An Application of the Real Option Framework to Large Infrastructure Projects: Evidence for Thailand's Transportation System

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Abstract

Governments from many countries, specifically developing countries, have sought private participation in large-scale infrastructure projects because of their limited resources and budgets. Then, many public infrastructure projects have been privatized worldwide, where benefits and risks are substantially distributed between the public and private sectors. However, the complexity of the project arrangement has constituted a dilemma for governments to balance the benefits and risks between the public and private sectors, i.e., financial institutions and private companies. Large infrastructure projects typically involve various risk factors so that the successful implementation of those projects depends on the effective management of those key risk factors**.**

There is a requirement for a tool to help the government evaluate the delivery of value on the infrastructure projects while still sustaining the interests of private investment. This research studies the use of the real option methodology as a tool for the valuation of large-scale infrastructure projects. A comprehensive literature review of the real option methodology is undertaken and an application of the methodology to a large-scale public infrastructure project in Thailand is considered. More specifically, this research studies real options and the option interactions for a hypothetical toll road concession involving the Second Stage Expressway System (SES) in Thailand. Real options for the public and private parties are identified and evaluated. The interactions of the options are investigated in the form of multiple real options. The aim of the research is to demonstrate how real options can mitigate risks to the main stakeholders of the project.

The study provides a practical insight into project risks within transportation system projects in Thailand. This research studies options and the option interactions as applied in the SES project. Overall, the application of the real option approach in large infrastructure projects is promising. The evaluation shows that the value of options and their interactions can be significant. The findings of this research would facilitate the risk analysis and mitigation process that can be conducted by governments, financial institutions, or project developers prior to the development of the infrastructure project.

The real option applied to value an infrastructure project is complicated but the mechanism can help for policy design and implementation. The findings from the real option model

indicate that governments, financial institutions and private companies play a crucial role in the risk allocation in large infrastructure projects. It is found that projects developed solely by government are insufficient and require a high government budget. The government can design an appropriate level of guarantee and type of guarantee which attracts private interest in the project as well as an affordable government budget. The research finds that many option combinations such as i) the combination of the equity guarantee option (government) and the deferral option (financial institution); ii) the combination of the deferral option (financial institution) and the grant option (private company) iii) the combination of the deferral option (financial institution) and the deferral option (private company) and iv) the combination of the deferral option (financial institution), the abandonment option (financial institution) and the deferral option (private company) are recommended for policy design and implementation. With such option combinations, governments can properly evaluate the economic viability of such arrangements prior to offering optimal option proposals to the project company. With real option application, this research study can critically compare the effects of different policy designs in order to design a suitable public financing scheme.

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Chapter 1. Introduction

1.1 Introduction

Governments worldwide have turned to private funds to finance large-scale public infrastructure projects. Many governments have established Public Private Partnerships (PPP) as the arrangement between the public sector and the private sector to produce an asset or deliver a service. In PPP contracts, the private sector has to finance, construct, operate and maintain the project within the specific period. It has been argued that the private sector, involved in the PPP, can perform certain tasks more efficiently than the government, thereby providing potentially huge benefits to the public (Zhang and kumaraswamy, 2001). Despite the widely acknowledged benefits of privatization, a number of PPP projects suffer a significant financial loss because of construction overruns, uncertainty of market demand, and reductions in tolls/tariffs (Zhang, 2005).

It is widely known that project financing is an alternative form of raising capital in terms of long-term debt for investment purposes (Hainz and Kleimeier, 2001). It is a financial arrangement for new investment projects by structuring the financing around the project's own operating cash flow and assets. The cash flow generated by the project itself is the main source used to repay the debt (Nevitt and Fabozzi, 2000). The use of project finance for funding large infrastructure projects in many countries, including Thailand since 1980, has highlighted significant problems. Historical evidence of project financing in Thailand and other countries shows that a project's profitability is typically uncertain and subject to various risks. In infrastructure projects, the risk profile undergoes important changes as the project comes to the operation stage, with a relatively stable stream of cash flow that is subject to market and regulatory risks (Devapriya and Alfen, 2003). Infrastructure development in Thailand has huge potential. Thailand needs billions of dollars from Public Private Participant (PPP) schemes to develop infrastructure investments. However, significant problems such as demand forecasting, procurement strategy, and the uncertainty of the projects' cash flows exist.

The general purpose of this DBA thesis is twofold. Firstly, it will identify and analyse the characteristics and risks of project finance as well as investigating their effects on a project's performance level. Secondly, it will apply the real option theory to answer fundamental questions in the context of project finance. The techniques employed in this DBA thesis include project cash flow analysis and risk management tools using the real option.

The development area of project finance is still at the embryonic stage in Thailand. This research fills a gap in the academic literature. In fact, the benefit of this study is that it can improve the structure and the performance of future project developments by pooling database evidence and applying quantitative analysis. The data set was partially constructed by the author during studies at the Asian Institute of Technology, School of Engineering and Technology. The data include information on large-scale infrastructure development in Thailand during the period 1980-2000. This dataset of new transportation project developments (from 2000-present) has been updated for the purpose of DBA study.

1.2 Problem Statement

Many large-scale infrastructure projects in Thailand have been initiated in recent years because of the government's desire to stimulate economic growth. Whilst governments often use economic analysis to appraise investment projects, the private sector evaluates the project based on its financial feasibility. It can be argued that the economic appraisal differs from the financial appraisal in several respects; the appraisal coverage, the life of the project and the discount rate applied, etc. It is important to ensure that these differences are understood and that each appraisal is properly used by the public and private sectors in the development of the project.

