

Quantitative Risk Tolerance Analysis and Simulation Template Development

by

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Abstract

In the current construction industry, simulation is an effective technology that can assist engineers' decision making on project planning and estimation. The key contribution of simulation is to model uncertainty and risk occurrence during the construction process; however, this method still lacks a quantitative method to determine how much risk the decision maker is willing to accept. This thesis aims to develop an approach that can assist decision making on what percentile from a cumulative distribution function (CDF) of project cost reflects the organization's risk appetite and overall acceptance of risk. In order to enhance this quantitative risk analysis, a special purpose template was re-developed in Symphony.Net, based on program evaluation and review technique (PERT). This template provides an integrated cost/schedule model, and transforms the model to simulation-based planning, in which the uncertainties of project cost and schedule are evaluated through computer simulation.

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1 Introduction

1.1 Background

A typical construction project can be categorized into five basic process groups, which are initiating, planning, executing, monitoring and controlling, and closing (Project Management Institute, 2004). Among them, planning is the most prominent process, and nearly half of the processes occurring in a project fall within this group. More importantly, a quantitative risk analysis (QRA) is usually done in this process, related to the project management plan, scope, and activities. The objectives of the QRA are to increase the probability and impact of positive events and decrease the probability and impact of adverse events (PMI, 2004).

A capital construction project undergoes various risk factors including funding risk, schedule risk, cost risk, and technical risk. Simulation is widely used as an effective risk analysis method in the project pre-planning process to estimate the impact of those uncertainties. This thesis focuses on quantitatively defining an organization's risk tolerance towards a certain project based on Monte Carlo Simulation results. The simulation supplies the decision maker with all the possible outcomes and the probabilities that they will occur, which is usually shown as a distribution. For example, the simulated result of a project cost can be displayed as a cumulative distribution curve (CDF) within a range between the lowest possible price and the maximum possible price. The Monte Carlo method delivers a new level of project estimation process compared to the traditional "cost plus contingency" method.

Over the past few decades, the construction industry has valued risk analysis as one of the most significant components of project success. When it comes to understanding risks, organizations need to focus on two dimensions of risk: investment risks and investor risk. Investment risk encompasses the risk traits of an investment or

project, and investor risk lies on the head of the investor. However, how much risk an organization is willing to accept is still debatable. Two key aspects (1) risk appetite and (2) risk capacity are currently used to assist decision making. Risk appetite is defined as “the amount of risk, on a broad level, an organization is willing to accept in pursuit value” (COSO, 2012). Nowadays, many construction companies have created their own risk appetite statements. A sample risk appetite statement can be defined as follows, “we expect a return of 18% on this investment, we are not willing to take more than a 25% chance that the investment leads to a loss of more than 50% of our existing capital” (COSO, 2012). Risk capacity is the amount of risk that the company can undertake. There are multiple ways to determine risk capacity; and normally it standards for the bottom line of a company’s risk seeking decision. For contractors, the risk capacity usually explores the dividing line between profits and losses. For owners, the risk capacity is the budget of a project where the profit and losses are transferred to savings to budget and exceeding of the budget. For the rest of the thesis, the terms profits and losses are used in the new developed approach.

Although the aforementioned two aspects are important in decision making, there is still a lack of comprehensive methods to express a company’s overall risk tolerance. The current recommendation for risk tolerance is at the 85th percentile of the aforementioned CDF, which means a 15% possibility of cost overrun (SMA Consulting). This research aims to develop an approach that can assist a decision maker to determine a more reliable percentile from the cumulative distribution curve so that the selected price will reflect the organization’s overall risk tolerance.

1.2 Purpose of the Study

Although risk analysis is not a new topic in the construction industry, risk tolerance is still worthy of study because of its subjectivity. The purpose of this study was to:

- Understand the QRA using Monte Carlo Simulation.

- Provide a list of possible factors which will influence an organization's overall risk tolerance.
- Provide a method for assisting decision makers in deciding on what percentile to use from the cumulative distribution curve that will reflect a company's risk tolerance. This thesis will mainly focus on defining an organization's acceptance of risk of project cost overrun. .
- Provide improvements to the user interface of a program evaluation and review technique (PERT) special purpose template developed in Symphony.NET.

1.3 Expected Contributions

- Develop a new approach to quantitatively assess an organization's attitudes towards risk, in order to help organizations to select the most comfortable project cost.
- Develop a simulation template based on PERT.

1.4 Research Methodology

This research was conducted using the following methodology:

- Conduct a literature review on risk tolerance, decision making, quantitative risk analysis, Monte Carlo method, and utility theory.
- Study a company's risk appetite and capacity in order to determine the factors that influence an organization's decision making.
- Study utility theory related to risk tolerance decision.
- Develop a method using utility theory to assist an organization to determine a reliable risk tolerance range.
- Interview professional engineers to simplify a simulation template which assists the research.

1.5 Thesis Organization

The thesis is divided into seven main chapters with a list of references.

Chapter 1 outlines the research background, research objectives, methodology, and expected contributions.

Chapter 2 contains a literature review of previous research about the risk attitude in construction fields. The chapter also provides the gaps of the previous research.

Chapter 3 presents an introduction to utility theory and explains the conceptual idea of using utility theory to model an organization's or individual's risk tolerance.

Chapter 4 explains the new approach developed for quantitative risk tolerance analysis. It introduces the procedure of how to measure an organization's risk tolerance using utility theory.

Chapter 5 introduces the re-developed template.

Chapter 6 describes a hypothetical road construction project that is simulated using the new template. It introduces the step-by-step procedure of creating a model in the related template.

Chapter 7 includes the conclusions, limitations, and future enhancements.

2 Literature Review

2.1 Introduction

Akintoye and MacLeod (1997) indicate that risk in construction has been an object of attention because of the time and cost over-runs associated with construction projects. Since construction is a risky business, effective risk management is important because it analyzes and controls risk as the key to profit. Quantitative risk analysis (QRA), with respect to an organization's risk tolerance, is a vital part of archiving risk management and it provides more detailed information compared to traditional qualitative risk assessment.

An organization's risk tolerance can be influenced by various categories. Kwak and LaPlace (2004) suggest that risk tolerance related to a project consists of three perspectives, which are firm, project manager, and stakeholder. It is so dependent on the human dynamic that a quantitative measure of an organization or individual's risk tolerance is difficult to achieve. Numerous research projects have been undertaken to examine the topic of risk management.

2.2 Definitions

There are numerous definitions of risk tolerance and risk appetite. The following is a select set of definitions that are commonly encountered:

- According to the PMBOK Guide (2013), risk tolerance is the “degree, amount or volume of risk that an organization or individual will withstand.” If an organization or stakeholder is willing to accept risks with high impact or high possibility of occurrence, they are considered to have high risk tolerance.
- ISO Guide 73 (2009) defines risk tolerance as an “organization's or stakeholder's readiness to bear the risk after risk treatment in order to achieve its objectives,” and risk appetite is defined as the “amount and type of risk that an organization is willing to pursue or retain.”

- COSO (2012) indicates that risk tolerance “reflects the acceptable variation in outcomes related to specific performance measures linked to objectives the entity seeks to achieve.” In COSO’s framework, risk appetite is defined as the “amount of risk, on a broad level, an organization is willing to accept in pursuit of value.” Each organization pursues various objectives to add value and should broadly understand the risk it is willing to undertake in doing so. For example, a financial organization with a lower risk appetite might choose to avoid opportunities that are more risky, but offer greater returns.
- KPMG (2009) defines risk tolerance as the “typical measures of risk used to monitor exposure compared with the stated risk appetite,” and risk appetite is defined as the “total impact of risk an organization is prepared to accept in the pursuit of its strategic objectives.” The corporation indicates that the amount of risk acceptable varies from organization to organization, and the risk appetite also varies across business units and risk types.

2.3 Examining an Individual’s Risk Tolerance

In the past few decades, individual’s risk tolerance has being examined through multiple dimensions. Three aspects are the essential targets used to analyze an individual’s risk tolerance:

1. Culture
2. Risk Perception
3. Risk Preference

2.3.1 Culture

The following section explores the links between culture and an individual’s risk tolerance. Risk is associated with culture. Individuals with different cultural backgrounds

will have different attitude towards risk. Furthermore, risk tolerance varies depending on gender, age, etc.

2.3.1.1 Culture Difference

Statman (2010) explores the relationship between cultural background and risk tolerance. From his research, various factors have been discovered that can influence an individual's risk tolerance. Table 1 summarizes the key factors from Statman's research that link culture and risk tolerance.

Table 1 Culture & Risk Tolerance (Statman, 2010)

Risk Tolerance	
High	Low
Collectivistic Countries	Individualistic Countries
Low Income-Per-Capital	High Income-Per-Capital
High Social Spending	High Uncertainty Avoidance
	Egalitarian Countries
	Harmonious Countries

Before Statman explored the correlation between culture and risk tolerance, other research had already been conducted on the same topic. Fan and Xiao's (2003) study on this topic compared risk-taking attitudes and behaviors between Chinese and Americans. The findings show that Chinese are more risk tolerant than Americans in their financial decisions, which is similar to Statman's statement (2010).

Hsee and Weber (1998) suggest that risk perception varies between cultures. They indicate that those from a collective country will have a lower risk perception than those from an individualism country, which results in a higher risk tolerance level (1998). Hsee and Weber (1999) also prove that systematic cross-national differences in risk preference

exist. Their research aims to quantitatively analyze risk preferences between Americans and Chinese and study the correlation between risk preference and risk perception. Weber (2013) examines the correlation between personality and risk tolerance by conducting an investigation of risk-taking behavior. The results show that people with large worries about finances have a higher probability of being risk averse and people with virtually no worries about finances are more likely to be risk prone.

Griffin et al. (2009) investigate the role of national culture in corporate risk-taking using individual data at the firm level from 35 countries. Based on their research, three factors (1) harmony, (2) individualism, and (3) uncertainty avoidance are identified from the national culture that may impact risk-taking attitudes. The research reveals that harmony and uncertainty avoidance are negatively associated with an individual's risk tolerance, but individualism is positively associated with risk tolerance.

Frijns et al. (2013) examine the role of national culture in corporate takeover decisions to show that culture affects financial decision making at the individual level. The research team collect a sample of 25,750 acquisitions made by 7,681 firms from 39 countries to find that countries with higher levels of religiosity and uncertainty avoidance will have a lower risk tolerance.

Ryack (2011) explores how family relationships and financial education impact an individual's risk tolerance using a sample of college freshmen and their parents. The results show that higher levels of financial education will lead to lower risk tolerance; however, the education level of relatives has no significant impact on an individual's risk tolerance.

2.3.1.2 Gender Difference

Statman (2010) indicates in his research that women have lower risk tolerance than men in both portfolios and jobs. In this, Statman is consistent with many others. Beckmann et al. (2008) suggest that women are significantly more risk averse, tend to be

less overconfident and behave less competitively-oriented in the financial industry with risk taking and decision making. Charness and Gneezy (2007) identify consistent results that women invest less, which indicates that they tend to be more financially risk averse than men. Watson and McNaughton (2007) suggest that women choose more conservative investment strategies than men, which directly results in relatively lower retirement benefits. Lemaster and Strough (2013) again indicate the gender difference that men are more risk tolerant and make riskier financial decision than women from the perspective of core biological mechanisms.

2.3.1.3 Age Difference

Several studies mention that risk attitudes and tolerance vary with age. Weber (2013) classifies that as age increases, risk tolerance decreases. In addition, the research indicates that married individuals are more likely to be risk averse, and their risk tolerance is in a direct ratio towards their number of children. In this, Weber is consistent with other research. Sahm (2007) explores the impact of life cycle on an individual's risk tolerance through a measure of a gamble test response under macroeconomic conditions. The researcher indicates that each year of age is associated with a 1.7% decline in an individual's risk tolerance.

2.3.2 Risk Attitude

Despite culture factors, an organization's leader's attitude towards risk will have greater impacts on decision making. Frijns et al. (2013) indicate that risk decisions are affected by the company leader's personal traits and interests. Their research was conducted on a company's takeover decisions, and the results show that a CEO's appetite for risk or perception of risk involved may play a decisive role.

The methods to determine an individual's risk attitude have been examined through research for many years. Risk attitude is composed of risk perception and risk

preference. Statman (2010) indicates that wealthy people may have the same risk preference as poor people in the same situation, yet their risk perceptions are likely to be different. The same proposition can be made on the project cost and company assets for decision maker's risk perception of a construction organization.

2.3.2.1 Risk Perception

Perception is an important factor to be taken into account when communicating risks. Risk perception is usually understood as the subjective judgement that people make about the characteristics and severity of a risk. The risk perception is generally influenced by an individual's beliefs, attitudes, judgements and feelings (Akintoye & MacLeod, 1997). Solvic (2004) suggests that risks and benefits are positively correlated in real life; however, risk perception and benefits are negatively correlated. Based on Solvic's work, Nyre and Jaatun (2013) constructed a multi-dimensional risk perception model to quantitatively measure an individual's risk perception.

2.3.2.2 Risk Preference

Risk preference is the tendency of an individual to choose a risky or less risky option. It can be applied to any decision that involves risk. Several types of risk preference exist, and the associated risk involved generally depends on the decision maker and for whom the decision maker takes the risk.

Risk Preference Definition

In decision theory, risk refers to the attitude of a decision maker towards a particular lottery (Keeney & Raiffa, 1976). Wild (2013) suggests that this risk attitude is characterized by the preference of the decision maker either for the certain amount "z," or for a risky lottery "L" with expected value "z." Based on this research, a person is considered risk averse if he/she prefers the amount "z" to any risk lottery "L" with expected "z," i.e., $z > L$; a person is considered as risk seeking if the lottery "L" is preferred to its

expected value “z,” i.e., $L > z$; and risk neutrality means that the decision maker is indifferent between every lottery and its expected value, i.e., $z = L$.

Despite the decision theory of risk averse or risk seeking, Hanna et al. (2001) classify risk preference into 5 standard statements, as follows, which are determined through a set of questionnaires.

1. Take substantial financial risk expecting to earn substantial returns.
2. Take above average financial risk expecting to earn above average returns.
3. Take average financial risk expecting to earn average returns.
4. Take low financial risk expecting low returns.
5. Not willing to take any financial risk.

Risk Preference Measure

Individuals' risk preferences have been measured in a variety of ways. Gilliam et al. (2010) concluded that two common methods to assess financial risk tolerance are (1) single risk-tolerance item found in the survey of consumer finances (SCF), and (2) 13-item financial risk-tolerance scale (Grable & Lytton, 1999).

Barsky et al. (1997) attempt to elicit individual preference parameters about risk through questions derived from economic theory. The research team obtained the measure of risk aversion by asking respondents about their willingness to gamble on lifetime income. A sample question is shown as follows:

Suppose that you are the only income earner in the family, and you have a good job guaranteed to give your current family income every year for life. You are given the opportunity to take a new and equally good job, with a 50-50 chance it will double your family income and a 50-50 chance that it will cut your family income by a third. Would you take the new job? (Hanna 2001).

Hanna et al. (2001) indicate four effective methods of measuring risk preference.

1. Asking about investment choice,
2. Asking a combination of investment and subjective questions,
3. Assessing actual behavior, and
4. Asking hypothetical questions with carefully specified scenarios.

2.3.3 Individual Decision Makers' Risk Attitudes towards Construction Organizations

“Construction, like many other industries in a free-enterprise system, has sizeable risk built into its profit structure” (Mustafa and Al-Bahar, 1991). Although previous work intended to examine an individual's attitude towards risk, a decision maker's risk attitude towards a construction organization is still considered risk aversion.

An individual's risk tolerance is still a debatable topic because of its human dynamic; however, early studies found that individual decision makers are risk averse (Pratt, 1964 & Arrow, 1965). Kaheman and Lovallo (1993) suggest that project managers are “extremely susceptible to unjustified optimism and unreasonable risk aversion.” Their research proposes that project managers or decision makers will intuitively become prudent risk takers themselves because of pressure from project uncertainties. Akintoye and Macleod (1996) indicate that risk management is important to construction organizations because of the need to limit professional indemnity and to protect companies' reputations. The study included several surveys of contractors on project management practices, and the results prove that decision makers are biased towards safer projects with lower profits as compared to risky investments. Hanna and Lindamood (2004) indicate that decision makers usually place a lower value on gain than they place on losses, which means that when individuals are confronted with risky investments, they are somewhat risk averse. Hulett (2013) indicates that decision makers may shy away from project alternatives that would expose the organization to significant down-side

results if they are to fail, even if these kinds of projects also offer a great opportunity of upside results and success.

Kwak and LaPlace (2005) argue that the pre-determined risk tolerance level is nullified without the proper recognition of risks. The researchers suggest that project managers should weigh the credit and blame before making any decisions. The importance of a project will also influence a project manager's risk tolerance. For example, if a manager possesses a promotion chance, he or she may accept more risk in a highly visible project to gain accolades; however, the project manager may have less incentive to take risks in smaller projects (Kwak and LaPlace, 2005). This risk attitude is in contrast with the firm's risk tolerance profile because construction organizations are willing to take risks on relatively smaller projects that have little impact on the entire company environment.

2.4 Examining Organization's Risk Tolerance

In order to survive in the market, organizations have developed their own risk management processes, which are now commonly referred to as enterprise risk management (ERM). The COSO (2004) identifies the ERM as "a process, effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risks to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives." In order to achieve effective risk management, organizations must know how much risk is acceptable as they consider ways to accomplish objectives, both at the organization level and individual level. ERM is often qualitative in nature; however, this approach aims to quantitatively analyze risk appetite. Three major steps are essential to the objective: (1) risk identification, (2) quantitative risk analysis, and (3) develop risk appetite.

2.4.1 Risk Identification

Risk management is divided into four stages: risk identification, risk analysis, risk mitigation, and risk control (AbouRizk, 2009; Abdelgawad, 2010). Among them, risk identification is an indispensable process because insufficient or unrealistically defined risks may mislead the management of an entire project. PMI (2000) defines risk identification as the process of investigating risk events that might become threats or opportunities to the projects. Huang and Wang (2008) indicate that one-off construction projects have greater uncertainty than other activities, so that identification and management of construction risks becomes more difficult and imperious. Perry and Hayes (1985) and Mustafa and Al-Bahar (1991) have defined key risk sources to construction activities, which are physical, environmental, design, financial, legal, construction and operation risks.

2.4.1.1 Risk Factor Identification

There are multiple ways to identify risk factors for a construction project. Huang and Wang (2008) indicate five common methods for construction project risk assessment, which are: (1) investigation and expert marking method, (2) fuzzy mathematics, (3) analytical hierarchy process, (4) analytic network process, and (5) artificial neural network. Their research also suggests that experts should evaluate the project with the consideration of its multidimensional characteristics. Before Huang and Wang's work, Wilemon and Cicero (1970) pointed out that risk can be identified into two categories: project risk applies to the uncertainties for a project manager in achieving project goals in terms of time, cost, and performance; and professional risk deals with a project manager's uncertainties with respect to future job advancement and rewards.

In the current construction industry, the risk identification process is still mainly based on expertise and past experience. The typical techniques are standard checklists, expert interviews, facilitated brainstorming sessions, and the Delphi technique. Mustafa and Al-

Bahar (1991) introduced the analytic hierarchy process (AHP) for project risk assessment. With the risk preferences provided by the decision maker, the AHP can provide risk classification, and the corresponding impact weight of each risk can be determined. Zou et al. (2007) explore twenty key risk factors (in rank) in construction projects by analyzing the data collected from postal questionnaire surveys. The result showed that project risks are mainly related to contractors, clients and designers; among them, “tight project schedule” and “design variations” are the top two risk factors that can influence project objectives in multiple categories.

Russell and Orozco (2013) introduce a holistic approach of risk identification as a function of project context. In their research, project context is divided into four components, which are physical, process, participant, and environment. The risk register process is based on a hierarchical view consisting of categories, issues, and events. For example, the category of construction phase risk may encounter the issue of migratory birds, and the risk event is that the alignment is full of nests during surveying in breeding season (Russell & Orozco, 2013).

2.4.1.2 Risk Impact Identification

In order to estimate the uncertainties, two key factors: (1) likelihood and (2) severity must be examined. AbouRizk (2009) shows a table that illustrates the relationship between the likelihood and its linguistic interpretation (see Table 2).

Table 2 Risk Likelihood and its Linguistic Interpretation (AbouRizk, 2009)

Likelihood	Low	High
	Probability	Probability
HL--Highly Likely: Almost certain that it will happen	70.00%	100.00%
LI--Likely: More than 50-50 chance	50.00%	70.00%
SL--Somewhat Likely: Less than 50-50 chance	15.00%	50.00%
UN--Unlikely: Small likelihood but could well happen	1.00%	15.00%
VU--Very Unlikely: Not expected to happen	0.01%	1.00%
EU--Extremely Unlikely: Just Possible but would be very surprising	0.00%	0.01%

In the same study, an assessment of risk impact was also developed to verbally and quantitatively express the influence of events, as shown in Table 3 (AbouRizk, 2009).

Table 3 Risk Verbal Expression and its Corresponding Impact (AbouRizk, 2009)

Verbal Expression	Cost Impact	Schedule Impact
Disastrous	\$ 100 M	3 seasons
Severe	\$ 50 M	2 seasons
Substantial	\$ 10 M	1 seasons
Moderate	\$ 2.5 M	6 months
Marginal	\$ 1 M	3 months
Negligible	\$ 0.1 M	1 months

However, previous research does not have a consistent definition of risk impact; the influence of risk is still based on the organization environment and project characteristics.

2.4.2 Quantitative Risk Analysis

“Risk analysis is a phase of quantifying the effect of risk events on the project’s objectives such as scope, cost, time, and quality” (Hong, 2012). Quantitative risk analysis (QRA) assesses the project uncertainty in terms of cost and schedule by multiplying the probability of the occurrence and its corresponding impacts in order to gain a value for risk severity (CII, 2012). A common methodology is to create a QRA model based on Monte Carlo technology. In a QRA model, each of the risk factors is assigned by the quantified probability of occurrence and the related cost or schedule impact. Through Monte Carlo Simulation, each individual risk is combined together to estimate the overall impact to the project’s cost and schedule.

2.4.2.1 Monte Carlo Simulation

The modern version of Monte Carlo algorithms was invented by Stanislaw Ulam in the late 1940s in the Los Alamos Lab in order to simulate the neutron activities for nuclear weapon development, which is known as the Manhattan Project. Nowadays, it is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making (Palisade Corporation). Monte Carlo Simulation depends on statistical sampling to evaluate possible outcomes. The objective of this method, when used in the construction industry, is to derive all the possible outcomes into a form of distribution so that under uncertainties, the estimated cost or schedule can be shown as a probability distribution rather than a single number.

Li et al. (2011) introduced the standard steps for implementing Monte Carlo Simulation:

1. Determine the evaluation objectives, such as project cost, project schedule, etc.
2. Determine the risk variables and their probability distribution, which exerts impact on the evaluation objectives.
3. Take the random numbers in line with the established probability distribution of variables via computer.

