University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology – Risk Management	Spring semester, 2013 Open / ~~Restricted access~~
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External supervisor(s): -

Title of thesis:

On the Use of Risk and Uncertainty Analysis in Conceptual Stage of Petroleum Project

Credits (ECTS): 30

Key words: Risk and Uncertainty Analysis, Conceptual Stage, Petroleum Project, Monte Carlo	Pages: 73 + enclosure: 11 Stavanger, 14 June 2013 Date/year

On the Use of Risk and Uncertainty Analysis in Conceptual Stage of Petroleum Project

Master Thesis Submitted as Partial Fulfillment of the Requirements of Degree Master of Science in University of Stavanger

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Summary

Several development scenarios are assessed in the conceptual stage of petroleum project. Among all of the alternatives, a scenario will be selected which forms the basis for further detail engineering and project execution. Uncertainties exist during this conceptual stage due to limited information. Therefore, risk and uncertainty analysis is required to review potential benefit and downside of each scenario. The result from this analysis forms a valuable input for decision maker. Hence, appropriate analysis of risk and uncertainty is required to perform in order to give a broader picture of the decision's problem.

Current practice of risk and uncertainty analysis for scenario assessment in the petroleum project conceptual stage still lacks of scientific platform. As a consequence, the analysis cannot provide complete information on risk and uncertainty faced by each scenario. This thesis presents deep review in the practice and limitation of current risk and uncertainty analysis approach and as an outcome it suggest a new proposed approach to overcome those limitations. Emphasize is given to uncertainty as major component of risk. The proposed approach is outlined based on solid foundation basis and theory. Present work also highlights the study case to illustrate practicability of proposed approach to review petroleum project scenario. It is expected that decision maker will have complete picture of risk and uncertainty by adopting the proposed approach.

Key words: risk and uncertainty analysis, conceptual stage, petroleum project

Acknowledgments

I would like to thanks to God almighty for giving me health, opportunity, and chance to pursue my master degree in University of Stavanger, Norway. It has been wonderful years to experience new life adventure over the past two years.

I express my gratitude and appreciation to my wife, Irma, and our baby to born. Both of you are the reasons for me to keep striving, struggling, and enjoying every single moment in this life. Endless support from my wife has always encouraged me to always do my best in academic, professional, and social life.

I give my big thanks to both of my parents who always support me from far away. Their prayer, guidance, support, and words of encouragement are irreplaceable.

Special gratitude is given to my professor, Terje Aven, for his time, comment, and discussion in developing this master thesis. His effort, hard discussion, challenge, structured thinking, and prompt replies of my queries are to be appreciated. Flashing back two years ago when I received his course in risk analysis in my first semester. It was an eye-opening course for risk management, uncertainty analysis, and decision-making. I realized afterward that risk is not just probability multiply consequence. It gains my interest to deepen more thorough concept in risk and uncertainty analysis.

I would like to give appreciation to all reviewer of my final work: Irma, Rauan Zhamangarin, Hermanto Ang, and Robert Baligira. Your help and time to read this thesis, give constructive feedback, and exchange ideas are really valuable for me. Good luck guys for your journey ahead!

Last but not least, acknowledgement goes to PHE ONWJ and my friends and colleagues in offshore technology master program. They have filled my time during this study and it was such a wonderful things to always remember.

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Abbreviation

BBTU	Billion British Thermal Unit
CAPEX	Capital Expenditure
CPP	Central Processing Platform
DCF	Discounted Cash Flow
E&P	Exploration and Production
FEED	Front End Engineering Design
IRR	Internal Rate of Return
MBO	Million Barrel Oil
MMBTU	Million Metric British Thermal Unit
NPV	Net Present Value
OPEX	Operational Expenditure
USD	US Dollar

Chapter 1. Introduction

This chapter contains the background, description, motivation, and scope of this work. Structure overview of each chapter is outlined to give reader a brief picture of this thesis.

1.1. Background of Thesis

Uncertainties exist during conceptual stage of petroleum project. In this stage, uncertainties involved are related to the subsurface (geological structure, reservoir, well placement, production rate), surface (type of facility, processing facility, transportation), and commercial (oil price, NPV, fixed and variable cost).

Risk and uncertainty analysis are one of major concern in decision-making process to select the ‘good’ project. This analysis is required to refine all benefit and potential downside of each scenario in petroleum project as the decision maker consideration will rely on information from the analysis. Therefore, appropriate risk and uncertainty analysis is required to perform in order to have broad picture of the decision problem.

This thesis will review the current practice approach, identify the limitations, and proposed more appropriate approach of risk and uncertainty analysis for implementation in petroleum project conceptual stage. The result of this analysis will have significant influence in determining which scenario has to be taken by the company and bring forward into detail engineering and execution phase.

1.2. Problem Description

The current assessments of uncertainty for petroleum project scenarios are mainly based on the technical feasibility (reservoir and subsurface assessment, facility design code, engineering judgment, constructability review) and economic criteria (cost, expected NPV, IRR, and cost benefit analysis). Sensitivity analysis is used to measure variation of final output based on changes in the input. The decision criteria are mainly based on mechanistic criteria of those economic evaluation results. Meanwhile, the current applicable approach and framework for petroleum project still lacks of strong basis in assessing uncertainties. Most of the approaches mainly use calculation of expected value and probability. Expected value does not show the uncertainty which exists, hence it cannot reflect the associated risk and benefit involved in each scenario. Probability assignment used in the most of approaches is based on the analyst background knowledge (Aven, 2008a, Aven, 2011a). Poor knowledge in the probability judgment will hide the uncertainties and mislead the decision maker in reviewing the risk and uncertainty for respective scenarios. These limitations could create inability of choosing the right scenario. It will result in cost overrun, minimal benefit, or undesirable consequence that potentially create financial loss for company. Improper selection of option will overlook a potential opportunity that might create larger benefit in the future. It might also result in a non-optimum development during the field lifecycle and is not adequate to provide appropriate information for decision maker. Many literatures have been published in the uncertainty analysis of conceptual project, but the aim of those is not to discuss and present the fundamental basis of risk and uncertainty analysis. Review of the limitation on current approach will provide insight on how uncertainty analysis should be carried out in respect to petroleum project.

1.3. Objectives

The objective of this thesis is to review current applicable approach for risk and uncertainty analysis in the conceptual stage of petroleum project. The limitation on current approach will be identified. This thesis will also review fundamental basis and theory of more representative approach in risk and uncertainty analysis discipline. The proposed implementation on that approach in conceptual stage of project will be provided. The intention is to overcome the limitations in current applicable approach in assessing petroleum project uncertainties. Study case and example is illustrated for practicality of proposed approach in project scenario assessment.

1.4. Scope and limitations

This thesis reviews current implementation of risk and uncertainty analysis in the petroleum project. It only put focus on framework without going detailed or extensive into uncertainty in each of technical discipline. The scope of present work will not include HSE, social, management, and natural environment uncertainties in the petroleum project. This thesis will only include petroleum upstream project.

1.5. Methodology

This thesis will discuss implementation of risk and uncertainty analysis in the petroleum project conceptual stage. Conceptual stage refers to the initial stage of the project, after the exploration study is conducted, where the feasibility study, concept selection, and pre engineering phase are performed. The analysis will emphasize particularly in concept selection where the selection of alternatives prior to more detailed engineering is taking place and require appropriate analysis to select the "good" project scenario.

It reviews the current practical aspect to quantify and give a picture of uncertainty related in each scenario during assessment of conceptual stage. A deep review of literature was performed from journal, papers, and book covering the related subjects. There are a lot of publications in selection analysis of petroleum projects but only few has provided a broad analysis of uncertainties analysis.

1.6. Structure of the report

There are several chapters in this report. Chapter 1 provides the introduction which consist of background, scope, objective, and methodology of why this topic is investigated. In this chapter, the problem is described and scope of this thesis is presented.

Chapter 2 provides the current applicability, practical approach, and implementation of the risk and uncertainty analysis in assessing scenario during conceptual stage. The limitations on those approach and framework are reviewed and analyzed with potential disadvantage of using the current method in this chapter. Findings are presented with strong reasoning.

Chapter 3 outlines a review on risk and uncertainty analysis theory and framework which can capture uncertainties in more representative way. The chapter also explains how to overcome the weaknesses of current risk and uncertainty analysis method. The applicability of more representative risk and uncertainty analysis in the conceptual stage of project as well as adjustment for implementation in project basis is presented in this chapter.

Study case is highlighted in the Chapter 4 to illustrate how the risk and uncertainty analysis presented in the Chapter 3 can be implemented. Recommendation for further work is given in Chapter 5 whereas conclusion is outlined in Chapter 6 to ensure continuity of effort on using the approach presented in the Chapter 3 and possible implementation of approach in industrial work.

Chapter 2. Current Approach on Uncertainty Analysis in Petroleum Project Conceptual Stage and Its Limitation

The risk and uncertainty in the petroleum project conceptual stage is large due to many uncertain parameters and limited information involved. Furthermore, the declining of the production and field discovery, increasing operating cost, and low oil price add risk and create the complication to the petroleum industry (Simpson et al., 2000). Therefore, a better understanding in the risk and uncertainties in early project phase to provide the good information for decision-making is necessary. It can be accomplished by improving the conceptual basis, methodology, technique, and practical basis for risk and uncertainty analysis in project.

2.1. Risk and uncertainty definition

Risk and uncertainty are often used interchangeably in the project. Term of risk and uncertainty is often given the different meaning. Several distinctions between risk and uncertainty in the conceptual stage and project exist. The classic differentiation between risk and uncertainty probably is the Knight definition (Knight, 2012). In this definition, risk is described as the condition where probability distribution can be assigned objectively while uncertainty is defined as the condition where the analyst cannot give the probabilities or probability assignment should be made subjectively. Perminova et al. (2008) made a distinction between risk and uncertainty. Uncertainty is the event which has positive or negative impact to the project. It is an unexpected event to occur and might result in risk as a negative event or opportunity as a positive event. While the author described risk as a negative event with known potential dangerous event and therefore measures should be prepared to prevent them occured. The paper by Virine and Rapley (2003) highlighted risk as the condition when there is a chance or probability of failure or success while uncertainty is related to interval values or probability distributions of the event. Alessandri et al. (2004) presented that under risk, the decision maker (manager) tends to use analytical and quantitative approach to find the decision. In the other hand, qualitative and judgmental process is utilized under uncertainty condition.

Moore et al. (1995) defined the important variables as the parameter which are uncertain and the range of uncertainty (interpreted by use of confidence interval) can have significant consequence to final output. Suslick et al. (2008) outlined that risk depends on probability, potential opportunity or loss, and money while uncertainty is linked with range of probabilities. Another definition is made by Simpson (2002) through his paper that explained risk as the probability of a project or event will work whereas uncertainty is defined as range of possible outcome or parameter values described by the probability distribution. The author argued that uncertainty measurement can be performed using sensitivity analysis and tornado diagram. Term of uncertainty is also often used if the exact value cannot be estimated. This term is used widely in the exploration and geology discipline where it linked with the classification of resources and maturity of project, see (Ross, 2004) for detail classification.

Uncertainty and risk are used frequently in the area of risk analysis where risk consists of event, consequence, and uncertainty (A, C, U) (Aven, 2008a). Uncertainty can result in negative or positive consequence. It can be treated as threat or opportunity (Aven, 2011a, Hultzsch et al., 2007). Uncertainty is the major component in risk which determine the performance of a system and therefore the effort to represent uncertainty is the fundamental part of risk analysis (Aven and Zio, 2011). The uncertain quantity of interest is due to variation (aleatory) or lack of knowledge (epistemic). The detailed explanation between uncertainties is not scope of this thesis but the reader can refer to (Paté-Cornell, 1996).

As practical implementation of the risk and uncertainty analysis developed, there is no consensus on single definition of this subject in the petroleum project discipline. Lack of agreement is occurred in theory and practice. This thesis would not like to propose an attempt to give the distinction between risk and uncertainty, rather it will adopt the term (A, C, U) (Aven, 2008a) due to its strong basis and broad range of application in various discipline, including in the petroleum project discipline. Uncertainty should be highlighted as the main component of risk. Risk and uncertainty analysis approach adopted in this thesis will focus on assessment of uncertainty involved in petroleum project case.

2.2. Uncertainty in the petroleum project

Uncertainty is introduced through many properties used in petroleum project discipline. In the conceptual stage of petroleum project, many uncertainties are involved in terms of technical and non-technical issues. Treatment of these uncertainties will affect the decision making process and corporate strategy. The uncertainties involved in petroleum area are commonly related to:

a. Reservoir
   Behavior and thermodynamic of fluid, drainage area, reserve quantification, recovery factor, productivity and production rate, constraint on production rates, decline rate, soil properties, relative permeability, saturation, commercial quantity of oil and gas.
b. Geology
   Geological structure, reservoir seals and traps, source rocks, reservoir storage capacity, or hydrocarbon movement.
c. Drilling

Well placement, choice between vertical or horizontal well, requirement for injector, choice between wet or dry tree, selection of vertical X-mas tree or horizontal X-mas tree, success of the wild cat well drilling.

d. Facility

   Choice of facility for fluid processing, distance from nearest facility, tie-in development, project schedule, transportation and distribution facility, storage, metering, processing technology, and operation.

e. Technological

   Use of new technology, improvement of existing technology, applicability of technology

f. Economical

   Oil price, gas price, discount rate, inflation rate, crude demand, cost of subsurface and surface facility

g. Others

   There are several uncertainty not related to technical and commercial (Gu and Gudmestad, 2011), such as

   - Social uncertainties. It is related with regulation, political/government (law, regulation, war), systematic risk (market movement, inflation, investment environment), social environment (health, education, culture, welfare system)
   - Natural environment uncertainties. Impact of natural environment to the facility built (tsunami, earthquake, hurricane)
   - Management uncertainties. Uncertainties related to project management and execution. It has influence on organizational and individual performance, corporate procedure, control of work, organization.
   - HSE uncertainties. Uncertainty with personal safety and HSE culture, working environment, and corporate safety culture.

These factors are involved in various aspects of discipline and present uncertainties for risky decision making. Chamanski and Gudmestad (2002) conducted the research based on questionnaire to several petroleum project experts which has purpose to identify key parameter with large uncertainties in the petroleum project. They identified that the main challenges in the petroleum industry are related to the difficulties and complexity in finding the resource, large complex facility to build, requirement of expertise in various discipline, and huge amount of funding required starting from development, operation, and abandonment. Based on this questionnaire, the most uncertain parameter in the conceptual stage of oil and gas project is the production profile and reservoir properties. The second uncertainty is related to investment fund and operating cost (CAPEX and OPEX). The result also showed that professional dealing with uncertainty treatment still prefers to use single criteria or deterministic approach which based on average value.

This thesis will explore uncertainties involved in the conceptual phase/early stage of project. Particular stage will be given in the concept selection where all alternatives examined shall be selected prior steeping the selected scenario into successive stage. In this early stage, the limited information creates large uncertainty to parameter investigated. Conceptual phase of the project refer to the phase where the exploration and subsurface studies are completed and various scenario of petroleum project are planned. This phase normally consist of feasibility study, concept selection, and pre engineering (FEED) phase. This early stage of project will result in selection of an appropriate scenario which subject to further detailed assessment in next phase. The project can be a new field development, expansion of existing facility, or reactivation of the old field. See Appendix A for more detailed explanation of petroleum project conceptual stage. In the early stages of project planning, the complication in the decision making process for selecting feasible scenario is due to influences from number of options to choose, uncertainties involved (particularly in reservoir and facilities), and impact those uncertainties into production operation strategy (Suslick et al., 2008). Cost overrun, delay schedule, or inappropriate concepts are the examples of failure in uncertainty treatment during early phase of the project.

2.3. Common approach of risk and uncertainty analysis in petroleum project conceptual stage

There is a need to figure and understand uncertainty aspect in the initial project phase in order to provide good information for decision maker. In traditional thinking, the worst case approach is frequently utilized by putting conservative value in assessing uncertainty. Meanwhile this approach has potential to create unnecessary valuation and leaving the scenarios seems not interesting. Hence, it might value loss more than the opportunity. Additional conservatism does not provide the real valuation during consideration of the scenario. Established standard and procedures for dealing with uncertainty are required to provide the guidance as well as continuous learning process after the decision is established. Moreover, the continuous improvement of analysis method and best practice to adapt with the new changes is required (Perminova et al., 2008).

Implementation of risk and uncertainty analysis in the petroleum industry becomes widespread. The new approach, method, and ways to perform better analysis are always employed in order to provide more accurate result and appropriate information to aid decision-making process. In the same way, the simpler method is also suggested to be more attractive and easy to understand without substantial loss of accuracy. The purpose of risk and uncertainty analysis is to determine the uncertainty in the result based on uncertainty in the input and through its propagation using model introduced. The model is employed as a representation of the underlying phenomena based on analyst knowledge. Output parameter is known as the variable of interest in which the measure of uncertainty and quantification of interest in this parameter become the output of uncertainty assessment (Aven, 2010c). Risk analysis is a tool for uncertainty quantification in relation to decision alternatives. These analyses are carried out to provide the consequence in relation for taking specific decision compared to another. Multi objective and complex decision can be handled by proper approach in risk and uncertainty analysis and assist in prioritization of the project. Many literatures proposed risk and uncertainty analysis framework in petroleum project conceptual stage application.

2.3.1. Pretreatment in current approach of risk and uncertainty analysis

Meanwhile, there are no agreements on established practices or guidelines for uncertainty and risk analysis in conceptual project phase. Based on various literature in the subject studied (Moore et al., 1995, Savvides, 1994, Suslick and Schiozer, 2004, Virine and Rapley, 2003), the author of this thesis summarize the step for uncertainty and risk analysis includes pretreatment of parameter phase. This phase is seen to seek uncertain input parameter as critical parameter (which considered has large uncertainties) for further uncertainty and risk treatment. Pretreatment of risk and uncertainty involve determination of parameter studied, modeling, sensitivity analysis, and selection of uncertain input parameter. Details of those are as follow:

a. Identification, investigation, and determination of parameter studied
   All the alternatives and scenario are identified in this stage. The scenario must be technically feasible and is able to be implemented in the field. Goals and objectives of the project are presented. The parameter related to produce the output quantities are selected and defined. This parameter will serve as the input in the assessment. In subject this thesis studies, the parameter can be in the form of technical or economic parameter. For example in the reservoir engineering discipline, the porosity and permeability are the input parameter to study the reservoir reserves. Pressure, temperature, and flow are examples of input parameter to examine the mass and energy balance in the surface facility processing. Oil and gas reserves, oil price, tax, and production profile are parameter that should be defined to analyze project cash flow.

b. Modeling
   Model is built as a representative to link between input parameter and output quantities that are going to be assessed. During petroleum project phase, the model is normally used to represent all of properties in subsurface, surface, and commercial area. Model is utilized to give a future prediction on the production profile, declining rates, and production rates. For example tank model act as the representative mathematical model of the reservoir parameter, (Hultzsch et al., 2007) or geological model represents uncertainty of geological features. The geological model is first built with the potential well location. Then, porosity, permeability, and correlation between them is generated through model (Potlog, 2003). Suslick and Schiozer (2004) through their paper highlighted the integration of geology and commercial uncertainty using representative model. In the petroleum project phase, the model to link all technical with commercial is commonly developed with NPV as the final outcome. A balance between tolerance on accuracy and simplicity should be

made thus the analysis still will be focus on its objective to provide support for decision making. A rough model in some way is preferred due to its simplification and has ability to capture the important features.

c. Deterministic assessment
In the deterministic assessment, all the parameter values are assumed fixed (reserve, production rate, oil price, cost, discount rate, tax, and other parameter) and model is utilized to produce the final result. The average value is normally used. This is also called as static assumption.

d. Sensitivity Analysis
Deterministic case often results in the underestimated risk and overestimated benefit, as studied by Brashear et al. (2001). Consequently, sensitivity analysis is conducted with the range of values to determine the critical parameter (the variables which have large range and swing movement will give great effect to the final output). The important part in the risk and uncertainty analysis is to investigate validity of the assumption used in the analysis (Gatta, 1999). It is part of the assessment to investigate the changes of the parameter based on input variation. In this commercial evaluation of project conceptual stage, the changes on the technical input (for example in reserves value) might create the significant impact to the project final NPV. Those are the critical variables that have to be taken into account. The critical variables have the greatest influence to the project and determine whether the project is commercially viable or not. Critical parameter will be studied further in the risk and uncertainty analysis. Non-critical variables are usually not included to reduce time and cost. In many cases, the cost of focusing to the non-critical parameter is outweighing the benefit. The typical sensitivity study in the commercial evaluation is frequently conducted for:

- Production capacity
- Facility cost
- Number of wells
- Oil and gas price

Tornado diagram is a good representation and diagrammatic approach for the result of sensitivity analysis. It shows the range of uncertainty in the parameter studied.