The conflicts of interest between the public sector and the private sector in project development decrease the efficiency of project performance. Typically, the public sector is only interested in the economic appraisal of the project whilst the private sector focuses on the financial appraisal. For valuing an infrastructure investment, governments usually focus on the economic and social value that would cause the development to be financially infeasible (Tanaka et al., 2005). To invest in the public project, the private party is normally looking for risk-sharing, incentives and support from the government. On the other hand, the government has to ensure that incentives and support are provided at the appropriate level, relative to its risks (Tanaka et al., 2005). In general, the government prefers the qualitative approach to evaluate risks because it is inexpensive where there is a lack of knowledge, lack of sufficient data, and it is difficult to quantify risk (Akintoye et al., 2001). Meanwhile, the private sector requires the quantitative method to ensure that risk factors are taken into account in the project evaluation.

Typically, risks inherited on the project may be represented through the amount of the discount rate applied to evaluate the project. Public projects may use different methods for calculating the discount rate such as the market rate of interest, the government borrowing rate, and the social opportunity cost rate. However, these measures have various limitations and should be used carefully for evaluating projects.

It is generally known that governments with limited resources and budgets try to motivate the private sector to participate in projects through the Public Private Partnership (PPP) program. For a typical PPP project, the risks are mostly transferred to the private sector. Private sector companies normally evaluate projects using the WACC or the CAPM, which are significantly higher than the level of the discount rate used by the government. These approaches may yield misleading conclusions by choosing to implement the project from the public sector perspective, while in fact it may not provide the optimal benefits. This study is concerned with the question of how to incorporate risk and how to effectively allocate risk into the project.

Within this framework, the study targets the enhancement of knowledge in the field of project evaluation and project risk management. It initially investigates the existing methodology for evaluating projects and assessing risk in order to identify the deficiencies, the limitations and the areas for improvement. The present situation of large transportation system projects in Thailand will be analysed and used to identify the main risks. Next, this research will present the real option method to evaluate the risk allocation alternatives or options. Lastly, this research will propose the alternative risk sharing frameworks in the context of project finance to be applied in the development of future projects.

1.3 Research questions

It is generally known that the development of large infrastructure projects either by using traditional procurement methods or the PPP strategy encounters various risks in several aspects. In general, the existence of project risk cannot be totally eliminated but alternatively the expected risks can be mitigated by allocating them among the project's stakeholders. The main challenge of this research was to define the best strategy on how the stakeholders manage the risks by using the real option methodology. This challenge was addressed with the following research questions:

- Given that the traditional evaluation approach, i.e. NPV, IRR is not a sufficient tool for evaluating the project, is the real option methodology effective and efficient for valuing projects?
- How are those risks that are generally identified from the previous studies in the literature managed by the real option method?
- What types of real options are appropriate for the main project stakeholders: the government, the private company and the financial institution? Are options valued for PPP projects?
- Is the interaction effect of the option combination significant enough to the project's value?
- What is the appropriate level of risk allocation among the government, the private company and the financial institution in infrastructure projects?

1.4. Scope of the study

The scope of the study is specific in order to allow the undertaken study to be completed within the appropriate time frame and with a reasonable budget. The DBA thesis will be classified into two parts to be written within the study period.

1.4.1 *Part I (Chapters 2-3)*: Review of the literature on project appraisal, risk management, risk allocation among stakeholders on large-scale transportation system projects, and the real option methodology.

PPP projects have been encouraged by the governments in many countries including Thailand. There are different types of procurement methods, appraisals, concessions and PPP procurements in large-scale infrastructure projects that will be discussed in this study. Research will focus on the evidence of major stakeholder involvements and the types of PPP that have been designed to support the project.

Infrastructure appraisal is complex and challenging because of some specific risks associated with infrastructure projects. The public sector attempts to mitigate risks and transfer these risks to the private sector as much as possible. As a result, the risks may be transferred to the party that may not be the best managed. In addition, overall risks of the project may increase when the allocation is not appropriate. Therefore, it is essential to study how risks are allocated between the public and private sectors.

With this regard, it is important to develop an effective project valuation tool in order to resolve these problems and to facilitate the risk allocation process between the public sector and the private sector. The proposed project valuation tool also necessitates verification as to whether it can be practically used in large infrastructure developments. From the background and the earlier described problem statement, this research is highly motivated to study the areas of risk management application and risk allocation in large-scale infrastructure projects.

Mun (2006) describes real options as a useful tool for valuing capital investment decisions. A corporate decision to invest in a project is analogous to a call option because the corporation has the right rather than the obligation to invest (Luehrman, 1998). Real options also help the corporation to assess the impacts of risks on the performance of the project. Therefore, the study of the real option method and its applications in project evaluation is important. The application of real options in assessing risks of the project will be studied. In summary, the following literature will be reviewed:

- The economic and financial appraisals of the project
- Procurement methods for infrastructure projects, risks in project finance
- The role of Public Private Partnerships (PPP) in project finance
- The role of the discount rate used for evaluating large-scale infrastructure and PPP projects
- The role of government, the private sector and the financial institution in the project development
- Risk profile and risk preference of the public and private sectors in the project
- Risk management techniques and applications in managing projects
- Risk allocation and mitigation in PPP infrastructure projects
- Real option theory and its application in project finance
- Options for the government, the private company and financial institution in the project

The literature will be separated into two main chapters as follows:

Chapter 2: Chapter 2 comprises three sections:

Section I: Reviewing the appraisal methodology for transportation system projects. This chapter will review the project appraisal methods for transportation system projects, including the economic and financial appraisals. Public Private Partnerships (PPP) in transportation projects will be addressed and discussed in this chapter. In addition, the discount rates used in the economic appraisal and the financial appraisal are identified.

Section II: Risk management in large-scale infrastructure projects. Risks in PPP transportation projects are identified, analysed and measured. The risk management framework is proposed in this section. This chapter also presents risk identification, risk analysis and the impact of risk with case studies of PPP infrastructure projects. The study will focus on risk assessment of large infrastructure projects in Thailand. The evidence of the success and failure of infrastructure projects in Thailand will be identified. This chapter will address the typical problems of PPP projects with case studies of Thailand's large-scale transportation system projects. This part also gives reasons for the unsuccessful large-scale transportation projects in Thailand. Risk management practice in transportation system projects in Thailand is analysed and criticized. The following case studies in Thailand will be used for risk identification and analysis purposes:

- Bangkok Mass Transit System (BTS)
- Mass Rapid Transit Authority of Thailand (MRTA) Project
- The Second Stage Expressway System (SES) Project
- Bang Na – Bang Phli – Bang Pakong Project
- Don Muang Tollway Project
- The Airport Rail Link Project

Section III: Risk Allocation in large-scale infrastructure projects. This section will focus on the types of risk allocation among the public and the private sectors. The study will discuss the different types of risk allocations and risk mitigations in transportation system projects. Risk allocations between the public and the private parties are discussed.