4. Set up a mathematical model. The model structure will closely follow the WBS.
Then calculate the evaluation objective based on the random variables.
5. Repeat step 3 and 4 until the pre-determined experiment time is reached.
6. Collect the simulation result, and draw a cumulative probability map.

A more detailed application of Monte Carlo Simulation for quantitative risk analysis related to Project Evaluation and Review Technology (PERT) will be given in Chapter 6.

2.4.3 Organization's Risk Appetite

An organization's risk appetite will have a huge impact on the decision making regarding overall risk tolerance. Companies with higher risk appetite generally focus more on the potential for a significant increase in value and earning that they may be willing to accept higher risk in return; conversely, companies with relatively lower risk appetite are more risk averse, as their focus is on stable earning (RIMS, 2012). The COSO (2004) framework formalized a requirement for organizations to become more explicit about their risk appetite. An organization with an aggressive appetite for risk might set aggressive goals, while an organization that is risk-averse, with a low appetite for risk, might set conservative goals. The company strategy should align with the organization's risk appetite.

2.4.3.1 Developing an Organization's Risk Appetite

"An organization must consider its risk appetite at the same time it decides which goals or operational tactics to pursue" (COSO, 2012). Rittenberg and Martens (2012) suggest that an organization should take three steps to determine its risk appetite, which are (1) develop risk appetite, (2) communicate risk appetite, and (3) monitor and update risk appetite. In the same research, they develop a list of considerations that affect an organization's risk appetite, as shown in Table 4.

Table 4 Considerations Affecting Risk Appetite (COSO, 2012)

Considerations Affecting Risk Appetite	
Existing Risk Profile	The current level and distribution of risk across the entity and across various risk categories
Risk Capacity	The amount of risk that the entity is able to support in pursuit of its objectives
Risk Tolerance	Acceptable level of variation an entity is willing to accept regarding the pursuit of its objectives
Attitudes Towards Risk	The attitudes towards growth, risk, and return

KPMG (2012) conducted a study of risk appetite through a group of senior risk executives from large public and private Australian companies. The result showed that only a quarter of organizations have determined a formal risk appetite statement. The findings showed that most organization have experience in describing risk appetite in traditional areas such as regulatory compliance; however, there is shortage of statements that define risk appetite in qualitative areas such as company reputation.

RIMS (2012) introduced several types of risk appetite statements with respect to both quantitative and qualitative. The quantitative risk appetite statements should address categories such as the maximum tolerance for market, credit and operational losses, and the qualitative risk appetite statement should address risks such as regulatory risk, reputation risk, or operational risks in the execution of business plans. This thesis focuses

on the quantitative risk appetite in order to quantitatively determine an organization's risk tolerance. An example quantitative risk appetite statement is shown as follows (COSO, 2012).

We expected a return of 18% on this investment, we are not willing to take more than a 25% chance that the investment leads to a loss of more than 50% of our existing capital.

Kindinger (2002) suggests using a frequency and consequence risk matrix to identify risk events and qualitatively or quantitatively categorize them. A risk matrix is a matrix used to define risk severity as the product of the likelihood and impact. Figure 1 shows a sample risk matrix of a risk averse organization. The numbers in the matrix represent the risk tolerance coefficient which stands for the willingness to accept risk.

impact	1	0.2	0.4	0.6	0.8	1
	0.8	0.16	0.32	0.48	0.64	0.8
	0.6	0.12	0.24	0.36	0.48	0.6
	0.4	0.08	0.16	0.24	0.32	0.4
	0.2	0.04	0.08	0.12	0.16	0.2
	0	0.2	0.4	0.6	0.8	1
	probability					

Figure 1 Sample risk matrix

The red area shows high risk that an organization must avoid in any circumstances, the yellow area is the medium risk that the organization is capable of bearing, and the green area is the low risk that the organization is comfortable with.

2.5 Literature Limitation

Risk tolerance is still a developing area of research, because of its human dynamics. In reality, the definitions of risk tolerance or risk appetite are vague and the gap between theory and practice is wide. Past research has not developed a clear solution to quantitatively illustrate how much risk an organization is willing to take. Further analysis is required in order to achieve this objective.

3 Determining Risk Tolerance: Utility Theory

3.1 Introduction of Utility Theory

Since risk tolerance is generally concerned with an individual's and an organization's risk attitude and perception, basic problems of risk assessment can be adequately treated within the comparative framework of utility theory (Geiger, 2005). In the economics and game theory, utility is the happiness or satisfaction derived by a person from the consumption of a good or service. In another words, it is an alternative way of measuring the attractiveness of the result of a decision. Utility function in decision measures the attractiveness of money by transferring monetary units to another measure.

In the construction industry, utility theory is an effective tool to quantify and measure an individual's or company's aversion towards risk taking decisions. However, for substantial risks, organizations as well as individuals tend to be risk averse. Expected value is widely used to examine risk attitudes.

3.2 Expected Value

The expected value combined with willingness-to-accept (WTA) and willingness-to-pay (WTP) in decision theory are commonly used to determine an organization's risk tolerance attitude. Willingness-to-accept and willingness-to-pay are two effective methods for the valuation of lotteries (Wild, 2013).

Willingness-to-accept

Willingness-to-accept (WTA) is the amount that a person is willing to accept negative to keep something positive or when they will abandon a good thing based on too much negative. In economics, WTA is the minimum monetary amount accepted for sale of a good or acquisition of something that is thought of as undesirable.

Willingness-to-pay

Willingness-to-pay (WTP) is the maximum monetary amount an individual is willing to sacrifice to pursue a good or avoid something undesirable. Since decision makers in the construction industry are generally risk averse, the WTP is a more important measure for an organization to value their risk tolerance because construction organizations are more willing to pay to avoid risk.

Different from decision theory, expected value is the simplest method to test an individual's or an organization's risk attitude with a lottery or gambling. Risk averse, risk neutral, and risk seeking are three most common attitudes towards risk. For example, if there is a 1 in 80 chance that a person can win \$100, the expected value of this gamble is \$1.25 as compared to a sure award of \$1.00 with this gamble.

$$\text{expected value of the gambling} = \$100 \times \frac{1}{80} + \$0 \times \frac{79}{80} = \$1.25$$

- Risk averse: if the person is willing to accept the sure amount of \$1.00, then he is considered risk averse because the expected return of the gamble is greater than the certain amount guaranteed.
- Risk neutral: if the person is indifferent between playing the game and receiving the sure amount, then he is considered as risk neutral.
- Risk seeking: if the person is willing to gamble for the \$100 prize, then he is considered to be risk seeking.

Expected value (expected return) is also a good method for an individual or an organization to make a decision between alternatives. For example, if a person is asked to play a game with two alternatives: (1) 50 percent chance of winning \$100, 50 percent chance of losing \$50, or (2) 50 percent chance of winning \$120, or losing \$60:

$$\text{expected return of alternative 1} = 50\% \times \$100 + 50\% \times (-\$50) = \$25$$

$$\text{expected return of alternative 2} = 50\% \times \$120 + 50\% \times (-\$60) = \$30$$

Since the expected return of alternative 2 is greater than that of alternative 1, most individuals will choose alternative 2. However, Kahneman and Tversky (2000) suggest that most of the decision makers violate the expected value theory that there is risk in the choices because humans have their own attitudes towards risk. When there is risk in the choices, people are usually risk-averse and prefer to get something for sure. The researchers proved their statement through a survey. For example, assume there are two choices: one plays a \$3000 lottery with a probability of 1, while the other plays a \$4000 lottery with a probability of 0.8, and otherwise nothing. If a decision maker maximizes the expected value, the decision maker should choose the second choice as the expected value is higher. However, the experiment showed that out of 95 respondents, 80% choose the first option (Kahneman & Tversky, 2000). Hulett and Hillson (2004) indicated that most organizations are cautious in situations where they think they might be vulnerable to losses. As a result, the expected value theory is not appropriate to use when risks are involved, especially substantial risk that can cause project collapse.

3.3 Expected Utility

Since the expected value theory is inappropriate for organizations to evaluate a project with risks, a theory that “allows for the accommodation of all kinds and degrees of individual risk attitudes was proposed by Cramer (1728/1954) and Bernoulli (1738/1954) and has become known as expected utility” (Wild, 2013). Similar to the expected value theory, the decision maker’s risk preference between two alternatives is transferred from a certain monetary value to a utility through a mathematical utility transformation. For example, consider the following game in which a gamble infers 99% of losing \$10,000, and 1% of winning \$1,000,000. The payoff table is shown as follows:

Table 5 Gamble Payoff

	State of nature	
Decision	99%	1%
Play	-\$ 10,000.00	\$ 1,000,000.00
Do not Play	0	0

The probability of losing and winning are 0.99 and 0.01, respectively. If the decision maker follows the rule of expected value, the expected returns of whether to play the game or not are:

$$\text{expected return (play)} = -\$10,000 \times 0.99 + \$1,000,000 \times 0.01 = \$100$$

$$\text{expected return (do not play)} = 0 \times 0.99 + 0 \times 0.01 = 0$$

Since the expected return of playing is greater, the decision maker should play the gamble if he follows the criterion of expected value. However, if analyzing the same problem using expected utility theory, the result will change. Suppose the two alternatives of the game stand for the best utility and worst utility in a range of [-1, 1], thus, the expected utility for losing \$10,000 is "-1," and the expected utility for winning \$1,000,000 is "1," and the value of zero stands for a utility of zero.

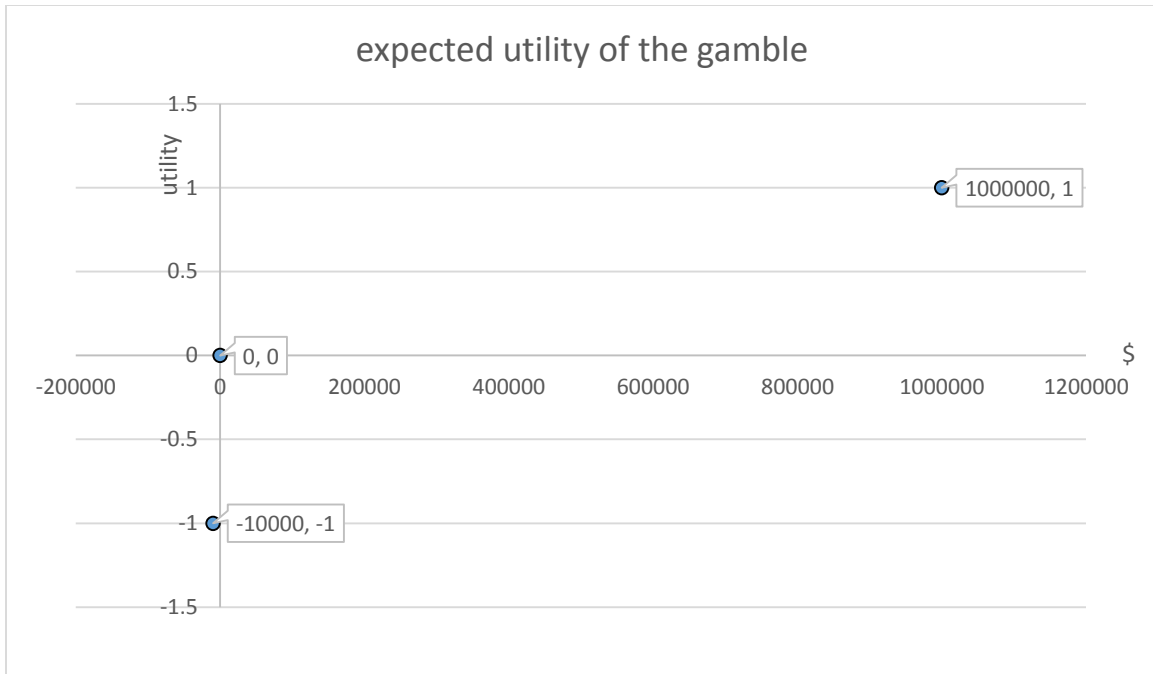


Figure 2 The expected utility for the game

The calculation of expected utility is the same as the calculation of expected value, thus, the expected utilities of whether to play the game or not are:

$$\text{expected utility (play)} = 1 \times 0.01 + (-1) \times 0.99 = -0.98$$

$$\text{expected utility (do not play)} = 0 \times 0.01 + 0 \times 0.99 = 0$$

Since the expected utility of do not play the game is greater, the decision maker should not play the gamble. Wakkler (2010) indicates that expected utility is considered a reasonable theory of choice under risk for one-shot decisions for large stakes. However, numerous researchers suggest that expected utility theory is correlated with initial wealth. The initial wealth is usually not expressed in the outcomes, but will influence the utility transformation process. The expected utility curve is commonly used to determine the utility of a certain value.

3.3.1 Expected Utility Curve

Decisions made by risk-averse organizations tend to be best represented by models that maximize their expected utility (Hulett and Hillson, 2004). Organizations can build their own utility functions that give serious negative utility to the possibility of large losses, in comparison to the serious positive utility to the possibility of large gain, according to their attitudes towards risks. Although most organizations are considered risk-avoiders, the utility curve can still present three risk attitudes, which are: (1) risk averse, (2) risk neutral, and (3) risk seeking. However, the first rule of expected utility curve is that it is a non-decreasing curve, since more money is always at least as attractive as less money.

Risk Averse

If the decision maker is considered risk averse this can be understood as the decision maker is more sensitive when he loses money as compared to when he gains. For example, if an individual receives money from \$0 to \$400, his utility of each hundred value can be determined as a certain number. Assume the utility is in a range of [0, 1], and the utility of each hundred is shown in the following table.

Table 6 Sample Utility of Risk Aversion

monetary value	utility
\$ -	0.00
\$ 100.00	0.50
\$ 200.00	0.68
\$ 300.00	0.77
\$ 400.00	0.82

To illustrate, assume the initial outcome of the individual is zero, and he first receives one hundred dollars. The individual's utility increases by:

$$u(\$100) - u(\$0) = 0.5 - 0 = 0.5$$

Now, suppose the initial outcome of the individual is \$300, and he receives another hundred dollars, which increases his final outcome to \$400. Then the individual's utility is increase by:

$$u(\$400) - u(\$300) = 0.82 - 0.77 = 0.05$$

As a result, an additional \$100 is less attractive if an individual already has a certain amount on hand than it is if he starts with nothing. However, this can also be illustrated in the opposite way, where losing \$100 is more painful towards risk averse people.

The utility curve can be plotted out if the individual's utility towards the monetary value is determined. This specific case is represented in Figure 3.

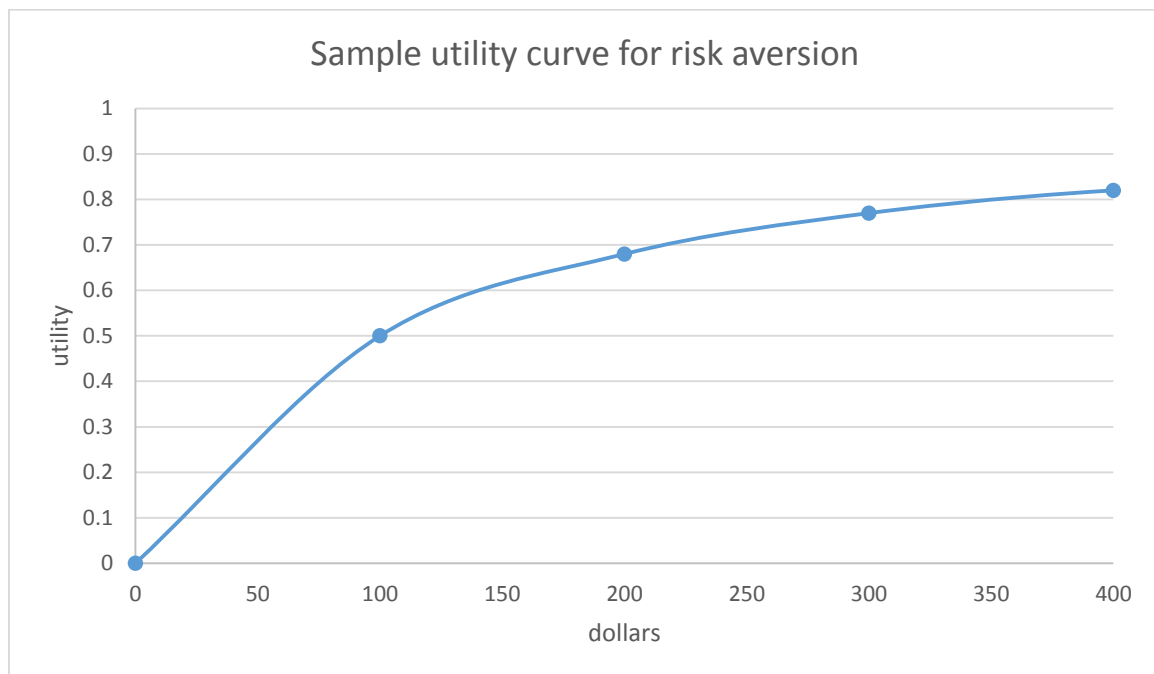


Figure 3 Sample utility curve for risk aversion

As a result, under expected utility theory, if an individual is considered risk averse, his utility curve must be concave, which means the gain of a specified number of dollars increases utility less than the loss of the same number of dollars decreases utility. Figure 3 also illustrates the form often chosen for utility function. The horizontal axis shows the possible values (monetary value), and the vertical axis shows the corresponding utility, where the utility is a numerical rating assigned to every possible value.

Risk Neutral

Different from risk aversion, if the decision maker is considered risk neutral, it means that gain or loss of a specific dollar amount results in the same magnitude in increasing or decreasing utility. In the aforementioned case, the utility of each hundred dollars then shares the same increment.

Table 7 Sample Utility for Risk Neutrality

Monetary Value	utility
\$ -	0.00
\$ 100.00	0.25
\$ 200.00	0.50
\$ 300.00	0.75
\$ 400.00	1.00

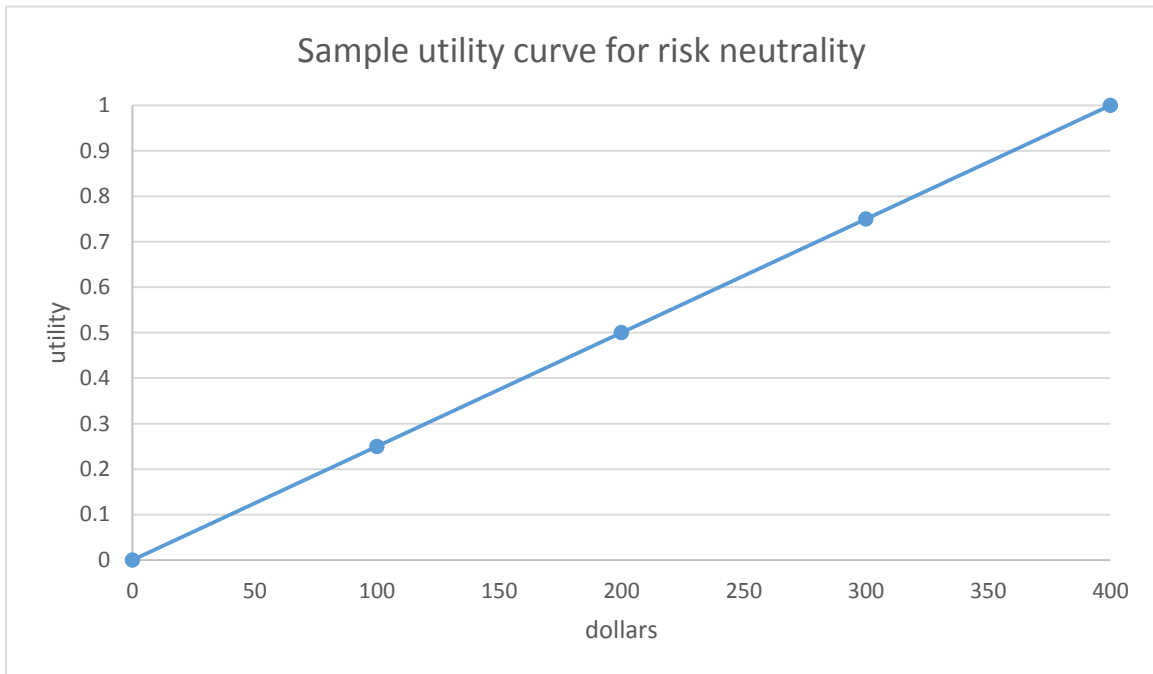


Figure 4 Sample utility curve for risk neutrality

The utility curve for risk neutrality is usually shown as a straight line, which is same as the risk indifference function.

Risk Seeking

Contrary to risk aversion, if an individual is considered risk seeking, it means that gain of a specified amount of dollars increases the utility more than a loss of the same amount of dollars decreases the utility.

Table 8 Sample Utility for Risk Seeking

monetary value	utility
\$ -	0.00
\$ 100.00	0.10
\$ 200.00	0.25
\$ 300.00	0.50
\$ 400.00	0.90

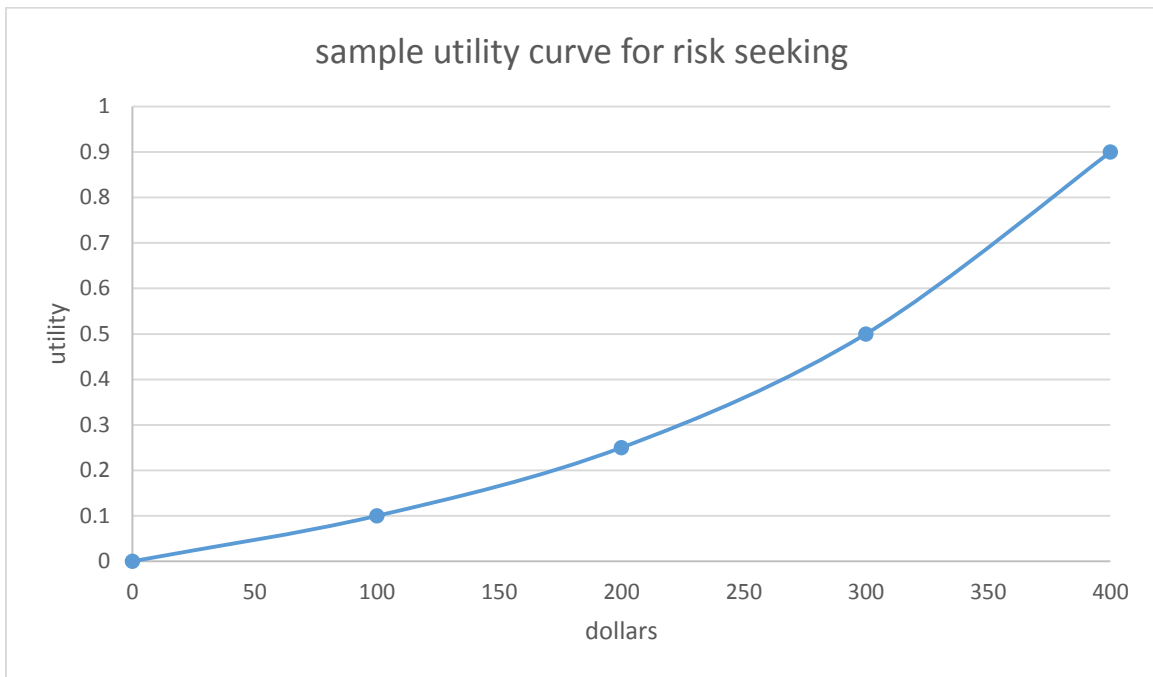


Figure 5 Sample utility curve for risk seeking

As shown in Figure 5, if the individual is considered risk seeking, his utility curve is always convex up.