2.3.2. Current approach of risk and uncertainty analysis

Many people prefer to deal with single value from deterministic approach due to its simplicity rather than thorough risk analysis through probability distribution which is more complicated (Cunha, 2007). Meanwhile the use of single value is not adequate to represent the uncertainties in the conceptual phase assessment. Therefore, based on result from pretreatment of analysis, critical parameter determined by sensitivity analysis will be the subject for further investigation in the risk and uncertainty analysis. The probability and stochastic concept are often applied in the risk and uncertainty analysis. Following are the approach generally utilized as risk and uncertainty analysis in petroleum project:

a. Estimate class
In the project, the estimate class is used for estimating purpose. It is considered as treatment for uncertainty in the project management. The class interval depends on the stage of the project. Table 2.1 shows classification system that is commonly used in the project stages.

Table 2.1 Estimate Class (Gudmestad et al., 2010)

Class	Description	Accuracy (p)
A	Prospect Study	Not Available
B	Feasibility Study	± 40%
C	Concept Studies	± 30%
D	Pre-Engineering	± 20%

Using this class, the uncertainties are reduced as the project moves to successive stage by utilization of such interval. This class uses the prediction interval that there is probability 1- α of specified parameter X in the interval of expected value EX ± p EX, where p is the percentage of estimate class. The motivation behind this class is to estimate surprise which could occur during project development, particularly in early stages of project where limited data and information is available.

b. Probability assignment and distribution
Probabilistic approach has been often taken to represent uncertainty in the input parameter of a model. In probabilistic concept, uncertainty is described by the probability assignment or distribution or confidence interval. Probability is able to define through two ways (Aven, 2003, Aven, 2010b):
- Frequency interpreted probability. It is interpreted as the fraction of times an event occurred if the similar situation is repeated over infinitely in the hypothetical population of similar situation. The underlying true frequency probability exists and hence it needs to be estimated. This type of probability is related with randomness or variation. Using this definition, the underlying true probability is determined through confidence interval or estimation.
- Knowledge based or subjective probability. It is interpreted as the measure of uncertainty about an event with the consequence based on knowledge of assessor. In this case, probability is the subjective measure of uncertainty seen through the eyes of assessor by comparing with the standard (Lindley, 2006). The probability of 0.1 means that the assessor compares his uncertainty with a particular bar in an urn containing 10 balls. Knowledge based probability is related with epistemic uncertainties, uncertainty due to lack of knowledge.

The probability number or distributions are set and applied to the uncertain variable. The pessimistic, most probable, and optimistic cases is specified based on the probability distribution of the parameter. The future state is predicted using propagation probability distribution in input parameter into model to obtain uncertainty for quantities studied. Monte Carlo simulation or experimental design theory method can be applied as propagation tools. Dejean and Blanc (1999) proposed another method called experimental design theory for linking probability in the input and output through the model. Finally, the probability distribution of quantity studied is generated and assessment on this result can be made. Various methods are proposed for probability assignment. Probability distribution such as triangular, normal, Poisson, or other complex distribution might be employed. Historical data from the past can be used to determine probability distribution. Estimates based on certain knowledge can also be proposed for probability numbers.

In the petroleum project, probability assignment and distribution are normally specified into technical input parameter. It is widely used for representing uncertainty in reserves, prospect, drilling, structural load and strength, or facility cost. Motta et al. (2000) predicted the model in the production forecasting with the decline curve which follows exponential profile. The distribution of the variables can give a probability distribution of the production-declining rate. Suslick and Schiozer (2004) highlighted the roles of probability assignment in the risk analysis of petroleum project conceptual stage. According to the author, the conceptual stage presents significant step in petroleum project due to various alternatives considered. It deals with how to apply integrated probability distribution in technical and economical issues. Rodriguez and de Oliveira Pádua (2005) shows the use of integrated probability distributions of CAPEX, OPEX, gas reserves, gas and oil price, and transport tariff parameter to assess the profitability of petroleum project in the conceptual stage. Using this method, the expected NPV and probabilistic result will provide risk picture to the decision maker.

c. Decision tree and expected value

Decision tree is derived based on the games theory and operation management science with focus on the probability of outcome. In the decision tree, probability is assigned in the chance node and decision that has to be taken is represented by decision node. One of advantages using decision tree and its expected value is that this method incorporates flexibility for assessing various scenario (Margaret and Bernard, 1999). Decision tree is exercised to represent all possible decision alternatives or scenario with probability occurrence of outcomes studied. Utilization of decision tree requires the expected value calculation of all potential outcome. The expected monetary value (EMV) is a sum of weighted value (commonly is represented by cost or NPV) and its conditional probability occurrence. By understanding EMV, it will be easier for a corporate to evaluate and quantify the risk they are exposed to.

Expected value is defined as the center of distribution. Project risk is often defined by its expected value. The expected value calculation is also used for (1) the value of information which means the cost of gaining information to reduce the uncertainty (2) expected loss ratio to account for the possible loss. In most of the cases, expected value is combined with standard deviation to inform the risk/return of parameter. Influence diagram, which shows the relationship between each parameter in the decision tree, is used along decision tree. Gatta (1999) shows the implementation of influence diagram to describe the relationship and interdependence between chance event, decision variables, and EMV of decision variable. This paper also shows the use of decision tree, Monte Carlo, and sensitivity analysis in the major oil field conceptual study in Kuwait. By using decision tree and expected value, the alternatives are ranked in order based on their expected value. Scenario with the largest expected value will achieve highest rank. Decision maker will select scenario with expected value and process the chosen scenario into further successive stage of the project. It is important for petroleum project to have high expected value to be judged as a 'good' alternative to execute.

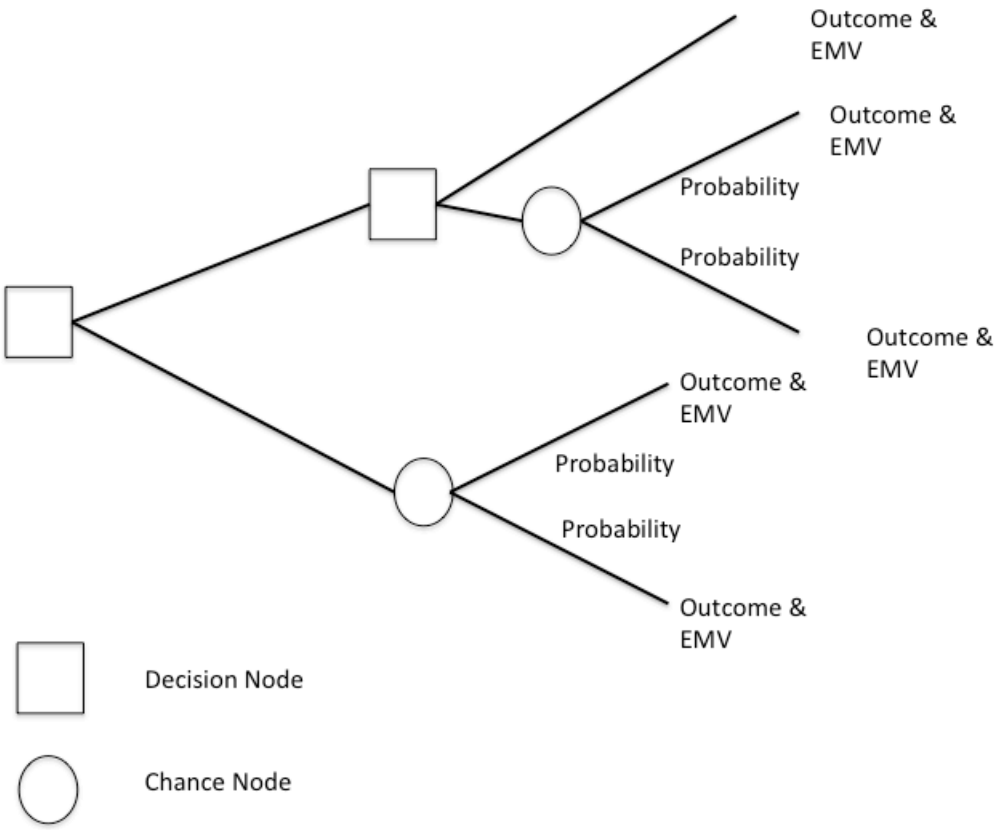

Figure 2.1 Decision Tree

d. Bayesian

Bayesian mechanism is an approach to model the uncertainty through subjective probability judgment based on the knowledge of the assessor. Through use of Bayesian theorem, it is possible to update the assessment using new available information. The chance or variation in the input is assessed using relative frequency probability approach. Prior distribution is assigned using subjective probability and it is updated to generate posterior distribution. The resulting distribution is employed to produce predictive distribution to reflect the variation and uncertainties due to lack of knowledge.

For Bayesian theorist, probability is treated as the measure of uncertainty based on individual and personal knowledge (subjective probability). Probability is property of an individual, not the "true" or objective property. Therefore, the probability of event A occurred is seen as P(A|K) with K as the background knowledge. Using Bayesian, the prior distribution is updated with new available data and will result with posterior distribution and can be seen as P (A|X, K) with X as the new available data. In the event of large data and new information available, the influence of prior distribution will be smaller than influence of those new information (North, 2010). The Bayesian equation can be rewritten as below:

$$p(\theta|data) = \frac{f(data|\theta)\, p(\theta)}{p(data)}$$

$$p(\theta|x) = \frac{f(x|\theta)\, p(\theta)}{p(x)}$$

$$p(x) = \int_{\theta} f(x|\theta)p(\theta)d\theta$$

where θ is the variables of interest and X is data, $p(\theta)$ represents the prior distribution (subjective probability) of θ, $f(x|\theta)$ is the new information which will be incorporated into Bayesian mechanism, $p(x)$ is the normalizing constant, and $p(\theta|x)$ is the posterior distribution. In the case of large data available, it can be converted to likelihood function as follow:

$$p(\theta|data) = c\,.L(\theta)\,.p(\theta)$$

where $L(\theta)$ is the likelihood function of θ.

Then the Bayesian can assess the uncertainty of θ. By combining with law of total probability, the probability of future event can be expressed as:

$$P(X = x) = \int_{\theta} P(X = x|\theta)F(d\theta)$$

where F(θ) is the prior distribution of θ and P(X = x | θ) is a chance distribution. If X is a sequence exchangeable variables or a Bernoulli sequence, then θ is the fraction and

$$P(X_1 = 1 \ldots . X_k = 1, X_{k+1} = 0 \ldots, X_n = 0) = \int_{\theta} \theta^k (1-\theta)^{n-k} F(d\theta)$$

where $\theta^k (1-\theta)^{n-k} F(d\theta)$ is the chance distribution and prior distribution of is shown θ by F.

In the Bayesian, credibility interval, which means that a subjective probability $(1 - \alpha)$ in which θ is in interval, can be generated:

$$P(\theta_L < \theta < \theta_u | data) = 1 - a$$

Moreover, the weight of data or prior distribution on Bayes can be derived by

$$\acute{\lambda}_{BAYES} = \frac{n}{\tau} \frac{\tau}{\tau + {}^{1}/_{b}} + ab \frac{{}^{1}/_{b}}{\tau + {}^{1}/_{b}}$$

$$\acute{\lambda}_{BAYES} = \lambda_{MLE} \frac{b\tau}{1 + b\tau} + \lambda_{prior} \frac{1}{1 + b\tau}$$

If MLE (maximum likelihood estimation) is close to the Bayes result then large amount of data is available (weak prior) and if prior is close to Bayes result then only little data is available (strong prior).

The choice of prior distribution is the challenging part in the Bayesian procedure. Assumption of conjugate distribution is often used and it means that the posterior distribution is same type with prior distribution. It will simplify the calculation for the Bayesian. There are informative and non-informative prior distributions in the Bayesian. The informative prior distribution is when all the parameter have the fraction between 0 and 1 while non informative prior distribution is used when the parameter have the same fraction.

During the assessment of the scenario in the conceptual stage, use of Bayesian can be performed by updating probability distribution of specific parameter in case additional information is available. Bayesian is also carried out as the project moves to the successive stages prior its implementation. All the technical and commercial information is updated to produce new probability distribution. The probability distribution of reserves estimation is updated as the wild cat drilling finds any oil and gas. Uncertainties on CAPEX cost estimation in concept selection are revised as new information on facility scope is received during feasibility study and survey.

e. Real option

A valuation based on static assumption can mislead the decision maker since it does not account for options after the decision is made. Real option is proposed to consider adjustments that corporate can make after the project is selected. Real option is carried out with decision tree where the option to expand, delay, or abandon the project are deliberated and taken into account. In the scenario selection, options are exercised to consider future possible scenario. The results are recalculated considering the option to implement. Success or failure probability of a scenario is multiplied with outcome to get expected value of the scenario in real option. In some cases, real options can show result that putting investment in a project is more profitable even the investment cost is higher than its expected NPV. Value of information and flexibility are the key understanding for real option theory. The decision maker can also delay the decision if the current situation such as profitability of the field, information from reservoir, oil price, and another cost is not as high as expected. Flexibility value is calculated from differences of expected value with implemented option and without implementing it.

Ekern (1988) showed the implementation of real option and value of flexibility in assessing petroleum project on development stage. In the project commercial assessment, use of real option is mainly to deal with limitation of DCF method. Alessandri et al. (2004) outlined combination of qualitative assessment and real option to assess uncertainty in the project. Lund et al. (1999) proposed the value of flexibility during early stages for development in marginal field of Norwegian Continental Shelf. Armstrong et al. (2004) introduced Bayesian mechanism in real option implementation.

During early stages of project (post exploration), limited information is available and operator should make the decision under uncertainty and incomplete knowledge. Development strategy during early stages of project influences the value of successive stage. Value of flexibility is utilized to consider all options and to decide the right time to develop the field into detailed design phase. Real option analysis has the ability to assist management to seek expanded options. Consider that there are two scenarios for developing an oil field. Based on simple assessment, scenario A has expected NPV smaller than scenario B. Expansion option for both scenario is assessed and NPV is recalculated using real option evaluation. The expected

NPV considering expansion option for the scenario A now is larger than for the scenario B. Decision maker might consider to select the scenario A with regard to this option.

f. Portfolio assessment and efficient frontier plot

This method is utilized to compare several portfolios, which consist of mix of selected securities (stocks, bonds, or projects), commercially using expected return and its standard deviation. Using this method, risk (represented by standard deviation value) and expected return is plotted. Markowitz (1959) presented in his paper that risk and return has the correlation and this paper is the pioneer of portfolio analysis through efficient frontier idea. The author introduced the efficient frontier plot where mix of portfolio in which no combination will result in higher return without higher risk or lower risk without lower return. The portfolio which maximizes the return and minimize risk (respective to standard deviation) is the most efficient portfolio. This approach is originally intended for stock and bonds portfolio. It replaces the traditional portfolio selection which relied exclusively on expected return.

Employing portfolio theory shows how the combination of portfolio would eliminate unsystematic risk associated to each security. Unsystematic risk is related to specific project or industry. It includes labor strikes, shortages of material, accident in the project. This type of risk is termed as diversifiable risk as diversification will eliminate unsystematic risk. Systematic risk is related to market risk, such as energy price, inflation, or purchasing power. It cannot be removed by diversification. Dependence and relationship between portfolios are addressed by covariance and correlations. Covariance measure weighted average of deviation from expected return from a set of portfolio. Correlation divides covariance with standard deviation of each portfolio. Correlation values are always between +1 and -1. Positive correlation means that all portfolios return are higher than average at the same time. Negative correlation implies that when return of a portfolio is higher than average, another portfolio will have return lower than average. The relationship between securities in portfolio is shown by equation as follow (Aven et al., 2004):

$$Var_{Portfolio} = \frac{1}{N}Var + \left(1 - \frac{1}{N}\right)Cov$$

Where N is number of securities in a portfolio, Var is average variance of securities, and covariance is average covariance between securities. The first term is unsystematic risk. As the number of securities (projects) increased, this type of risk will be reduced. Second term links to systematic risk.

Implementation of portfolio optimization method in the exploration and production area is growing rapidly. Many paper highlighted the adaption use of portfolio theory in systematic fashion to petroleum upstream project stage (Rodriguez and de Oliveira Pádua, 2005, Adekunle and Curtin, 2006, Orman and Duggan, 1999, Walls, 2004). In the application of portfolio theory in petroleum segment, the expected return is characterized by expected NPV (multiplication of probability and NPV in success and failure) and risk is represented by standard deviation. Alternative measure for characterizing risk is proposed through use of semi standard deviation. This measure only calculates the downside of portfolio while in the standard deviation context, the portfolio with extreme downside and upside is equally undesirable. See (Orman and Duggan, 1999) for application semi standard deviation in petroleum portfolio assessment.

Using this method, an oil and gas company can divide the investment into several projects or alternatives at the same time and combining them into portfolio. The capital of corporate will be allocated across different project. Distribution of investment on various projects is assessed with efficient frontier concept. Selection of profitable project is made from assessment on expected return and standard deviation. Combination of project in a portfolio is maximized by employing efficient frontier plot. Ranking of project could be performed across efficient portfolio. Implementing portfolio theory will allow corporate to review whether higher expected return drive to higher risk. Set of project in portfolio which composes higher return and lower risk based on its efficient frontier plot will be selected by the company.

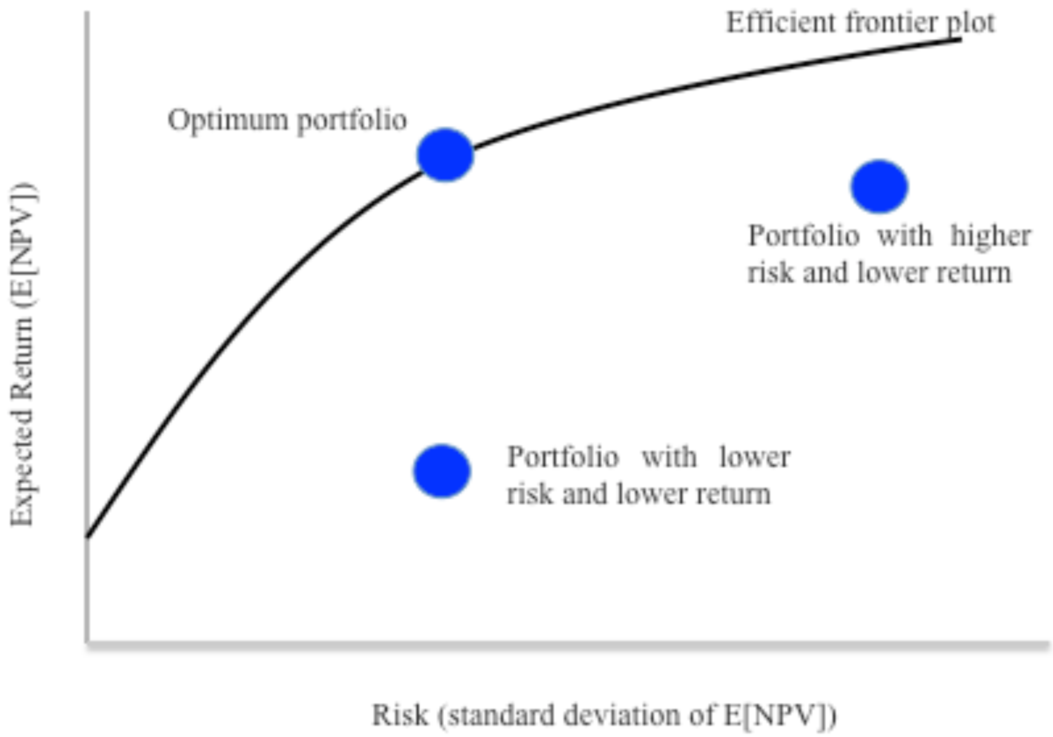

Figure 2.2 Efficient frontier plot

g. Adjusted economical measure assessment
Discounted cash flow (DCF) is the most often used analysis to assess profitability of the project. In DCF method, net present value (NPV) of cash flow in the particular time is employed and sum of the NPV or expected NPV (if the cash flow is uncertain) during the project life is measured to indicate profitability of the project. The NPV is calculated using the formula:

$$E[NPV] = \sum_{t=0}^{T} \frac{Cf_t}{(1+r)^t}$$

where E[NPV] is expected NPV, Cf_t is cash flow of a scenario for particular year t, r is discount rate, and T is the field life in years

In concept selection phase, all alternatives being studied are assessed using this DCF method to show which alternative is the most profitable. NPV for all scenarios during their respective lifetime is compared. In most of the cases, project with the largest NPV will be undertaken and chosen for further detail stage. Virine and Rapley (2003) conducted survey in the UK that reveal majority of the oil and gas company still use DCF method to analyze profitability of project.