Chapter 3: Chapter 3 will present real option theory and its applications. In this chapter, real options and financial options are compared. Types of real options and their applications are summarised. This chapter describes methods for pricing real options, the real option process, the interaction between options and the limitations of real options. Lastly, this chapter defines the approach to explore a suitable research design and methodology in answering the research questions proposed in the literature review.

1.4.2 ***Part II (Chapters 4-6)*****:** The real option model for risk allocation among the government, the financial institution and the private company. This part explores the theory of real options in the context of project finance.

The roles of the main stakeholders involved in the development of large infrastructure projects will be discussed. The main project participants are the government, the private company, and the financial institution (which this research calls GPF). The level of GPF's risk allocation will be discussed within this part along with practices in Thailand's large-scale transportation projects. It will focus on the impact of risk allocation on project performance.

Part two will focus on the application of real options to evaluate the different risk allocations among GPF. In theory, the real option analysis extends valuation models of pricing financial options to apply them in investments in real assets or real markets (Cobb and Charnes, 2004). Real options compensate for the shortcomings of the traditional project evaluation approach (NPV, IRR) in that it considers the option associated with the investment project (He, 2007). The mathematics of real options will propose the model project's cash flow behaviours. The real option model will be simulated from a selected hypothetical transportation system project. The impact of financial performance of GPF options and their combinations will be analysed and investigated. In cash flow analysis, an appropriate discount rate will be selected to evaluate Thailand's transportation system projects.

The model will examine and propose the financing strategy and GPF modes for new project developments in Thailand. Two objectives will be investigated. The first is to provide a theory of real options that links risk, leverage, and value and is particularly applicable to GPF. Secondly, the research will provide an economic rationale for GPF which organizes a new project financing scheme.

Part two will propose the strategies of GPF from real options to improve the project performance. The set of real option combinations from the major stakeholder will be simulated. The hypothetical project will be used to analyse the impact of real options on the project performance. A real option model which represents the risk allocations and mitigations will be used to evaluate the project. Real options will be used to measure project performance.

Infrastructure projects are normally initiated by governments. With limited budgets, governments provide concessions to private companies to build, own and operate projects, while project financing is normally the responsibility of financial institutions. To develop the project, the private company may require support from the government such as revenue guarantees and debt or equity guarantees.

The project's lenders will attempt to limit their risks by allocating them to other participants such as the government and the project's sponsor. Project lenders may require support from the sponsor. These may include a sponsor completion guarantee, or a debt repayment and equity commitment (Khan and Parra, 2003). Lenders may call project sponsors the equity commitment when cost overruns exist during construction, or to repay debts. The project company, on the other hand, may require support from lenders in the form of equity injections, prolonged debt service, or bank guarantees.

The typical problems for large infrastructure projects such as railways and mass transit systems are that they cannot generate the revenues from fares to cover the investment cost of the infrastructure. Indeed, support from the government and the private sector is required in order to make such projects viable. For example, for the London underground project, in order to drive project feasibility, the government provided grants for maintenance and capital investment for the new expansion line.

For developing large-scale infrastructure projects, governments generally mitigate their own risks through private participants. Private sector participation can also help to achieve project success. However, lenders and private investors do not attempt to participate in high risk projects. They may require higher rates of return to compensate for the higher project risk. The public and private sectors have their own interests in such projects. Therefore the risk allocation among GPF is important for project success. However, the risk allocation is quite subjective. This research tries to provide quantitative and mathematical analysis to explain the risk allocation among GPF.

The study will be separately presented into 4 chapters:

Chapter 4: SES case study: The Financial institution option. This chapter introduces real option applications for policy design and implementation in infrastructure projects. Risks of lenders in PPP infrastructure projects are identified. The case of the Second Stage Expressway System project (SES) is used as a hypothetical project for valuation. Real options for financial institutions are proposed and valued using the binomial lattice model. The sensitivity of the outcomes, to differences in key parameters (i.e., volatility and risk-free interest rate), is tested.

Chapter 5: This chapter is divided into two sections:

Section I: SES case study: Government options in infrastructure projects. This chapter focuses on the government support in infrastructure projects. Real options of government support are valued separately. Furthermore, the options are combined and valued to enhance the value of the project. Also, the sensitivity of the outcomes, to differences in key parameters (i.e., volatility and risk-free interest rate), is performed.

Section II: SES case study: Private company options in infrastructure projects. The specific options of private companies are selected and valued. These options are combined and valued to increase the value of the project. Furthermore, sensitivity analyses with respect to the two key parameters (i.e., volatility and risk-free interest rate) are performed in this section.

Chapter 6: The option combinations. Chapter 6 demonstrates the importance of proper option combinations for the government, the financial institution and the private company. Bundles of options are selected and valued. The appropriate option combinations are recommended to implement the project. Furthermore, sensitivity tests are carried out for key parameters such as volatility and risk-free interest rate.

Chapter 7: Conclusions and Recommendations. The last chapter summarises the research findings and the policy design and implementation in large-scale infrastructure projects. It concludes the DBA thesis and the achievements of the research objectives. Limitations of this research and recommendations for future study are presented in this chapter. The theoretical contribution to the body of knowledge is presented in this chapter.