3.3.2 Create Utility Function

As mentioned in the previous section, the utility curve can be plotted if the utilities are pre-determined; however, sometimes the utility of a monetary value is difficult to

determine because of its human dynamic. In order to mathematically map the physical measure of monetary value and the perceived value of money, utility functions are required to assess utility.

Lee Merkhofer (2003) suggested that the goal of a risk averse decision maker is to maximize a certain equivalent. The researcher defined the term “certain equivalent” as the amount of pay off that an agent would have to receive to be indifferent between that pay off and a given gamble. The utility function is used to estimate the results from the simple gamble, and the outputs can be used to infer certain equivalents of more complicated risks. For example, a decision maker is facing a risky project that ranges from \$0 to \$1,000,000. It is difficult to determine the certain equivalent for this project directly; however, a certain equivalent can be determined when the risky project is transformed to a two-end gamble with an equal chance of yielding \$0 or \$1,000,000. Although the expected return of the gamble is \$500,000, the certain equivalent will be less than the expected return if the decision maker is considered risk averse. Assume the outcome \$0 has a utility of zero, probability of “p” and the outcome \$1,000,000 has a utility of one, probability of (1-p). The certain equivalent holds that:

$$u(\text{certain equivalent}) = p \times u(\$0) + (1 - p)u(\$1000,000)$$

In this case:

$$u(\text{certain equivalent}) = 0.5 \times 0 + 0.5 \times 1 = 0.5$$

So, the certain equivalent is the monetary amount that has a utility of 0.5 generated from the utility function. As shown in Figure 6, if the decision maker is risk averse, and the utility function is concave down, the certain equivalent is less than the expected return. If the decision maker is risk neutral, the utility function is a straight line, and the certain equivalent is equal to the expected return. If the decision maker is risk seeking, the utility function is convex up, and the certain equivalent is greater than the expected value.

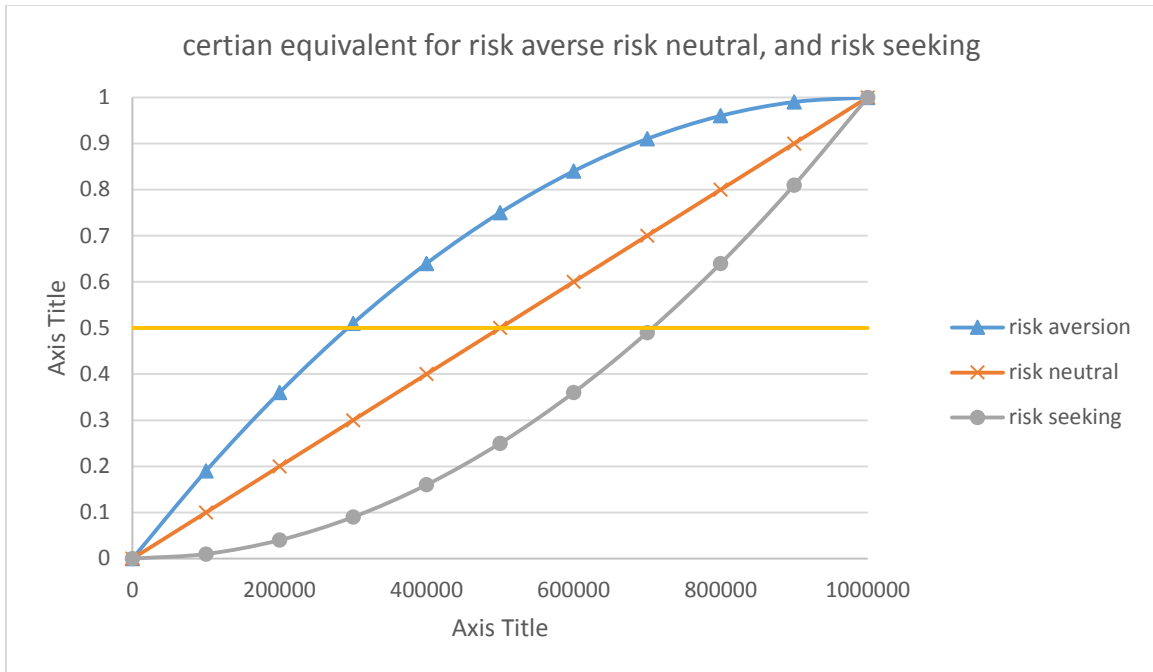


Figure 6 Equivalent value for risk averse, risk neutral, and risk seeking

In 1738, Bernoulli first raised the idea of utility function as a solution to the St. Petersburg Paradox. The modern form of the utility theory is developed by von Neumann and Morgenstern in 1944. The researchers also created several axioms underlying utility functions:

- Different utility functions are considered independent because utility functions are random variables.
- All outcomes are assigned with a utility from the utility function.
- Transitivity: if alternative 1 is preferred to alternative 2, and 2 is preferred to 3, then alternative 1 must be preferred to alternative 3.
- Utility function must be continuous.
- It is a non-decreasing function, " $u'(x) \geq 0$ " always holds.

Two advantages of the utility function are: (1) it has a pre-determined shape, and (2) requires the assessment of only a few parameters. These two are also correlated with

each other as the parameters will determine the shape of the utility function, and the shape of the utility function determines the degree of aversion of taking risks. For example, Figure 7 shows two concave utility functions: utility function 1 and utility function 2, and both of them are considered as risk averse.

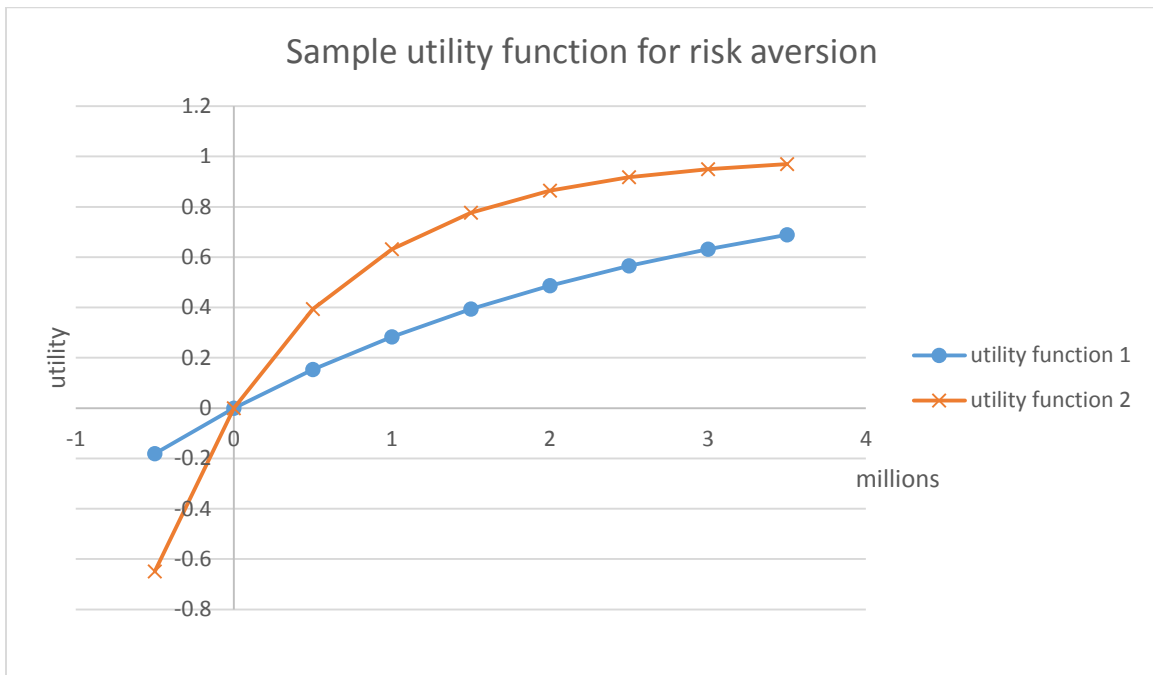


Figure 7 Sample utility function for risk aversion

In general, both utility functions in Figure 7 are considered as risk averse; however, if comparing the two utility functions to each other, utility function 1 is relatively risk seeking and utility function 2 is relatively risk averse. The reason is that utility function 2 converges faster than utility function 1, so the same amount of monetary value will bring an organization that holds utility function 2 a higher satisfaction level, which is a higher utility value. As a result, for the risk averse utility function, the more the plot bends over, the more risk aversion is represented. In parallel with the risk averse utility function, Figure 8 shows two utility functions for risk seeking: utility function 3 and utility function 4.

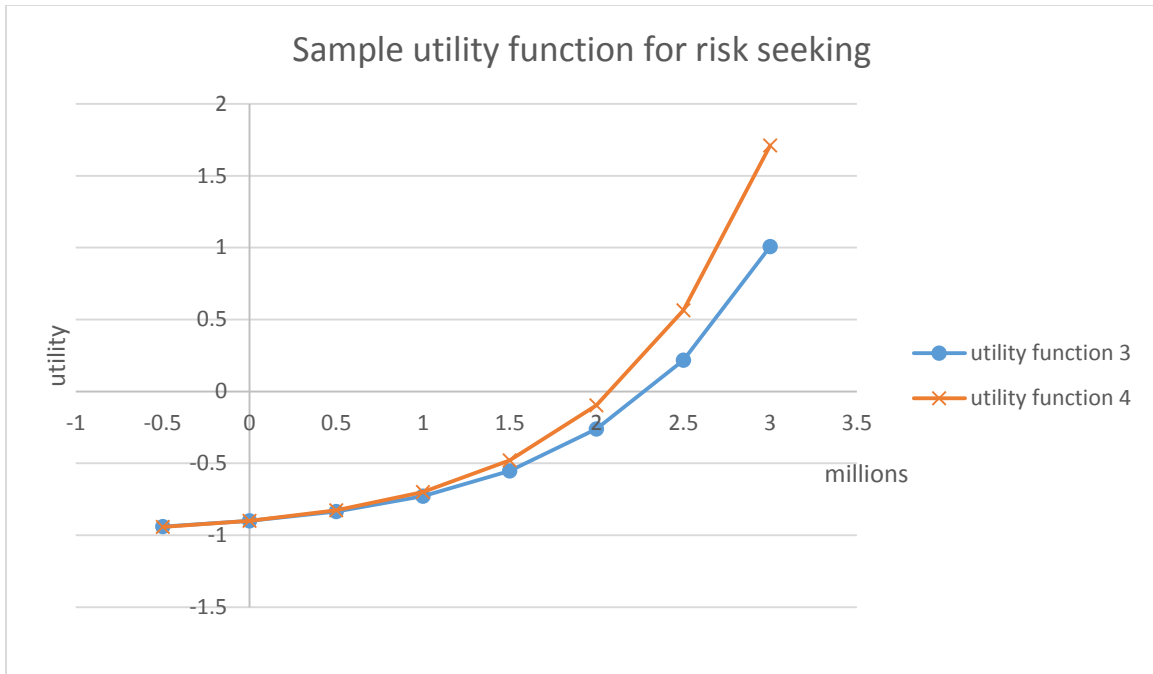


Figure 8 Sample utility function for risk seeking

Utility function 3 and utility function 4 are considered risk seeking, since the shape of both curves are convex up. However, utility function 3 is considered to be relatively risk averse when compared to the other, because the same monetary amount increment brings more utility to utility function 4.

3.3.3 Common Types of Utility Functions

From previous research, the most commonly used utility function are:

1. Exponential utility function:

$$u(x) = 1 - e^{-\alpha x}, \alpha > 0$$

2. Logarithmic utility function:

$$u(x) = \log(x)$$

3. Power utility function:

$$u(x) = x^\alpha$$

4. Iso-elastic utility function:

$$u(x) = \frac{x^{1-\eta}}{1-\eta}, \eta < 1$$

Although these four utility functions are widely used, this research tends to focus on exponential utility function to model construction organizations' risk tolerance.

3.3.3.1 Exponential Utility Function

Any decision facing the organization can be analyzed best if the organization's attitude towards project risk is well known and represented in the analysis by an appropriate utility function (Hulett, 2013). As mentioned in the previous section, construction organizations often perceive a greater aversion to losses from failure of the project than they benefit from a similar-size gain from project success. For example, in the construction industry, the fear of losing \$1 million usually outweighs the benefit of gaining \$1 million. Exponential utility function is a common choice for representing a construction organization's risk averse attitude, because of its convenience when risk are presented. It also has an appropriate curvature for risk aversion since the normal exponential utility function is always concave.

Exponential utility function can have multiple forms, such as:

1. $u(x) = -e^{-\alpha x}$, for any coefficient of risk aversion $\alpha > 0$
2. $u(x) = A - Be^{-\alpha x}$, for any coefficient of risk aversion $\alpha > 0$
3. $u(x) = 1 - e^{-\frac{x}{R}}$, for any coefficient of risk aversion $\alpha > 0$

In this thesis, the third exponential utility function is used most to determine a construction organization's risk aversion. For an exponential utility function $u(x) = 1 - e^{-\frac{x}{R}}$, the degree of risk aversion is determined from its concave curvature, which is directly influenced by the parameter "R," known as the risk tolerance. The risk tolerance parameter R can be illustrated as the indicator of the decision maker's or organization's willingness to accept risk; however, it is not the maximum amount of risk that the organization can

organizations would make the investment because most of them can bear the risk. However, if R is very large, those organizations would not make the investment because they cannot afford to lose. As a result, organizations with relatively larger risk tolerance R are considered to be less risk averse. Lee Merkhofer Consulting suggests that the typical risk tolerance at the CEO or Board level are often equal to about 20% of the organization's market value for publicly traded firms.

However, sometimes this method, when used to determine risk tolerance parameter, is still vague for a decision maker of an organization. The question will be clearer if this investment question is transferred to a lottery question. A sample lottery question is shown as follows: "Assume there is a lottery game with two alternatives: the first alternative is to win \$50,000, the second alternative is to lose half, which is \$25,000. Will you play this lottery game?" If the decision maker's answer is positive, by increasing the monetary value, there is a peak point that the decision maker will not play this lottery game, where the peak point is described as the risk tolerance parameter R .

Once the risk tolerance parameter is set, the exponential utility function can be plotted for further analysis. Figure 10 illustrates the difference between exponential utility functions corresponding to the different risk tolerance parameter R.

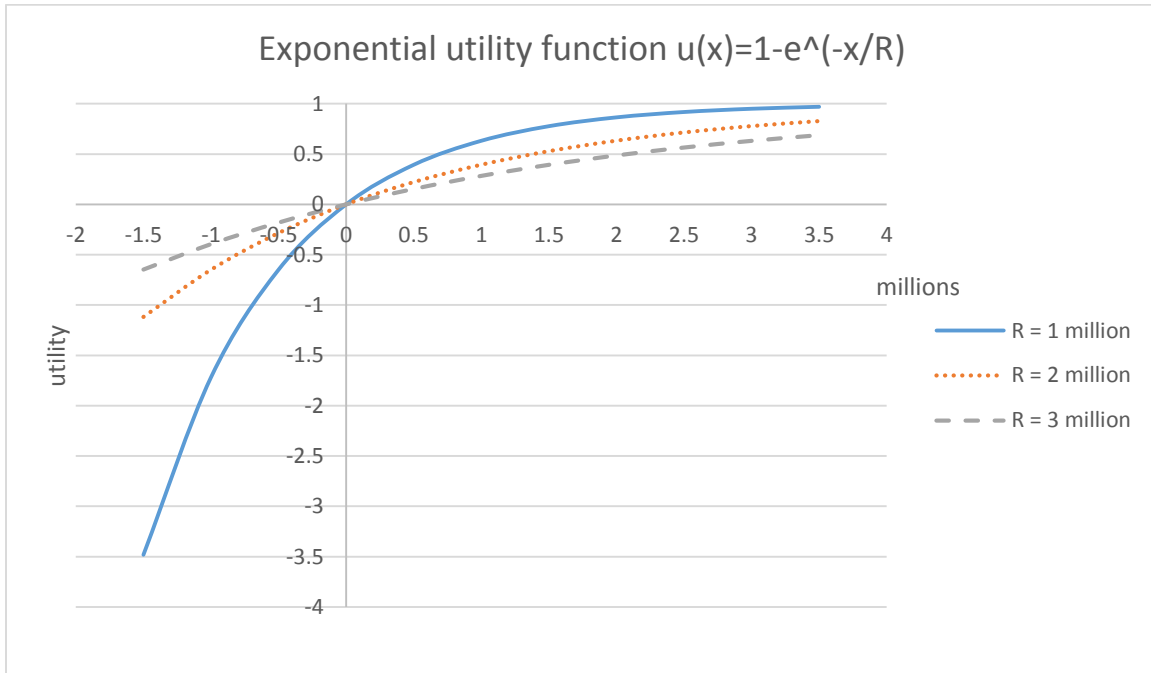


Figure 10 Sample exponential utility function

As shown in Figure 9, the utility function of the risk tolerance parameter R is equal to 1 million bends over the most that it holds the highest risk aversion among these three utility functions. When the exponential utility function is determined, it can be used to compute the certain equivalent. Assume R equals 2 million, and the risk is a 50% chance of -\$1.5 million and 3.5 million. The procedures to define its certain equivalent are listed as follow:

1. From Figure 10, determine the utility of -\$1.5 million and \$3.5 million.

$$u(-1.5 \text{ million}) = -1.117$$

$$u(3.5 \text{ million}) = 0.826$$

2. Determine the expected utility for this risk, which is

$$0.5 \times u(-1.5 \text{ m}) + 0.5 \times u(3.5 \text{ m}) = 0.5 \times (-1.117) + 0.5 \times 0.826 = -0.146$$

3. Locate the expected utility (-0.146) on the vertical axis and determine the corresponding certain equivalent on the horizontal axis, as illustrated in Figure 11. The horizontal coordination of the intercept on the graph indicates the certain equivalent. For this particular case, the certain equivalent is equal to -\$0.273 million.

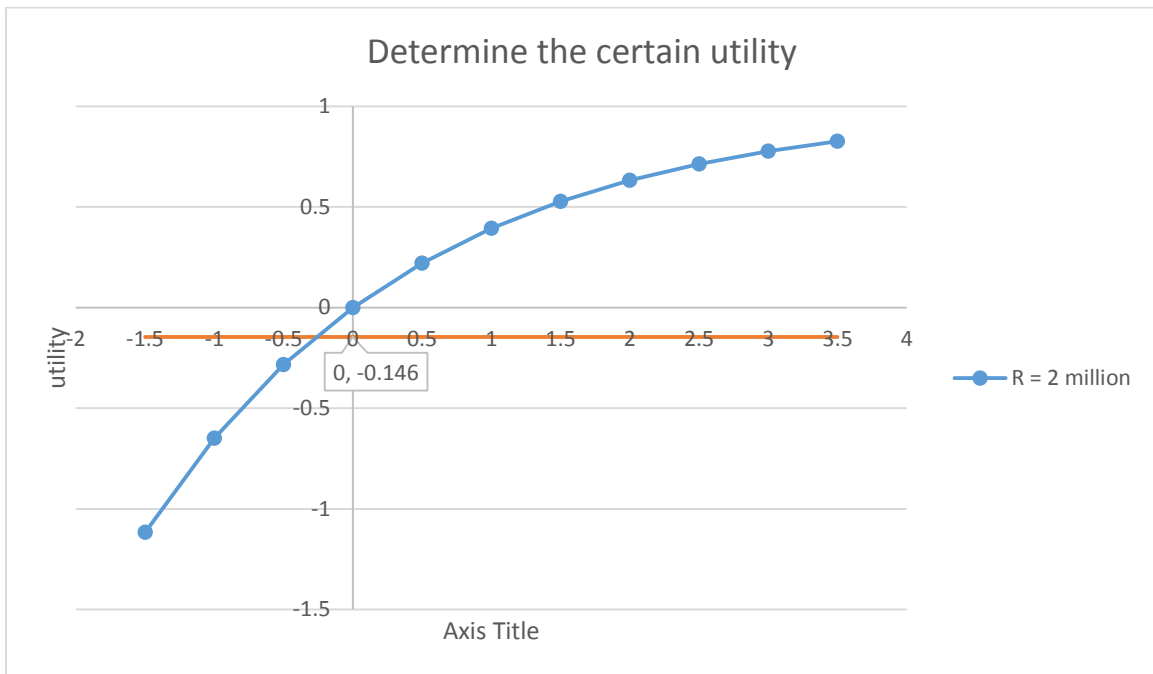


Figure 11 Determine the certain equivalent

Another method used to define the utility function is to track and evaluate an individual's view of the utility by presenting a pre-determined utility function. For example, Figure 12 shows two pre-determined utility curves: utility 1 and utility 2. By comparing the utility increment at the same profit level, the decision maker will have a preference towards one utility function. In this case, the increment of utility Δu for utility 1 is greater than utility 2 before 4 million, but smaller after 4 million. The decision maker can customize the utility curve until the increment of utility Δu reaches the expectation at all monetary levels. Once

the utility increment of a utility curve at each level is agreed upon by the decision maker through the trial, this final utility curve expresses the decision maker's attitude towards profit. This method is more accurate than the utility function, but it requires more inputs and time compared to the previous method.