The cash flow is discounted by given discount rate. Discount rate generally implies the rate of return expected by investor in the particular project. In the financial and economic theory, it is termed as the weighted-average cost of capital (WACC). This measure has been the most often used instrument for investment decision making in the oil and gas industry. Using discount rate or WACC, the cash flow of a project is adjusted to net present value. If NPV is positive, project will be accepted, otherwise decision maker will reject the project. Additionally, internal rate of return (IRR) is also assessed in profitability analysis of a project. IRR measures the discount rate value that generate zero NPV. Project is accepted if the resulted IRR is greater than discount rate. With regards to economic risk, discount rate considers systematic risk (market risk) and portfolio theory manages unsystematic risk.

There are several methods to treat economic risk and uncertainty in project such as (Aven et al., 2004):

1. Discount factor or rate of return will be adjusted to accommodate risk and uncertainty in future cash flow. Higher uncertainty means that the discount factor will be higher. Higher return rate will discount the cash flow into lower net present value. Unfavorable project (with high uncertainty) is outweighed by discounting cash flow with higher discount factor.
2. Scenario for project NPV is assigned using most probable, optimistic, and pessimistic cases with its particular probability. The expected value of NPV is compared and the higher expected NPV will be chosen. This scenario uses the rate of return on market risk free instrument. Probability distribution can be assigned to input parameter of cash flow and uncertainties are measured using Monte Carlo simulation. Having this method in application, NPV distribution will be generated.
3. Combination of those two methods. It implies the uncertainty using scenario analysis and involves adjusted rate of return. Many analysts argue that by using this procedure, the uncertainties is taken into account twice in the probability distribution of input parameter and adjusted rate of return.

h. Utility Theory

Suslick and Schiozer (2004) described that the use of uncertainty and risk analysis are required to deal with the value preference in the decision making context. Savvides (1994) highlighted that risk and uncertainty analysis are a tool to connect between the analyst and decision maker. For example, the decision maker preference on specific probability distribution is informed to the analyst and applied in the uncertainty analysis. The value preference of decision maker and risk analysis result is combined and decision is established based on those assessments. Risk and uncertainty are often linked to expected utility theory in which how people value losses or benefit. In the theory of rational decision making, the decision is maximized based on utility of individual (Lindley, 1991). To apply expected utility, decision maker must be coherent in this preferences and uncertain quantities. This coherence is stated through several axioms. See (Abrahamsen and Aven, 2008) for brief explanation of those axioms.

The decision rationality theory is popular since the paper of Von Neumann and Morgenstern (1945) existed. The principle assumes the perfect market and information available. Von Neumann and Morgenstern (1945) developed the expected utility theory based on their books describing how people behave in the decision making situation. According to expected utility theory, corporate risk preference and attitude towards risk can be represented using utility function. The pleasure of gaining profit and loss versus its profit and loss diagram draws the profile of corporate's utility. Utility function describes how the decision maker behavior towards the uncertainty and their preference.

Let X be the variable of possible outcome and u(X) is utility function on how X is perceived by the people. Then expected utility function is E(u(X)). By assigning the probability on the each outcome and utility function, one can define the preferences on particular outcome provided that he/she behaves rationally. Utility function is described with the graph of monetary value and how the decision maker perceives the value (utility). Another approach to assign utility function is to follow exponential utility function (Schuyler, 2001). Certainty equivalent is derived from utility function and describes the condition when decision maker is indifferenct towards an offer with uncertainty and another offer with certainty. The differences between expected value and certainty equivalent is called risk premium. It is the amount the decision maker pay to avoid risk. Risk neutral is the situation when the decision maker is indifference between the uncertain and certain offer. Risk aversion is situation when decision maker prefers to accept less amount of certain money rather than taking uncertain offer with higher amount. Risk averse is considered when $E(u(X)) < uE(X)$. Risk seeking is the situation when decision maker values the uncertainty rather than certain offer.

Consider the all the scenarios analyzed in selecting the type of structural facility for a new wellhead platform. Scenario A is based on new technology and offer cheaper concept. Scenario B is the most often installed type of platform and company already uses it for another field. Based on analysis, scenario A might be selected due to its low cost. But since corporate is risk averse based on its utility function, scenario B is the selected option in order to avoid risk due to new technology.

Motta et al. (2000) illustrated the step for portfolio selection by using utility function and risk aversion for Brazilian field. The option with maximum certainty equivalent is chosen as the optimum decision. The utility function is defined by using interview and exponential utility function. The preference utility function commonly consists of the level of risk aversion and certainty equivalent.

2.4. Limitations of current approach risk and uncertainty analysis in petroleum project conceptual phase

Approach presented on the chapter 2.3 for risk and uncertainty analysis has several pitfall and limitations in the fundamental concept. All these methods create strong element of arbitrariness and lack of fundamental basis in risk and uncertainty analysis. These deficiencies will result in improper treatment of uncertainties. Those limitations are presented here to give the reader a reflection on the use of current risk and uncertainty analysis in the practical case of the conceptual project phase.

2.4.1. Limitations of pretreatment current risk and uncertainty analysis approach

In the current methods for risk and uncertainty analysis, sensitivity study is utilized to determine the critical parameter for subject of analysis. This rationale can be questioned. Sensitivity analysis is not uncertainty analysis. Sensitivity only concerns on output consequence as alteration of input parameter. Uncertain input parameter is not determined through use of sensitivity analysis. The analysis on how uncertain input parameter is not included in this analysis. The objective of risk and uncertainty analysis is to predict future performance of uncertain observable quantities which are not known at the time of analysis. Imagine the effect of oil reserves to cumulative NPV of a field. If reserves has large amount of oil contained, project NPV might be positive. Otherwise, NPV might be negative because cost will be higher than oil sales given that reserves are below certain amount of value. Sensitivity analysis is conducted to investigate how oil reserves influence NPV. It has nothing to do with how uncertain the reserves, uncertainty of reserves below certain value, or cumulative probability of reserves between high and low value. Sensitivity analysis is not used to determine uncertain input parameter for risk and uncertainty analysis.

2.4.2. Limitations of current risk and uncertainty analysis approach

a. Estimate class

   Use of estimate class does not have the appropriate basis. Uncertainty assessment has to be seen linked with all aspect. Putting attention on estimate class is only understood as isolation for uncertainty management. Predefined uncertainty interval/contingency should not be seen narrowly. Absolute compliance to class might provide inappropriate picture of uncertainty. Further optimization for benefits and disadvantages on particular concept need to be carried out. Use of predefined contingency interval for uncertainty reduction should be performed in care. The uncertainty reduction is not just mere fulfillment of reduced contingency. All the benefit and cons should be taken into consideration in the optimization effort. Reducing contingency that will assume uncertainty reducing is not considered as value added is not seen as the benefit (Flage and Aven, 2009b). The tangible parameter (for example expected NPV and cost) that will give more picture benefit and disadvantage should also be considered. Use of expected NPV should be accompanied with assessment on how the E[NPV} could vary from expected value, not only magnitude of variation (as estimate class address)

Flage and Aven (2009) also presented several aspects that should be considered during project phase rather than putting focus only into prediction interval. In the conceptual phase, those activities are:

a. Assessing the uncertainties for the alternatives
b. Calculate the NPV for each scenario
c. Define the potential surprises

These type of activities can contribute to optimization of the alternatives in the conceptual phase. Uncertainty reduction should not be implemented in the use of prediction interval. All alternatives should be assessed carefully in order to maximize value of corporate in the future and during its life cycle.

b. Probability assignment and probability distribution

Savvides (1994) argued that by setting the frequency interpreted probability distribution, the true value is still in the range limit. It means that the situation should be repeated infinite times to get the true value (frequency probability). It is impossible to get the same situation for a unique type of project. Of course a petroleum project case is always unique and there is no any possibility to get the same case for in the large number. If frequency probability is applied in the measuring the uncertainty of reservoir reserves, the large (infinite) population of similar reservoir condition (trap, seal, porosity, parameter) should be built in order to define true meaning of probability. Same case applies for others parameter. Similar data might be used but if those data are looked in detail, it is not true to have the same value with object studied. This term of probability might be useful if large population or mass production of an object could be defined. But it is hard imagine in the petroleum project case. Therefore the frequency probability is failed to use in conceptual stage of the project.

Knowledge based or subjective probability is assigned by the analyst based on certain knowledge. The knowledge might come from information, historical data, or experience. In the case of estimating the probability of offshore facility cost below a certain amount of money, an analyst may assign a probability number or distribution based on data from historical prices alone. He/she can justify probability of 0.8 that topside equipment will not be above 50 million USD. But another analyst also can use another more representative information, such as cost from similar project, interview with expert, or fundamental analysis on topside equipment movement cost. Based on his/her knowledge and information assessed, different value can be assigned. It is clear from this example that different knowledge may result in different number of facility cost. If probability approach is seen in restriction, the number derived from poor knowledge is used and the resulting risk and uncertainty analysis is not representing uncertainty involved. Classic adage saying "garbage in, garbage out" is seen in this case.

Based on two argument presented above, probability assignment cannot represent all of the information into one probability distribution or assignment or probability numbers. The decision maker might not agree with the assignment made by the assessor since not all of the knowledge can be represented by the probability assignment (Aven, 2011c) and it might not be the information that decision maker wants. The expression of probability can mislead the result if attention is only put for probability to reflect uncertainty. Probability should be treated as an expression of uncertainty based on particular background knowledge of the assessor. Therefore probability should not be solely associated with the uncertainty.

Background knowledge for assessing the uncertainty depends on the knowledge of the assessor, assumption used, model introduced, data availability, expert elicitation and judgment (Flage and Aven, 2009a). The analyst might assign same value of probability based on different background knowledge. An analyst in assessing profitability probability of an petroleum project scenario might use several assumptions, for example certain value of oil price, well fitted specified distribution for reserves, or fixed operational and maintenance mode, but those assumptions should be justified and assessed further. There is a need to extend uncertainties beyond the probabilistic approach. If the knowledge is poor, the assignment does not reflect sound representative of the uncertainty. According to Aven and Zio (2011), due to incomplete knowledge of underlying phenomena, uncertainties exisst in the model and parameter. The lack of knowledge could not be described by mathematical or probability distribution and analysis beyond assignment number should be conducted. There is a need to extend uncertainties beyond the probabilistic approach. Use of probability assignment is not rejected but care should be exercised when using probability. Surprise can occur and it is beyond probabilistic world (Aven, 2008a, Aven, 2011b). Subjective probability is more representative for use in petroleum project case. But its use should not be seen as solely uncertainty measure.

c. Decision tree and expected value

The decision tree will result in expected value (or EMV) based on weighing possible outcome gain and probability for each outcome. Expected value is often used because it summarize all the probabilities and consequence into single value number, then it will be easier to represent and compare the alternatives based on this value (Schuyler, 2001). Probability assignment has the pitfalls as it was discussed in previous point. Decision tree is a useful method but the result of expected value also has difficulties to interpret. Expected value does not represent the risk and opportunity involved. There are extreme outcome/consequence/opportunity with low probability occurrence that is hidden by expected value. Using expected value based method will result in no differences for treating an event with extreme consequence and low probability with another event which occur in regular basis with high probability but has low consequence. Imagine that a field development option has high conditional probability of occurrence with low NPV and another option has low probability of occurrence with high NPV. Expected value for both of them could be same value but those two extreme positive and negative NPV is not informed by expected value. Decision maker might be misled by this value due to hidden uncertainties involved on it.

Utility function is described to be more representative than expected value in assessing the scenario. Since this utility function represent the behavior of decision maker towards uncertainty. Different corporate will express different behavior for equal alternatives with same expected value. A large company with vast experience in executing worldwide oil and gas project will express different choices compare to a small local company if both of them are faced with same several potential petroleum projects. Their attitude in valuing uncertainty is different and these differences cannot be represented only with expected value. The details in utility function will be explained below but attention here is paid on how expected value is failed to represent risk and uncertainty involved in oil and gas project. Extreme consequences should be accounted when analyze risk and uncertainty. The tradition thinking of using expected value to reveal the true value of properties is not valid to use in petroleum project case. Surprise factor and extreme outcome should be accounted in the risk and uncertainty analysis to capture what expected value cannot capture.

d. Bayesian approach

Probability world is introduced in Bayesian through parameter probability distribution and prior probability distribution set up. As discussed previously that probability alone is imperfect representation of uncertainties. Imagine that in concept selection of new type of compressor installation project, assessment of compressor lifetime (λ) should be carried out to give information on equipment reliability. Feasibility study has not shown any lifetime data. As the project continues to concept selection, the lifetime is measured from data of similar compressor. True value is not known. Therefore, the measured data is assigned to probability distribution (say) exponential distribution. Prior distribution of lifetime is set as uncertainty of compressor lifetime. Expert assign gamma distribution as uncertainty measure with parameter a and b.

Uncertainty assessment on real value of λ is carried out using Bayesian and updating the assessment as new information of measured data available. Using Bayesian, parameter λ as the true expected lifetime of compressor is introduced. Hypothetical thinking of large (infinite) similar population of compressor lifetime is generated to obtain this parameter. It is not possible to define the true similarities between alternatives or by solely referred to "similar" project. If the population is extended to include more projects, then the "similar" project is harder to find. Parameter λ is direct observable quantities. It is rather hard to measure. Focusing on unobservable quantities and fictional parameter is not practical and easy to implemented. Focus should be put on quantities and parameter that easy to measure.

Bayesian use the predictive distribution to combines posterior distribution, which represent uncertainty due to lack of knowledge (prior distribution) and probability distribution. It is fit in the case of large amount data available. Meanwhile the use of predictive distributions alone is not sufficient to represent the uncertainty since it mixed up all the uncertainty into one single distribution (Dubois, 2010). Moreover, in the conceptual stage of project, use of Bayesian has limited applicability due to its complicated procedure. If there is new information available, all basis and modeling is required to be reassessed, rather than automatically updating it using Bayesian mechanism (Aven et al., 2004)

Aven and Kvaløy (2002) have presented the alternative approach on for dealing with limitations Bayesian mechanism. In this new approach, all the uncertainties are treated as the epistemic uncertainty due to lack of our knowledge. Using this approach, modeling of random variable is not required because it is treated directly as uncertainty measure with confidence measure related to particular parameter based on background knowledge (say, $P(\lambda|K)$). Using this method, the Bayesian calculation is simplified. Furthermore, it prevents introducing hypothetical thinking of infinite population and only focus on observable quantities. This approach is based on assignment of subjective probability. It is rather simple and effective to use. Its implementation in the context of petroleum project is somewhat easier. Refer to example of compressor type alternatives, analyst is required to assign probability of lifetime certain compressor type. In case of new information exist, reanalyzing of basis, modeling, and having data for probability assignment of compressor lifetime will update the information.

e. Portfolio and efficient frontier plot

Risk and uncertainty analysis using portfolio theory should be exercised carefully. Having this method to select project solely on expected return and its standard deviation could hide uncertainty in each scenario. The use of standard deviation to represent the risk is not the representative measure.

Standard deviation is rather a statistically value and it depends on the variation from the expected value as the "true" value. It should be used with care as the statistical parameter is not the good representation of uncertainty. Portfolio theory also use expected value by considering huge amount of project (Aven and Flage, 2009). The expected value has the limitation as highlighted in discussion in the chapter 2.4. To generate the portfolio assessment, probability distribution is utilized. It is not clear whether it is frequency interpreted probability or subjective probability used in this method. This thesis has presented subjective probability based on certain knowledge is preferred. But its use depends on particular knowledge of analyst. Poor knowledge has huge effect on the low quality of analysis. Extreme outcome might occur beyond probability number and assignment. Better method should be proposed to capture this surprise.

f. Real option

Real option provides the flexibility to assess the uncertainty. It has the option to delay, abandon, or expand the project. Value of information and flexibility can be calculated. Meanwhile real option has pitfalls as probability modeling and expected value is the basis in executing this method. This approach is imperfect representation of uncertainty. Probabilistic and expected value might provide narrow analysis for decision maker. Probabilistic and expected value setting should not be used exclusively as criteria to choose scenario under uncertainty condition. There is a need to see beyond calculated expected value. Use of Bayesian should be prevented without meaningful parameter and defined population.

g. Adjusted economical measure assessment

The approach with economical measure seems to provide treatment for risk and uncertainty in profitability assessment of a scenario/project. Meanwhile, discount factor adjustment only provide uncertainty to systematic risk. Strong argument says that unsystematic risk will be treated by portfolio theory. Portfolio theory assessment is reflected through expected value calculation of NPV which is not appropriate to express risk involved. Another method to include scenario analysis in NPV result makes no sense since it is founded on probabilistic thinking. Probability is good tools but its use should not be seen narrowly.

h. Utility Theory

Preference and utility theory is difficult to implement for reflecting the attitude towards risk and uncertainty in the corporate scale (Virine and Rapley, 2003). Adoption of this type of quantitative preference and utility theory in the risk and uncertainty approach is not such simple thing to perform. The certainty equivalent value is not easy to determine. Consider following effort for determining utility of decision maker:

The exponential utility function can be written as follow:

$$U(x) = r\,(1 - e^{-x/r})$$

where x is outcome value n present value units of money, r is the risk tolerance coefficient in units of money

The expected value of U(x) is called EU

The inverse function for obtaining the certainty equivalent (CE) is:

$$CE = -r\,ln\,(1 - \frac{EU}{r})$$

The risk tolerance is obtained using the method of 50-50 lotteries as shown in Figure 2.3.

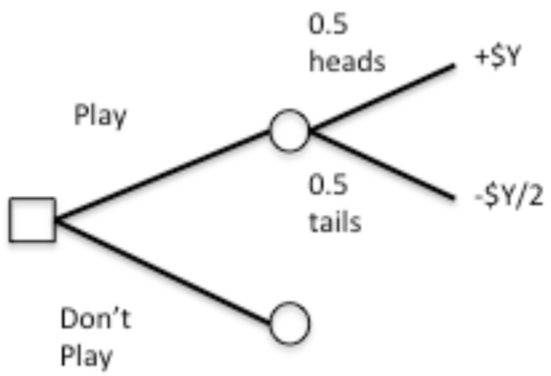

Figure 2.3 Risk tolerance assessment

Y is the highest payoff and –Y/2 is the worst payoff. Decision maker is asked what is value of Y whereas they are indifference between taking the offer or receiving 0 for certain. Value of Y is the risk tolerance. It is not an easy task to assign the utility values for outcomes. How about if the decision is decided by collective voting of a group decision maker? The reader can also refer to another detail example on determining utility function by Aven (2003).

The utility assignment for each outcome is not easy to assign. Furthermore, how to make sure that all decision maker will follow that utility function? The expected utility and rational theory is just the normative theory through the use of mathematical problem in order to reflect the decision maker's preference. Kahneman and Tversky (1979) presented several cases in which the decision maker might not follow the rationality principle for decision making under uncertainty. In the practical case, it is not easy to gain the utility function of decision maker. The expected utility analysis provides the transformation of variable into one utility variable. Meanwhile it is difficult to achieve, interpret, and communicate (Aven and Kørte, 2003). The rationality of expected utility theory applies for individual. In the project, there are several decision maker (group) which are reviewing the development options. It is difficult to express the utility function for a group of people. Each individual has different preferences. The utility function selection is arbitrary.

In view of above discussion, all these approaches of risk and uncertainty analysis in conceptual stage of petroleum project lack of fundamental basis. Risk and uncertainty is not incorporated representatively and it has element of arbitrariness. Summary of those lack rationale for current approach can be seen in Table 2.2.