Chapter 2. Literature Review: Appraisal and Risk Management in Large-Scale Infrastructure Projects

This chapter provides a review of the existing literature on the traditional methodologies used for transportation system project appraisals. This chapter also provides a review of the literature on risk management and risk allocation in the context of infrastructure project financing and discusses the risks associated with large-scale infrastructure projects in Thailand, including the Second Stage Expressway (SES) project, which is the case study for this thesis. The SES project is analysed in more detail in chapters 4-6.

Section I: Literature review: appraisal methodologies for transportation system projects

The development of large-scale transportation projects involves massive resources and is a highly capital-intensive process. As a consequence, public private partnerships (PPP), which pull the public and private sectors together to share risks and rewards, are often required (Tánczos and Kong, 2001). To ensure a project's success, governments initially carry out a project appraisal process to assess the investment options and determine the avenue that will provide the best value for money. Appraising the investment options is considered to be an important procedure in PPP project development. Similarly, the social-economic and financial analyses are major parts of the project appraisal (Tánczos and Kong, 2001).

It can be argued that the government evaluates PPP procurement as an alternative investment option. In general, the government evaluates what PPP option will provide the most efficient project development in relation to that implemented with traditional public financing (Tánczos and Kong, 2001). The appraisal can be done by both economic and financial analysis. In principle, there are some conceptual and methodological differences between economic and financial appraisals, which will be discussed in next section.

2.1 Economic appraisal

Economic analysis provides information on the project's impact on all entities, including society, public, private, and other major stakeholders. The main objective of economic analysis is to help the government decide whether the private or public sector should undertake projects and to select the project that best contributes to the welfare of a country

(Belli et al., 1998). Economic analysis evaluates the project's benefit and cost to society as a whole as opposed to the more narrow perspective provided by financial analysis.

Though there are various appraisal methods used in economic analysis, cost benefit analysis (CBA) is one of the most popular techniques. CBA is favourable for appraising infrastructure, environmental, health care, cultural, and sports projects (Brzozowska, 2007). The history of CBA in the United States goes back to the 1930s, when a methodology was developed to allow the Senate to evaluate dam projects more efficiently. CBA has now become the most frequently used appraisal technique in developed countries (Preez, 2004). CBA methodology is based on the theory that the objective of a government project is to maximize the welfare of society (Bhasin, 2003). The core principal of CBA is to evaluate a project on the basis of i) Pareto efficiency, ii) willingness to pay (WTP), and iii) shadow price.

Pareto efficiency: The main concept of the Pareto efficiency in the context of CBA is that a project may be selected only if its benefits can compensate for project losses. The project should proceed if there is a Pareto improvement in that someone can gain whilst nobody loses (Boardman et al., 2006).

Willingness to pay: In the context of CBA, WTP involves measuring the impact of a project on a person's welfare. It is assumed that people are willing to pay to acquire the benefit or to avoid the cost associated with a project. In economic theory, a demand curve for goods represents a person's willingness to pay for an additional (or marginal) unit of goods on the basis of diminishing marginal utility. On a demand curve, WTP comprises two parts: the amount actually paid and the amount in excess of what people are willing to pay over what is actually paid. This is called the consumer surplus or net benefit to society.

Shadow price: A key concept of economic appraisal is to use shadow price based on the social opportunity cost instead of the distortion of market price (European Commission Guidelines, 2008). Shadow price in the context of economic appraisal is defined as the prices used to reflect the opportunity costs of inputs and/or consumers' willingness to pay for outputs. It can be argued that monopoly or oligopoly markets such as the power sector, where price is distorted from imperfect market or government ruling, may fail to reflect an opportunity cost of inputs (European Commission Guidelines, 2008).

The general rule in CBA is to select the project that is met by net benefit criteria. The selected project should allow the gainers to fully compensate the losers and still be better off (Boardman et al., 2006). The decision criteria may be used from three methods: i) the net present value (NPV), ii) the internal rate of return (IRR), and iii) the discounted benefit-cost ratio (discounted BCR). Though CBA is widely used in economic appraisal, it has two main limitations. First, it is difficult to quantify CBA in monetary terms in all relevant impacts. Second, efficiency is not the main objective for some projects. As a consequence, CBA may not be a good measurement (Boardman et al., 2006). In addition, CBA has been disputed in various topics, such as the appropriate discount rate used, externalities, risks, and irreversibility (Brzozowska, 2007).

CBA is a popular method in transportation project appraisals. In public transportation projects, CBA measures the benefit for users with the actual and forecasted usage of transportations (Geurs et al., 2006). The cost and benefits of users are measured in terms of WTP. Then, the total economic value is measured by the sum of all individual WTP for any change in well-being due to the project (Boardman et al., 2001). The benefits of transport projects include saving time, preventing accidents, and providing accessibility, among others. The total cost of transportation is primarily derived from construction costs, annual maintenance costs, transport user costs in vehicle operation, travel costs, costs transporting users due to a better facility condition, and other external costs (Kerali, 2003). External costs include social and environmental costs such as emissions, energy consumption, noise, and the welfare of the nearby population. In addition, social and environmental effects can be incorporated into economic appraisals if they can be quantified in monetary terms (Kerali, 2003).

The economic appraisal process can be divided into five major steps (European Commission Guidelines, 2008): i) conversion of market price to accounting price, ii) monetization of non-market impacts, iii) inclusion of additional indirect effects, iv) discounting the estimated costs and benefits, and v) calculation of the economic performance by indicators.

Though CBA is the core technique for economic appraisals, other quantitative and qualitative analyses are frequently used. Those techniques include cost effectiveness analysis (CEA), multi-criteria analysis (MCA), risk benefit analysis (RBA), and others.

Cost effectiveness analysis: CEA evaluates projects that have benefits that cannot be translated into monetary terms or are not able to access market price. CEA is appropriate when the evaluated project has a single goal or if the project has multiple goals (Belli et al., 1998). The decision criterion of CEA is to select a project based on the cost-effectiveness ratio, which is the ratio between cost and non-monetary benefit. Thus, CEA can be calculated by the following formula:

CEA ratio = total cost in monetary units / units of effectiveness.