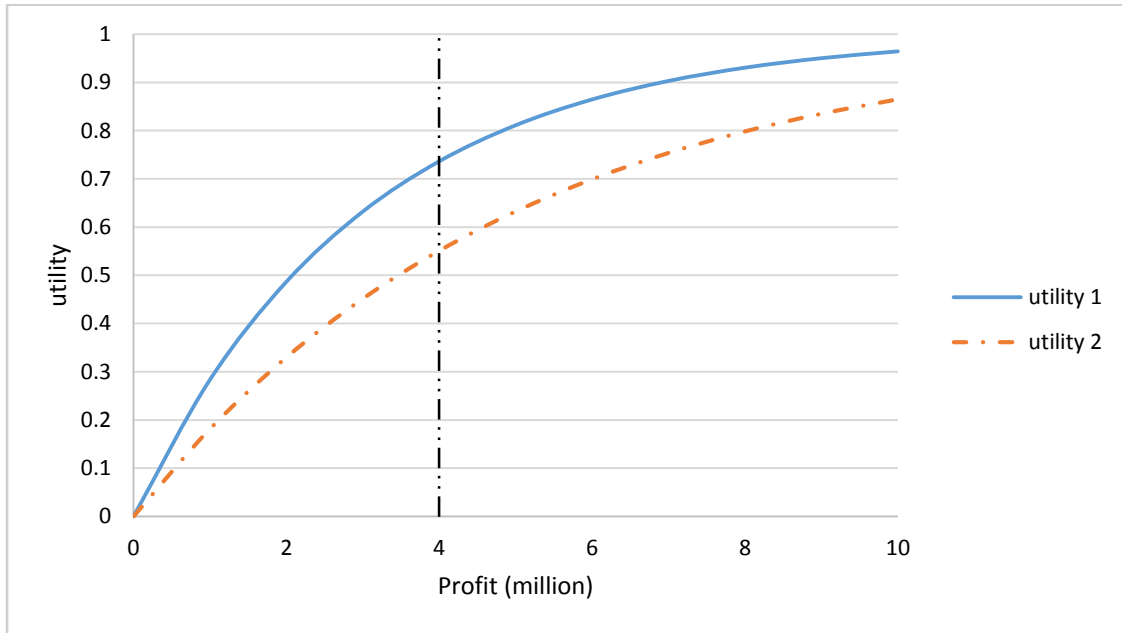


Figure 12 Example of customized utility function

4 Application of Utility Theory

4.1 Determine the Utility Curve for a Cumulative Project Cost

A cumulative distribution of project cost can be generated from the simulation tool that reflects all the possible outcomes from the risks. Since a construction project usually involves multiple risks, it is difficult to create a series of utility functions for each risk factor encountered. Instead, the utility theory is applied to the cumulative distribution function (CDF) as a whole. In order to fit CDF to the aforementioned exponential utility function, the cumulative distribution of project cost is transferred into a distribution of potential profit.

The potential profit of a project can be defined through a pre-determined project budget. This project budget is the critical value on the cumulative distribution of project cost that also stands for the maximum risk capacity an organization can afford to lose.

4.1.1 Risk Capacity

Risk capacity (contractor) or budget (owner) is defined as how much risk the individual or organization can afford. In detail, the Financial Service Authority Guidance (2011) defines the capacity for loss as:

[The] customer's ability to absorb falls in the value of their investment. If any loss of capital would have a materially detrimental effect on their standard of living, this should be taken into account in assessing the risk that they are able to take.

In the construction industry, risk tolerance and risk capacity are always indispensable topics to discuss in the project planning process. Although organizations with different risk attitudes will lead to different risk tolerances, the risk capacities will not be influenced by the risk attitudes. Malkiel (1996) proposed that risk tolerance is subjective, but individual's risk capacity can be measured by their position in the life cycle. A project's state can be reflected by comparing an organization's risk tolerance and capacity. A large risk tolerance

with low capacity is a dangerous condition for a project, while a low tolerance with large capacity means a missed opportunity. However, in contrast, risk capacity can affect the risk tolerance. If a company has a large risk capacity, it may be more risk seeking in investment since it can bear more loss, while a company with low risk capacity may be more risk averse since it cannot afford to fail.

For a construction organization, especially for contractors, risk capacity is understood as the amount of risk that the company is able to support in pursuit of its objectives (COSO, 2012). In other words, the maximum risk capacity can be determined as the bottom line of a project cost, where any cost exceeding the maximum risk capacity will result in a negative net return in the end. There are multiple ways to determine the maximum risk capacity for a project. Three major facts need to be considered.

- Initial wealth – The more an organization has, the more it can afford to lose.
- Existing risk profile – If a construction organization undergoes multiple projects, its risk capacity may be relatively small compared to a same level organization that only has one project at a time.
- Project conditions – Risk capacity of a construction company varies between different projects. A project with diverse risk factors will result in a higher risk capacity, while a relatively safer project will decrease a company's risk capacity, since the possibility of the occurrence of unexpected consequence is small.

Similar to the previous section about the risk tolerance parameter R for expected utility, the maximum risk capacity can be determined from a questionnaire and what if analysis. However, most organizations determine their risk capacity from the company's situation, past history, and the market situation.

4.1.2 Create Utility Curve

Once the maximum risk capacity is determined, the potential profit can be calculated from the original cumulative project cost as follows:

$$\text{potential profit} = \text{maximum risk capacity} - \text{original project cost}$$

For example, assume a project suffers from various risk events. The simulated result gives a project cost minimum \$269,430.19 to maximum \$324,739.12. Figure 13 is the plot of the project cost as a cumulative distribution function.

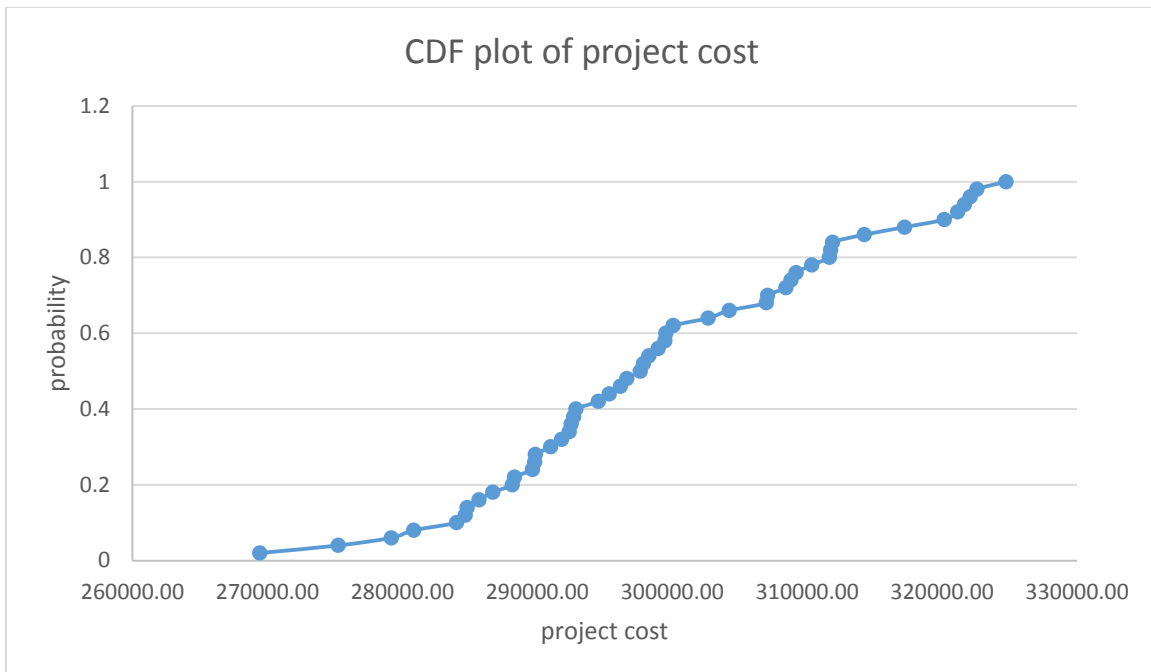


Figure 13 CDF plot of project cost

Before processing further analysis, a probability distribution is fitted to the series of the cost data collected. Vose (2010) indicates that a common problem in risk analysis is fitting a probability distribution to a set of observation for a variable in order to be able to make forecasts about the probability or frequency of occurrence in the future. Using probability distribution is a scientific way of dealing with uncertainty and making informed business decisions. In this case, normal distribution is selected as the fitting distribution of

the CDF, as shown in Figure 14. For example, if the construction organization wants to have 95% confidence that the project can be finished, the corresponding results from the CDF are determined to be around \$321,200.

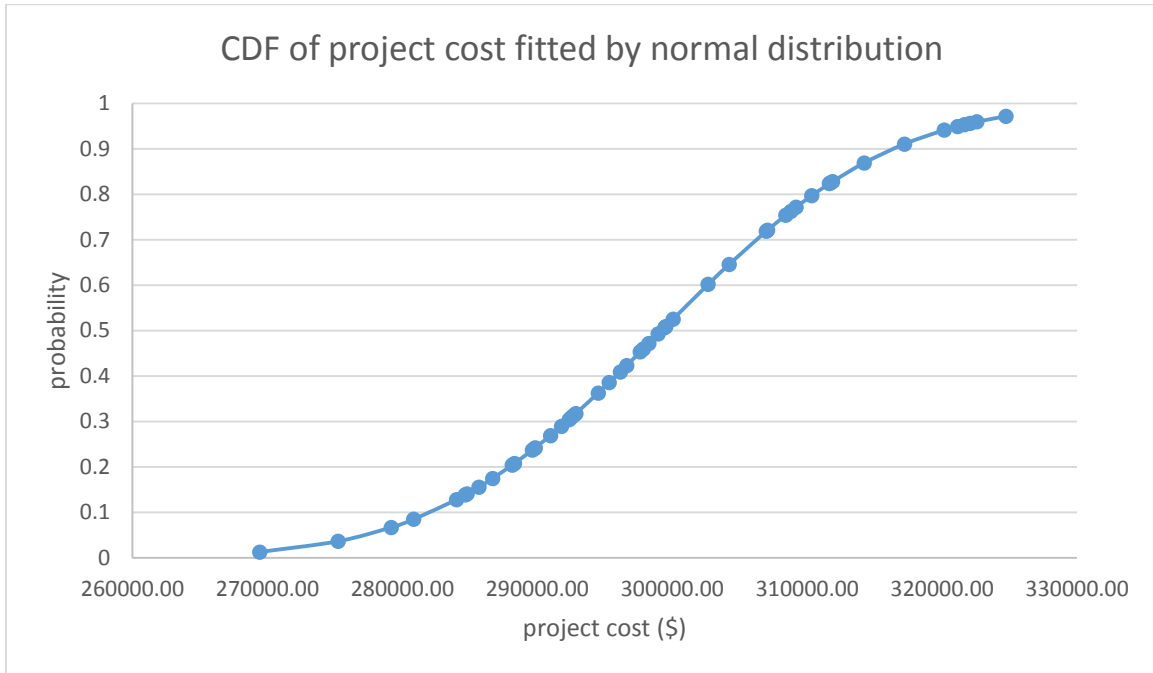


Figure 14 CDF of project cost fitted by normal distribution

For this particular example, assume the maximum risk capacity is \$310,000. The potential profit is determined in the following Table 9. The resulting maximum potential profit occurs when the project is finished within its minimum possible cost, which is \$40,569.81, while the worst situation is that the project loses \$14,739.12 when the simulation reaches the maximum project cost.

Table 9 Project Cost and Potential Profit

Probability	Project Cost	Maximum Risk Capacity	Potential Profit
0.0131025	269430.19	310000	40569.81
0.03684085	275251.83	310000	34748.17
0.06734714	279173.43	310000	30826.57
0.08515186	280842.80	310000	29157.20
0.12828786	284013.76	310000	25986.24
.....
0.94927746	321153.39	310000	-11153.39
0.95300505	321646.75	310000	-11646.75
0.95607325	322076.96	310000	-12076.96
0.95942121	322575.00	310000	-12575.00
0.97164611	324739.12	310000	-14739.12

As shown in Figure 15, the x axis is the probability generated from the normal distribution, and the y axis is the potential profit with respect to the probability confidence. The result shows that there is nearly 80% chance that this project can be finished within the budget.

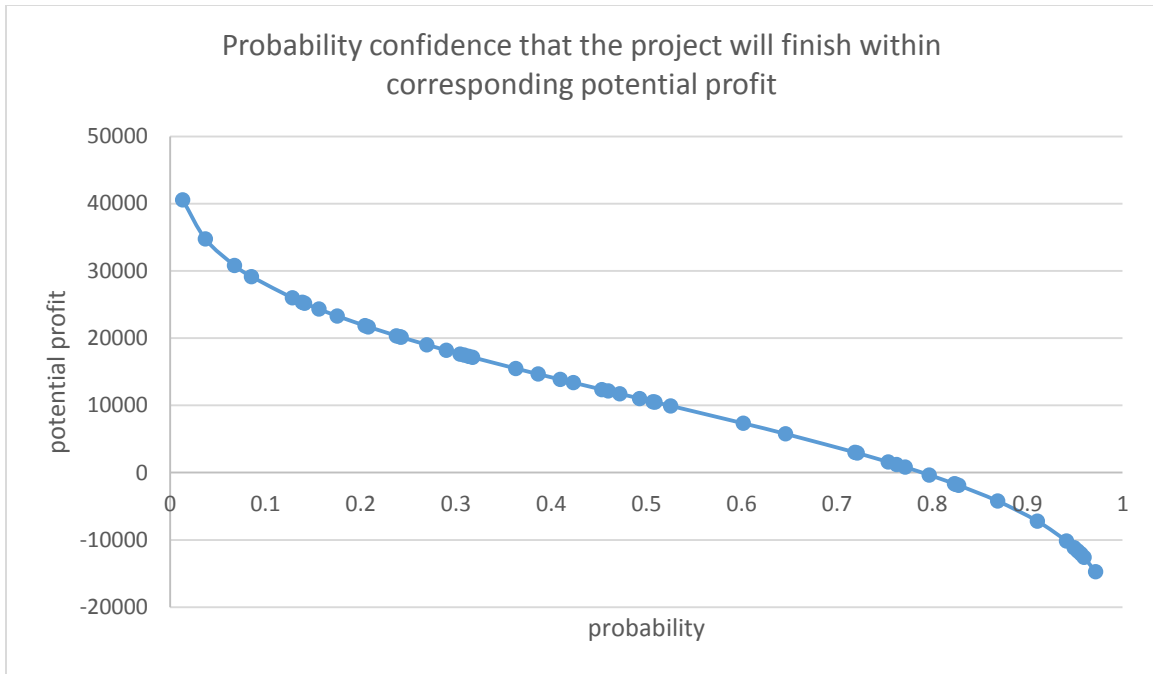


Figure 15 Probability confidence vs. potential profit

As the potential profit distribution is known, it can be applied to the utility function determined in the previous section:

$$u(x) = 1 - e^{-\frac{x}{R}}$$

For this particular case, assume two opposite conditions:

1. The construction organization is risk averse and the risk tolerance parameter R is equal to \$10,000.
2. The construction organization is relatively risk seeking and the risk tolerance parameter R is equal to \$30,000.

Figure 16 shows the actual plot of the exponential utility function for the potential profit with respect to the two different risk tolerance parameters.

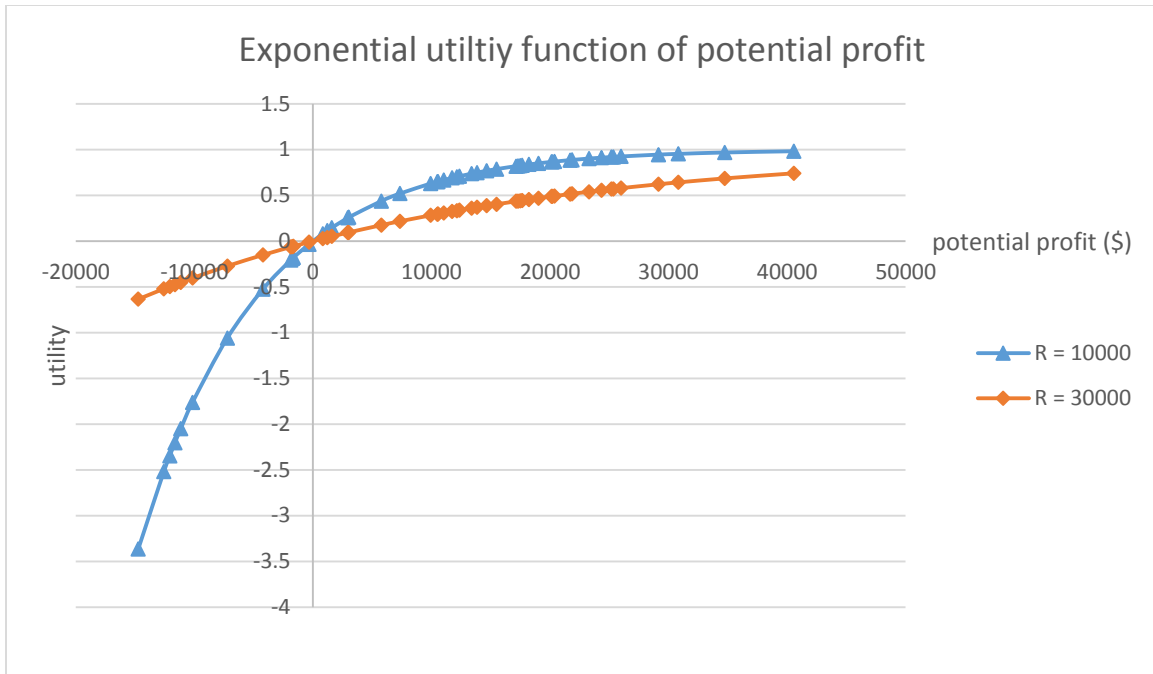


Figure 16 Exponential utility function of potential profit

4.2 Determine the Utility for Project Risk

For a cumulative distribution function of project cost, a simple utility function cannot be used to determine risk tolerance because the greatest utility will always be the preference, which occurs at the minimum project cost in the series of data. However, as the simulation result in Figure 13 shows, the probability to finish the project within the minimum project cost \$269,430.19 is nearly zero. In order to modify the exponential utility function, another utility function of project risk is created.

The project risk utility function should also fulfill the requirement that the overall risk attitude towards the project is risk aversion, and the utility is always proportional to the project cost. Since the maximum project cost leads to the largest probability confidence to finish the project within the estimated budget, the corresponding utility of the maximum cost is determined to be 1, while on the opposite side, the minimum project cost should have the lowest utility.

4.2.1 Determine the Shape of the Risk Utility Function

As mentioned in the previous section, the risk utility function is always risk averse, which means a higher uncertainty will reflect a larger drop in the overall utility. Assume a project cost varies from \$3 million to \$4 million. The risk utility function should be plotted in a concave curve as shown in Figure 17.

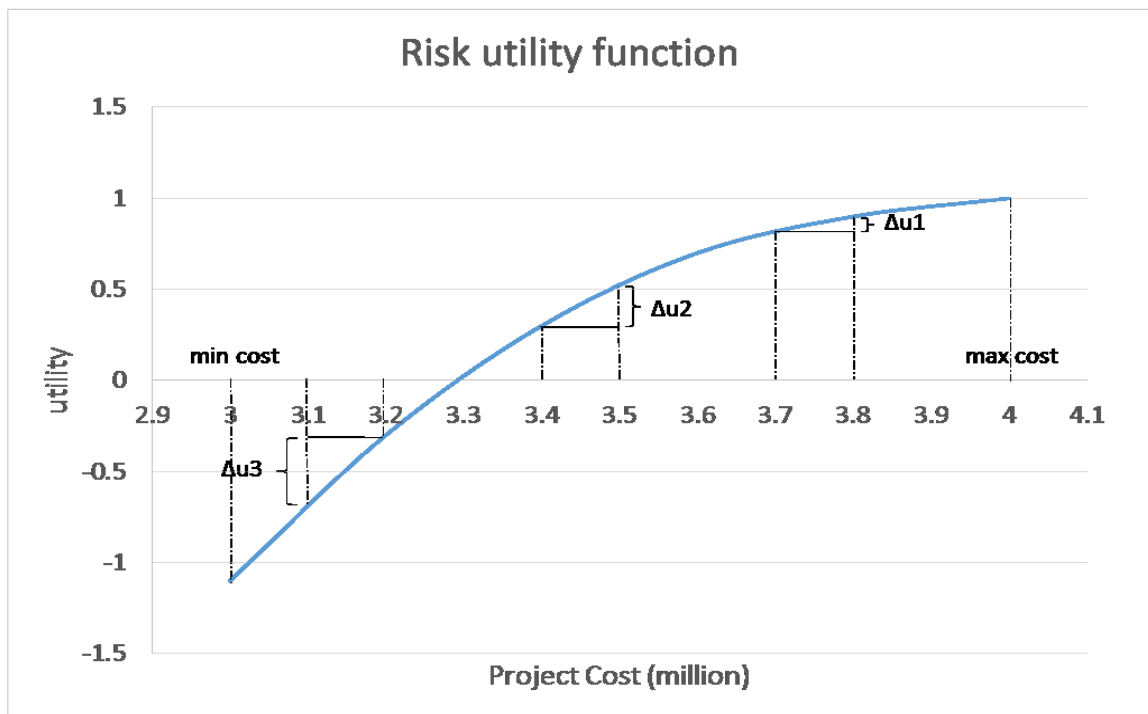


Figure 17 Sample risk utility function

The risk utility function should fulfill the requirement that $|\Delta u_1| < |\Delta u_2| < |\Delta u_3|$, thus, logarithmic or exponential function is an appropriate choice for the utility function. However, in order to estimate the risk utility more accurately, questionnaires can be used for further analysis.

4.3 Two Utility Function Combination

As mentioned in the previous sections, one cumulative distribution curve of project potential profit or project risk cannot be used to determine the risk tolerance because the

greatest utility will always occur at the maximum profit or maximum confidence. In order to integrate both profit and maximum, this thesis suggests combining two utility functions together as:

$$u_{overall\ tolerance} = u_{potential\ profit} + u_{risk}$$

A property called “additive utility” has been developed in the economic system to solve problems with multiple attributes; however, the combination of two utility function in this thesis is different from the original additive utility theory.

4.3.1 Utility Function Normalization

When the potential profit utility and the risk utility are determined, the following step is to normalize the utility functions. The reason for utility normalization is to make sure both the utility functions are in the same dimension for adding up. After the normalization, the profit utility and the risk utility are in the same range of [-1, 1].

For example, the original profit utility function is $u(x) = 1 - e^{-\frac{x}{R}}$, and the maximum utility is 1, but there is no boundary for the lowest minimum utility. In order to make the utility function more reliable, an improved exponential function $u(x) = A - B \times e^{-\frac{x}{R}}$ is developed to represent the organization’s profit utility. The coefficient A and B can be solved by:

$$u(x) = \begin{cases} -1, & x \text{ is the maximum loss} \\ 1, & x \text{ is the maximum profit} \end{cases}$$

If using the sample in Section 4.1.2, the new exponential function should be:

$$u(x) = \begin{cases} 1 - 0.448 \times e^{-\frac{x}{R}}, & R = 10000 \\ 1.4 - 1.4 \times e^{-\frac{x}{R}}, & R = 30000 \end{cases}$$

Compared to Figure 16, Figure 18 shows the plot of two utility functions after normalization with respect to different risk tolerance parameters.