Table 2.2 Summary of limitations in current approach of risk and uncertainty analysis

Argument	**Current approach on risk and uncertainty analysis**								
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**j**
Use of estimating range in isolation	■								
Use of subjective probabilty based approach as imperfect representation for risk and uncertainty		■		■		■			
Use of frequency interpreted probabilty based approach to introduction of large (infinite) fictious population		■		■		■			
Expected value based approach is not adequately capture risk and uncertainty			■			■			
Systematic risk is not considered					■				
Unsystematic risk is not considered							■		
Utilization of quantities that is difficult to measure				■					
Mathematical model is not adequate to reflect preference in decision making								■	
Sensitivity analysis is treated as an method to determine uncertain/critical parameter									■

Notes:

a. Estimate Class

b. Probability assignment and distribution

c. Expected value calculation

d. Bayesian mechanism

e. Portfolio theory

f. Real option

g. Adjusted economical measure

h. Utility theory

j. Pretreatment in risk and uncertainty analysis

Chapter 3. Proposed Risk and Uncertainty Analysis Approach in Petroleum Project Conceptual Stage

As mentioned previously, this thesis attempts to propose the different method from current practical approach and suggest modified framework of risk and uncertainty analysis to be applied in conceptual stage of petroleum project. In the Chapter 2, weaknesses and limitations of current approach have been documented and those findings are equipped with strong argument and rationale. This chapter will go further into detailed proposed method and framework. Fundamental and theory in uncertainty analysis are presented first to give the sound basis for proposed approach and framework.

3.1. Fundamental basis and representative approach in risk and uncertainty analysis

Uncertainty is the main component of risk and uncertainty analysis. It is linked to uncertain quantities, quantity that is not known in assessment/analysis but the value will be known in the future (Flage and Aven, 2009b). Uncertainty means there is lack of understanding or knowledge in the observable quantities. Observable quantity is the quantity that observable and measurable. This quantity can be measured exactly and has correct value (Aven et al., 2004). There will be some problem in accuracy and measurement for accurate value, but it is not the issue here, provided the quantity can be measured. For example, the production of oil/gas, operation time of platform, or NPV is the observable quantity. The risk and uncertainty analysis with focus on observable quantities is the objective of this thesis. Focusing on unobservable values and unreal quantities will create difficulties in assessing the uncertainty. The assessment is intended to predict the values of that quantities based on knowledge of analyst (expert knowledge is derived by analyst in assessment). By focusing on observable quantities, the quantity of the interest could be measured and predicted using risk and uncertainty analysis.

There are several representative methods and perspectives for risk and uncertainty treatment. The focus is on observable quantities, modeling, and propagation. The variable of interests are denoted by Z. The uncertainty of Z will be assessed by introducing the fixed value (d) and uncertainty description of input variable X which linked to Z by model G, Z = G (X,d). Using this model and link, the uncertainty description of Z is obtained. The result of uncertainty measure will be compared with decision criteria. Feedback process is highlighted if an input altering is required to meet the decision criteria. Sensitivity analysis is also carried out to see how the changes input will affect the output. Importance parameter ranking is assessed to provide summary of the essential factor in the uncertainty analysis. Decision criteria selection is applied along this framework for the choosing best decision. This framework is established by de Rocquigny et al. (2008). This framework can be used throughout various disciplines and provides a good methodology to assess the uncertainty related in the decision-making problem. The framework is able to carry out for probabilistic and non-probabilistic thinking.

The revision of the framework is proposed by Aven (2010c). The use of probabilistic method should be based on subjective probability since the relative frequency probability is a representation of variation in a population. It does not represent an uncertainty due to lack of knowledge. Aven (2010c) provided the proposed decision criteria and managerial review & judgment method to replace the mechanistic decision criteria evaluation and feedback process. This quantitative framework of risk and uncertainty assessment is exercised and resulted in distribution of key quantities variables and uncertainty on quantities of interest (expected Z or variance Z). Meanwhile a qualitative judgment and broad process beyond the quantitative analysis to review the quantities, limitations on the model, basis, and assumption behind the analysis, is required. The sensitivity analysis is vital to reflect on how the parameter changes based on the specific input value change. It is not risk and uncertainty analysis but it is part of this framework. Another framework for uncertainty treatment in risk analysis is also proposed by Aven (2003), see Figure 3.3. Similarly, Winkler (1996) presented the way to deal with uncertainty. It consists of:

1. Utilization of expert judgment for probability distribution
2. Apply the model and use sensitivity analysis
3. Combination of information and updating the information
4. Assessing the value of information

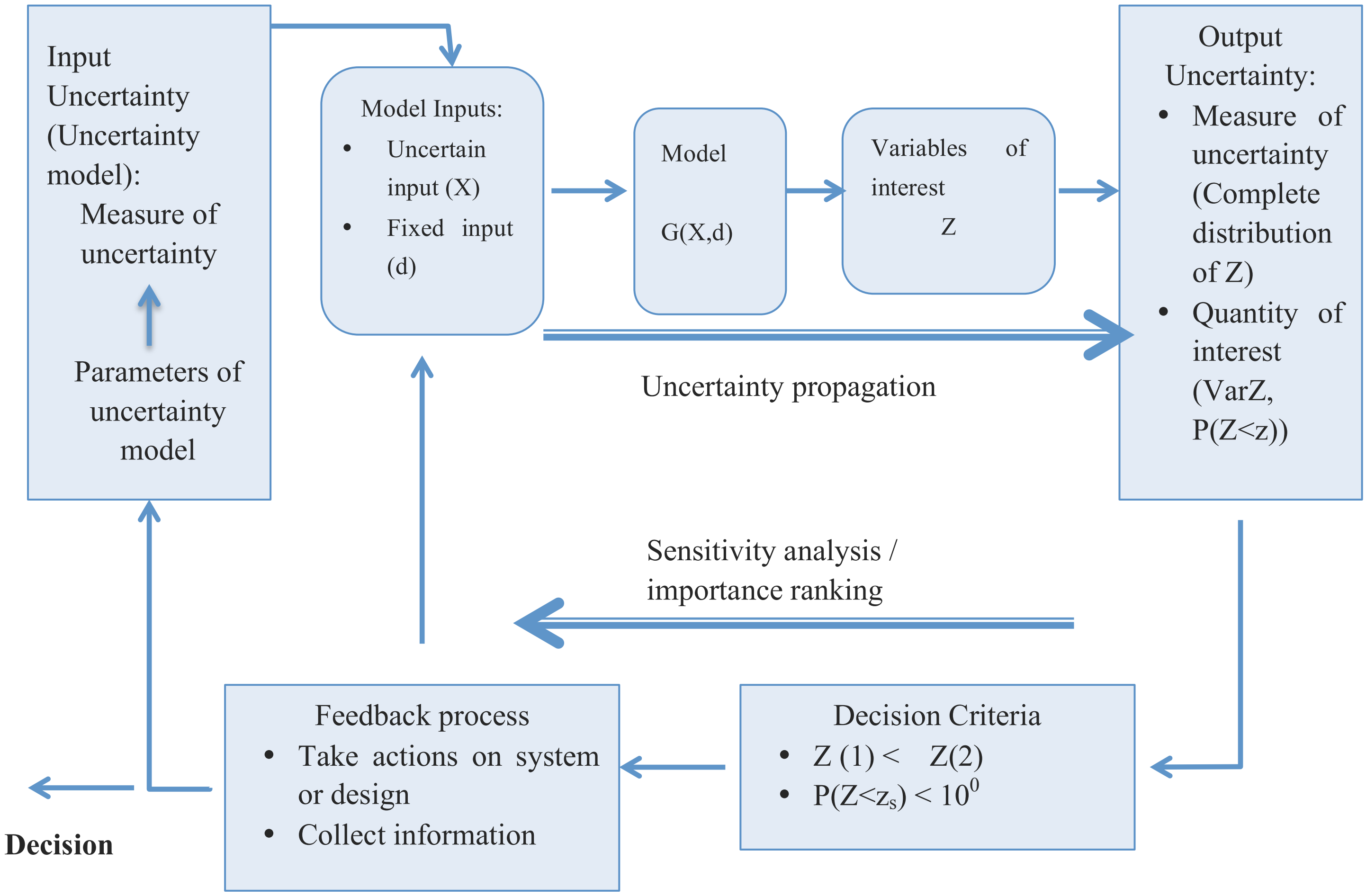

Figure 3.1 Uncertainty assessment framework based on de Rocquigny et al. (2008)

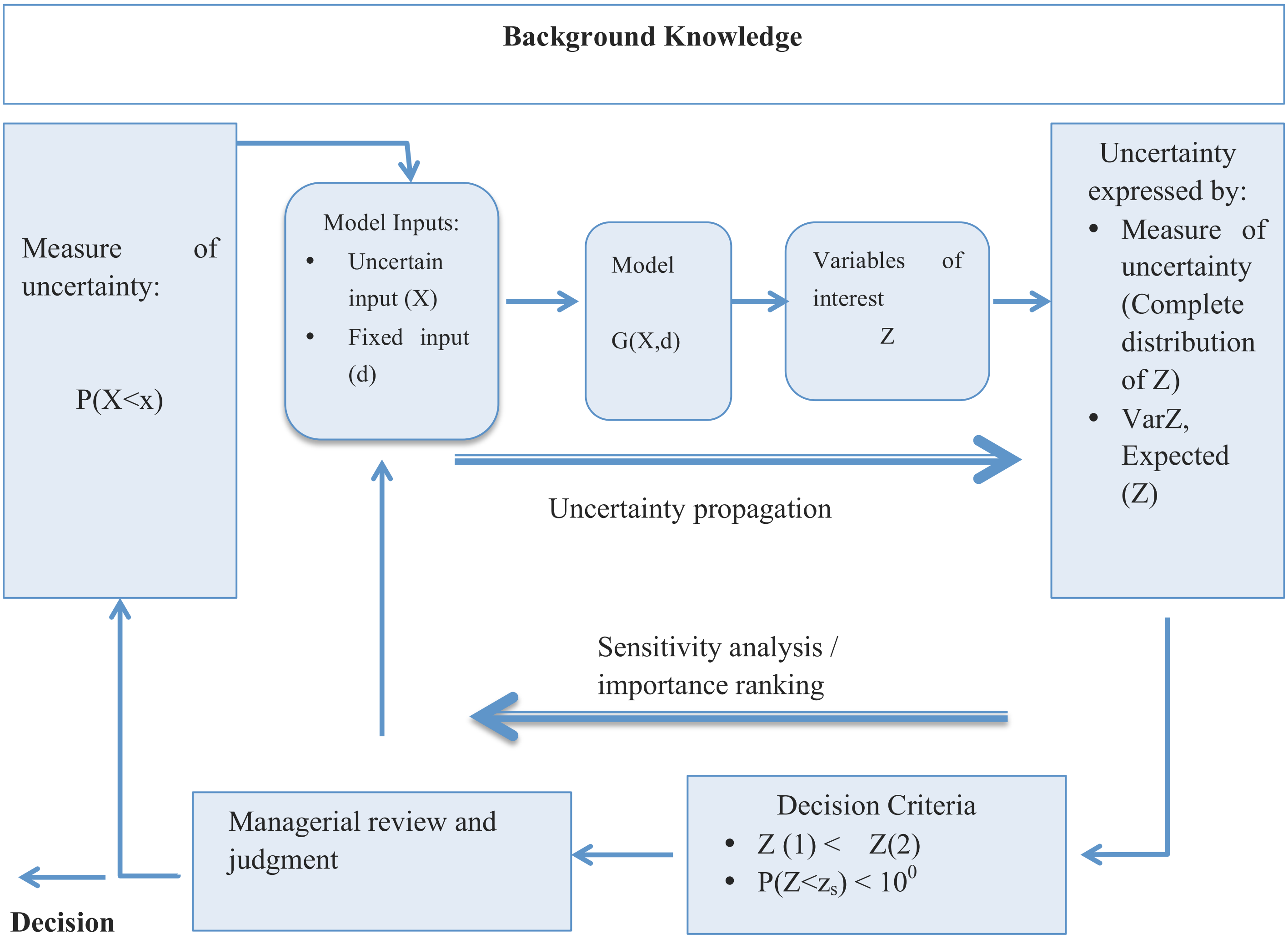

Figure 3.2 Uncertainty assessment framework modified by Aven (2010c)

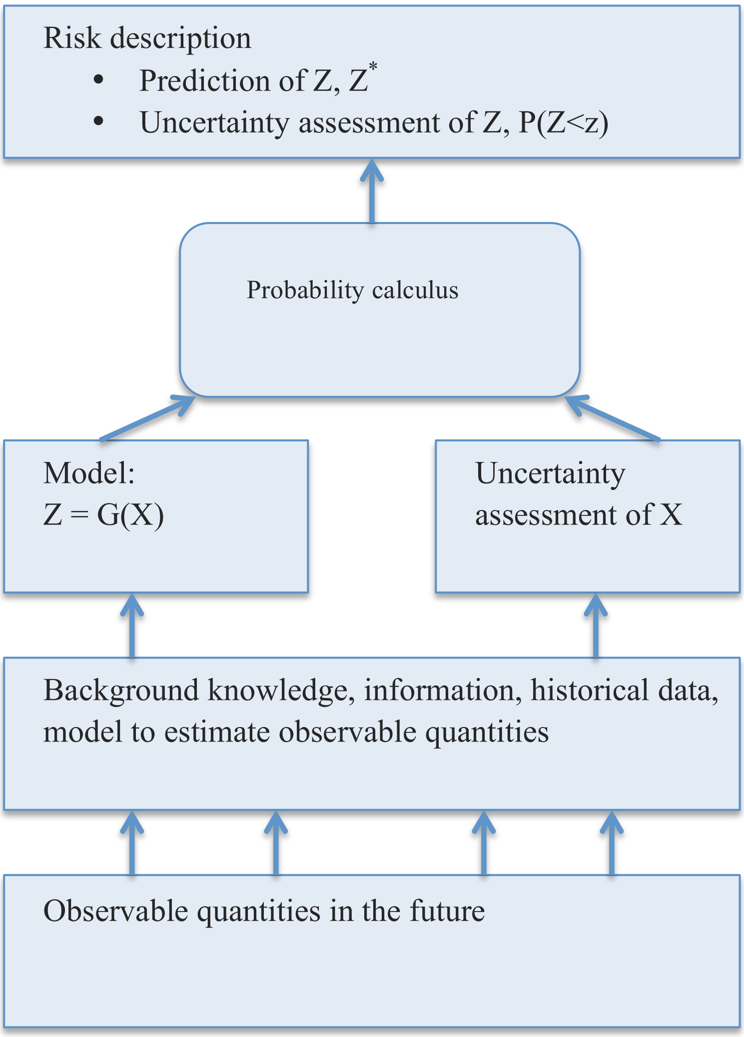

Figure 3.3 Risk assessment framework (Aven, 2003)

Following chapter 3.2 will present structured thinking for utilizing these approaches in project conceptual stage area. Argument will be provided on how these approaches considered more representative in capturing risk and uncertainties with regards to petroleum project implementation. In general, the approach adopted in this thesis will adopt Aven (2010c) with some modifications for practicality in assessing scenario in conceptual stage.

3.2. Implementation of representative approach risk and uncertainty analysis in petroleum project conceptual stage

In order for risk and uncertainty analysis to create well information to the decision maker, the basic principles of the modified approach should apply as:

a. Uncertainty is well defined and result of lack knowledge

b. Observable quantities are understood well
c. Model should link the uncertain quantities and variable of interest
d. Background information is clearly structured and documented with the assumption and supposition used.

Those principles should be highlighted to provide representative uncertainty analysis to the subject assessed. Review of all feasible scenarios needs to be performed carefully in order for proper quantification of risk and benefit of all option. Following argument will address above basic principles for the proposed approach to result in more representative risk and uncertainty assessment. Several important component on the proposed approach as follow:

a. Determination of uncertain parameter

   It is presented in Chapter 2 that sensitivity analysis is the method to determine critical and uncertain parameter. These parameters are the subject of risk and uncertainty analysis. As sensitivity analysis is not intended to determine uncertain parameter, current method should be rejected. Sensitivity analysis is part of risk and uncertainty analysis, but it should not be employed to address uncertainty in the project. As the purpose of risk and uncertainty analysis is to assess uncertainty in variables of interest (output parameter), input parameter should be concerned. There are fixed (d) and uncertain input (X) parameters. Uncertain input is parameter which the analyst and decision maker is not known the exact value. Prior analysis, it is not difficult to determine uncertain parameter. The parameter which is in range or fixed value is unknown can be categorized as uncertain parameter. Consider in the concept selection of petroleum project, uncertain parameter such as uncertain reserves, oil price, lifetime of new technology, reliability of new crude transfer pump, content of CO_2 in the fluid, or cost of OPEX can be settled without difficulties. The variables of interest (Z) as output parameter is also selected in this phase. In petroleum project, this variable can be in the form of project NPV, oil and gas reserve, or reliability of equipment.

b. Measure of uncertainty/uncertainty representation

   As the analysis role is to provide information for decision-making, the appropriate representation of uncertain parameter is required. Several number approaches have been proposed by researcher for interpretation of uncertainties. Many of them involved complicated mathematical modeling. There are several uncertainty representation/description used in the framework uncertainty assessment. In this thesis, probability distribution and assignment are adopted as representation for uncertain input parameter. It does not mean that probability is solely used as representation of uncertainty. Its use will be evaluated later.

   Subjective or knowledge based probability based on certain knowledge is used as representation for uncertainty. By adopting the frequency probability, a true value of probability will be known. It is estimated by an estimate value. Over infinite times repetitions, fraction of success (an event to occur) is generated. Historical data usually is utilized to provide such an estimate. Meanwhile, the infinite or large repetitions of similar cases cannot be always generated in real world. This is unclear situation and it is not quite common in the project case where there is no similar situation of the same project. In conceptual stage cases, each option/scenario is rather unique. If the population is available in the large number, then it is justified to use frequency probability. Using past data to estimate this probability should not be seen in isolation. Historical data alone cannot capture the uncertainty. The direct transformation of historical data to represent uncertainty should be avoided (Aven, 2008b). Variation showed is occurred due to randomness or variation in very large population with true value of the probability.

In the subjective probability point of view, the probability always depends on the knowledge of assessor. It is on how the assessor expresses the uncertainty. Subjective probability is often referred to standard. In this case, if the probability assignment equal to 10%, it is compared with the draws the 1 particular ball from an urn containing 10 balls (Lindley, 2006). Another definition is often linked subjective probability with the betting interpretation. It is related with the payment to the assessor if an event B occurred or no payment if it is not occurred. Meanwhile betting interpretations is related with the behavior of the assessor towards the money and it should be excluded here to provide the independence standard outside realm of value judgment, behavior towards price, preference, or desirability (Aven, 2011a). The interpretations of subjective probability should not be linked to the desirability of assessor for the money. Therefore this definition cannot be seen in relation with gambling. The decision problem is better to be decomposed and all available information should be used to identify the uncertainty based on subjective probability. Under the subjective probability concept, there is no what so called true probability. It is non-sense and meaningless to discuss true probability in the concept of probability which is assigned subjectively based on assessor knowledge. The state of knowledge is conditional based on the assessor judgment and it is believed to always changing (North, 2010).

There are several methods for assigning the probability assignment. Two common method are used, judgment from analyst using information and expert elicitation method.

- **Judgment using information**

In this case, the assessor needs to be experienced in transforming uncertainty into probability and can distinguish between the each probability number. The assessor could for example think the repetitive cases in which an event will occur (Aven, 2003). For probability distribution assignment, the assessor needs to specify the probability for an event is not exceeded or not lower than any value. The parameter of certain distribution class can be assigned and will result in specific probability distribution.

- **Expert Elicitation**

The subjective probability assignment could be derived from expert elicitation. Elicitation of expert judgment might be adequate for use of probabilistic approach in the context of decision-making. Expert elicitation problem is on how to transfer the opinion of expert into probability judgment based on knowledge (Hjorteland and Aven, 2005). This capturing process is challenging and in some way is exhausting. Meanwhile, expert elicitation is found very useful when no data is available. By comparing with standard (for example, an urn), the probability can be generated to represent the knowledge of the expert. Analyst is required to have the knowledge or training to capture the expert judgment and convert it to probability.