CEA has an advantage in that it includes non-monetary benefits into the project efficiency measure. The project with the lowest CEA ratio is the most favourable. Although CEA is also used in economic appraisals, it is not guaranteed that the project with the lowest CEA ratio should be selected if CEA cannot monetize the unit of effectiveness (Boardman et al., 2001). CEA requires all outcomes of the project to be in monetary terms, which is difficult to find (Touminen et al., 2015). Therefore, CEA is considered to be a supplementary method rather than the main appraisal method, with monetary appraisals such as CBA being used by many evaluators.

Multi-criteria analysis: One of the most common techniques used in economic appraisals is MCA. In project evaluation, economic efficiency is not the only objective of project development. Other objectives, such as an equal distribution of income, may be included as a goal in the project development. MCA evaluates a project based on the objectives led. The objective of MCA is to maximize with respect to a set of socially based objectives rather than market values (Grant-Muller et al., 2001). MCA often incorporates various objectives and multiple indicators of project effectiveness (SOAS, 2009).

The MCA technique is based on the impact matrix, which includes criterions for project selection and the weight of each criterion. MCA assigns weight and score to each criterion. The project impact is obtained by multiplying the score for each criterion by the weighting (SOAS, 2009). MCA has an advantage over CBA in that it provides various criterions that cover qualitative factors opposed to the lone quantitative factors in CBA. Though MCA has many advantages, it is rather subjective and therefore dependent on the judgment from decision makers. Decision team members give their own judgment and may not agree on the scoring and ranking of criterions.

Risk benefit analysis: RBA is an analysis in the context of risk events (Tánczos and Kong, 2001). It assesses the costs and benefits of a selected project activity, which involves risks. Factors such as construction, operation, and market risks are used for the analysis. In RBA, risks can be compared similarly with benefits in CBA.

Other methods: There are also other techniques that have been used in project evaluation, such as environmental impact assessment (EIA), social impact assessment (SIA), and environmental and social impact assessment (ESIA). These methods are encouraged by many governments and international organizations, such as the World Bank and the Asian Development Banks (ADB), to be used as the formal tool for evaluating large-scale infrastructure projects. These techniques focus on the long-term sustainability of projects that include social, cultural, economic, and environmental issues (SOAS, 2009). EIA and SIA have similar objectives and approaches that analyse, monitor, and manage biophysical and social consequences. Because of the close objective and process between EIA and SIA, there is a trend towards the integrated ESIA, which appraises both the project's social and biophysical issues (SOAS, 2009).

2.2 Financial appraisal

Financial appraisal is also frequently used for valuing a project. Financial analysis is the method used to evaluate the viability of the investment project by assessing its net cash flow. The first step of financial appraisal is to assess the cost and benefit. The benefit of a transportation project is measured by the market price that the project's user is expected to pay for the service (Belli et al., 1998) whilst the financial cost is mainly the construction and operation costs, including material, equipment, and labour. The project is financially feasible if the project benefit exceeds the project cost. In the case of mutually exclusive projects, the investment criterion is to select the most profitable project. The key measurements of financial appraisals are net present value, internal rate of return, payback period, and benefit to cost ratio.

Financial appraisal is necessary for the private sector to use as a main technique for evaluating project investment. Financial appraisal is frequently used to value large-scale infrastructure projects, which are typically funded using a project finance arrangement. Project finance is long-term funding method for large-scale infrastructure projects that are financed by the project's own operating cash flow and assets (Chege and Rwelamila , 2001). In project finance, the project investors rely mainly on the expected cash flow from the project to repay loans and to earn a return on their investments.

2.2.1 *Measurements of financial appraisal*

There are several methods used for financial appraisal: the net present value (NPV), the internal rate of return (IRR), and the benefit-cost ratio (B/C Ratio). The following table summarises the definition, the shortcoming, and the key decisions for each method.

Key Measurement	**Definition, shortcoming, and key decisions**
NPV	**Definition:** NPV is an analysis technique used to decide whether or not to invest in the capital asset. The NPV is calculated as the sum of the present value of the project's cash inflows minus the present value of the project's cash outflows. **Shortcoming:** NPV is a simple tool for calculating the value of the project with limitations being the following: i) NPV does not provide safety margin information. ii) It is difficult to calculate the appropriate discount rate of NPV. NPV assumes a constant discount rate over the investment period, and interest rates may not stay at the same level throughout the entire time period. **Criteria to accept project:** NPV > 0
IRR	**Definition:** IRR is an internal rate of return used in capital budgeting to measure and compare the profitability of investments. IRR is defined as the discount rate that equalizes the NPV of the investment’s costs and benefits. **Shortcoming:** IRR is a valuable means to calculate and compare the value of investment projects. However, it also has some limitations: i) The IRR of a project may have multiple values if the project’s cash flow is not a traditional pattern. ii) When comparing projects with different life spans, IRR tends to favour short-time horizontal projects more than long-time horizontal projects.

Key Measurement	Definition, shortcoming, and key decisions
	iii) Though NPV and IRR are closely related, NPV and IRR may provide conflicting results in some circumstances when projects are mutually exclusive or when projects have unfair even distributions of benefits over time. iv) IRR cannot handle a multiple discount rate, so IRR is not appropriate for long-term projects in which discount rates are expected to vary. **Criteria to accept project:** IRR > the cost of capital (the required rate of return)
B/C Ratio	**Definition:** B/C ratio attempts to identify the relationship between the benefit and cost of a project. The B/C ratio is defined as the present value of project benefits divided by the present value of project costs. **Shortcoming:** Though B/C ratio is useful for ranking projects, it has some limitations as well: i) B/C tends to select a project with the lower cost. ii) B/C does not consider the actual amount of net benefits. **Criteria to accept project:** B/C ratio >1

Table 2.1: Key measurements of financial appraisal

Sources: European Commission Guidelines (2008), SOAS (2009)