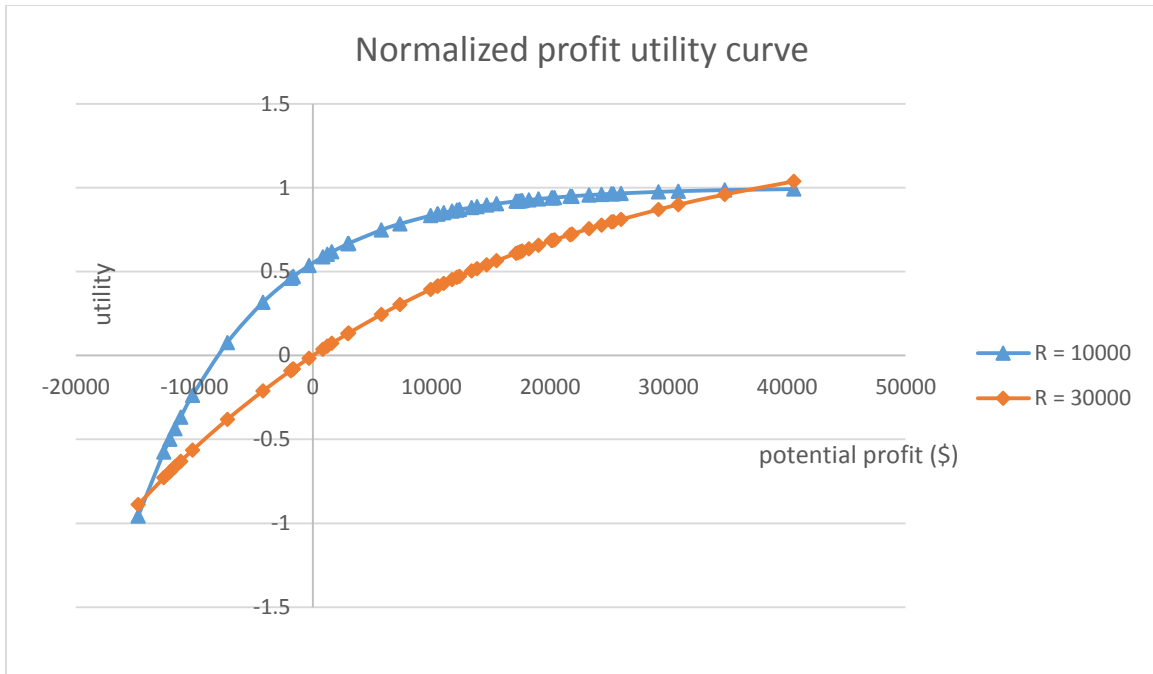


Figure 18 Normalized profit utility curve

After the normalized profit utility curve is generated, organizations can compare their risk appetite with the determined curve. For the above example, the maximum profit of the project is rounded to \$40,000 and the maximum loss is \$14,700. Assume there is an investment with two alternatives, winning the same amount as the maximum profit, or losing the same amount as the maximum loss. An organization can self-determine the probability distribution of these two alternatives; thus, the organization will participate in the investment with the determined probability distribution. Assume an organization is risk averse with a risk tolerance parameter R equal to 30000, as shown in Figure 18, the probability “P” of winning \$40,000 should fulfill the following equation:

$$1 \times P + (-1) \times (1 - P) = Y - \text{intercept} \approx 0.5$$

Thus, the probability “P” of winning is at least 0.75 in order to participate. If the organization is relatively risk seeking and its risk tolerance parameter R is equal to 10000, the probability “P” of winning is dropped from 0.75 to 0.5. Organizations can self-check the

potential risk utility function using the above approach in order to determine the correct risk aversion attitudes.

The project risk utility function can also be normalized to a range of [-1, 1] by adding a coefficient to the utility equation. For the example in Section 4.1.2, assume the original risk utility function uses logarithmic function to represent its risk aversion degree, the risk utility function is determined as $u(x) = 1 + A \times \ln\left(\frac{x}{\text{maximum project cost}}\right)$, which fulfills the requirement that utility equals 1 when the project cost is at its maximum. The coefficient A can be generated from the point (minimum project cost, -1). In the end, the risk utility function for the above example is determined as the following equation:

$$u(x) = 1 + 10.67 \times \ln\left(\frac{x}{325000}\right)$$

4.3.2 Overall Utility Formation

The core approach to determine an organization's risk tolerance is to sum both profit utility and risk utility together to obtain an overall utility function indicating the risk attitudes with respect to not only the profit, but also the potential risk from seeking profit. The normalized utility function will ensure that the overall utility equals zero in both the best and worst cases, because the maximum project cost has a utility of -1 for potential profit and 1 for project risk, while the minimum project cost has the opposite situation. In order to plot the overall utility function, the x-axis of the project potential utility function should transfer from the profit to the project cost, which can be done by reflecting the curve about the y-axis, as shown in Figure 19. Based on the sample project in section 4.1.2, the project risk utility function is shown in Figure 20.

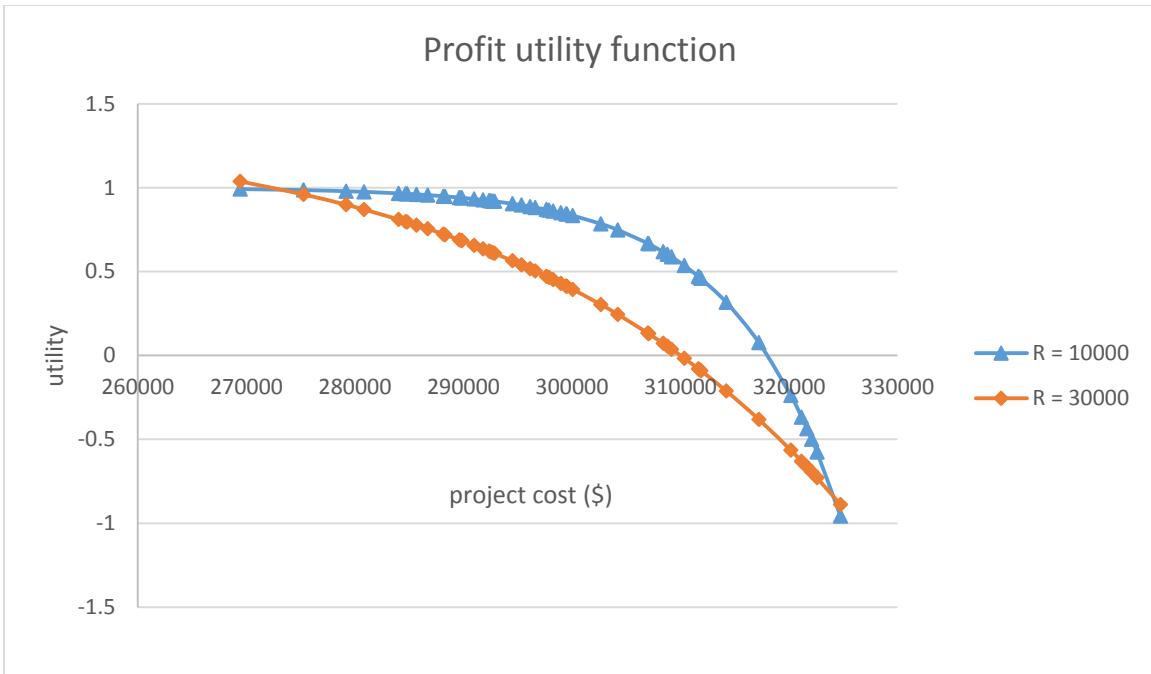


Figure 19 Profit utility function with respect to project cost

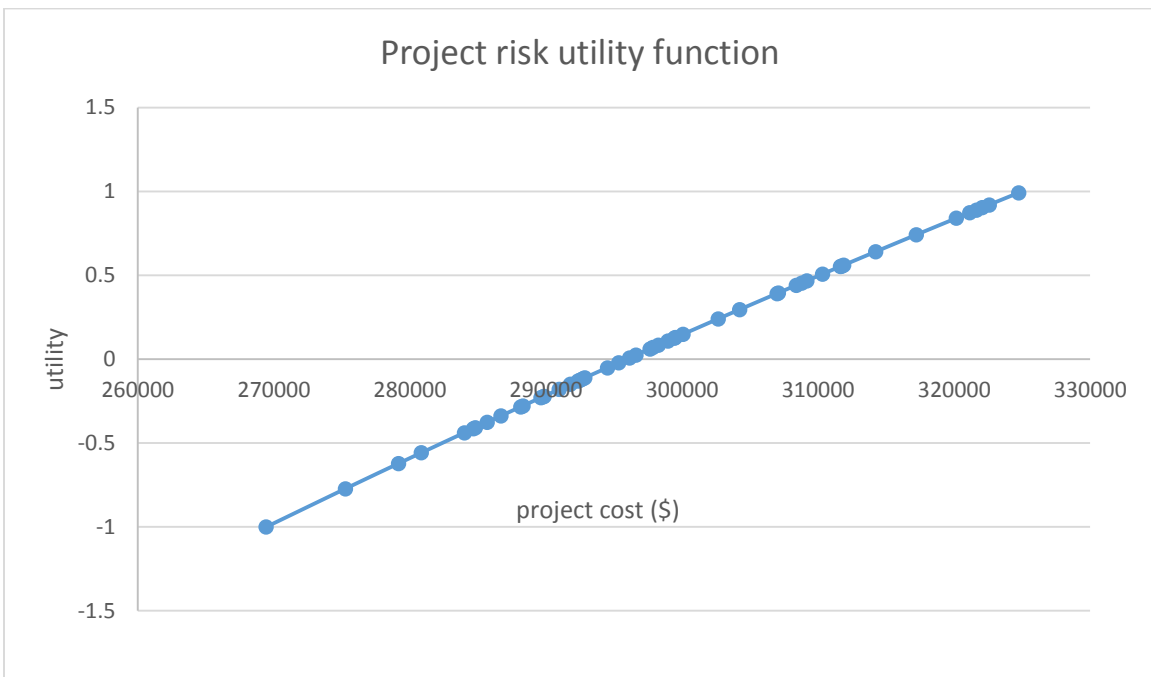


Figure 20 Project risk utility function with respect to project cost

Once the potential profit utility function and the project risk utility function are in the same dimension, the following step is to add two functions to create an overall utility curve that represents the organization's overall risk tolerance, as shown in Figures 21 and 22.

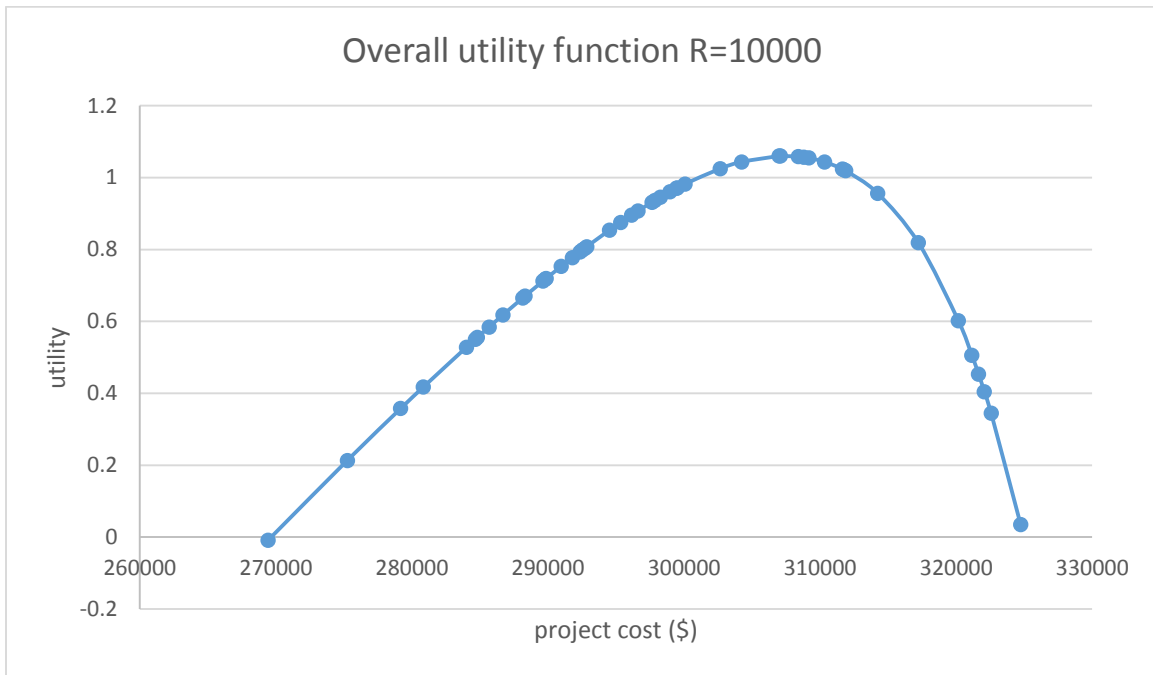


Figure 21 Overall utility function R=10000

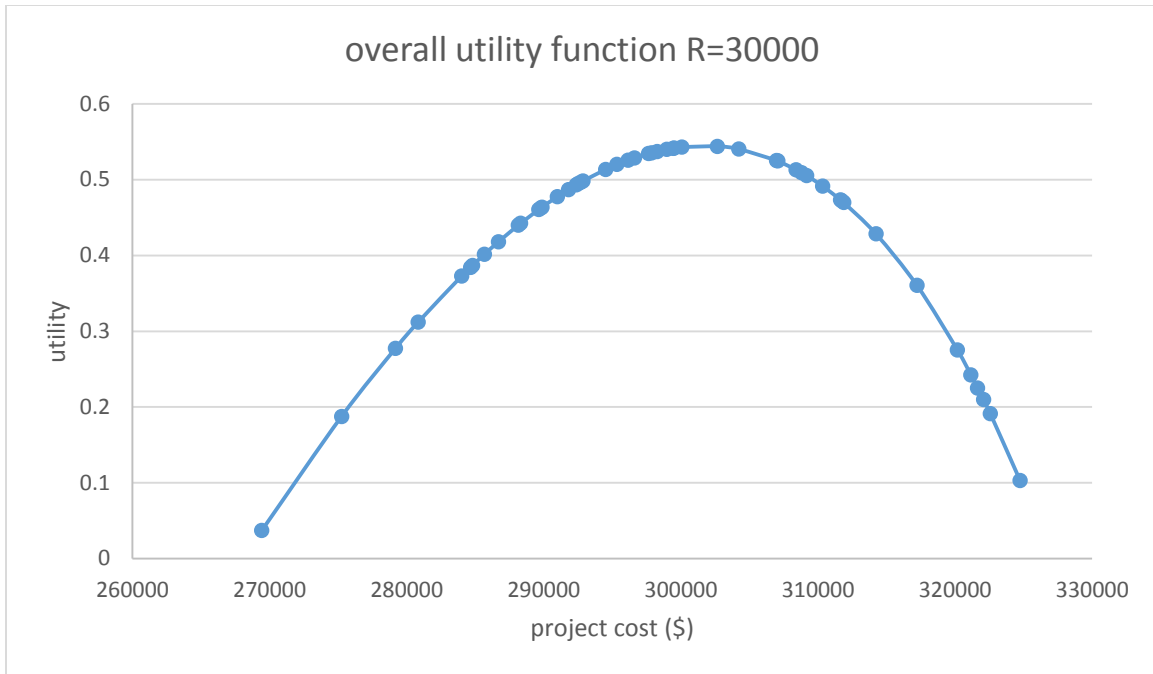


Figure 22 Overall utility function R=30000

As shown in the above figures, the optimal project cost for R equal to 10000 is somewhere between \$306,978.2 and \$307,070.9, while the optimal project cost for R equal to 30000 is between \$300,067.4 and \$302,664.7. Since the sample is a hypothetical small project, the estimated project cost for different risk tolerance parameter R is relatively close; however, the organization with a higher risk aversion has a larger project cost.

4.3.3 Determine the Weight of Utility Function

Although the normalization process translates two utility functions into the same range for analyzing, the profit utility function and risk utility function may also be weighed for other purposes. The weighed utility function should have the following formula that balances the potential profit and risk:

$$u_{overall} = \lambda \times u_{profit} + (1 - \lambda) \times u_{risk}$$

Although the approach of adding utility function is based on a rule that construction organizations are always risk averse towards any type of project, there is still bias between

how much risk the organization is willing to bear and the resulting profit it is willing to pursue. In a normal situation, assume a construction organization is totally unbiased between profit and risk; the related weight coefficient λ should be 0.5. However, the attitude towards gain and loss is always a human dynamic that varies in different circumstances. For example, if the organization values profit more than the corresponding risks, the λ under such circumstances may have a range between (0.5, 1), which provides a heavier weight to the profit side. To illustrate this graphically, assuming the new estimated λ for a relatively aggressive construction company with a risk tolerance parameter of R equal to 30000 is 0.7, the new overall utility curve from the previous example is plotted in Figure 23. The optimal project cost is between \$298,965.74 and \$299,516.62, which is less than the original value.

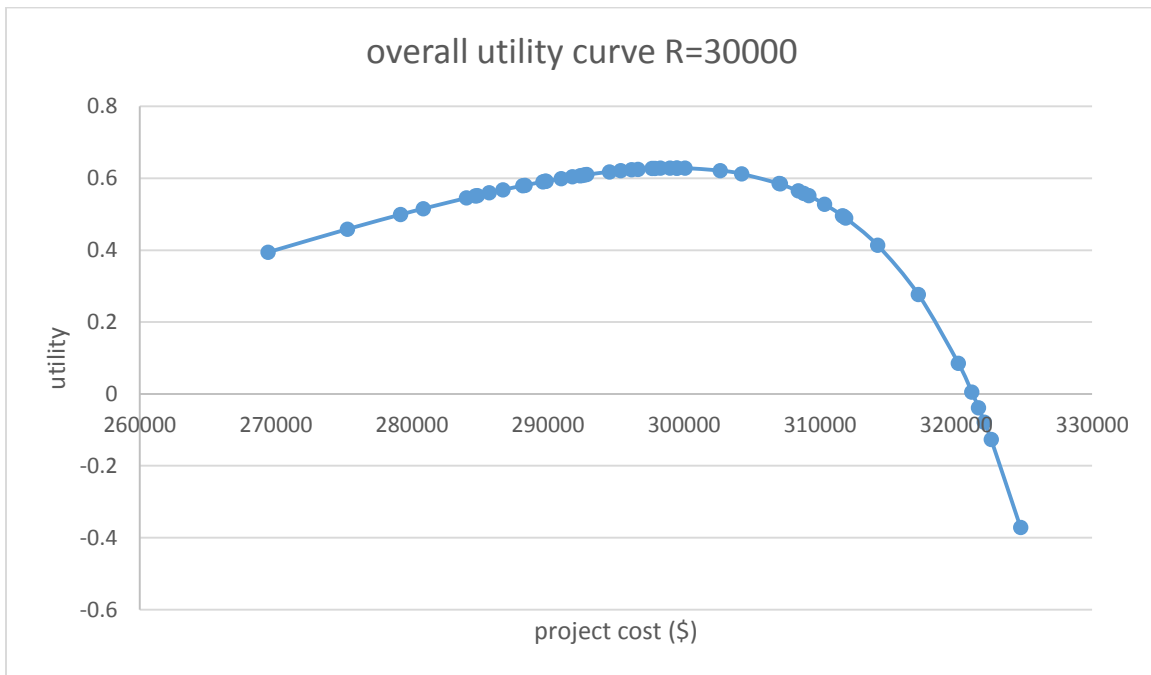


Figure 23 Overall utility curve with applied weight coefficient

4.3.3.1 Weight Assessment

There are multiple ways to determine the weight coefficient. Survey is an effective method to assess individual's preferences between risk and profit, but it is difficult to quantitatively determine the ratio between these two factors.

A simple method to determine the weight of utility function is to compare individual's preferences by assigning a hypothetical rate to the risk and profit. If an organization can directly specify the ratio of the weights as $\lambda_{profit} = 2\lambda_{risk}$, then λ_{profit} equals to 2/3 and λ_{risk} equals to 1/3.

Another method is to compare the uncertainty amount with a sure amount in order to manage the ratio between risk and profit. For example, if a project suffers from an uncertainty which may cause 20% chance of losing \$10,000, the organization is asked to determine the sure amount they are willing to pay to eliminate the potential risk. Assume the following equation holds; the ratio between the risk utility and profit utility can be calculated from the sure amount determined in the above hypothetical question:

$$\frac{\text{expected risk impact}}{\text{sure amount determined}} = \frac{\lambda_{profit}}{\lambda_{risk}}$$

The expected risk impact is calculated as the total impact multiplied by the occurrence possibility, which is \$2,000 in the above sample. If an organization is willing to pay \$1,500 to eliminate the risk, then the ratio " $\frac{\lambda_{profit}}{\lambda_{risk}}$ " is determined to be 4/3. Since the organization only accepts to disburse \$1,500 from potential profit to manage a risk with expected impact of \$2,000, the organization is considered to be profit biased.

5 Development of Simulation Tool

This chapter is intended to introduce a revised user interface of a simulation template developed in Symphony.NET. The template is based on Program Evaluation Review Technology (PERT), which is designed to represent and analyze the tasks involved in a given project. PERT was first developed by the US navy in the 1960's to measure and forecast progress in the Polaris submarine missile research. However, nowadays, it is widely used in the construction industry to model the construction schedule and the related risks. Several software tools such as Microsoft Project, Primavera 6, which is commonly used in project management, are designed in a PERT base.

5.1 Framework of PERT

The early version of PERT used to model project complete duration consists of three core steps:

1. Identify the specific activities.
2. Determine the proper sequence of the activities.
3. Construct a network diagram.

Nowadays, PERT also can be used to model the project cost with respect to the project uncertainties. The following sections briefly describe the theory of how PERT works in the project planning process.

5.1.1 WBS

The first step to model the project schedule using PERT is to determine all the tasks that the project requires and the order in which they must be completed. A work breakdown structure (WBS) is the most appropriate method used to determine all the tasks of a project. PMI (2004) defines the WBS as “a deliverable-oriented hierarchical decomposition of the work to be executed by the project team, to accomplish the project objectives and create required deliverable.” According to the Project Management Body

of Knowledge (PMBOK®), WBS can be used to effectively decompose the project scope, to improve estimating, to better control the project execution and to more accurately verify project completion (PMBOK, 2013).

In construction engineering, a common WBS allows people to visually see the overall work scope. A typical WBS is presented in the form of a tree structure. Generally, a project can be classified into three hierarchical levels, which are project, work package, and work task. Figure 24 shows a sample WBS diagram of a simple house construction. The highest level is always the project level, which only consists of one element that identifies the project. In this diagram, the project of house construction includes three work packages, which are internal work, foundation work, and external work. Each work package also includes several sub work packages, and the lowest level of the WBS is the work tasks allocated under the sub work packages. For example, the internal work has two sub work packages, electrical and plumbing, and the electrical work package consists of three work tasks, rough-in electrical, install and terminate, and HVAC equipment.