Cooke (1991) used classical method as elicitation method to represent the uncertainty of the expert. This method is pioneer and well known method to assign probability based on expert opinion. Calibration and information scores as the quantitative measures are utilized to:

1. Quantify expert judgment into probability assignment
2. Combine distribution of expert
3. Validate the combination of expert elicitation

The principles by Cooke (1991) for expert elicitation are:

1. Reproducibility. The calculation must be possible to reproduce
2. Accountability. All data, records, and assumption should be accountable and subject to peer review
3. Empirical Control. The assessment is subject to empirical control
4. Neutral. Method utilized for expert elicitation should allow the expert to express their true opinion (unbiased)
5. Fair. All opinion from expert is treated with fairness prior combining the result of observation.

The use of expert elicitation in risk and uncertainty analysis has been discussed in (Cooke, 2012). The paper present three generation of risk and uncertainty analysis which includes, first generation (the expert elicitation, the differences between variability and epistemic uncertainty, and use of Monte Carlo), second generation (subjective probability of expert, expert elicitation using equal weighting, process of deriving the expert judgment), third generation (expert performance evaluation and combination of expert judgment based on their performance, dependence elicitation, and probabilistic inversion). Uncertainty should be based on the observable quantities and performance of the assessor should be able to validated.

Hjorteland and Aven (2005) presented the use of direct probability assignment based on expert elicitation instead of traditional Bayesian analysis in order to express the uncertainty. It shows the use of expert elicitation in the stage of conceptual development where limited historical data available can be significant to predict the observable quantities of a system. In some cases, use of traditional Bayesian is quite complex and requires vast number of subjective probability distributions for each parameter. Expert judgment might be used in the case of strong background information and unavailability of historical data. The paper shows that the difference is not significant between direct probability assignment based on expert elicitation and Bayesian approach if background information is available. Later, expert elicitation and historical data can be combined with the weighing method. Hjorteland and Aven (2005) shows the Table 3.1 for weighting between expert judgment and historical data. By using this table, it is possible for analyst to combine those two kinds of information.

Table 3.1 Combination of expert judgment and historical data (Hjorteland and Aven, 2005)

E% - H%		Expert Judgments (E)		
		1	2	3
Quality of Historical Data	1	50%-50%	60%-40%	80%-20%
	2	40%-60%	50%-50%	60%-40%
	3	20%-80%	40%-60%	50%-50%

Note: 1 is the better and 3 is the worst

Expert elicitation method comparison was done by Hammitt and Zhang (2013). In their paper, five method of expert judgment elicitation was compared (copula, frequentist, best expert, performance, equal weight). In summary, expert elicitation is seen as the way to capture the expert subjective probabilities. This method can be seen useful for early phases of planning in the project development where the situation with lack of information exists. A workshop for collecting expert judgment and assessment could be conducted and use of expert elicitation might be explored and performed in order to gain more basis in assessing uncertainty in this planning phase.

In scenario development for oil and gas field, probability should be defined based on subjective or knowledge-based approach. The probability of reservoir size above some value, probability of reliability of new surface production technology below certain criteria, probability of production profile will not be lower than a value, probability of resources has potential commercial value, or probability of fluid will produce certain amount corrosion rate is the value to assign based on expert knowledge. Provided the method for elicitation above, subjective probability for each uncertain input parameter can be assigned. Workshop consist of expert from various discipline might be carried out to provide probability number or distribution. Training for transforming knowledge into probability might be conducted for all experts. If there is similar project in the company, information might be used, but care has to be shown in order to avoid use of historical data/similar information in isolation.

Another approach such as interval/imprecise probability can be used. It is seen as the combination of probability and interval analysis. Interval/imprecise probability is used to represent uncertainty by assigning interval rather than exact value probability (Coolen et al., 2010, Ferson and Ginzburg, 1996, Walley, 1991, Walley, 1997). There are several uncertainty representation that have similar interpretations with interval/imprecise probability, such as Dempster Shafer theory (theory of belief and evidence) and possibility measures, This report will not go further into detail of these uncertainty representations, but for detail and summary of those representations that exist, see (Aven, 2011c, Aven and Steen, 2010, Aven and Zio, 2011, Flage et al., 2009)

c. Uncertainty modeling, propagation, and sensitivity analysis

The history of risk and uncertainty analysis modeling is come from mathematical field study with focus on probabilities in around 17th centuries. The approach is to build the mathematical model to quantify uncertainty. Model in uncertainty analysis is used to describe the relation between input and output of observable quantities. The model complexity depends on several factor such as basis knowledge, system complexity, information available, and analyst itself (Nilsen and Aven, 2003). Model is divided between the physical model and logical model. Physical model is the model which relates physical of observable quantity with set of input. The model function is based on accepted theories from physic, chemistry, and empirical. Logical model relates the causal relationship of an event.

Uncertainty of observable quantities is expressed through uncertain input parameter which propagates into model to produce that observable quantities. There is no the true model since all model is “wrong”. Model is only used for connecting the cause and effect relation between quantities. In the classical approach, the terms of error between model and real world is taken into account. Meanwhile, it only creates difficulties in the practice and introducing hypothetical populations.

The propagation of uncertainty through model (G) and input (X,d) is commonly carried out through Monte Carlo simulation. The resulted propagation process is variables of interest (Z). Along with variables of interest (Z), the uncertainty factor importance ranking will be performed in order to highlight the uncertainty factors. Sensitivity analysis is part of uncertainty analysis but it is not uncertainty assessment as a whole. It is not linked with how uncertain parameter. Uncertainty and sensitivity analysis is the different analysis. In the existing applicable method of risk and uncertainty analysis in scenario selection, the role of risk and uncertainty analysis is often connected with sensitivity analysis. The analysis to predict uncertainty in input variables is not performed in the sensitivity analysis (Bedford and Cooke, 2001).

As discussed in the Chapter 2 that model in petroleum project can be in the form of technical model (reservoir size model using input of geology parameter, structural strength prediction using strength and load distribution, or process energy balance using thermodynamic properties) and commercial model (NPV model using cost and sales of product). Consider following example. Provided model that link recoverable volume with stock tank oil in place (STOIIP) and recovery factor (RF) should be provided, recoverable oil volume in a reserves can be calculated. STOIIP calculation requires input in gross reservoir volume (GRV), net/gross volume ratio, porosity, saturation, and formation volume factor for oil (FVF). Those two models are written as follow:

$$Recoverable\ volume\ oil = STOIIP\ x\ RF$$

$$STOIIP = GRV\ x\ \frac{net}{gross}\ volume\ ratio\ x\ porosity\ x\ saturation\ x\ FVF$$

Uncertainty of recoverable volume of oil can be assessed through uncertainty (represented by uncertainty description as outlined above) in all input parameter and propagation into the models using Monte Carlo simulation.

d. Qualitative assessment of assumption and uncertain parameter
After the uncertainty on quantity of interest is derived based on uncertainty propagation through uncertainty description and the model, the assumption and uncertain parameter are required to assess. The motivation is to provide representative basis due to limitation of assumption and probability as uncertainty measure. By only putting attention to the probability, the uncertainty is hidden and essential features of uncertainty cannot be replaced by probability since probability assignment is based on background knowledge and assumption. Poor knowledge will lead to poor assignment probability to reflect uncertainty. Uncertainties cannot just be translated into simple mathematical and probabilities. It cannot describe and express uncertainty involved in the risk and uncertainty analysis. It is argued that qualitative assessment can capture essential feature in uncertainty. Alessandri et al. (2004) agree that quantitative model is not sufficient to model the real world and then qualitative approach is suggested.

The uncertainty assessment will help to determine the categorization and strategy required for treating uncertainty satisfactory. It will assist decision maker to make a good decision by providing reliable uncertainty and assumption assessment. This uncertainty element needs to be highlighted to inform decision maker along with numerical numbers. Courtney et al. (1997) proposed the four levels of uncertainty which assist to categorize the uncertainty faced in the business. Meanwhile, this category can be applied in the other field in order to characterize and treat the uncertainty. This author argued that the level of uncertainty determines the tools for risk and uncertainty analysis. Those categories are tabulated in Table 3.2:

Table 3.2 Level of uncertainty (Courtney et al., 1997)

Level	Description	Detail	Strategy
1	Clear enough future	Single forecast is available since uncertainty is very low.	Market research, analysis of cost and capacity, value capacity
2	Alternative future	Few discrete scenarios for future determination are available.	Establish the valuation model and probabilities
3	A range of futures	Limited number of key features are available. No natural discrete scenarios. Range of outcome can be identified.	Development of possible outcome into alternative scenario, avoid developing redundant scenarios, develop scenario with range,
4	True Ambiguity	Combination of several dimension of uncertainty. Inability to predict the range of outcome.	Identification of possible and impossible outcome, identification from analogue case, identification pattern as the information developing.

Another approach is proposed by Flage and Aven through uncertainty characterization (Aven, 2008b, Flage and Aven, 2009a). Uncertainty is assessed using qualitative assessment to rank the important factor and its criticality. Although the proposed method is intended for QRA, it can be implemented to other practicalities in which uncertainties involved. Selvik et al. (2011) have presented the implementation of this method for assessing uncertainty in the RBI method. Risk and uncertainty analysis extends beyond the conventional RBI with the new proposed method called ERBI. Isolation of the analysis to the expected values will mislead the prioritization for uncertainty factor. Quantitative and detailed uncertainty analysis beyond the subjective based probabilities will not ensure that uncertainty will be treated well. Qualitative uncertainty analysis which can capture the essential aspect on uncertainty can be proposed as a good method for uncertainty assessment. As Aven said in (Aven, 2010a):

> *Trying to be precise and accurately expressing what is extremely uncertain does not make sense.*

The qualitative uncertainty analysis presented by Flage and Aven (Flage and Aven, 2009a) depends on the uncertainty and sensitivity level. If an element has significant uncertainty and high degree of sensitivity (it means that high degree variable input will produce variable output), then it will get the highest point and has the significant effect to the analysis. It will inform the decision maker and give more information regarding the uncertainty involved in the assessment. The proposed method has the categorization tabulated in Table 3.3.

Table 3.3 Qualitative uncertainty ranking (Flage and Aven, 2009a)

Description	Uncertainty	Sensitivity
Significant	a. Phenomena is not well understood b. Models cannot give the good prediction c. Strong assumption and supposition d. Unavailability data e. Lack of consensus among expert	f. Small input will result in variable output
Intermediate	• Phenomena is adequate understandable • Models is enough to give rough prediction (Simple model is used) • Several assumptions are not reasonable • There are debate among expert regarding phenomena • Few data available	• Changing input will give some significant effect on output
Minor	• Phenomena is well understood • Models can give the good prediction • Assumptions is reasonable • Consensus among expert • Data is available	• Changing input will not give too much effect on output

The common framework that exists is describing uncertainty as the probability dimension (see Figure 3.4). This framework is failed, as the probability itself is not adequate to express uncertainty. As probability assignment is based on knowledge of the assigner and two assigners can express the same probability with different knowledge. There is a need for basis to justify the knowledge strength. Surprise is also part of uncertainty element and this surprise has to be considered in the uncertainty analysis. Thus in more detail, uncertainty is described probability + knowledge dimension + surprise as shown in Figure 3.5 (Aven, 2013b). Therefore, there exist alternative uncertainty factor assessment for knowledge basis in which risk and uncertainty analysis is built on. Surprise factor will be outlined on next point.

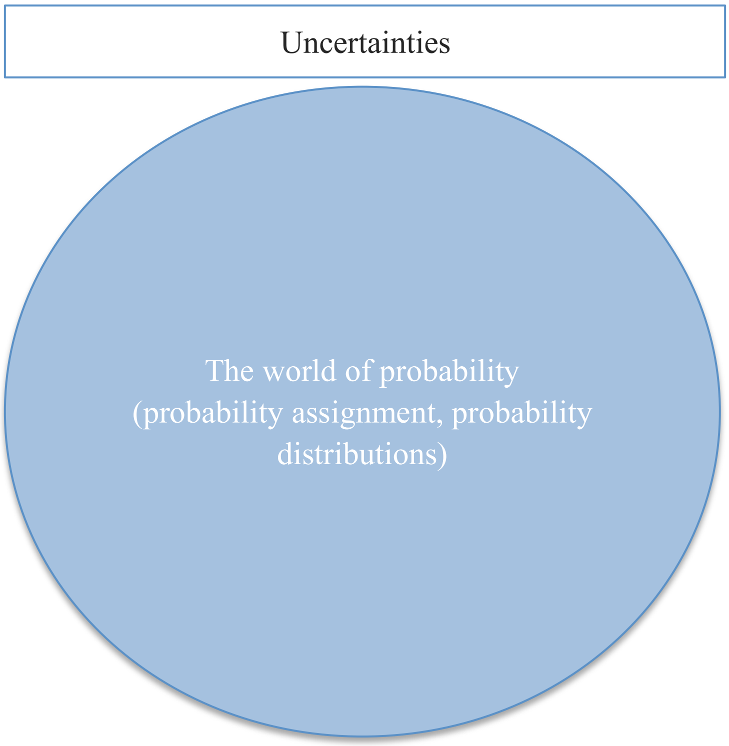

Figure 3.4 Uncertainty representations based on probability

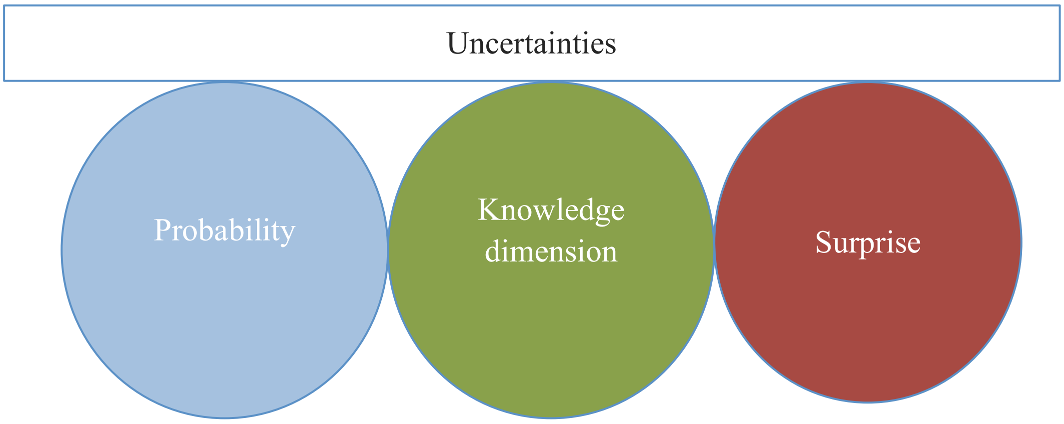

Figure 3.5 Uncertainty representations (adapted from Aven) (Aven, 2013b).

Aven (2013b) presented a method to assess the strength of knowledge by using new approach called the assumption deviation. Each uncertainty factor or assumption is outlined and the scale of deviation is assigned. For simple and rough characterization, Table 3.3 is used (without sensitivity category as deviation will replace sensitivity category role in this case) to categorize those uncertainty factors with knowledge strength. If the level is considered as "significant", it can be concluded that those factor have the weak knowledge and given high assumption deviation risk. Detailed assessment of knowledge can be carried out using following category. Each of deviation is analyzed and high risk is assigned if the assumption meets these three categories (Aven (2013b) mention it as Kaplan Garrick's risk triplet):

a. High magnitude of deviation
b. High probability to occur
c. High consequences affected by assumption

Then knowledge that founded on those three categories is assessed (strong, medium, or weak knowledge). The result is combined with the assumption deviation assessment based on those three categories. High risk with weak knowledge implies high assumption deviation risk. Combination of medium risk with weak knowledge can result as well in high assumption deviation risk. In summary, the uncertainty factors are reviewed based on uncertainty characterization and how it is affected by extent of deviation in assumption.

In this thesis, assumption deviation risk is considered representative to assess the assumption and uncertain parameter which base risk and uncertainty analysis. Those parameters are basically founded on knowledge and this knowledge should be assessed.

e. Surprise

Surprise factor has to be taken into account in the risk and uncertainty analysis as probability and other uncertainty measure has limitations in capturing this surprise. Surprise might be in the form of extreme positive and negative outcome. This surprise is termed as Black Swan. The term of Black Swan is coming from Taleb books (Taleb, 2010). It is defined as an extreme event that highly improbable to occur and outside of the present knowledge of the assessor and expert. Taleb (2010) wrote that people used to believe that all swans are white until the discovery of Australia which proves the existence of Black Swan. In the area of risk and uncertainty analysis, it is defined as an extreme event unlikely to occur or an extreme event happened beyond of current knowledge (Aven, 2013a). The latter terms depends on the background knowledge of the assessor and event to be analyzed. In some cases, an extreme event can be treated as the Black Swan in the eyes of particular person but in another cases it is not. This surprise factor needs to be taken into account by not isolating focus on expected values and probability.

Probabilistic thinking is not able to predict Black Swan. People often ignore Black Swan by using predictable occurrence and mathematical theory to predict probability of an event and do not take into account dependence between factor of occurrence for an event. Using the probability concept to take into account the Black Swan will create a loss of uncertainty. Uncertainty should not be simplified with probability. The surprise factors should be highlighted and create awareness to the analyst. The number showed in probabilities assignment cannot fully capture all the uncertainties since it is based on certain background knowledge (knowledge based probability). In the case of frequency interpreted probability, the situations characterized are unique and in most of the circumstances are not available for large population of similar cases.

Black Swan is occurred outside of realm of regular expectation and outside of the past record. Therefore, assessment based on historical data should consider the surprises. Risk and uncertainty cannot be interpreted based on historical numbers and classical statistics alone. It might suit with the analysis if the number of sample is large and relationship between the factors is known. In many cases, the near miss in accident is sign of an accident which later people refer as Black Swan. Although, it is resulted due to untreated near miss (Paté-Cornell, 2012).

To assess surprise event related to Black Swan, this procedure can be followed (Aven, 2013b):

a. List of event with low risk score on probability, consequence, and strength of knowledge
b. Review the assumptions, supposition, argument, and evidence

c. Review on historical records and expert judgment
d. Present and include the event in the category assessment

Kloeber (2010) suggested thinking outside realm, putting the alternatives into the model, taking into account the unlikely event (not merely ignore it), and brainstorming for large losses that decision maker can hold on can assist analyst during analysis to prepare for Black Swan event. Savage (2012) through his book "The Flaw of Averages" pointed out several times that Black Swan is outside of probabilistic and statistical reasoning but it should be considered. Innovative thinking and discussion on what and how an event will go wrong is required to list potential extreme event.

In our case, the surprise event/Black Swan list will accommodate consideration extreme event for informing decision maker in selection of conceptual stage project scenario. The extreme event, such as very high oil price or severe accident, that considered as Black Swan might be included and presented here.

f. Decision making & managerial review

This thesis emphasizes repeatedly the role of risk and uncertainty to provide information for decision maker. The results from the analysis need not to implement directly as the basis for decision. There is a review prior decision is made. It is essential that decision making process should not be represented by mathematical function as expected utility theory try to describe. Numbers cannot capture essential aspect in decision consideration. Decision-making is an activity beyond the mathematical function. Risk and uncertainty analysis should always be carried out in the case preference and utility function cannot be described. A person should be coherent in the preference of consequence but this is difficult in the real world. There are aspects beyond quantitative analysis that should be considered by decision maker such as the socio economic benefits, the flexibility, safety aspect, environmental concern, political aspect.

Quantifying uncertainty with complex mathematical can overlook the decision problem for decision maker. In many cases it does not provide insight of the decision problem or scenario studied. The motive and political preferences can be a driver for decision and it is beyond the rational behavior. Uncertainty analysis is performed to provide a broad and clear picture of the problem (in this case the option valuation for project) with the information for decision maker. In this stage, many aspects are considered and many stakeholders, with their own values, judgment, and preference, are involved. It is difficult to transform preference and all aspect considered into prescriptive decision theory. The limitations, benefit gained, assignment of probability, assumptions, and model involved in the risk and uncertainty analysis will be reviewed in the broader process than the mere calculation. Risk and uncertainty analysis should be as independent as scientific assessment in which the professional assessor can do assessment and not interfered with the preference.

There are several arguments to include management and qualitative judgment as part of decision-making. The flexibility in organization and reflective learning should be considered as the most important part to deal with the uncertainty (Perminova et al., 2008). Aven and Kørte (2003) highlighted that the risk and uncertainty analyst shall know the limitation of risk analysis in the context and framework of decision-making. Their approach is to emphasize the outcome, consequence, and uncertainty related in the analysis rather than utility function in the decision making process. It does not mean that the analysis result should be ignored, but the result from the analysis should be treated as information support rather than as the direct basis for making decision. Aven (2008a) acknowledged the need for managerial review and judgment as the qualitative process beyond the numbers in decision making process.