2.3 Comparison between economic and financial appraisals

In practice, the decision criterions to select investment projects are different between the public and private sectors. The public sector or policymaker selects projects based on the outcomes of the social and economic analysis, whereas a private company (or project owner) and lender consider a project based only on the financial viability (Tánczos and Kong, 2001). The financial appraisal of a project is normally limited to an analysis of commercial profitability and the return on investment capital for the private investment. On the other hand, economic appraisal extends the analysis of the benefits and costs broader, including those incurred outside the project. The economic appraisal expands the scope of the analysis beyond the project to cover the economic welfare of the region or country (European Commission Guidelines, 2008). It evaluates the infrastructure project, covering all impacts to the entire society, not just the investors (as in financial appraisals). In principle, the economic appraisal differs from the financial appraisal in the following three factors (SOAS, 2009):

i) **The scope of evaluation**: The economic appraisal captures a wider range of impacts than in financial appraisals. The scope of economic appraisal extends to cover externalities, such as a third party's impact.

ii) **Market Price:** The market price in the economic appraisal is difficult to find or it may not reflect the marginal benefit and cost that project may receive.

iii) **The discount rate**: The discount rate used in the economic appraisal may differ from the financial appraisal.

Economic and financial appraisals are used by practitioners to evaluate large-scale transport projects. There are many studies in the field of transport appraisals. Among those studies are Grant-Muller et al. (2001), Kerali (2003), Shaoul (2002), and Tánczos and Kong (2001). It should be noted from these studies that there are some important differences between economic and financial appraisals, which are summarised in the following table:

Topic	**Economic appraisal**	**Financial appraisal**
Focus	National wealth	Project feasibility
Objective	Maximize public benefit	Maximize shareholder or owner wealth
Viewpoint	Public, society	Private, PPP
Perspective	Evaluates from a national perspective, which takes a broad view of the benefits and costs.	Evaluates from a project-specific perspective, which takes a more detailed view of the benefits and costs.
Appraisal coverage	Financial, social-economic, environmental, and policy	Focus on financial analysis
Technique	CBA, MCA, qualitative assessment	NPV, IRR, cash flow model, return on equity (ROE), return on investment (ROI)
Project variables	Tries to define variables in monetary terms with market price. However, shadow price and	Uses the actual market price and the actual cost in monetary terms.

Topic	Economic appraisal	Financial appraisal
	opportunity cost may be used instead of the market price if: - The market price did not provide a good measure of the social opportunity cost of inputs and outputs. This is because the market price may be distorted from an inefficient market. - It is difficult to find an observed price for environmental, social, or health effects.	
Timeline	Lifetime or longer than the expected life of the project	Project or concession life, usually between 15-30 years
Discount rate	The discount rate should take into account the opportunity cost, risks, externalities, and taxes. The discount rate used should reflect how the future economic benefits and costs are to be valued against the present values of the benefits and costs.	The discount rate uses the interest rate quoted in the financial market. The discount rate uses the private discount rate that ignores externalities (impact to third parties). Market failure or inefficiency may cause differences between the economic discount rate and the financial discount rate.
Project alternatives	Minimal project alternatives, without project alternatives, or select one or more project alternatives	Select among project alternatives
Taxes, subsidies	Excluded	Included
Important issues	Choices of the discount rate used	Choices of the discount rate

Topic	Economic appraisal	Financial appraisal
	The sensitivity analysis of the impact of the discount rate on the project's NPV The difficulty of finding monetary value or a market price that reflects the true benefits and costs of the project	used The sensitivity analysis of the impact of the discount rate on the project's NPV The sensitivity of the impact of other factors, such as traffic growth and construction costs, on the project's NPV

Table 2.2: The differences between economic and financial appraisals

Sources: European Commission Guidelines (2008), Grant-Muller et al. (2001), Kerali (2003), Shaoul (2002), Tánczos and Kong (2001)

In summary, the economic (or social and economic) appraisal is mainly measured by the public sector whereas the financial appraisal evaluates the financial viability of the project by the private sector. The economic appraisal of an infrastructure project is proposed to determine the types of project investments (alternatives), investment sizes, and the expected economic return (Kerali, 2003). For a publicly funded project, the evaluation should be conducted by an economic appraisal that represents the true impact of the project on the economy system. With limited budgets and resources, governments have encouraged private investments in projects through PPP methodology. The private sector normally evaluates the feasibility of a project via analysing the project's cash flow in which the return on investment is a significant criteria.

The appraisal methods that are used differently by the public and private sectors have created a gap. The gap between economic and financial appraisals increases when the project investment is economically feasible but financially non-viable. To close the gap, support from the public and private sectors in the project is necessary, though such support is subjective and non-quantifiable. Concerning the aim of this research, an attempt to quantify the value of support from both the public sector and the private sector, including the financial institution, was made. The main objective of this study was to apply financial tools, such as real option, to quantify the value of government and private sector support. The main focus of this study is financial appraisal, which is mainly used by private companies and financial institutions to evaluate the financial viability of a project.

2.4 Economic and financial appraisals of transportation system projects

The aim of an economic appraisal of a transportation project is to select the project that provides the best economic return. In general, the methods used for appraising transportation projects can be classified into two groups; single criterion (monetary approach) and multi-criteria analysis (Tsamboulas et al, 1999). A monetary approach such as CBA is traditionally used for evaluating projects. However, this method has limitations in that it cannot capture all the relevant impacts of a project, such as the environmental and social factors, into monetary terms. Specifically, its limitations include ironing individual risk, a low level of objectivity, and transparency (Brzozowska, 2007). The appraisal of transportation projects has been extending wider in scope to cover not only time, cost, and safety impacts, but environmental, social, cultural, and economic impacts as well (Grant-Muller et al., 2001). With CBA's limitations, additional appraisal methods are required to compensate.