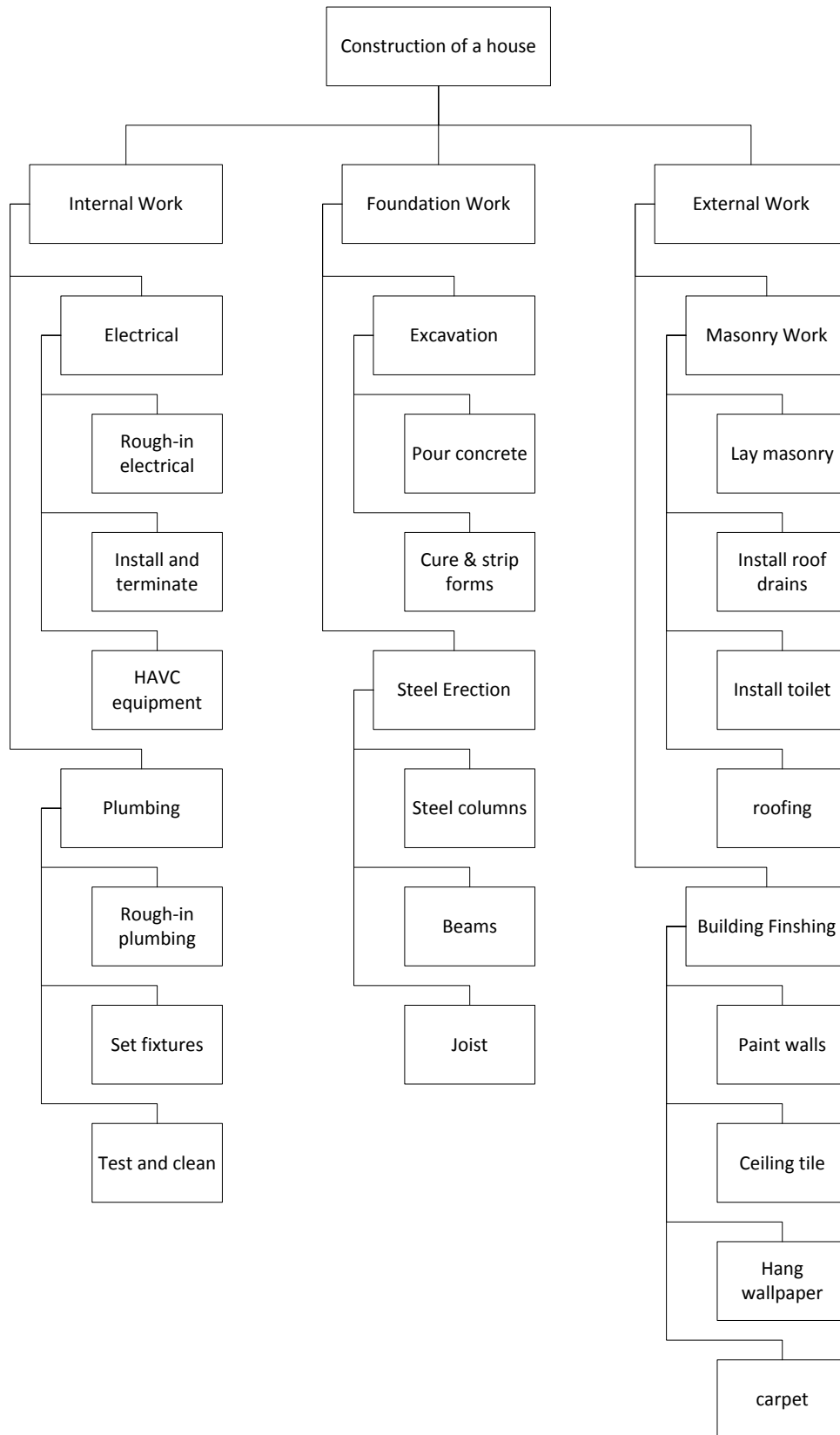


Figure 24 Sample WBS for house construction (Mark Swidersik, 2012)

5.1.2 Basic Theory of PERT

In order to model the project schedule using PERT, the sequence of each work package and the duration of each work task must be identified in the beginning. A sample project precedence shown in Table 10 illustrates the general requirements for creating a PERT model.

Table 10 Sample Project Sequence and Duration

Work Task	Predecessor	Estimated Duration			Expected Duration
		Optimistic	Mode	Pessimistic	
A	-	3	6	8	5.83
B	-	5	9	14	9.17
C	A	4	7	9	6.83
D	A	2	7	10	6.67
E	C	4	10	15	9.83
F	B, C	3	5	7	5.00
G	D	4	8	11	7.83
H	F	2	3	7	3.50

The conventional PERT method incorporates uncertainties in duration using three estimates: optimistic, most likely, and pessimistic.

- Optimistic time is the minimum possible duration required to accomplish a work task,
- Mode time is the most likely duration which is the best estimate duration to represent the work task, and
- Pessimistic time is the maximum possible duration required to accomplish a work task.

The expected duration “T” is calculated using the formula:

$$T = \frac{\text{optimistic duration} + 4 \times \text{mode duration} + \text{pessimistic duration}}{6}$$

However, the conventional PERT method has its weakness. Each work task can only have one duration, instead of random activity duration. Lu and AbouRizk (2000) indicated that one promising solution to PERT’s defects is to perform a formal stochastic simulation such as the Monte Carlo Simulation. In the simulation based network analysis, work task durations are randomly selected from the distribution that the user specifies, and the overall project duration will be displayed in a cumulative distribution curve. Moreover, the stochastic simulation can also be applied to the estimation of project cost, which reflects the impacts of the uncertainties. By allowing users to consider the schedule risk and cost risk associated with a project, the simulation based network analysis results in a more accurate and realistic estimation of project completion time and overall cost (Hong, 2012).

5.1.3 PERT Network Diagram

PERT network diagram is usually presented as a chart that graphically represents all the tasks in a project. There are two types of network diagrams, activity on arrow (AOA) and activity on node (AON). The simulation template created in Symphony.NET is based on AON network. To create an AON diagram, it is recommended to start with a node named “start” and to finish with a node named “finish.” These two nodes are considered as two activities with no durations. For example, Figure 25 is an AON diagram based on the information given in Table 10.

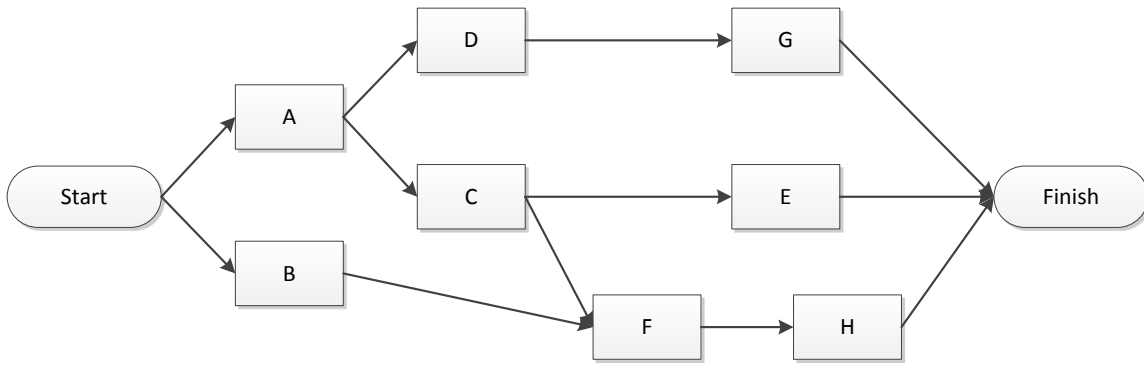


Figure 25 Sample AON diagram

The direction of the arrows on the lines indicates the sequence of tasks. In this diagram, for example, activity A, D, and G must be completed in sequence, or activity F can only start when both activity B and C are completed, etc.

The duration schedule calculation for a conventional PERT model is straightforward by following the critical path method scheduling rule. Figure 26 shows the sample scheduling for the project in Table 10. “S” means the start time of the activity and “F” means the finish time. In a PERT network diagram, the finish time is usually equal to the start time plus the activity duration.

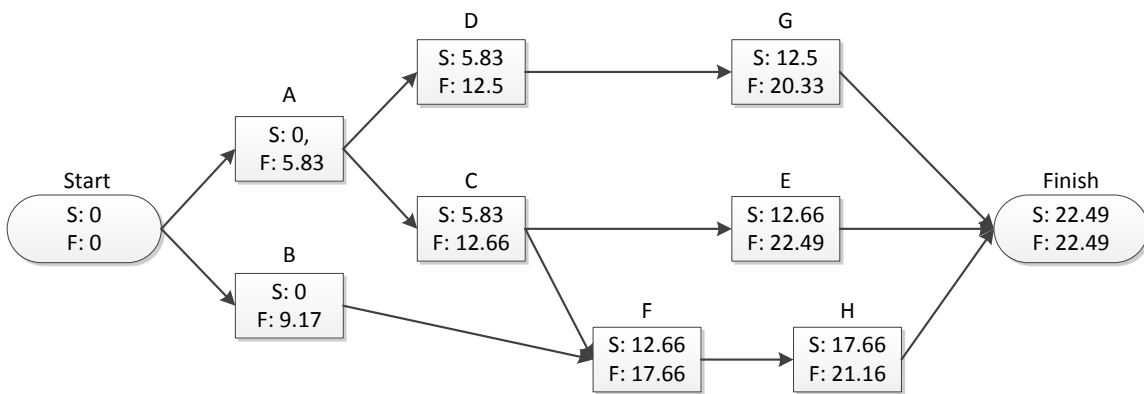


Figure 26 PERT scheduling

5.2 Original PERT Template in Symphony.NET

The original PERT template in Symphony was developed by Hong and AbouRizk in 2012. This section will briefly introduce the interface of the old template and identify the limitations.

5.2.1 Structure of Original PERT Template

The original PERT template in Symphony consists of three core components, WBS, RBS, and resource block.

WBS

The work breakdown structure is the main body of the template configuration shown in Figure 27. Each node stands for one work task and they are connected in sequence using the direction arrows as mentioned in the previous section.

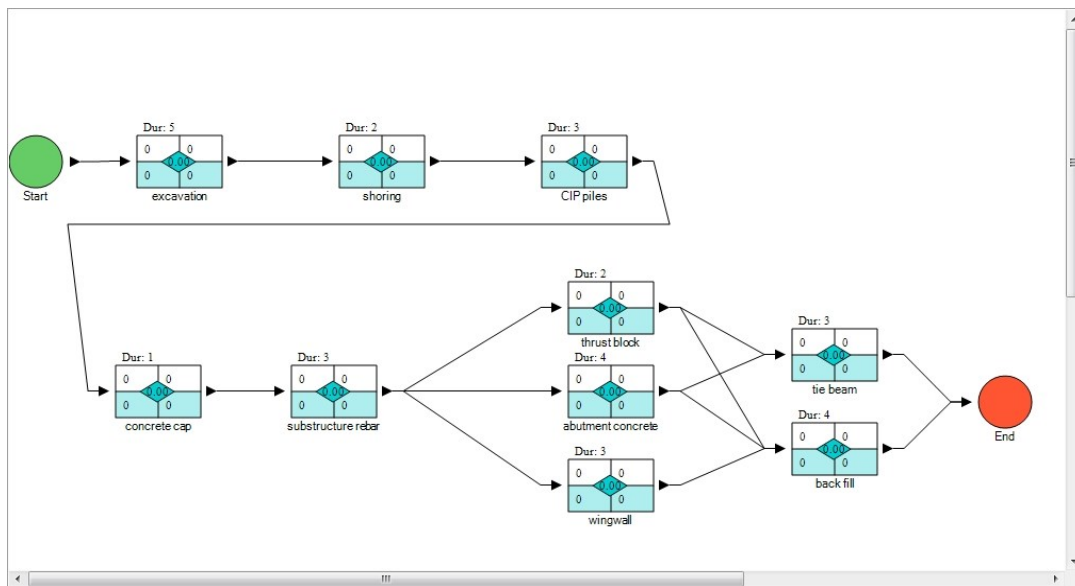


Figure 27 Sample WBS for PERT template

There are multiple inputs for one work task, such as duration, fixed cost, variable cost, and the resource allocation and risk assignment, which should be provided with the project information.

Resource Block

Resource block is a collection table shown in Figure 28 that identifies all the resources used in the project. Three categories: labour, equipment, and material, can be inputted in the left side of the table, and the right side of the table identifies the operation cost and the risk factors that influence the resource.

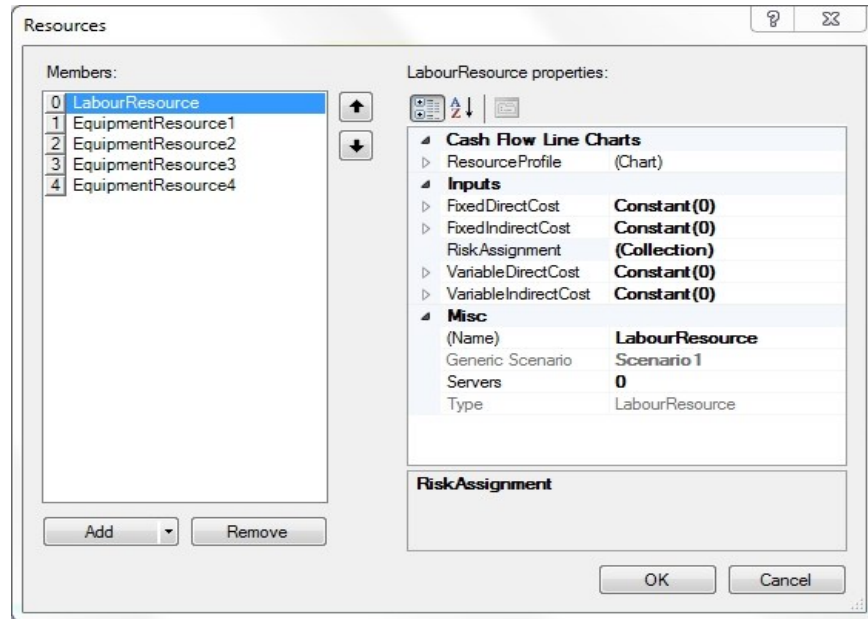


Figure 28 Resource block

RBS

The risk breakdown structure states the possible risk that influence project cost and schedule and the resource operation. As shown in Figure 29, the RBS consists of the risk category element, which is the intermediate level of RBS, and risk factor element.

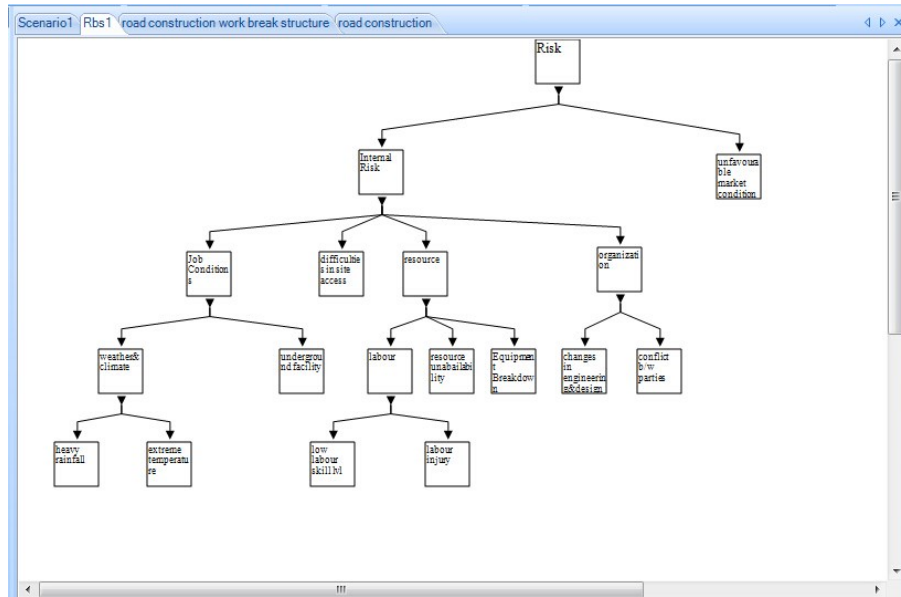


Figure 29 Risk breakdown structure

The risk factor is defined at the lowest level of an RBS, which will be assigned into work tasks and resource block. Each risk factor will require three inputs: (1) impact on cost, (2) impact on delay, and (3) likelihood. During the risk assignment process, the user is asked to determine the sensitivity of a risk factor that stands for the degree of the impact.

After the model is completed, the simulation process is developed, based on the flowchart shown in Figure 30.

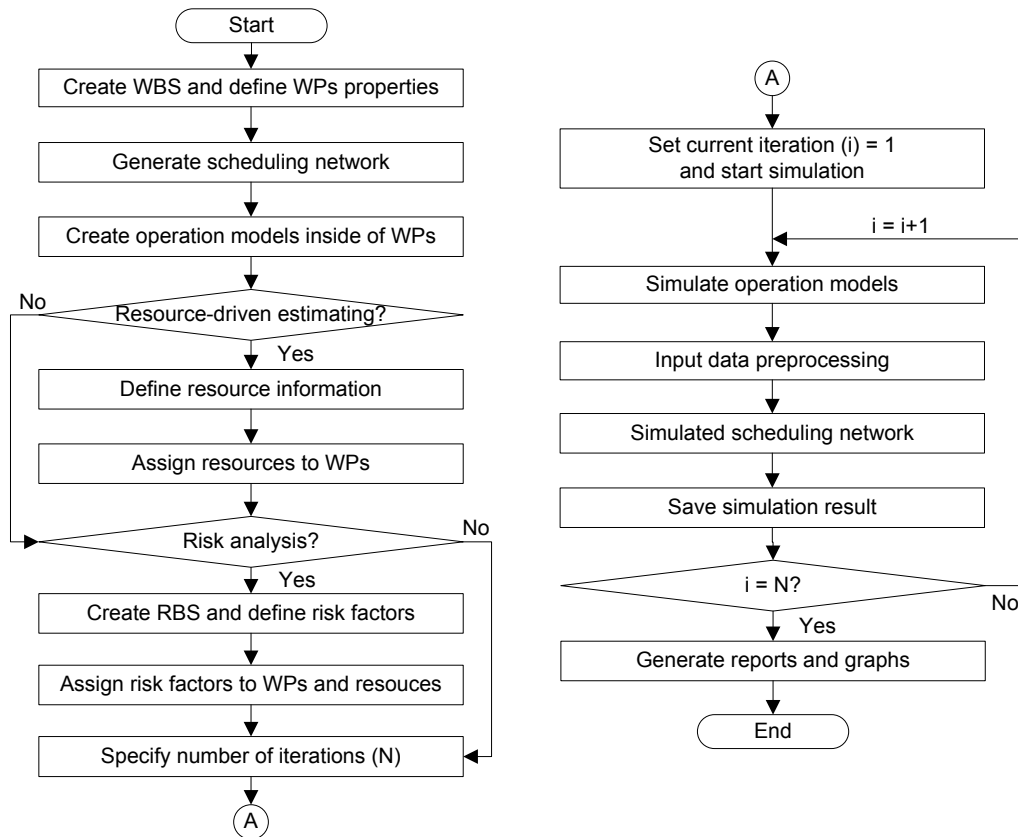


Figure 30 Flowchart of simulation process (Hong, 2012)

5.2.2 Limitations of Original Template

Several limitations of the original PERT template interface are found during application. This section includes a discussion of current limitations.

1. During the application, it was found that the time required to build a simulation model in the PERT template is much longer than other special purpose templates.
2. The WBS appearance is still based on the CPM network instead of the PERT network, and the project duration calculation is also based on the CPM method.
3. The template currently assumes an unlimited supply of resources. It can be modified to consider resource-constrained scheduling.

4. For a construction company use, it is difficult to determine the risk breakdown structure related with the impacts and corresponding sensitivity.
5. With an initialized RBS, a risk factor assigned to different work tasks will share the same likelihood and impact.
6. The determined risk factors can only affect work packages; however, there are risks that may influence the entire project (e.g., inaccurate estimation in the planning).
7. The risk allocation process is complicated since both resources and work packages need to be assigned by risk factors.

5.3 Revised PERT Template Interface

This section will introduce the new user interface of the revised PERT template. Section 5.3.1 presents the modeling elements and their relationship. Section 5.3.2 gives the information about input and output data processing.

5.3.1 Modeling Elements of PERT Template

The modeling elements of the revised PERT template are linked to each other, as shown in Figure 31. The first element created in the template is the project element, whose properties are the general information of the project. The project element requires two inputs: (1) all the resources involved in the project including labour and equipment, and (2) risk factors that will influence the entire project as a whole, such as inaccurate estimation in planning, etc. The outputs of the element contain the report of the overall simulation results, such as project schedule and cost.

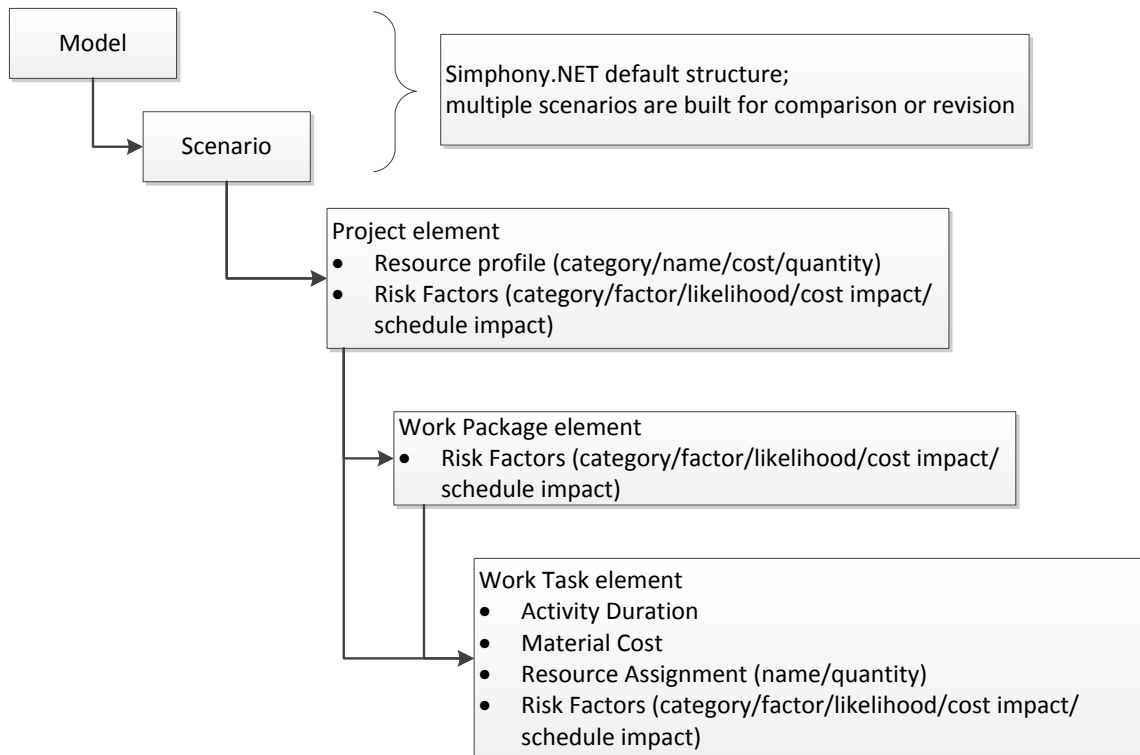


Figure 31 Template elements and relationship

The project element contains two child elements, work package element and work task element, which structure the WBS of a project. The work package is an intermediary element between project and work task, which integrates a series of work tasks into a package.

There is only one necessary input for work package element, which is the risk assignment. The risk factors assigned to a certain work package will influence all the work tasks under it. The work task element is the main object to be analyzed in simulation-based network scheduling. It includes properties such as duration, material associated with the task, resources associated with the task, and the risk factors that will influence the task. Figure 32 shows the network chart of the template.