In the conceptual stage of project case, the aspect such as reputation (regards to risk for certain options or benefit gained by executing high value project) or politics (to gain respect from partner regarding certain option selected) can be faced. Consider a case where an oil company has expertise in onshore operation. The company would like to enter into offshore operation in order to build the reputation. This reputation is significant for company's long term planning in negotiation for offshore block building with government in certain country (in bidding process, reputation of company in operation of specific field is highly considered). Suppose that there are two operating asset that will be divested by another two different oil company. One asset is onshore operating and the other is in offshore. Risk and uncertainty analysis is conducted and the result shows onshore field is promising (in terms of NPV, reserves, and other consideration). As the company prefers to have experience in offshore field, the offshore asset might be selected by decision maker. This preference is difficult to describe by utility function.

From argument presented above, modified approach to capture risk and uncertainty in more representative way can be established with potential implementation in conceptual stage of project. In this phase, many types of uncertainty exist and these uncertainties have to be treated them appropriately. Proper treatment of uncertainty will result in the good information for decision maker to choose which option they should select for further stage (detail engineering). Simple example is outlined in each section to provide practicability in the subject this thesis studied. In summary, risk and uncertainty in the concept stage of petroleum project can be viewed as shown in Figure 3.6. Modified framework from the presented risk and uncertainty analysis approach can be established. The framework can be seen in Figure 3.7.

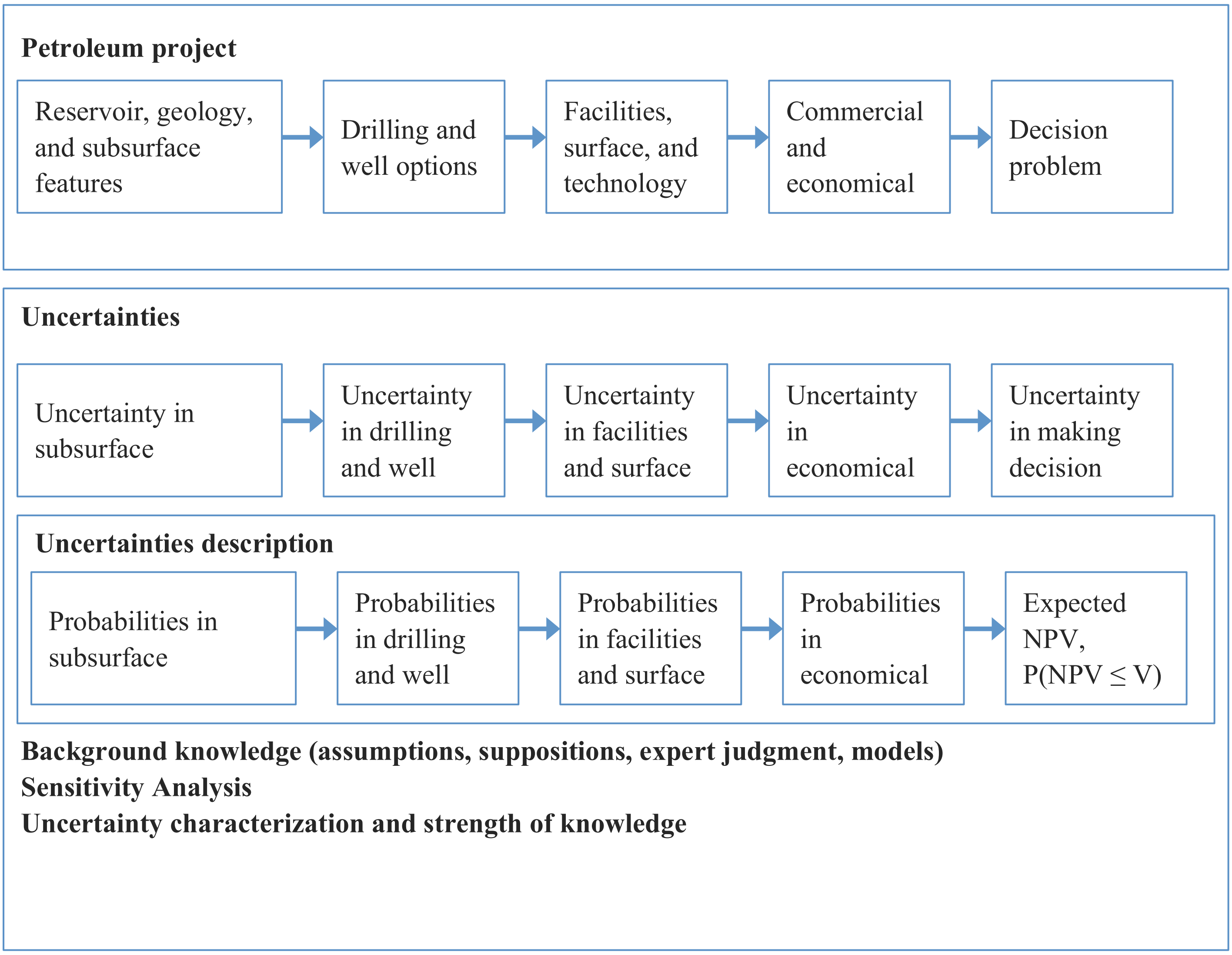

Figure 3.6 Risk and uncertainty in conceptual phase petroleum project

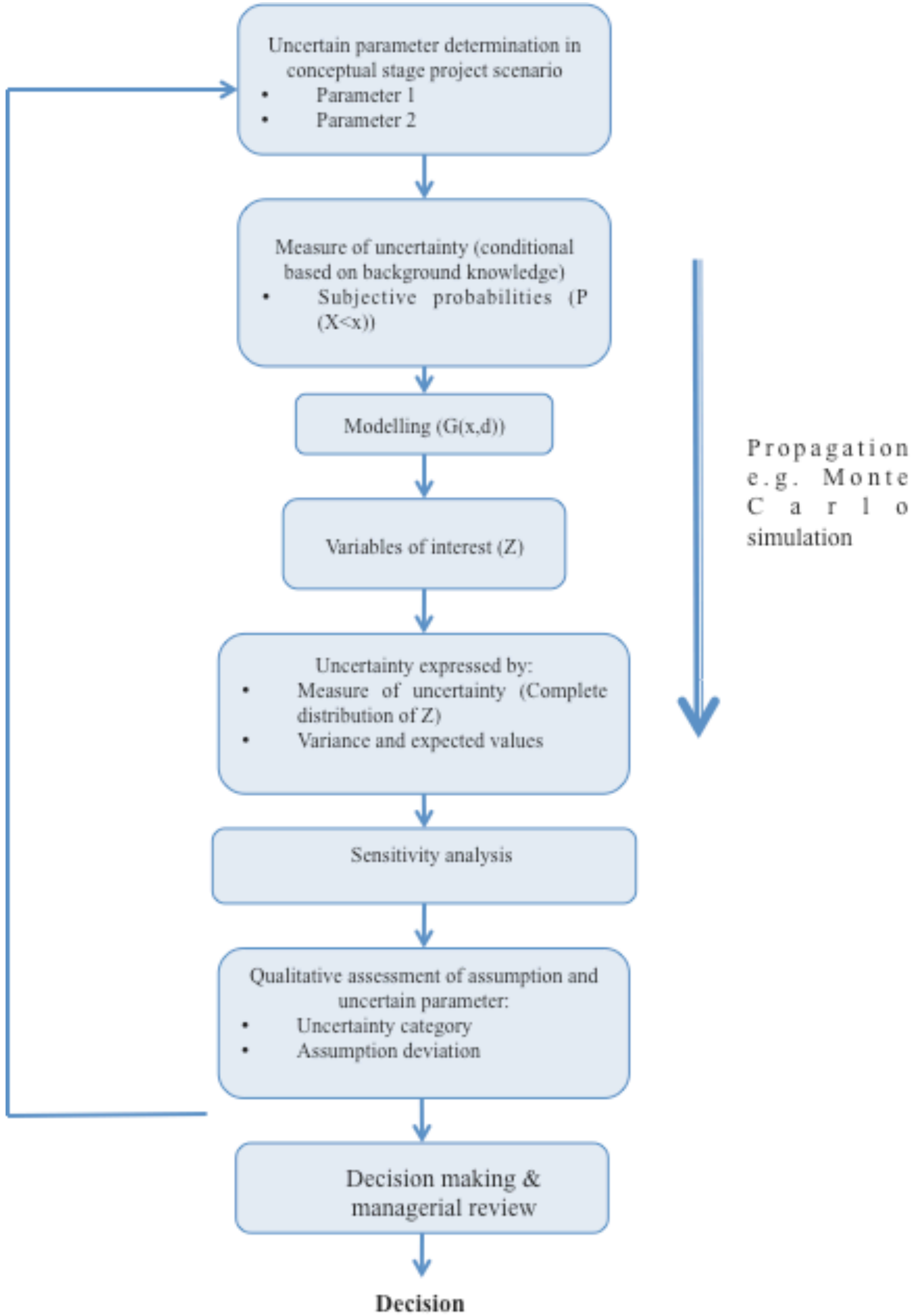

Figure 3.7 Proposed framework for uncertainty analysis in the conceptual project phases

Chapter 4. Study Case

In this chapter, a study case will be presented to illustrate the suitable use and applicability of approach and framework from Chapter 3. The intention is to present the appropriate risk and uncertainty analysis in assessing scenarios/options for petroleum project conceptual stage. The data is hypothetical but it is considered valid for presenting the implementation of framework. The study case is representative for showing how the framework works in the context of this thesis. The focus should not be put on the data of study case since the motivation is to put the attention and consideration on essential component of the presented framework.

4.1. Description of study case

A hypothetical oil company Indira Energy (IE) would like to reactivate one of its field (Alfa Field). Alfa adopt unmanned operation philosophy. This field has been shutdown for 3 years due to integrity and leakage problem on pipeline and topside facility. Based on reserves report, the field still has substantial oil and gas resources. The board director IE currently evaluated the result from feasibility study and is faced with several facility and operation mode options to select in conceptual stage. Risk and uncertainty analysis needs to be carried out to select the proper concept for Alfa field. Detailed descriptions are described on appendix C. The summary of those options can be seen in Table 4.1:

Table 4.1 Summary of Charlie reactivation scenario

Options	Facility Modification	Operation Mode	Pipeline System
Option 1	Reactivation of facility excluding separator	No prior fluid separation is performed for well fluid. Fluid is sent directly using multiphase mode to Charlie platform	Utilize existing oil pipeline system
Option 2	Reactivation of all facility	Prior fluid separation is performed for well fluid. Separated fluid is sent to separate existing oil and gas pipeline to Charlie platform	Utilize existing oil pipeline system. Existing gas pipeline will be replaced with the new one.
Option 3	Reactivation of all facility	Prior fluid separation is performed for well fluid. Separated fluid is sent to separate existing oil and gas pipeline to Delta patform	Laying new oil and gas pipeline.

4.2. Applicability of framework

Using available alternatives data and information, risk and uncertainty analysis is required to perform to give the decision maker the information of uncertainty in each scenario. Proposed framework from Chapter 3 is used and the applicability of proposed framework is as follow:

a. Uncertain parameter determination

   Input parameter with uncertain and fixed value (X and d) will be determined. The analyst consults with several experts from various related discipline to select these parameters. The variable of interest (Z) is also determined. In this case, oil price, gas reserves, oil reserves, facility cost, pipeline cost, and repair cost are judged to have uncertain value and those are the input parameter. Fixed input parameter in this assessment are tariff for oil and gas transportation, OPEX fixed cost, well work cost, discount rate, gas price and taxes. Tariff and well work are based on contract that company has with third party. Company already signs long-term gas price contract agreement with one of its customer. OPEX fixed cost and taxes are based on company standard. The variable of interest is project NPV since our objective is to investigate the uncertainty in NPV based on uncertainty in the input parameter.

b. Uncertainty representation

   As presented in Chapter 3, present work will use probability as uncertainty representation. The assignment for subjective probability and probability distribution is exercised during early stages of the project. Experts from related field and background are called. Workshop is carried out to perform expert elicitation method for each of uncertain parameter. As discussed previously, this thesis will put attention on observable quantities for uncertain parameter. It will perform much simpler assessment than if focus is put on unobservable quantities. In the expert elicitation workshop, the probability distribution for all uncertain parameter is specified. This method is very useful in case lack of data. Meanwhile, the information and historical data might be used to give the expert and analyst some information. It is not advised to base the judgment narrowly with the historical data without consider another information. In this study case, it is assumed that, some uncertain parameter (say) is defined based on the expert elicitation. The expert assigned particular distribution to the following parameter (detail value for each assignment can be seen in Appendix C):

Table 4.2 Probability distribution for each uncertain parameter

	Parameter	Distribution
General	Oil Price	Triangular
	Gas Reserves (BBTU)	Lognormal
	Oil Reserves (MBO)	Lognormal

	Parameter	Distribution
Option 1	Topside repair without separator	Triangular
	P/L Repair	Triangular
	Liquid P/L	Triangular
Option 2	Topside repair with separator	Triangular
	New Gas P/L	Triangular
	P/L repair	Triangular
Option 3	Topside repair with separator	Triangular
	New Gas P/L	Triangular
	New Liquid P/L	Triangular

The uncertain parameters under "General" label are applied for each option since all of those scenarios using the same value and distribution of those parameters. Expert assigned most likely value, minimum, and maximum value for triangular distribution during expert elicitation. For lognormal distribution, analyst interpret the mean and standard deviation from the expert.

c. Modeling, propagation, and sensitivity analysis

Model is developed to linked all the input (uncertain and fixed) parameter to produce required output. In this study case, the NPV model is used since our objective to assess the economically and uncertainty of each scenario. The NPV equation as follow:

Revenue = (production oil * oil price + production gas * gas price)

Expenditure = (CAPEX + OPEX fixed cost + OPEX variable cost + well work cost + tariff for oil transport + tariff for gas transport)

Cash flow = (revenue – expenditure) * (1 - tax rate)

$$NPV = \sum_{t=0}^{T} \frac{Cash\ flow_t}{(1 + discount\ rate)^t}$$

Propagation of uncertainty in input parameter into model is performed using Monte Carlo method. By using Monte Carlo with 1000 iterations, the simulation is provided for uncertainty analysis based on probability distribution specified on input through model equation. The result of Monte Carlo can be seen in Figure 4.1.

The result shows the probability of particular value of NPV for each option. Probability distribution of each option replaces the deterministic assessment and gives uncertainty picture for each scenario. Based on this result, the option 1, which proposes the existing operation mode and minimum modification, is considered as the most prospective scenario with the highest NPV distribution. It is followed by option 2 and option 3. If the mechanistic procedure is used, the option 1 will be selected for further detail engineering and project execution. Meanwhile, present work approach is based on the expert elicitation to assess the uncertainty involved in each option. The qualitative evaluation is essential to capture the factor behind the number and quantitative simulation.

Sensitivity analysis is conducted to investigate which parameter has the significant impact on NPV. In this study case, sensitivity analysis is carried out by assigning 5% and 95% percentile of value of parameter studied. Sensitivity analysis result for all option can be seen in Figure 4.2, Figure 4.3, and Figure 4.4. Based on result of this analysis, oil price and oil reserves are those two parameters which contribute to largest NPV movement. Since all options use the same basis for oil price, oil reserves, and gas reserves, decision maker have to be aware on influence of those parameters to NPV. Facility and pipeline modification have no significant effect to NPV value. But as stressed previously that sensitivity analysis is not used to address uncertainty, hence, uncertainty assessment of those parameters should be performed further.