Many researchers, such as Tsamboulas et al. (1999), Grant-Muller et al. (2001), and Feng and Wang (2005), have aimed to improve the appraisal process of transportation projects. Those studies attempted to achieve a comprehensive methodology for transport appraisals and overcome the shortcomings of CBA. The multi-modal transport was initiated by the U.K. government in 1999 and covers all aspects of sustainable transport development in the broader strategies at the regional or sub-regional level (Rayner, 2004). The multi-modal focuses on five wider topics: i) environmental, ii) safety, iii) economy, iv) accessibility, and v) integration. The benefit of the multi-modal is that it includes both the monetary term and the assessment scale, which cannot be quantified in units (Bhasin, 2003). Multi-modal can be used with CBA to provide a more comprehensive appraisal framework for a transportation project. Whilst CBA may be used to monetize impacts, the multi-modal can help assess impacts that are difficult to measure in monetary terms.

In practice, the appraisal of a transportation project is framed by the multi-modal and the multi-agency including CBA. CBA is commonly used by policymakers to justify the transportation project investment. The CBA framework may include other techniques, such as multi-criteria analysis (MCA) and qualitative techniques.

It can be argued that a quantitative appraisal alone is insufficient. Most EU countries have applied both quantitative and qualitative methods to evaluate transportation projects. The appraisal framework is used by practitioners to rank and compare project alternatives. The appraisal framework of EU members can be classified into three groups: i) the direct transport impact ii), the environmental impact, and iii) the social and economic impact. Direct transport impacts are expressed in monetary terms, for which CBA is frequently used, whilst the environmental, social, and economic impacts take into account both qualitative and quantitative appraisals in their analyses.

CBA is mainly used by the U.S. government for economic appraisals of public projects. To enhance the practical usefulness of CBA, other tools such as CEA can be used to supplement. Procedural Guidelines for Highway Feasibility Studies, published in 1998 by the U.S. Department of Transportation’s Federal Highway Administration, provides a guideline for the economic appraisal of highway projects. The guideline consists of three general components: i) a benefit-cost analysis, ii) non-monetary but quantifiable, and iii) non-quantifiable (U.S. Department of Transportation, 1998). In addition to CBA, the National Environmental Policy Act (1969) imposed requirements regarding the analysis of social, economic, and environmental impacts to federally funded projects, including transportation projects.

Time-saving is a crucial factor in transport appraisals, and its value in transport projects has been studied since the 1950s. Many research studies have found that time savings account for about 60% to 80% of the quantified benefits of transport projects (Grant-Muller et al., 2001). The estimation of time-saving benefits is dependent on a set of assumptions and parameters, which are the ratio of non-working time to working time, the variation of value of time (VOT) with income, the VOT by mode of travel, and relative values placed on various aspects of travel, including walking, waiting, and traveling in a vehicle (Grant-Muller et al., 2001). In addition to the time-saving benefit, saving vehicle operating costs (VOC) is also an important benefit gained from transportation projects. VOC benefits are lower fuel costs and maintenance cost savings, which usually include lubricants, tires, and vehicle wear and tear (Belli et al., 1998). Other benefits of transport projects include lower transport costs, reduced accidents, travel comfort, convenience, and reliability of service, stimulating economic and environmental improvement (Belli et al., 1998).

2.5 Public private partnership (PPP) project appraisals

PPP projects are driven by the government to encompass limitations in public funding as well as expectations to improve the quality and efficiency of public services (European Commission Guidelines, 2003). PPPs can be defined as contractual agreements between public and private parties to deliver assets and services that have traditionally been provided by the public sector (Bettignies and Ross, 2004). In PPP, the public sector incorporates with the private sector to build, operate, and provide public responsibility, investment of resources, risk-taking, and mutual benefit (Allan, 1999). Public projects can gain more efficiency and reduce overall project costs by adopting PPPs. To understand the mechanism of the PPP concept, table 2.3 summarises the characteristics of PPP project appraisals, which have been studied by many researchers.

Topic	**PPP appraisal**
Focus	National economic impacts from a PPP project Trade–off between the private sector profit and economic and social benefits
Objective	To maximize the project's economic and financial value with the government budget constraint and to optimize the total project lifecycle cost
Viewpoint	Risk-sharing among the public sector and the private sector, and other related parties
Perspective	Evaluates from a national perspective, which takes a broad view of alternative costs (such as private offer), compared with the traditional cost.
Appraisal coverage	Both the economic and financial appraisals
Technique	Value for money (VFM), financial cost comparator, and qualitative techniques The assessment method is dependent on the project financing source, such that: - **Main source from public sector**: the cost and benefit analysis (both in monetary and non-monetary terms) of PPP options is applied.

Topic	**PPP appraisal**
	- **Partial source from public grant or support**: the cost and benefit gained from different PPP project alternatives are compared with various types of support. The assessment should ensure that the grant is optimally allocated in that the project is financially viable and sustainable, and the project can generate the maximal social and economic benefits but also control the private sector profits at a reasonable level. - **Financial self-support**: The private party has the main responsibility to appraise whether or not the project is commercially successful and if the project provides a suitable return on investment. VFM is used by the public sector to evaluate whether or not a PPP project is preferred over the alternatives.
Timeline	Lifetime or longer than the expected project life
Discount rate	It can be argued as to whether or not the discount rate should be used equally between the publicly funded project and the privately funded project. Many project evaluators still apply a higher discount rate for private projects. However, there is a tendency to use the same discount rate for both public and private projects (Grout, 2002). This issue will be discussed in detail in the next section.
Project alternatives	The decision maker selects the alternative that maximizes the VFM. Alternatives range from: -The main source of financial support from the public sector - Management and lease contract - Greenfield - Concession contract with public grant - Full concession grant/ financial freestanding project - Divestitures

Topic	PPP appraisal
Taxes, subsidies	- Included if no tax exemption
Crucial points	- Risk-sharing between the public and private sectors - The value of discount rate used for evaluating the project - The quantitative and qualitative factors used to evaluate VFM - The level of government support or subsidies; it should be carefully reviewed to ensure that the support is matched with actual needs.