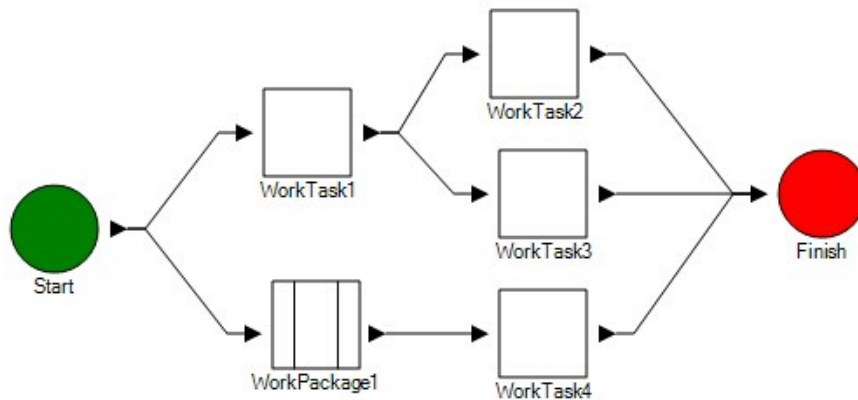


Figure 32 Network diagram of the revised PERT template

Each work task can have resources and risk factors assigned in the schedule network view. The resources assigned in the project element are directly applied to the work task in order to perform resource-driven scheduling. The quantity of each resource initialized in the project element will be considered as the resource constraint for simulation.

The risk assignment is identical for project, work package, and work task element. Risks applied to the project, work package, or work task have 5 properties: (1) risk category, (2) risk factor name, (3) likelihood, (4) cost impact, and (5) schedule impact. Each risk factor has an independent impact; therefore, a work task has a cumulative impact when multiple risk factors materialize at the same time. Both cost impact and schedule impact are entered, either deterministically (constant) or probabilistically (distribution), as a percentage of the initial duration or cost. For example, if a work task with a duration of 5 is influence by two risks (1) bad weather, and (2) bad geological condition, assuming both risks have a likelihood of 1 and a schedule impact of 20%, the new duration “D” for the task is calculated as:

$$D = \text{original duration} + \text{original duration} \times (B(1,1) \times 20\% + B(1,1) \times 20\%) = 7$$

B (1, possibility) is a binomial distribution, which means the event will either happen or not.

5.3.2 Input and Output Data Processing

5.3.2.1 Input Data Processing

The main interests in the simulation results are the statistics of the project cost and duration. Once all the required input data are determined by the user, the simulation can start. The project duration is calculated based on the PERT network; however, when there is risk applied on the schedule, the work task duration D_r is calculated as:

$$D_r = D_o + D_o \times \left\{ \left(\sum_1^i B(1, L_i) \times impact_i \right)_{workTask} + \left(\sum_1^j B(1, L_j) \times impact_j \right)_{workPackage} + \left(\sum_i^k B(1, L_k) \times impact_k \right)_{Project} \right\}$$

Where D_o is the original duration; L_i is the likelihood of risk factors in work task; L_j is the likelihood of risk factors in work package; L_k is the likelihood of risk factors in project level; and the impact is the corresponding schedule impact.

The project cost estimation is based on Monte Carlo Simulation, which is the same as @RISK in Excel developed by Palisade Corporation. The project cost simulation can be classified into three cases.

Case 1: No risk impact on both cost and duration

$$cost_{workTask} = cost_{resource} + cost_{material}$$

$$cost_{resource} = \sum_1^i (DC_i + IDC_i) \times Q_i \times D_o$$

$$cost_{workPackage} = \sum cost_{workTask}$$

$$cost_{project} = \sum cost_{workPackage} + \sum cost_{workTask}$$

Where DC_i is the direct cost of the resource; IDC_i is the indirect cost of the resource; and Q_i is the quantity of the resource assigned into the work task.

Case 2: Risks' impact on durations

$$cost_{workTask} = cost_{resource} + cost_{material}$$

$$cost_{resource} = \sum_1^i (DC_i + IDC_i) \times Q_i \times D_r$$

$$cost_{workPackage} = \sum cost_{workTask}$$

$$cost_{project} = \sum cost_{workPackage} + \sum cost_{workTask}$$

The calculation for project cost, which is influenced by schedule risk, is the same as the original cost calculation; however, the only difference is application of the new duration D_r into the resource cost calculation, since the duration change will only affect the operation cost of the resource.

Case 3: Risk impact on cost

If there are risk factors influencing the project cost directly, the calculation follows one rule: that the risks impact on duration is always applied before risks impact on cost.

$$cost_{workPackage} = \sum cost_{workTask}$$

$$cost_{project} = \sum cost_{workPackage} + \sum cost_{workTask}$$

$$cost_{workTask} = cost_o + cost_r$$

$$cost_r = cost_o \times \left\{ \left(\sum_1^i B(1, L_i) \times impact_i \right)_{workTask} + \left(\sum_1^j B(1, L_j) \times impact_j \right)_{workPackage} + \left(\sum_1^k B(1, L_k) \times impact_k \right)_{Project} \right\}$$

Where $cost_o$ is the original cost after risks impact on schedule; $cost_r$ is the extra cost of a work task caused by the risks impact on project cost; and the impact is the corresponding cost impact.

5.3.2.2 Output Data Processing

The outputs for the project, work package, and work task contain three statistics, the cost information, the start time, and the finish time. By implementing Monte Carlo Simulation technique in this PERT template, the ranges of possible duration and cost are calculated based on the impacts of associated factors. The statistics of outputs have various properties including mean, standard deviation, minimum, maximum, kurtosis, and skewness, etc.

The template's overall results are displayed in the form of histograms and cumulative distribution function graphs, as mentioned in the previous section. The template can generate both duration CDF, and cost CDF for use in decision making. Figure 33 shows a sample result of a cumulative distribution curve of project cost from the simulation.

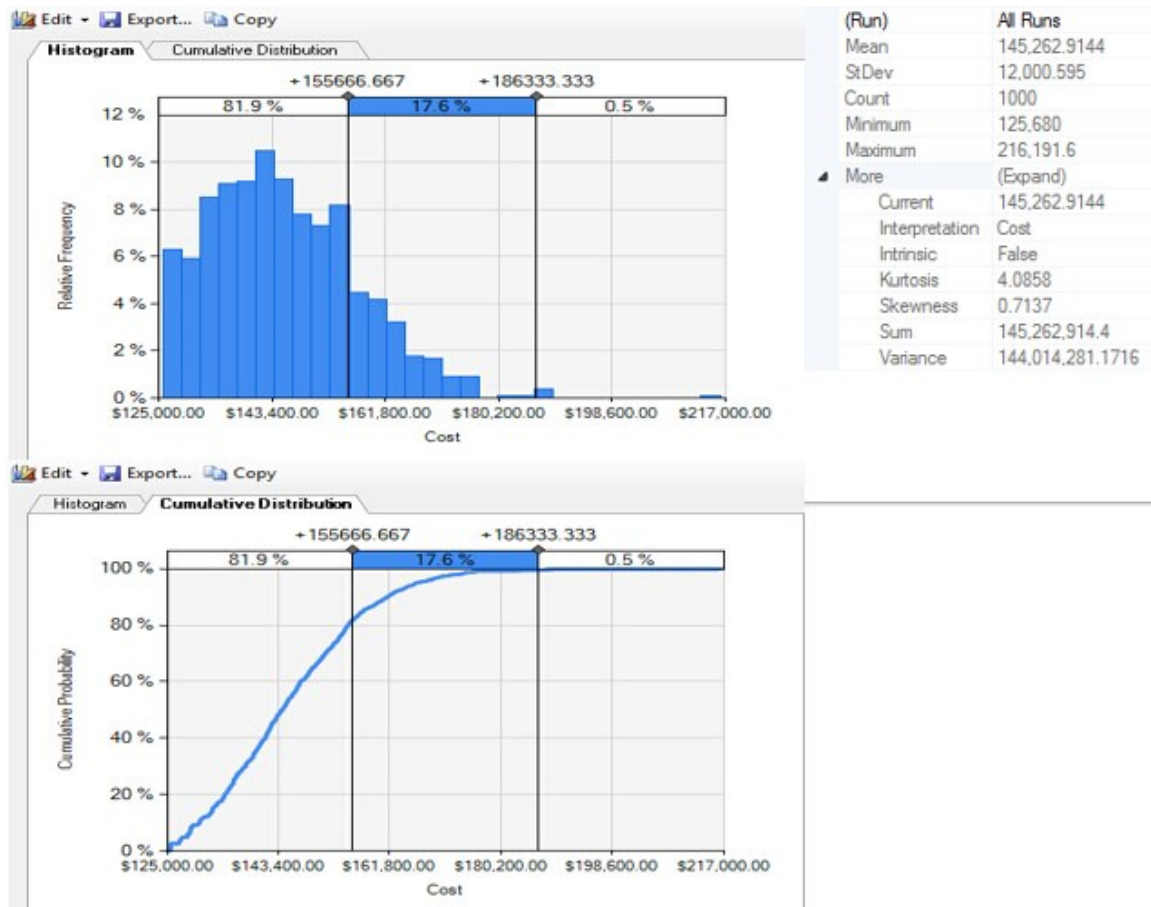


Figure 33 Sample cost result

6 Case Study

This chapter presents a hypothetical road construction case study in order to test the new developed approach and to verify the simulation template. The case study was used by Hong and AbouRizk (2011).

6.1 Project Information

The example used is a 1km long, one-way, two-lane road construction, which encompasses 19 work packages, as shown in Table 11.

Table 11 WBS of the Hypothetical Road Construction (Hong, 2012)

Code	Description	ID
1	Country road construction	0
1.1	Mobilization	1
1.2	Preparation	2
1.2.1	Site clearing and grubbing	3
1.2.1.1	Sta. 130 to 750	4
1.2.1.2	Sta. 750 to 1,000 and Sta. 0 to 130	5
1.2.2	Earth cut (Sta. 400 to 750) and fill (Sta. 130 to 320)	6
1.2.3	Drainages	7
1.2.3.1	Storm Sewer manhole connected to curbs	8
1.2.3.2	Culvert installation	9
1.2.3.2.1	Culvert at Sta. 220	10
1.2.3.2.2	Culvert at Sta. 360	11
1.2.3.2.3	Culvert at Sta. 600	12

1.2.3.2.4	Culvert at Sta. 900	13
1.3	Road work	14
1.3.1	Base layers	15
1.3.1.1	250mm deep lime-stabilized layer	16
1.3.1.2	150mm deep crushed 20mm gravel layer	17
1.3.2	Asphalt paving layers	18
1.3.2.1	110mm deep first asphalt layer	19
1.3.2.2	60mm deep second asphalt layer	20
1.3.3	Curbs	21
1.3.3.1	Cast-in place concrete curbs	22
1.3.3.2	Saw-cut at 20 meter intervals	23
1.4	Finishing work	24
1.4.1	Painting stripes	25
1.4.2	Sign installation	26
1.4.3	Fine grading and seeding work	27
1.5	Demobilization	28

6.2 Create Simulation Model in PERT

The procedure of creating the road construction model in the PERT template can be summarized as follows:

- (1) Create a project element, which is the top level of the model that indicates the project name and description, as shown in Figure 34.

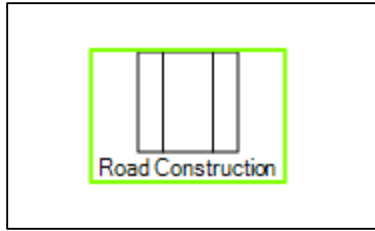


Figure 34 Project element

Under the project element, create the WBS structure, which is indicated in Table 11. The activity duration and the relationship should also be identified at the same time. Figure 35 displays the schedule network model created for the case study.

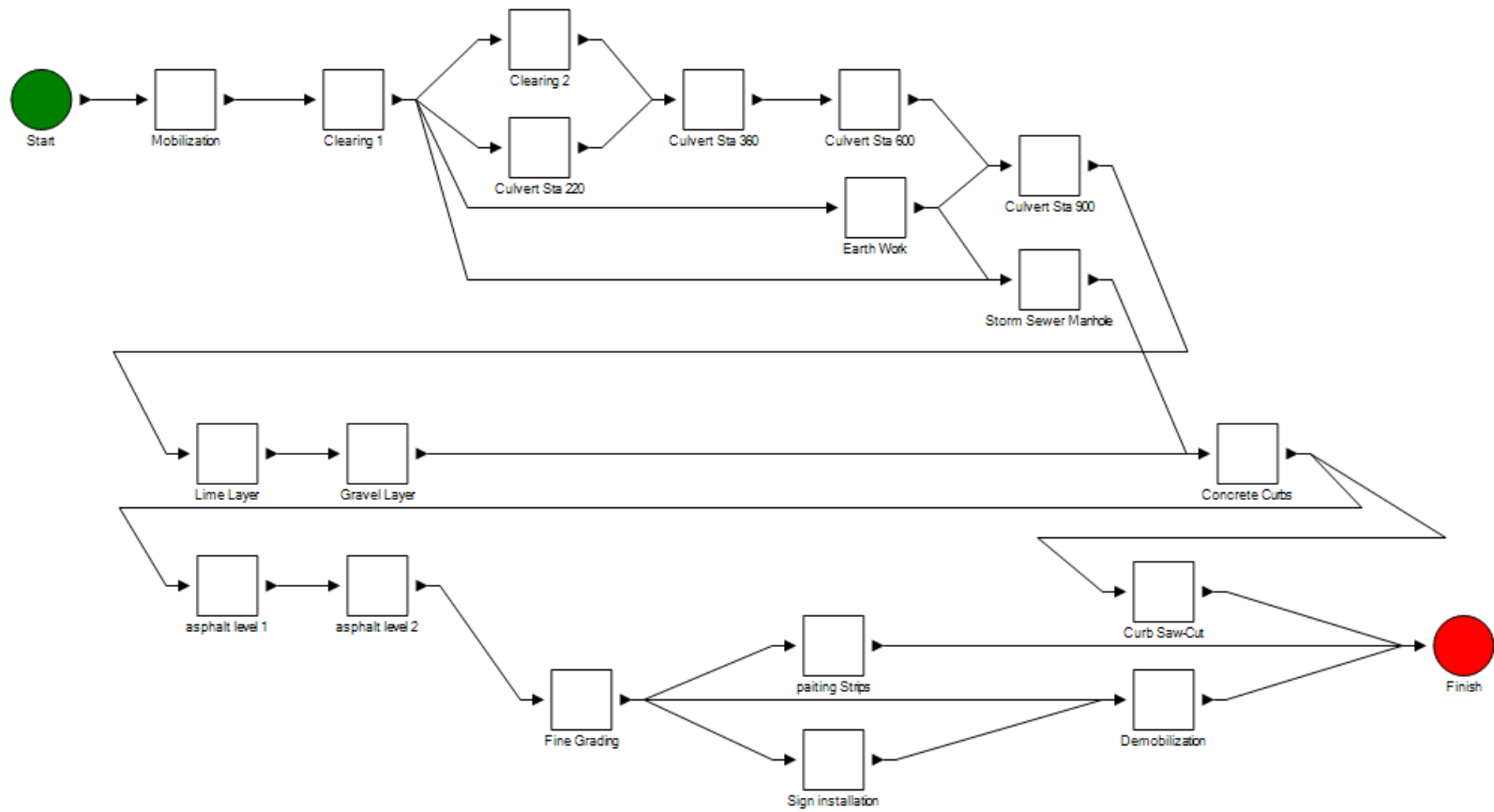


Figure 35 PERT network diagram

(2) Create the resource information under the project element. All the resources, including labour and equipment and their related cost and quantity, should be identified at this block. Figure 36 illustrates the user interface for the resource definition.

Category	Name	Quantity	Direct Cost	Indirect Cost
Labour	Labourer	15	\$33.50	\$18.50
Equipment	Loader	2	\$177.58	\$34.83
Equipment	Grader	1	\$120.73	\$29.13
Equipment	Vibration Roller	1	\$122.10	\$29.26
Equipment	Dozer	2	\$241.95	\$41.23
Equipment	Truck	2	\$70.15	\$21.10
Equipment	Paver	1	\$292.20	\$46.28
Equipment	Pneumatic Roller	1	\$85.10	\$25.26
Equipment	Tandem Roller	2	\$72.35	\$24.59
Equipment	Crane	2	\$78.93	\$25.50
*				

Category
The resource category.

OK Cancel

Figure 36 Resource input table

(3) Assign the resources indicated in the last procedure into each work activity according to the project information given. The quantity of resources also needs to be identified in this step. Figure 37 shows a sample of resource allocation of the activity “asphalt level 1”.

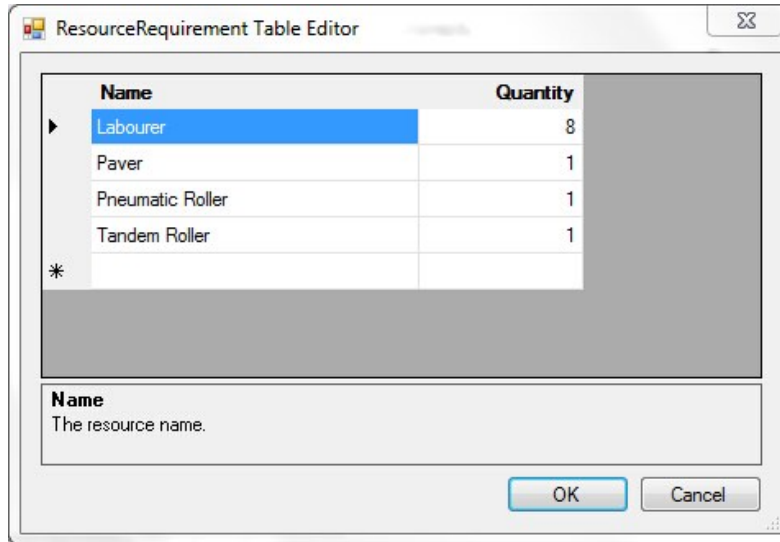


Figure 37 Assign resource into activities

- (4) Input the material cost for each activity if available. The material cost is determined as a lump sum price for each activity and pre-calculation is required. From the project information provided, the material cost can be calculated using the following equation:

$$\text{material cost} = \text{unit cost } (\$/\text{unit}) \times \text{quantity}$$

For example, the first asphalt layer is estimated to be 13,545 m², and the unit cost for asphalt is \$35.55/m², so the total material cost for this activity is \$481,524.8.

- (5) Identify the risk factors that influence the project, work packages, and work activities. Identify the risk impacts on both schedule and cost. A single work task can be impacted by multiple risk events, which are considered as independent. A risk factor consists of 5 components: (1) risk category, (2) risk factor, (3) likelihood, (4) impact on schedule, and (5) impact on cost. In order to create a simulation model to estimate the uncertainty of the project, the risk information should be provided in advance. In this hypothetical case, two risk events, conflict between parties and unfavourable market condition, are determined as the key

factors that influence the entire project. These two are directly assigned in the project level, as shown in Figure 38.

RiskCategory	RiskFactor	Likelihood	Cost Impact	Schedule Impact
Organization	Conflict between parties	0.003	Uniform(0.15, 0.25)	Triangular(0.08, 0.1...
Market	Unfavourable market condition	0.005	Uniform(0.15, 0.2)	Beta(3, 2, 0.2, 0.35)
**		0	Constant(0)	Constant(0)

RiskCategory
The risk category.

Figure 38 Risk assignment sample

Other risk factors such as weather condition, resource availability, and labour skill, etc. are assigned into each work activity as indicated in the project information.

- (6) After assigning all the risk factors into the WBS, specify the desired number of iterations for the Monte Carlo Simulation and the expected percentile for the result, then execute the simulation.

6.3 PERT Template Output

After simulating the model 200 times, the possible range of project cost and duration are generated. Figures 39 and 40 display the statistics of the estimated project durations and costs, respectively, in a CDF diagram. The results show that the completion time of this road construction project is in a range of [82.4, 105.4] days, and the mean completion time is 94.7 days. The 85 percentile of project duration is estimated to be 100.1 days, which means there is 85 percent chance that this project will be finished in 100 days. A possible range of the project completion cost is [2,506,257.417, 3,294,163.042] dollars

and 85 percentile of the project cost is determined by the CDF diagram provided which is \$3,055,374.417.

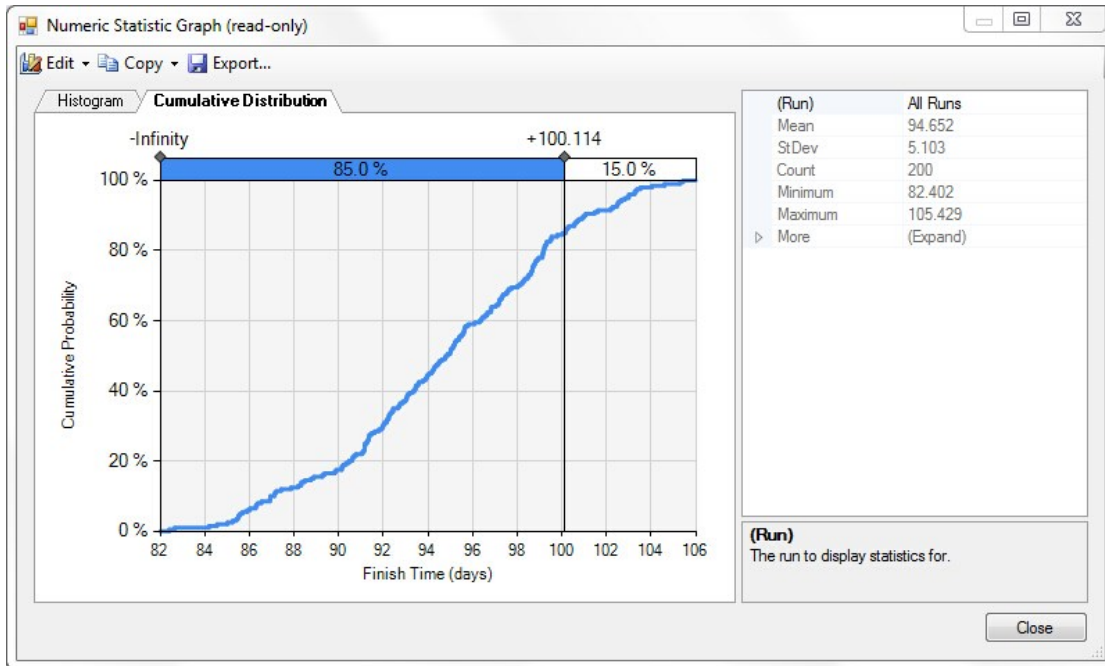


Figure 39 CDF graph of the project completion duration

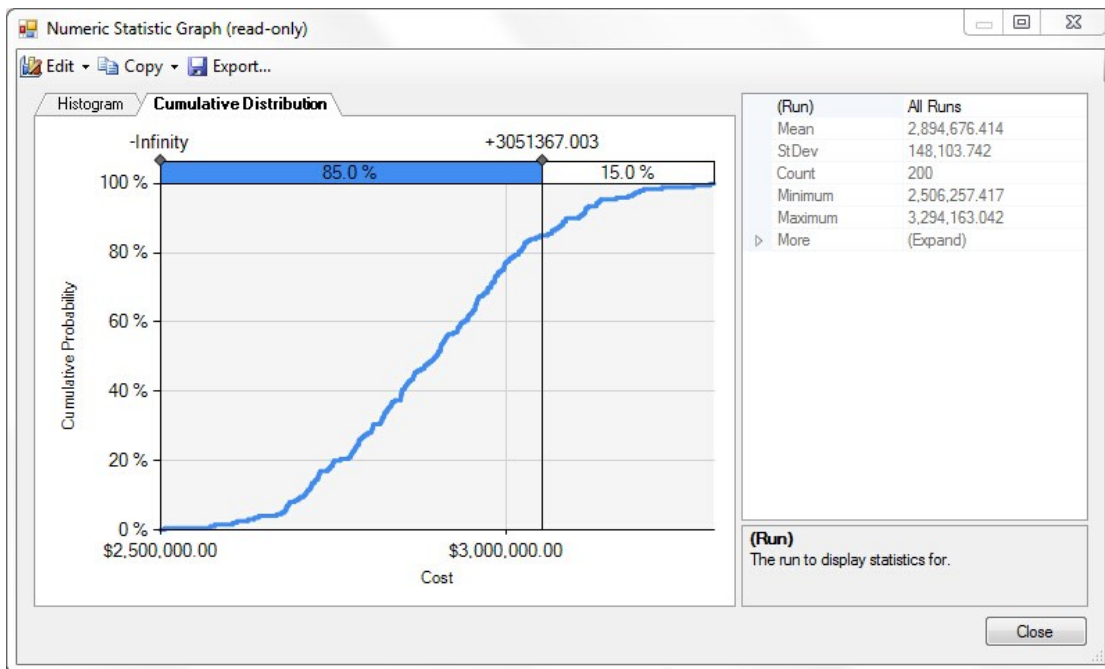


Figure 40 CDF graph of the project completion cost

The PERT template also provided reports for analysis. Table 12 displays the cost reports for each work activity, and the risk allowance explains the amount of money that organization spends on the risk events. Table 13 displays the cost report of the resource category.