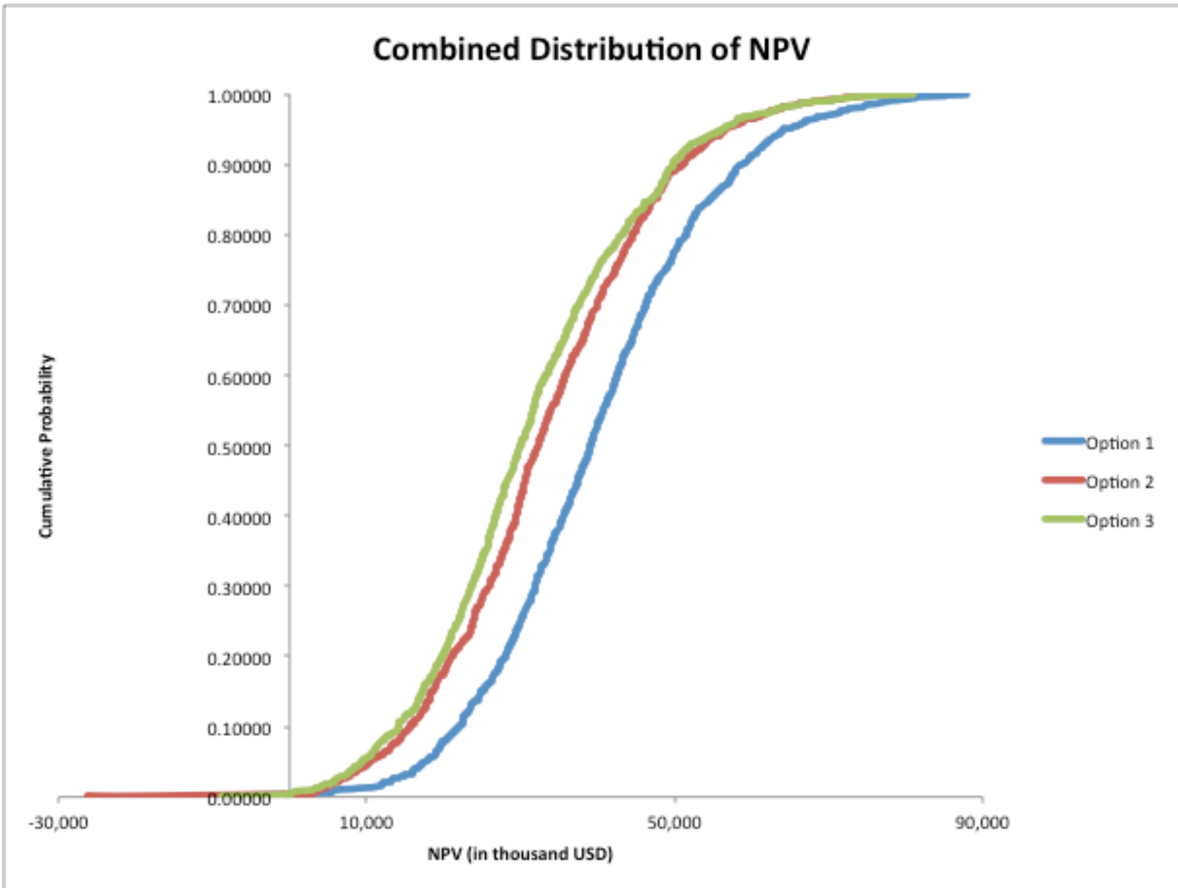

Figure 4.1 Monte Carlo results for NPV of all reactivation scenario

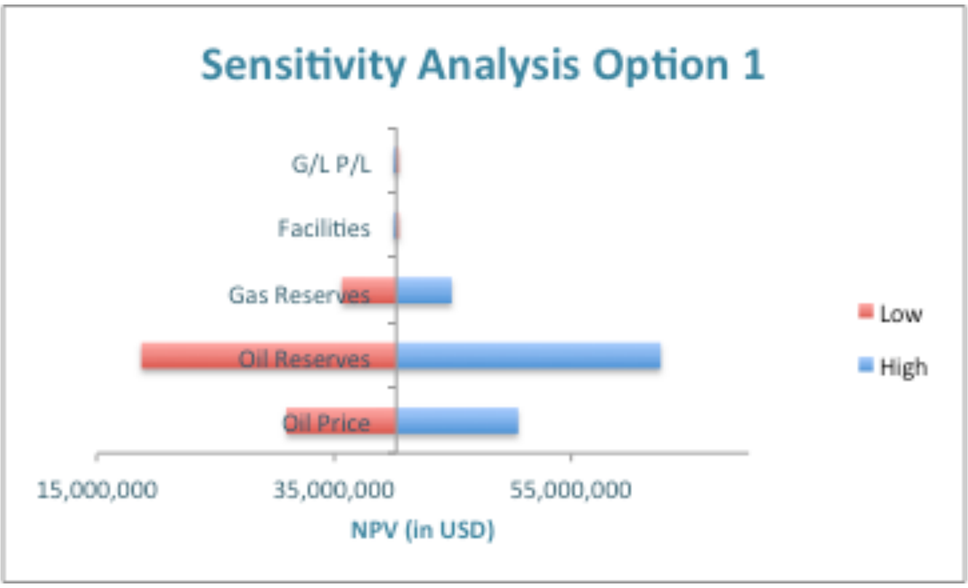

Figure 4.2 Sensitivity analysis result for option 1

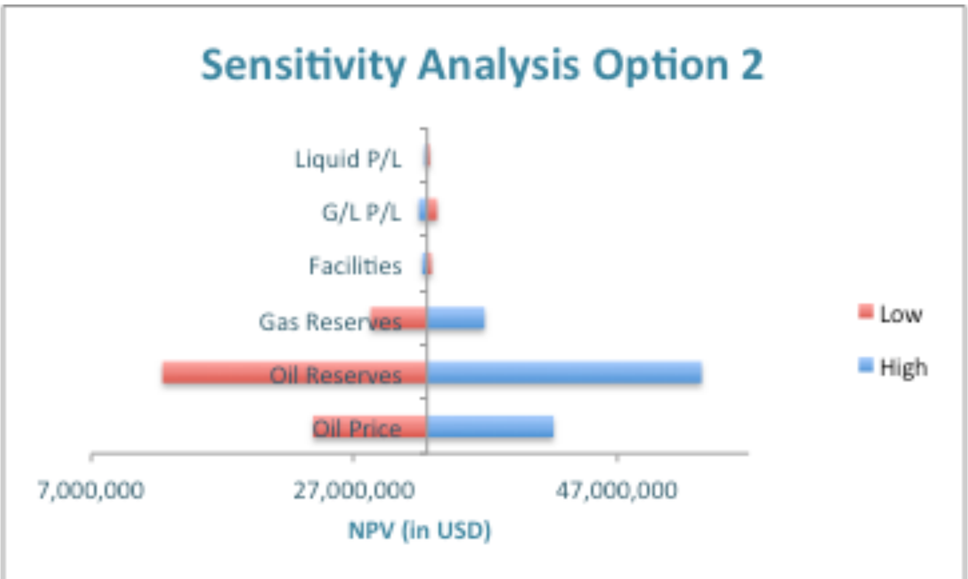

Figure 4.3 Sensitivity analysis result for option 2

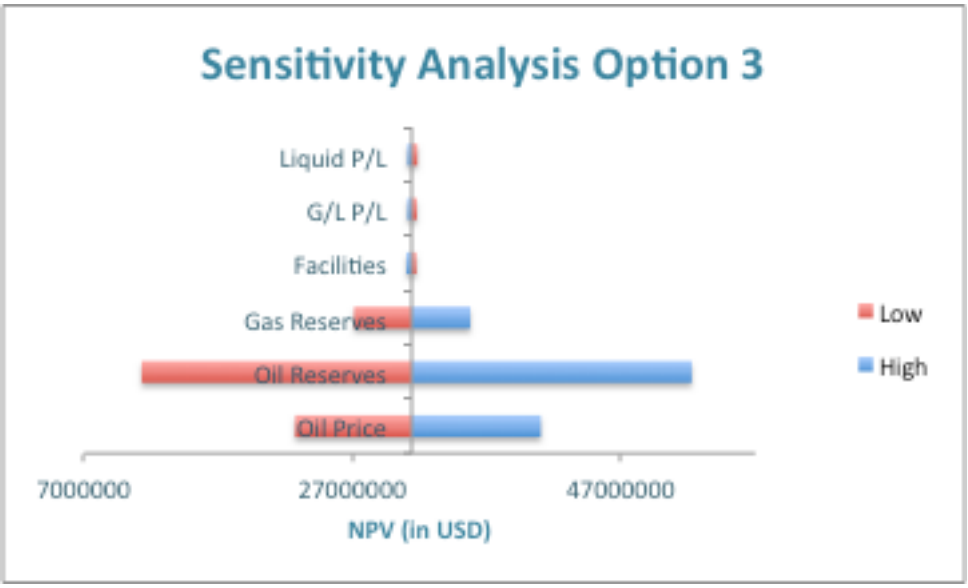

Figure 4.4 Sensitivity analysis result for option 3

d. Qualitative assessment of assumption and uncertain parameter
In this step, all main uncertainty and assumption basis are listed as the subject of knowledge strength assessment (as recommended by Aven (2013b) (see Chapter 3)). Using this method, qualitative uncertainty factor assessment is carried out first based on Table 3.3 (only "uncertainty" component column). This is the rough method on how the strength of knowledge is assessed. If the ranking resulted "significant" classification, the main assumption is based on weak strength of knowledge. The weak strength of knowledge refers to high assumption deviation risk. The detailed method can be performed by assigning deviation from the main assumption. The extent of deviation, probability to occur, and consequences (risk triplet) are the next factor which will be used to evaluate each main assumption using low, medium, or high category. The strength of knowledge which based on for those risk triplet are assessed. Combination of these evaluation (risk triplet and knowledge strength of risk triplet) forms the final assessment result. In this study case, all main assumption evaluation for these options are tabulated on Table 4.3

Table 4.3 Evaluation of strength knowledge on main assumption

Option	No.	Description	H	M	L
General	1	Oil price will follow the distributions assigned	X		
	2	Oil reserves will follow the distributions assigned		X	
	3	Gas reserves will follow the distributions assigned		X	
Option 1	1	Integrity of existing liquid pipeline	X		
	2	Historical integrity status of liquid pipeline	X		
	3	Flexibility for future development in Charlie		X	
	4	Corrossion rate on the existing liquid pipeline	X		
Option 2	1	Integrity of existing liquid pipeline	X		
	2	Historical integrity status of liquid pipeline	X		
	3	Flexibility for future development in Charlie		X	
	4	Corrossion rate on the existing liquid pipeline		X	
	5	Dependency of current option with liquid pipeline integrity	X		
Option 3	1	Flexibility for future development in Delta		X	
	2	Good integrity gas and liquid pipeline to Delta sattelite due to new condition			X
	3	Small effect to Delta Satellite			X
	4	Flexibility for future development in Charlie		X	

Notes:

High (H) refers to high assumption deviation risk (weak knowledge strength)

Medium (M) refers to medium assumption deviation risk (medium knowledge strength)

Low (L) refers to low assumption deviation risk (strong knowledge strength)

The sensitivity analysis result shows significant effect of oil price and oil reserves to the project NPV. One of main assumptions is oil price follow the probability distribution assigned. Knowledge strength behind these distributions is assigned. Rough evaluation using “sensitivity” category from Table 3.3 ranks significant category (weak knowledge strength or high assumption deviation risk) since the uncertainty in oil price during project development and field lifetime is considered high. The extent of oil price deviation, probability of deviation, and consequence of deviation to project NPV are assessed for detailed analysis. It gives high assumption deviation risk rank. Knowledge strength assessment behind risk triplet is carried out and resulted with weak knowledge strength rank. Combination of these assessments forms high assumption deviation risk (weak knowledge strength).

Assumption deviation risk assessment is also performed for oil and gas reserves. Rough method assessment (based on Table 3.3) gives intermediate category and hence, assumption deviation risk is considered to be medium. The reason behind this result is that the field already produced oil and gas prior its shutdown. Therefore, the reservoir model and phenomena are quite understandable. Reservoir expert also conducts history match to strengthen the model. For further detail assessment, deviation magnitude of reserves size (for example, 2,3, and 4 MBO for oil reserves and 2,5, 8 BBTU for gas reserves), probability, and consequence of reserves size to NPV are analyzed and results in medium score. Knowledge strength assessment for those risk triplets gives strong knowledge. Overall assumption deviation risk scores for oil and gas reserves is medium.

The evaluation of main assumption for option 1 and option 2 results high assumption deviation risk. For example is the main assumption of integrity of existing liquid pipeline. Since Alfa platform is already in idle condition for several years with no pigging and pipeline cleaning post last shutdown, the integrity of existing liquid pipeline is questioned. The rough evaluation gives significant ranking for this assumption. In the detailed method, the potential deviation can be seen from low thickness (low integrity) and high thickness (high integrity). High score is given to this deviation event consider the probability and consequence are large. High category is assigned for these risk triplet as the knowledge is weak. This combination results in high score for this assumption.

The same case applies for option 2's main assumption of dependency option 2 with existing liquid pipeline integrity. Option 2 planned to build the new gas pipeline from Alfa to Charlie as planned. Meanwhile the future operation mode depends on the integrity of existing liquid pipeline. If pipeline experiences leakage in short time after reactivation, the future operation mode cannot send gas and liquid separately. It should be back to multiphase mode, which means in this case it will have same operation mode with option 1. Meanwhile, the cash flow is lower since there is expenditure for laying new pipeline. Therefore this main assumption is evaluated. The deviation event is formulated as low dependence into high dependence of the option to existing liquid pipeline's integrity. High score is assigned to this deviation considering it has high probability and consequence. The weak strength of knowledge is given to this assumption which resulted in high score.

Based on this assumption deviation and strength of knowledge method, option 3 has medium to low assumption deviation risk. The option has flexibility in terms future operation mode and development in the vicinity of Charlie. Consider assumption of integrity for new pipeline is good. Deviation extent is set to quality of new pipeline from the pipeline contractor. Risk triplet is assessed and resulted in low rank since the pipeline contractor is selected based on rigorous tender process. High requirement is listed in the pre tender process hence only experienced offshore pipeline contractor can meet criteria. Quality of the pipeline resulted is checked with factory acceptance test by integrity engineer in the company as quality assurance. Strength knowledge for triplet risk is low. Therefore, total assessment achieve low category for this assumption. Decision maker is also informed that there are several new potential field developments on the Charlie area which means that by executing option 3, Alfa production does not need to be handled by Charlie.

e. Surprise

All the option considered has to be assessed for extreme event or Black Swan. This is the event that has low frequency to occur but extreme impact (whether it is positive or negative). Black Swan list is evaluated by listing events where surprise can be produced relative to the knowledge of expert and analyst in the reactivation conceptual stage of risk and uncertainty analysis. The list of Black Swan needs to be presented to give the decision maker the overview of all potential extreme event. It will help decision maker to prepare the strategy or action required to take in order to prevent or mitigate such event.

Table 4.4 Black Swan list for all option

Option	No.	Description
Option 1	1	Sudden severe rupture of existing liquid pipeline
	2	Earthquake in the vicinity of Alfa field
Option 2	1	Sudden severe rupture of existing liquid pipeline
	2	Earthquake in the vicinity of Alfa field
Option 3	1	Earthquake in the vicinity of Alfa field

Based on Table 4.4, it can be seen that all the extreme events might be occurred beyond the realm of expert and analyst for all proposed scenarios. Using this list, the presented quantitative and qualitative assessment will give a broad picture of uncertainty on all possible scenarios.

f. Decision making & managerial review

After uncertainty analysis, qualitative knowledge strength assessment, and Black Swan list are summarized, the results are subject for decision maker for their consideration. It is the rigorous process. The quantitative decision-making cannot capture all the essential aspect from decision maker point of view. It is the reason a mechanistic procedure for accepting or rejecting decision based on a number should not be adopted. Risk and uncertainty analysis result only acts as information for decision maker to make their judgment. There is value judgment aspect that plays in this stage. Since all aspect cannot be represented by number, the managerial review to capture the aspect beyond mathematical is still required. Furthermore, the utility function cannot capture the group of decision maker preference. Political, social, and ethical aspect cannot be substituted with number. The need of managerial review and judgment in the project stage is required as all aspect of value judgment is not a narrow mathematical process. It is a qualitative way to give the corporate the best decision in terms of lifecycle.

Based on result presented above, decision maker might choose to execute option 3, which gives the lowest NPV compare to option 1 and option 2.

Option 3 has the flexibility in terms of operation mode and few assumptions with strong knowledge strength. It is shown that these are the significant information which cannot be treated by numbers.

Chapter 5. Recommendation for Further Work

This thesis proposes risk and uncertainty analysis approaches based on fundamental theory in risk and uncertainty discipline. It also attempts to implement the approach in the context of petroleum project conceptual stage. Due to time and resource constraint, it is not possible to examine the approach and framework proposed with real environment of project. The applicability of this approach and framework needs to examine with the real case of project. Collaboration with the company might be established to illustrate how this approach and framework will work in the real world. The intention is to obtain feedback and continuous improvement to identify which part the framework can be upgraded. Implementation with real case will also provide input for practicability of this approach. Comparison methodology between the variables of interest assessed using the approach and real value (the value that is known later) should be established. This effort will ensure constant upgrade of conceptual basis for proposed approach as well as improve structure to be more robust.

The research in conceptual basis of risk and uncertainty analysis has been growing recently. There is a need to search for a better analysis which can give more complete representative views for risk and uncertainty. This scientific platform of risk and uncertainty analysis is interesting research area. Another uncertainty measure (such as interval/imprecise probability, possibility approach, or belief-evidence function) can be explored to replace probability in the proposed framework. Several increased discussion on fundamental basis in this approach (with application in petroleum project) are expected to occur in the near future. Work on knowledge strength assessment will also keep growing. Issues which linked to an extreme event, Black Swan, has taken enthusiasm and strong interest in the risk and uncertainty discipline, especially in the context of identifying this event. Hence, it is essential to follow on the study progress on those areas and followed by the practicality to be implemented in risk and uncertainty analysis of petroleum project conceptual stage.

Chapter 6. Conclusion

This thesis is aimed to review the fundamental basis for current approach in petroleum project risk and uncertainty analysis. The emphasize is given to conceptual stage where various alternatives and scenario is proposed for new field development, expansion of existing facility, or reactivation of inactive platform. Conceptual stage has substantial effect in overall project phase, therefore an appropriate risk and uncertainty analysis is essential.

Current practical risk and uncertainty approach needs to have stronger foundation and conceptual basis in order to capture all representative uncertainty for decision making information. Therefore, evaluation of uncertainty factor and assumption basis beyond probability and mathematical number is needed. Mathematical formula to model preferences is not adequate to reflect decision maker value. Broader process beyond the numbers is required.

Approach presented in this thesis is based on more representative risk and uncertainty analysis. Study case in the area of petroleum project conceptual stage is highlighted to outline the proposed approach. Identification of interested uncertain parameter in petroleum project, such as reservoir size, oil price, or facility, is not performed using sensitivity analysis. The intention of this analysis is not to address the uncertainty. Simple assessment can be conducted prior the analysis to determine uncertain parameter. Probability assignment and distribution is utilized as uncertainty measure. Lognormal and triangular distributions are assigned for uncertainty measure in oil price, oil and gas reserves, and facility cost. Model, such as project NPV calculation as presented in this thesis, is given to link uncertain input parameter with output parameter (NPV for each option). Propagation process using Monte Carlo simulation and sensitivity analysis are performed. Knowledge strength evaluations are carried out for all uncertain input parameter (oil price, oil reserves, and gas reserves). Extreme event (Black Swan) is identified. These assessment and list, along with Monte Carlo simulation result, are given to decision maker as information.

From study case example in Chapter 4, mechanistic procedure for selecting profitable project (project with highest NPV) should not be used as the selection basis. The qualitative assessment of knowledge strength and extreme event list will give broader picture for decision maker. Proper weight should be highlighted to assumption with weak knowledge. Surprises do occur and it also should be acknowledged through creative thinking on what will go wrong. Focus on these factors will ensure an open traced decision process and allow continuous feedback process to evaluate decision that has been performed. In summary, the proposed approach in present work offers method in capturing more complete information to decision maker to assess which suitable scenarios might be selected for the next stage of petroleum project.

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Appendix A. Conceptual Stage of Project

Petroleum project is divided into several stage from the conception of the idea into the implementation, operation, and decommissioning of the platform. In this thesis our attention is put on the upstream of the petroleum project which has the scope from the wellstream into the crude or gas customer. The petroleum project stage consists of series of successful stages from exploration, project development, operation, and decommissioning. Set of activities needs to be accomplished prior execution of the project. There are several milestones in between the stages. The successive stages of exploration and production phase can be seen in Figure A.1 (Gudmestad et al., 2010). Another similar petroleum project phase can be found at (Lund et al., 1999, Salazar-Aramayo et al., 2012, Weijermars, 2009).

This thesis will emphasize appraisal and development planning activity in the project development phase. This group of series planning stages is also called conceptual stage of the project (see Figure A.1). The conceptual stage of project comprise of feasibility, concept, and pre engineering (in some practice, it is called Front End Engineering Design) stage. This is the stage where scenarios are identified. In project for expansion existing field, exploration stage might not be followed. All the proposed concept is evaluated based on certain requirement on each sub phase before it is proceed to the next stage. In the project development stages, several decisive sets in each sub phase are available. These sets are called Decision Gates (DG). The decision should be made in each of stages by approving DG before continuing to the next sub phase. Particular emphasize will be put on feasibility study and concept selection where risk and uncertainty analysis plays important rule to select appropriate scenario.

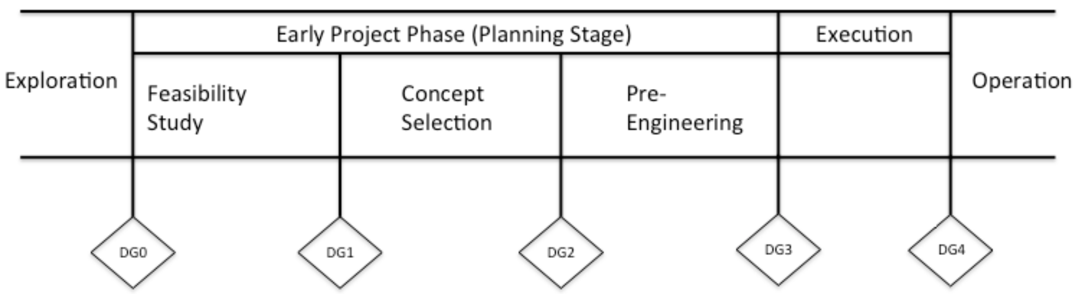

Figure A.1 Project Phases (Gudmestad et al., 2010)

The explanation for each stage in the conceptual phase are as follow:

- Feasibility study stage
  The feasibility stage is started based on exploration study result or modification proposal of the platform, for example, expanding existing platform. In this stage, corporate should undergo the review of the scenario or alternatives and screened whether those ideas are feasible (commercially and

technically) to undertake or not. Company values, objectives, and goals are taking the major part in considering all scenarios. It is important to meet the standard or regulation by authority since this phase is initiated. The source of uncertainty has to be defined in this stage. Decision should be met whether all alternatives is adequate for further development in the next stage, require changes prior of continuing to next stage, or should be terminated.

- Concept selection
  All scenario and alternatives that has been screened in feasibility study should be documented in order for further review in concept phase. In this stage, all the alternatives proposed are reviewed to select the best scenario which can maximize life cycle of the field and comply with the goals, objectives, and planning of the corporate. The profitability of selected alternatives will be exercised. Risk and uncertainty analysis is required to reduce the uncertainty based on the information received in this stage. The role of risk and uncertainty analysis is essential since the chosen concept has large influence and impact in the more detail engineering stage. Our scope of thesis will put attention on this stage where the company/decision maker should select appropriate concept based on limited information from feasibility study and exploration phase result. The explanation as the basis for selecting or rejecting all the scenarios has to be prepared. All the scenario considered shall be reviewed until the execution, installation, commissioning, and operation. It will provide good basis especially in the constructability and operation-ability of all related scenario. This consideration along with other technical viability might contribute to significant consideration between one concept with another. Statement of requirement from previous feasibility study is important to be included in conceptual selection as it provides the design basis for petroleum project. Based on Rapp (2007), the concept selection phase consist of several sub-stages: obtain and collect the required information, form the team, scenario development, scenario selection, and selected scenario to develop.

