipment (Other)			
12		Material	0	0	20 %
13	Drilling and wells	Human resource	-15 %	0	15 %
14		Equipment (Other)	-15 %	0	15 %
15	Management	Material			
17	Additional resource due to co-work		-10 %	0	10 %

Appendix 9 - Uncertainty compensation rate (Part 5)

		Cause of overrun										
		The Placing of orders before engineering is completed	The implementation of new technology without qualification	Insufficient operational robustness and maintainability of engineering	Lack of planning	Poorly defined work scope	Increase of price in primary construction materials	Delayed payment	Changes in specification	Material procurement process	Unclear project assumption in early phase	Optimistic interpolation of previous project assumption
Cost Risk	Estimate accuracy						✓	✓		✓	✓	✓
	Capacity in markets						✓		✓			
	EPC Contractor capacity			✓	✓		✓		✓			
	Design, development and changes	✓	✓			✓		✓		✓		
	Contractor constellation			✓		✓					✓	✓
	Detnor organization and communication					✓			✓	✓	✓	✓
	Weight development	✓				✓				✓		
	Pile refusal	✓									✓	
	Labor strike											✓
	Contractor or supplier insolvency						✓	✓				

Appendix 10 - Assessment of cost risks

		Cost Risks									
		Estimate accuracy	Capacity in markets	EPC Contractor capacity	Design, development and changes	Contractor constellation	Detnor organization and communication	Weight development	Pile refusal	Labor strike	Contractor or supplier insolvency
Schedule Risks	FEED progress	M			H			M			
	Weight development	L		M	H		H	H			
	SIMOPS	M		M			M				
	Capacity in markets	M	H				M				
	EPC Contractor capacity	M		H	M	M	M	M	H	M	L
	Design, development and changes	M		H	H	M	H	H			
	Drilling progress performance	L					L				
	Contractor constellation			M		H	M				
	Detnor organization and communication	M	M	M	H	L	H	H			
Weather conditions			M			M					

L: Low (0.3) M: Medium (0.5) H: High (0.8)

Appendix 11 - Correlation between time and cost risks