Table 12 Project Cost of WBS

WBS	Minimum	Mean	Maximum	% Percentile (0.85)	Risk Allowance
Road	\$	\$	\$	\$	\$
Construction	2506257.42	2894676.4	3294163	3048176.08	551826.27
asphalt level 1	\$	\$	\$	\$	\$
	585397.04	716639.35	966072.81	809654.4	131242.31
asphalt level 2	\$	\$	\$	\$	\$
	346631.14	427286	565870.3	479708.36	80654.86
Clearing 1	\$	\$	\$	\$	\$
	85033.8	103257.61	140543.43	114820.94	18223.81
Clearing 2	\$	\$	\$	\$	\$
	56689.2	68871.22	90972.27	76404.19	12182.02
Concrete Curbs	\$	\$	\$	\$	\$
	81936	82110.52	108365.03	84136.51	174.52
Culvert Sta 220	\$	\$	\$	\$	\$
	23737.12	29272.23	39100.25	32666.13	5535.11
Culvert Sta 360	\$	\$	\$	\$	\$
	23737.12	29119.65	39124.12	32339.05	5382.53
Culvert Sta 600	\$	\$	\$	\$	\$

	34625.68	42756.69	55537.48	47537.41	8131.01
Culvert Sta 900	\$ 34625.68	\$ 43014.76	\$ 54694.41	\$ 47713.35	\$ 8389.08
Curb Saw-Cut	\$ 2190	\$ 2199.93	\$ 2731.48	\$ 2266.17	\$ 9.93
Demobilization	\$ 14976	\$ 15751.75	\$ 20090.74	\$ 16754.45	\$ 775.75
Earth Work	\$ 206799.36	\$ 308729.28	\$ 463332.95	\$ 368194.58	\$ 101929.92
Fine Grading	\$ 103326.96	\$ 103736.44	\$ 136289.99	\$ 107240.45	\$ 409.48
Gravel Layer	\$ 357565.04	\$ 440647.63	\$ 613820.15	\$ 504365.49	\$ 83082.59
Lime Layer	\$ 289079.44	\$ 380813.77	\$ 518286.42	\$ 436892.68	\$ 91734.33
Mobilization	\$ 11232	\$ 11897.15	\$ 15339.51	\$ 12614.17	\$ 665.15
paiting Strips	\$ 21260	\$ 22514.84	\$ 27735	\$ 24352.26	\$ 1254.84
Sign installation	\$ 15858	\$ 15899.97	\$ 18965.95	\$ 16256.58	\$ 41.97
Storm Sewer	\$	\$	\$	\$	\$
Manhole	48150.56	50157.62	55167.95	52279.89	2007.06

Table 13 Resource Cost Report

Resource Category	Resource Name	Direct Cost			Indirect Cost			Total Cost		
		Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Labour	Labourer	101304	105281.94	119559.09	55944	58140.8	66025.2	157248	163423	185584
Labour Cost Subtotal		101304	105281.94	119559.09	55944	58140.8	66025.2	157248	163423	185584
Equipment	Crane	33150.6	34452.34	39124.37	10710	11130.6	12640	43860.6	45582.9	51764.3
Equipment	Dozer	121942.8	153239.09	212834.82	20779.92	26113	36268.6	142723	179352	249103
Equipment	Grader	75335.52	94258.22	128017.64	18177.12	22742.8	30888.4	93512.6	117001	158906
Equipment	Loader	134250.48	139522.14	158442.56	26331.48	27365.5	31076.4	160582	166888	189519
Equipment	Paver	42076.8	53769.34	74877.85	6664.32	8516.24	11859.5	48741.1	62285.6	86737.4
Equipment	Pneumatic Roller	12254.4	15659.72	21807.34	3637.44	4648.23	6473.01	15891.8	20308	28280.4
Equipment	Tandem Roller	20836.8	26627.05	37080.17	7081.92	9049.88	12602.6	27918.7	35676.9	49682.8
Equipment	Truck	25254	25329.4	30837.17	7596	7618.68	9275.33	32850	32948.1	40112.5
Equipment	Vibration Roller	266666.4	333647.4	453146.2	63903.84	79955.1	108592	330570	413603	561738

Equipment Cost Subtotal	731767.8	876504.7	1156168.13	164882.04	197140	259676	896650	1073645	1415844
Total	833071.8	981786.65	1275727.21	220826.04	255281	325701	1053898	1237067	1601428

6.3 Determine Organization's Risk Appetite

This section illustrates how the newly developed risk tolerance assessment approach works in this hypothetical case. Assume that after the model simulates 200 times, the overall CDF curve is shown in Figure 41. From the previous experience, we know that most likely, this curve can be converted into a normal distribution curve as shown in Figure 42.

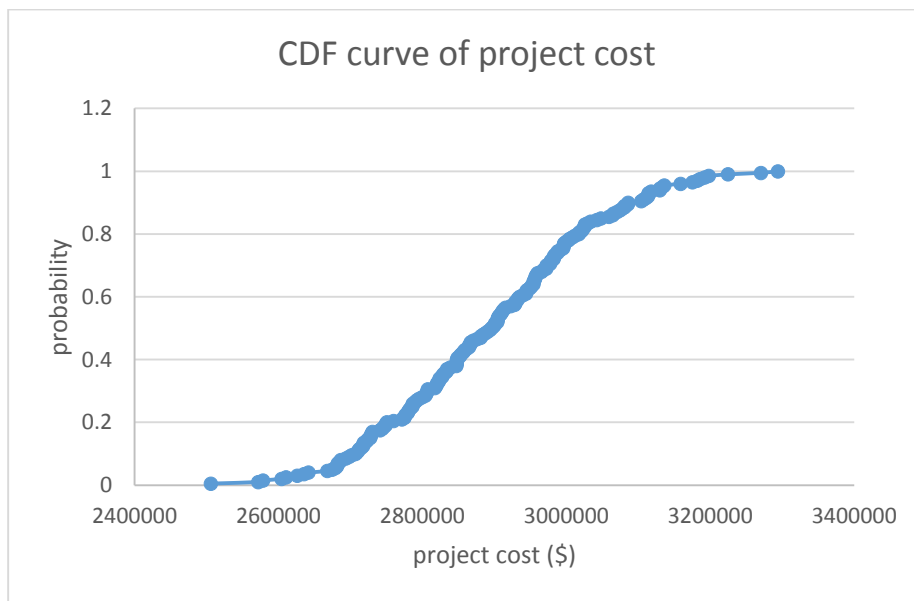


Figure 41 CDF curve of project cost

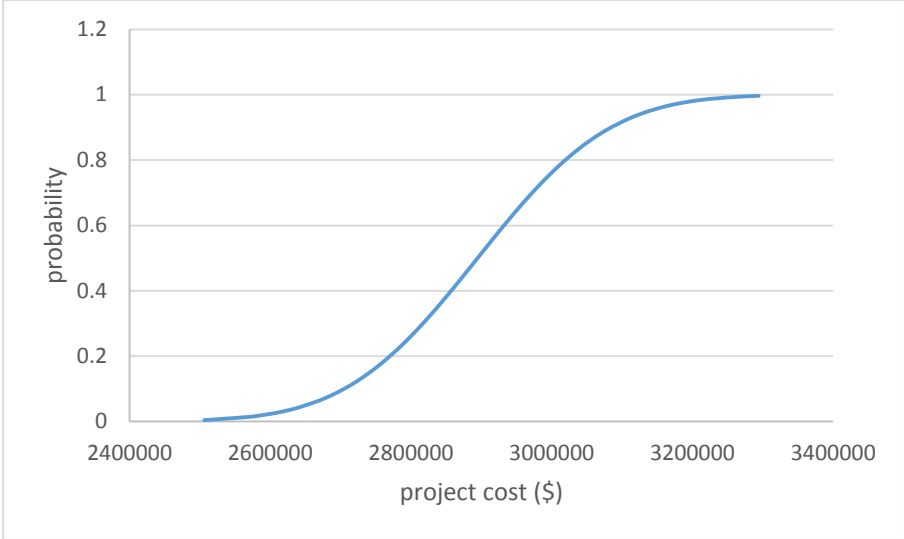


Figure 42 CDF curve of project cost converted to normal distribution curve

As mentioned in Chapter 4, the following step is to determine a cost capacity for the organization based on their company situation, market situation and other important factors. The capacity determined on the CDF curve will potentially illustrate the possible gain and loss in this road construction project. In this case, assume the risk capacity for an organization is determined to be \$3,000,000 for this road construction project, then the potential gain and loss graph is illustrated in Figure 43.

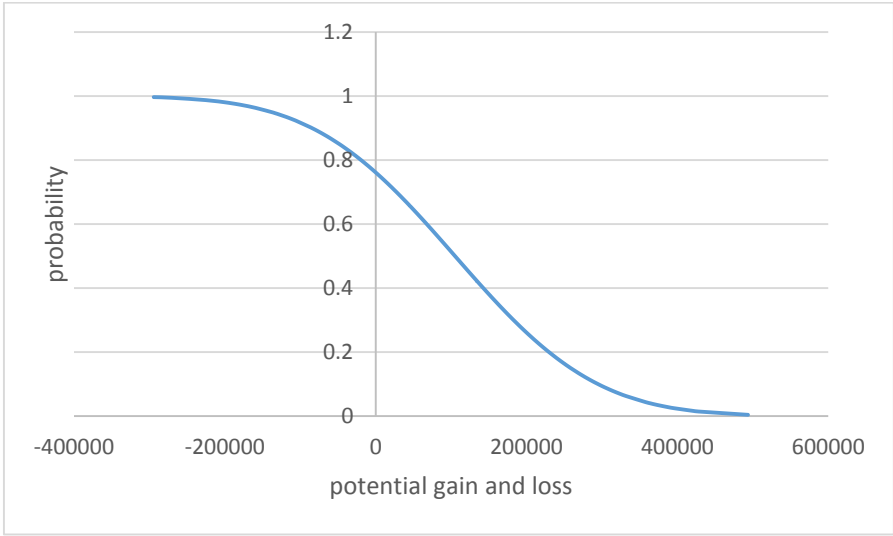


Figure 43 Potential gain and loss of the project

The y axis of the above diagram shows that the probability of making profit. For example, there is approximately only 10% chance that the organization can complete the project with at least \$300,000 gain, or there is approximate 40% chance that the organization can complete the project with at least \$150,000 gain. On the negative side, the organization can complete the project with 90% confidence that the worst situation of the outcome is only losing \$100,000.

The following step is to apply the utility function to the potential profit curve. The risk tolerance parameter R in this case study is pre-determined to be \$250,000, and the utility curve obtained using the following exponential utility function $u(x) = 1 - e^{-\frac{x}{R}}$, where R is 250000, is shown in Figure 44. Figure 45 shows the normalized utility curve for the potential profit where the new utility function is determined as $u(x) = 1.083 - 0.643 * e^{-\frac{x}{R}}$.

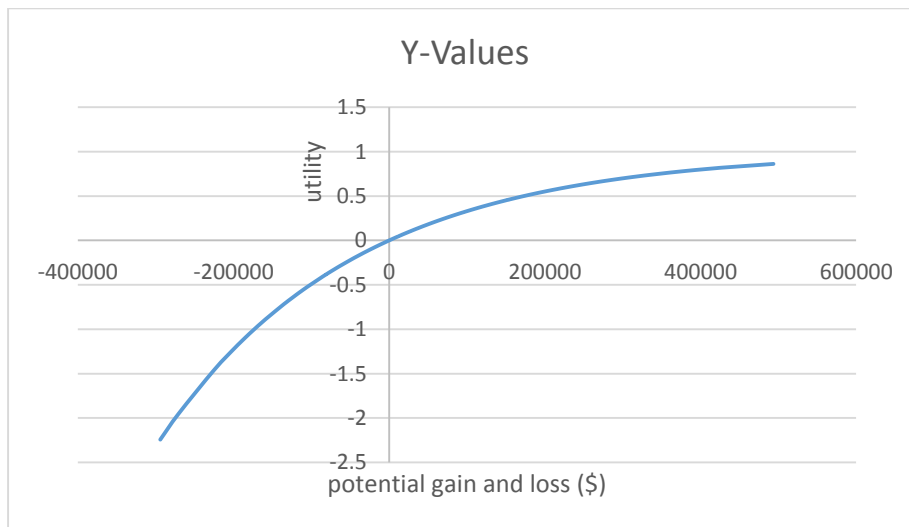


Figure 44 Utility function of potential profit

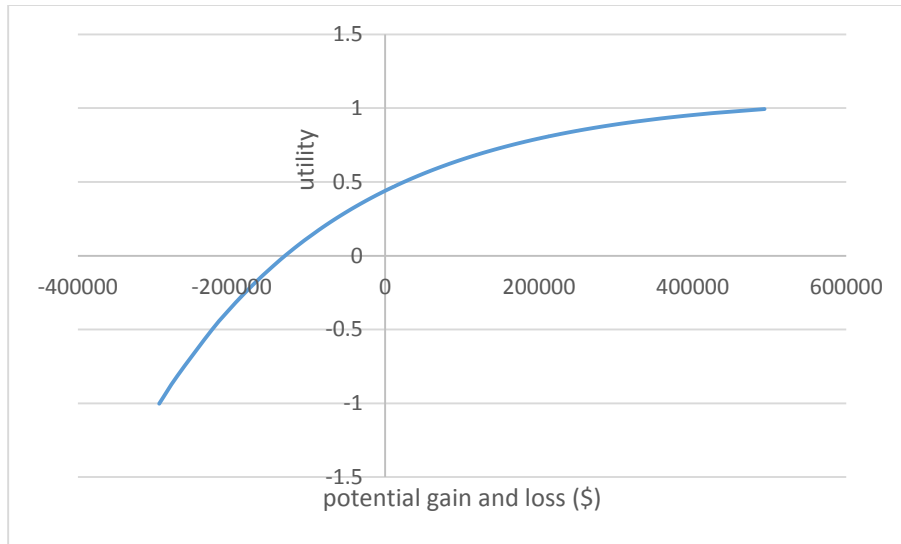


Figure 45 Utility function of potential profit (normalized)

The utility function of the potential risk is also required in order to determine the overall risk tolerance. The logarithmic utility $u = 1 + a \ln\left(\frac{\text{project cost}}{\text{max project cost}}\right)$ is used in order to plot the utility curve for the potential risk. Figure 46 displays the potential risk curve for this road construction project. "a" is determined to be 7.31 in order to normalized the utility curve into a range of [-1, 1].

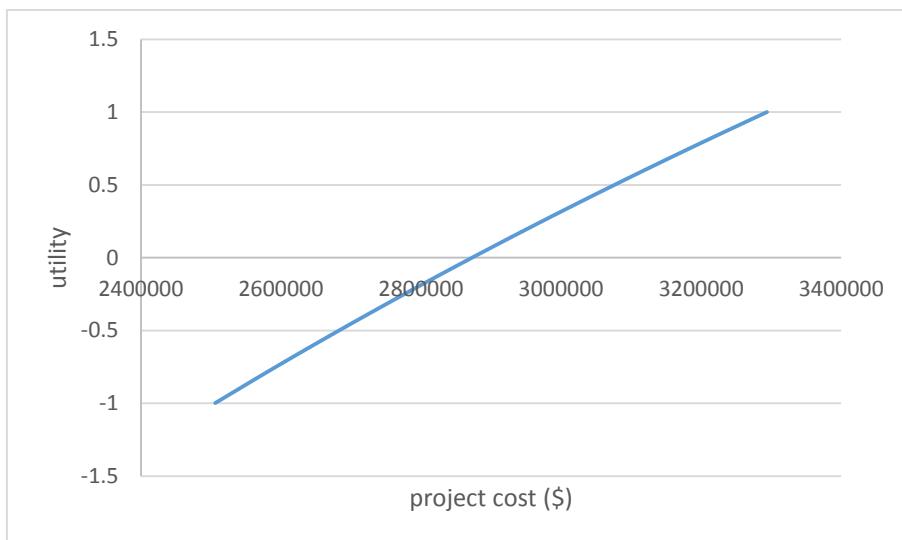


Figure 46 Utility curve for potential risk (normalized)

The last step is to determine the weight of both utility functions. The simplest way is to determine the ratio " $\frac{\lambda_{\text{profit}}}{\lambda_{\text{risk}}}$ " as mentioned in Chapter 4. In this hypothetical case, assume the decision maker is indifferent between seeking profit or safely completing the project, thus the overall utility for this project is shown in Figure 47.

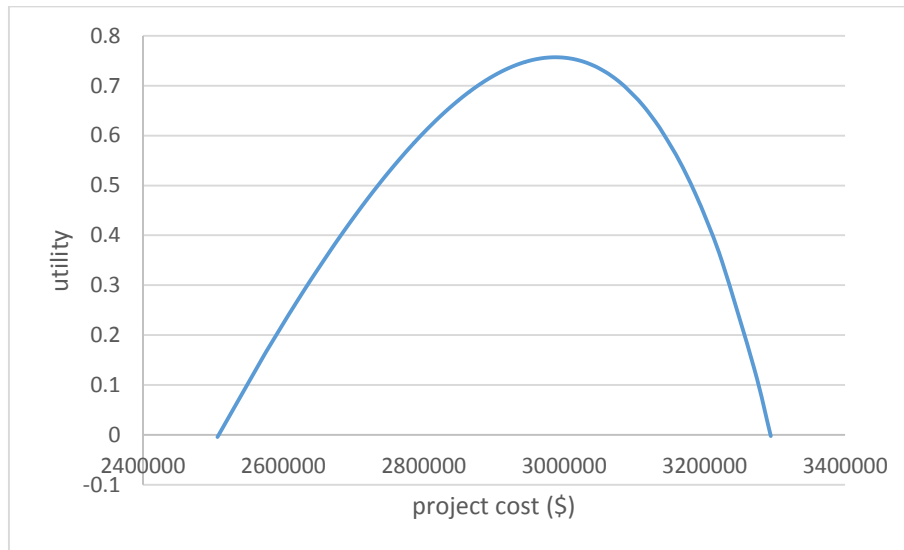


Figure 47 Overall utility function

At the lowest project cost, the organization has the opportunity to make the greatest profit, but there is almost a 100% chance that construction cannot finish within the budget; at the maximum project cost, the organization will have maximum confidence to complete the project, but the overall net value will be negative. From the data analysis, the highest utility occurs in the cost range [2988138.107, 2988200.85] dollars. So the most reasonable project cost, which will reflect organization's attitude towards risk, is around \$2,988,200. Compared to the original 85 percentile of the cumulative project cost (\$3,055,375), the new project cost is slightly biased towards risk. However, the new cost is still above the 80th percentile of the overall distribution, which means that the organization is still considered risk averse.

7 Conclusion

This chapter summarizes the work conducted in the research. It also outlines the gap of the current work and recommendations for future enhancement.

7.1 Conclusion

In the current construction industry, simulation is a significantly useful technology that can assist engineer's decision making on project planning and estimation, especially towards uncertainties. Although simulation can provide a range of project cost or duration, it is still short of an analytical method to determine how much risk the organization is willing to take. The objective of this research was to develop an approach that can assist decision making on what percentile to use from a cumulative distribution function of project cost to reflect the organization's risk appetite and overall acceptance of risk.

The main contributions of this research are:

1. It developed an approach based on utility theory that can model an organization's risk attitude towards profit and potential loss. Two utility functions were developed. One reflects an organization's appetite towards potential profit and the other reflects its tolerance towards potential risk in a specific project. Both utility functions are determined from the cumulative distribution curve of project cost, which was generated from the simulation tool. By combining the aforementioned two utility functions, a balanced utility curve is obtained that illustrates the overall utility for the organization towards a specific project.
2. In order to enhance the quantitative risk tolerance analysis, a special purpose template in Symphony.NET, based on program evaluation and review technology (PERT), was re-developed. The template provides an integrated cost/schedule model and transforms the model to simulation-based planning, in which uncertainties of project cost and schedule are evaluated through Monte Carlo Simulation.

7.2 Limitations and Future Recommendations

This research is intended to provide a prototype for organizations which raises the topic of how much risk they are willing to take. Utility theory is a good start to examine risk attitudes. However, risk tolerance is such a subjective topic that it keeps changing with the environment. It is difficult to have an approach that can 100% adequately model risk attitudes.

The limitations of this research are:

1. An organization's risk attitude is much more complicated than a simple exponential utility function. More factors need to be considered.
2. Organizations usually have their own risk statements that indicate how much risk they can bear. This research did not consider the risk appetite statement.
3. The re-developed simulation template is still on a 24-hour schedule, a calendar can be added to the template.
4. It is difficult to validate this approach because each organization has its own strategy for determining how much risk they can bear.

For future research on this topic, data are required in order to compare the analytical solution with the real situation. Surveys and interviews are also required in order to determine the key factors that may influence the organization's risk attitude. With all the information provided, the utility function of risk tolerance can be more complicated and reliable.

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