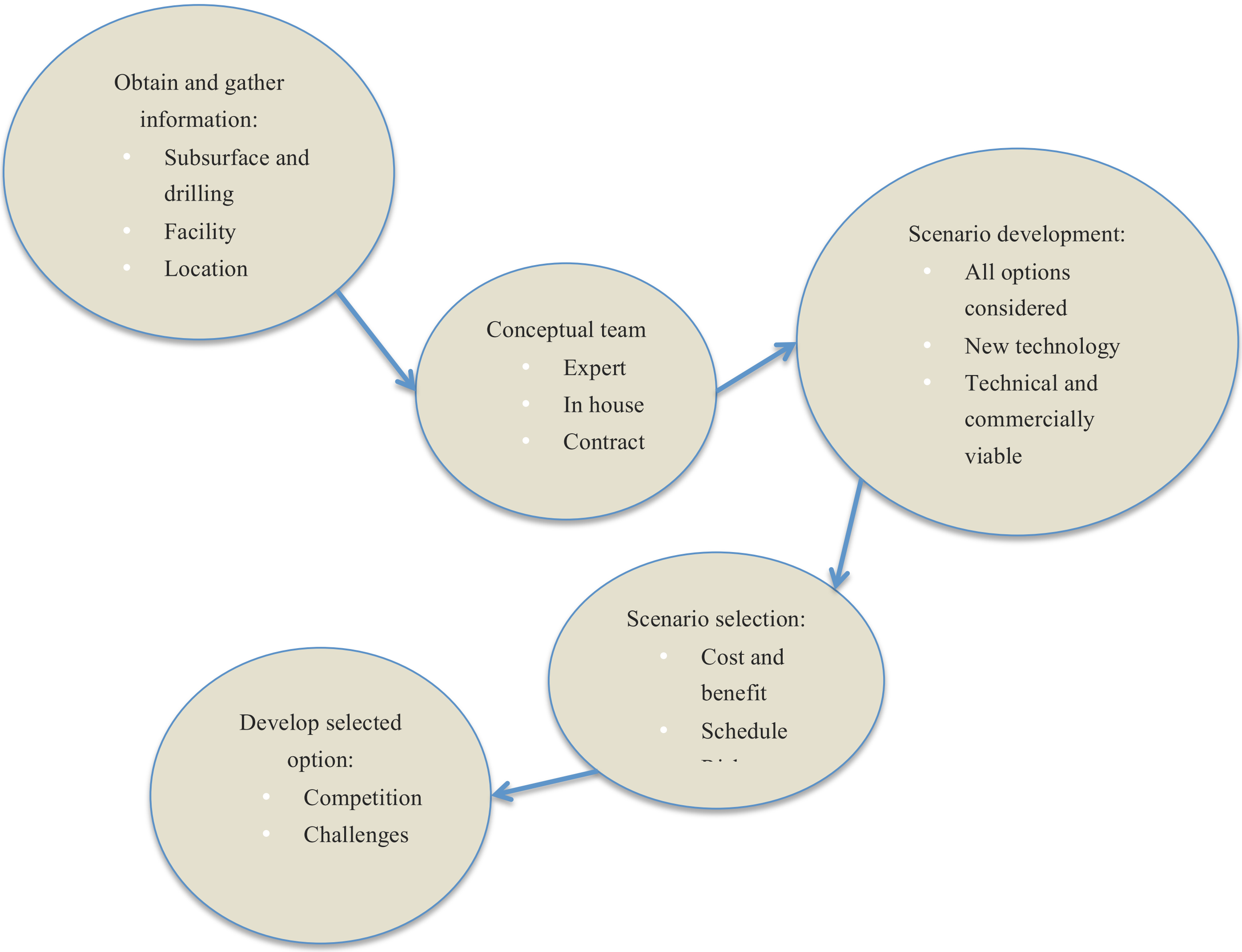

Figure A.2 Concept selection stages (Rapp, 2007)

- Pre-Engineering
  After all scenarios are identified and the selection is performed, the selected scenario is proposed to continue to next phase to start the more detail engineering work. In some cases it is termed as Front End Engineering Design (FEED). More engineering works will be carried out prior the execution of the project. In the FEED phase, the selected concept will be refined further in terms of technical and engineering, execution, and cost estimates. FEED will provide the document as the basis for project sanction and execution. All activities related to the project management and strategy are updated in this phase.

Appendix B. Monte Carlo and Probability Distribution

B 1. Monte Carlo Simulation

Monte Carlo simulation is the method for uncertainty propagation by generating random number based on probability distribution specified from input through the use of model. This method is believed can represent the real world (Aven, 2008a). Random number serves as sampling for the probability distribution. This simulation generates the model of a system using computer to investigate the real performance. Through performing simulation over number of times, the probability distribution for investigated system can be calculated. Monte Carlo keeps calculating results using different random number for probability functions.

The result will show the distribution of output based on simulation. Probability of system performance exceed a specified value can be derived from Monte Carlo simulation result. Monte Carlo is used as the quantitative and analytic tools for various field of study. By using Monte Carlo, all the extreme outcome and conservative consequence can be depicted from the analysis. Monte Carlo simulation can give good representation to model the system approach the real condition. Considerable amount of input should be specified using probability distribution to generate the informative result. This technique requires large amount of computation data/space.

Implementation of Monte Carlo in the petroleum area is come from the work of an Economist named Allais regarding complex probability analysis and the risk analysis of exploration of petroleum in Sahara (Virine and Rapley, 2003). The proper and good distribution must be fitted to the each parameter. Monte Carlo is preferable in the case of high uncertainty and probability distributions outcome is preferred and it provides the better view of uncertainty assessment due to detail of distributions used (Gatta, 1999). Virine and Rapley (2003) argue that Monte Carlo is best to illustrate the meaning of uncertainty by assigning possible distribution into input parameter.

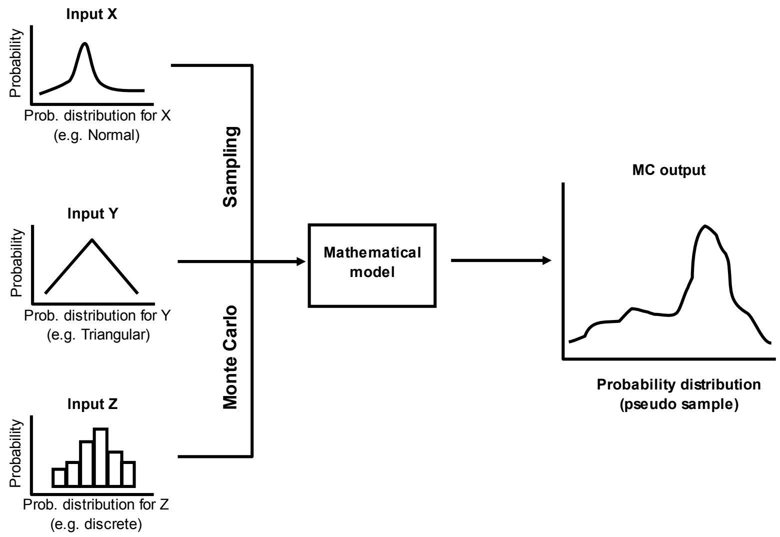

Figure B.1 Applications of Monte Carlo simulation (Virine and Rapley, 2003)

B 2. Probability distribution

Various probability distributions used in representing uncertainty such as:

- Normal. The normal distribution is properties of a population. It is also called with "bell curve". Specified value for normal distribution is its mean and standard deviation. Normal distribution is the symmetric distribution.
- Triangular. Triangular distribution is used when the information known is the minimum, most likely, and maximum specified value. The probability distribution can then be generated based on probability of most likely values. The minimum and maximum value have zero probability number. Triangular distribution is often useful and appropriate.
- Uniform distribution. This probability distribution type is used when the range of known possible values has the same probability. The uniform distribution is also used when there is no information specific for probability on specified value. The maximum and minimum value is specified with same probability and value in between has equal probability.
- Exponential. Exponential distribution is used for determine time between the event. It is used mainly to investigate lifetime of an equipment which following the exponential distribution.
- Lognormal. This distribution has positive skewed. Lognormal distribution has non negative lower boundary and unlimited higher boundary. Random variable is logarithmic distributed. Lognormal distribution is often used for economic, reservoir size, drilling time modeling.

Appendix C. Study Case Description and Result

C 1. Description and Data

A hypothetical oil company Indira Energy (IE) would like to reactivate an oil and gas field (Alfa field) that has been shutdown for 3 years due to leakage and several integrity problems. The board director IE has formed the team to conduct feasibility, concept selection, and FEED for investigating whether the reactivation of field Alfa is technical and commercially viable. Alfa reservoir still has considerable reserves. Alfa adopts unmanned operation philosophy. Alfa initially was operated with oil and gas delivery pipeline to Charlie Central Processing Platform (CPP) located 16 km from Alfa. Meanwhile since 5 years ago, Alfa gas pipeline was having severe leak. Therefore, Alfa operation mode was changed to send all its fluid (without separation) to the Charlie central processing platform through oil pipeline. It created additional backpressure on Charlie. Feasibility study has resulted in three options that are technically feasible for Alfa reactivation project. All those three scenarios/options are as follow:

Option 1

This option is the existing operation mode prior Alfa shutdown. Fluid from Alfa well will be sent without prior separation using existing pipeline. Gas lift is taken from insitu Alfa well. Engineering team is not certain with current condition of oil pipeline. There was no inspection neither pigging since the last shutdown. If the integrity was bad, project team should build new pipeline. But if pipeline has good condition, the company can use it until the end of field life. Reactivation on Alta topside facility is required since most of equipment is not maintained during shutdown and has corrosion, leak, rupture, and integrity problem. Meanwhile, reactivation is planned for piping system and wellhead excluding separator since there is no required separation process. This option is the simplest one since it uses all existing operation scheme as Alfa was operating.

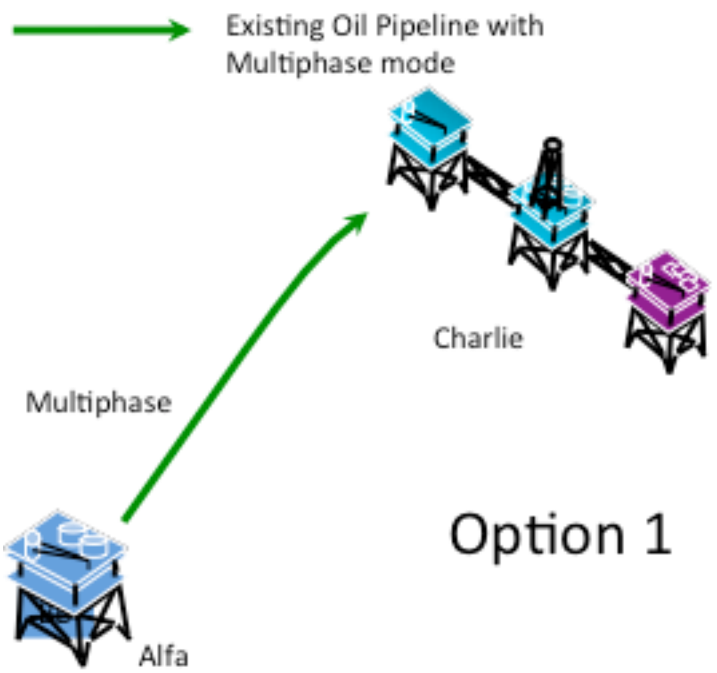

Figure C.1 Option 1 Alfa reactivation project

Option 2

This option is implemented by laying new gas pipeline to replace old gas pipeline. The fluid from wellhead will be separated first. Then liquid and gas will be sent through existing oil pipeline and new gas pipeline. As option 1, the integrity of existing liquid pipeline is unknown. Historical record shows the pipeline doesn't have any leakage but it has been operated for 10 years. Insitu gas lift will be utilized. Reactivation on Alta topside facility, piping system, and separator are required since most of equipment is not maintained during shutdown and has corrosion, leak, rupture, and integrity problem.

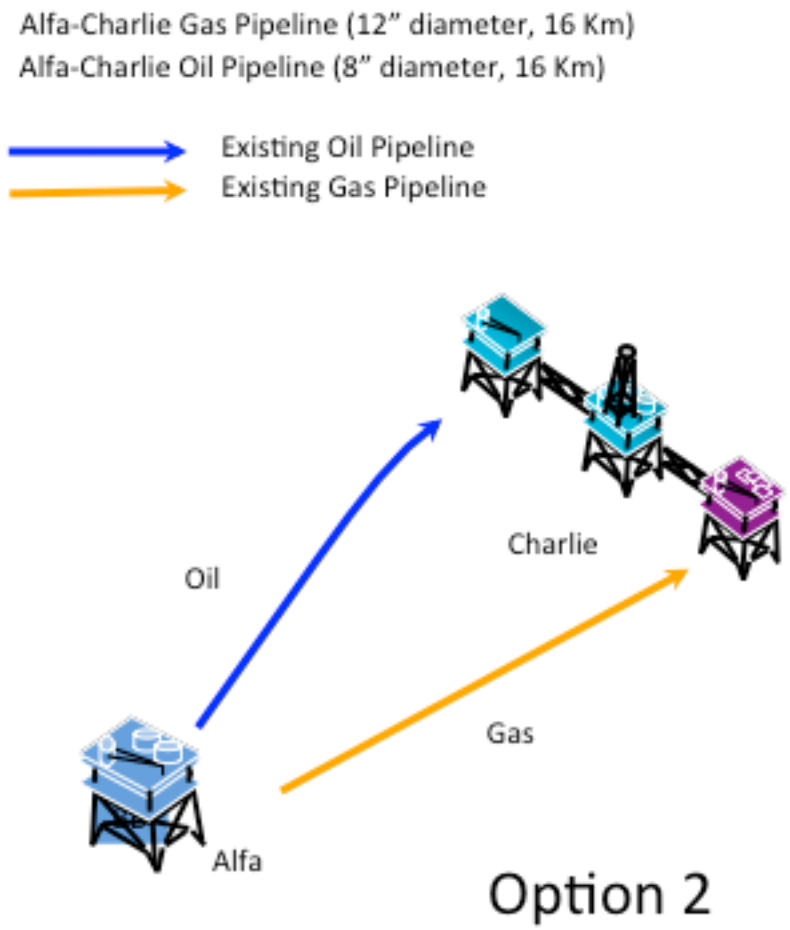

Figure C.2 Option 2 Alfa reactivation project

Option 3

The capacity in Charlie is limited and there are several field to develop around Charlie which might be connected to Charlie (still waiting the result of feasibility study). This option proposes to send Alfa oil and gas to Delta Satellite, located 10 km from Charlie. Delta satellite sends its oil and gas through separate existing pipeline to Delta CPP. Result from feasibility study has found that Delta satellite and Delta central processing platform has adequate capacity that can process fluid from Alfa. To execute this option, new oil and gas pipeline will be built connected Alfa to Delta Satellite. The fluid from Alfa will be separated and sent to Delta using new pipeline. Insitu gas lift will be utilized.

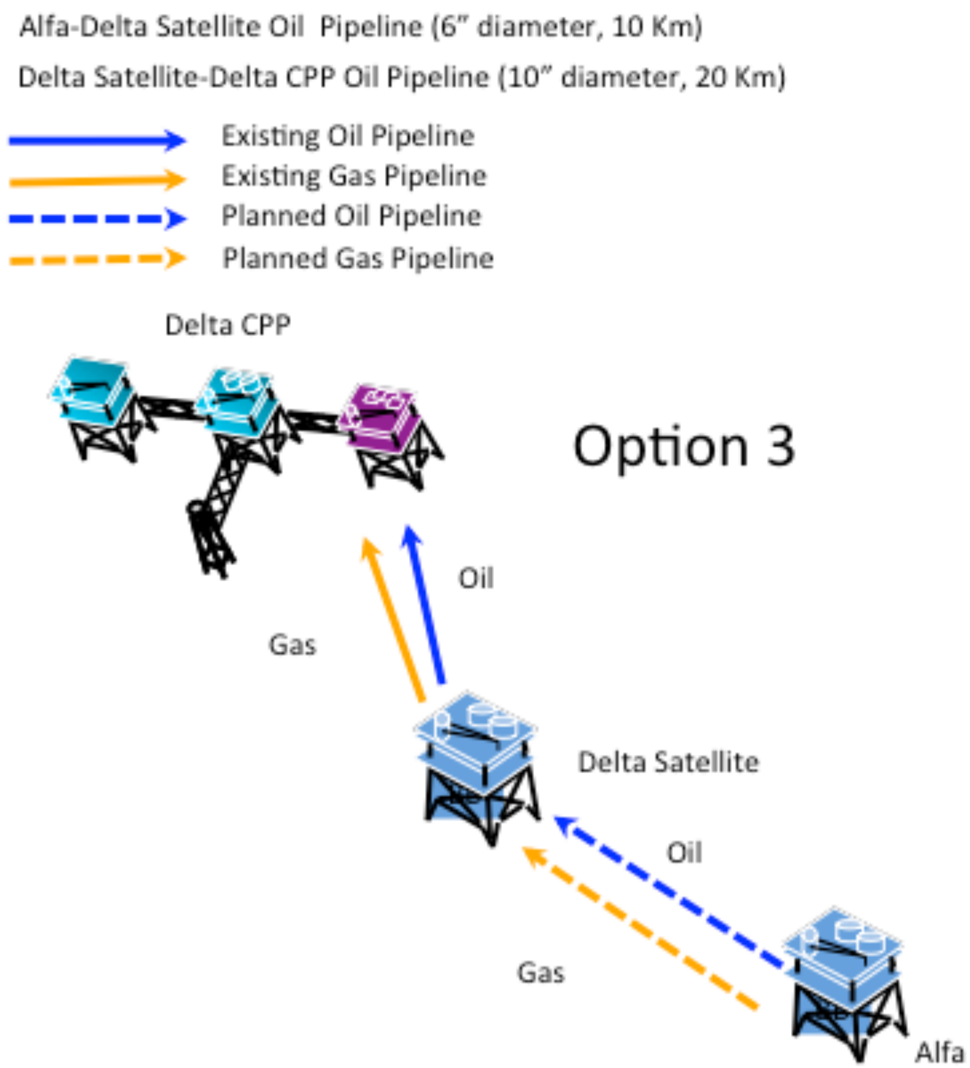

Figure C.3 Option 3 Alfa reactivation project

C 2. Basis Information and Assumption

- Price assumption
  - Gas price: 10 USD/MMBTU
  - Gas contract is long term contract prior which is signed for 10 years prior reactivation project is commenced
- Tariff assumption:
  - Oil: 2 USD/barrel
  - Gas: 1 USD/MMBTU
- Inflation and depreciation are not taken into account
- Discount rate: 7%
- Tax rate: 78%
- Heat content in gas, 1 BBTU = 1 MMSCFD
- Conversion

- 1 barrel = 0.159 Sm^3
- 1000 Sm^3 gas = 1 Sm^3 oil equivalents
- 1 Sm^3 gas = 35.3 scf gas

Table C.1 Probability distribution for each uncertain parameter

	Parameter	Distribution
General	Oil Price	Triangular
	Gas Reserves (BBTU)	Lognormal
	Oil Reserves (MBO)	Lognormal
Option 1	Topside repair without separator	Triangular
	P/L Repair	Triangular
	Liquid P/L	Triangular
Option 2	Topside repair with separator	Triangular
	New Gas P/L	Triangular
	P/L repair	Triangular
Option 3	Topside repair with separator	Triangular
	New Gas P/L	Triangular
	New Liquid P/L	Triangular

Table C.2 Probability distribution for oil and gas reserves

Parameter	Type	Mean	Stdev
Oil Reserves (MBO)	Lognormal	3	1
Gas Reserves (BBTU)	Lognormal	5	2

Table C.3 Probability distribution for oil price

Parameter	Type	Min	Most Likely	Max
Oil Price	Triangular	80	100	140

Table C.4 Probability and value assignment for each uncertain parameter

Options	Modification	Type	Min	Most Likely	Max
Option 1	Topside repair without separator	Triangular	7,000,000	9,000,000	10,000,000
	P/L Repair	Triangular	3,000,000	5,000,000	6,000,000
	Liquid P/L	Triangular	10,000,000	15,000,000	17,000,000
	Wellwork	Fixed	10,000,000		
Option 2	Topside repair with separator	Triangular	15,000,000	17,000,000	20,000,000
	New Gas P/L	Triangular	10,000,000	17,000,000	20,000,000
	P/L repair	Triangular	3,000,000	5,000,000	6,000,000
	Wellwork	Fixed	10,000,000		
Option 3	Topside repair with separator	Triangular	15,000,000	17,000,000	20,000,000
	New Gas P/L	Triangular	10,000,000	14,000,000	15,000,000
	New Liquid P/L	Triangular	10,000,000	14,000,000	15,000,000
	Wellwork	Fixed	10,000,000		