Table 2.3: Characteristics of PPP project appraisal

Sources: European Commission Guidelines (2003), Grout (2002), Tanaka et al (2005)

Lastly, European Commission Guidelines (2003) suggest focus points in the economic and financial appraisal of PPP projects:

i. The project appraisal should address the translation of risks between parties and whether the optimal risk allocations among them are determined. Risks should be transferred to the appropriate private parties that can manage them with cost effectiveness.
ii. The project should ensure the VFM for the entire development process.
iii. Grant or support from the public sector should be optimized.

2.6 Project discount rate

Determining the discount rate for PPP projects is one of the more crucial tasks in project appraisal. The discount rate used in economic appraisals is significant for the investment decision because the outcomes of the CBA are significantly influenced by the choice of the discount rate applied in the decision-making. There are two main discount rates used in economic appraisal: the social opportunity cost of capital and the time preference for consumption (Preez, 2004). The social opportunity cost is the rate of return that is required by the private sectors in order for them to invest. The time preference for consumption is the rate of return in which people are prepared to trade consumption today for consumption in the future. In an efficient market with perfect market information, the discount rate used in the economic appraisal is the rate that the social opportunity cost equals the time preference for consumption.

To assess the investment opportunities, the project's expected future cash flow needs to be calculated, in which the estimated future cash flow is under uncertainty. The future cash flow is then discounted by the discount rate to give the present value. The discount rate can be defined as the expected rate of return required to compensate risks. The selection of the discount rate impacts the investment decision as to select or discard the project. Many research studies have performed analysis to find the appropriate discount rate used in project appraisal. These studies include Evans and Sezer (2004), Evans (2008), Caplin and Leahy (2004), Mendelsohn (1983), and Grout (2002). It can be found from these studies that there is a range of discount rates used for evaluating a project, which affect the investment decision.

It can be concluded from many research studies that appropriate discount rates should be used in the project appraisal, otherwise it may lead to selecting a project that is not the best among alternatives. In practice, the discount rate is the best yield of all possible investment alternatives (Benes and Stary, 2009). In financial theory, the discount rate is comprised of two components: the risk-free rate and the risk premium. The government treasury yield rate can be a proxy for the risk-free rate. The risk premium of the project is measured by project risk combinations, such as credit, liquidity, and market risks. Theoretically, the value of the discount rate differs from project to project. For infrastructure projects, the discount rate should represent the opportunity cost of public expenses and risks associated with investment.

Many researchers have argued about the value of discount rates used in project appraisal. Whether or not the discount rate used for valuing a public project should be the same as the discount rate used in a PPP project is a particularly contentious issue. Grout (2002) argued for using the same discount rate for both public and PPP projects. He concluded that the lower discount rate for public finance should be applied.

The discount rate used in project appraisals has been applied differently in many countries. European Commission Guidelines (2008) suggest using 5% for a real financial discount rate and 3.5% for a real economic discount rate in project appraisals whereas the formal discount rate used in the U.K. has been reduced in recent years from 6% to 3.5%. Table 2.4 summarises the discount rate applied in project appraisals for selected countries. It can be seen in the table that the economic discount rate differs considerably between countries depending on their economic condition, the credit rating of the country, and their capacity to repay foreign borrowing.

Country	Credit rating by Moody's /S&P (as of March 2017)	Economic condition (GDP in 2010-16 :%)	Foreign reserve to import (month) in 2015	Discount rate (% of real term)	Method of discount rate
EU members **Source:** European Commission Guidelines (2008)	N/A	N/A	N/A	- 5% (financial appraisal) - 3.5% (social and economic appraisal)	- The opportunity cost of capital - The social time preference rate (STPR)
United Kingdom **Source:**The HM Treasury Green Book of 2003	Aa1/AA	0.7-2.7%	1.01	3.5% (social and economic appraisal)	STPR
France **Source:** European Commission Guidelines (2008)	Aa2/AA	0.2-2.1%	2.1	4% (social and economic appraisal)	STPR
Germany **Source:** European Commission Guidelines (2008)	Aaa/AAA	0.4-3.9%	1.6	3% (social and economic appraisal)	STPR
United States **Source:** CircularA-94 (1992)	Aaa/AA+	1.6-2.4%	0.2	7% (public investment displaces both private investment and consumption)	The social opportunity cost rate
United States **Source:** Circular A-94	Aa1/AA+	1.6-2.4%	0.2	For cost effectiveness, lease purchase,	The government borrowing

Country	Credit rating by Moody's /S&P (as of March 2017)	Economic condition (GDP in 2010-16 :%)	Foreign reserve to import (month) in 2015	Discount rate (% of real term)	Method of discount rate
(revised 2009)				internal government investment, and asset sales analyses 3-year project: 0.9% 5-year project: 1.6% 7-year project: 1.9% 10-year project: 2.2% 20-year and up: 2.7%	rate
Japan Source: ADB (2007)	A1/A+	(-0.5)-1.7%	N/A	4.5%	STPR
Australia **Source:** Partnerships Victoria (2003b)	Aaa/AAA	2.1-3.6%	1.9	6.5%	- Capital asset pricing model - Discount rate comprised of the risk-free rate and the risk premium.
Thailand **Source:** PPP guidelines	Baa1/BBB+	0.8-7.5%	10.1	- Not specific rate - Discount rate is calculated by the	The risk-free rate plus the project's

Country	Credit rating by Moody's /S&P (as of March 2017)	Economic condition (GDP in 2010-16 :%)	Foreign reserve to import (month) in 2015	Discount rate (% of real term)	Method of discount rate
(draft) by Public Debt Management Office (2013)				government's bond interest rate adjusted by the project's specific risks.	specific risk (risk premium)

Table 2.4: Summary of indicative discount rates used in selected countries

Table 2.4 summarises the discount rates applied in project appraisals for selected countries. It can be seen in the table that the economic discount rates differ considerably between countries depending on their economic conditions, the credit rating of the country, and their capacities to repay foreign borrowing (foreign reserve to import). There is a tendency to use a lower discount rate for developed countries (a high credit rating and a higher debt capacity) that anticipate smaller economic growth rates. In addition, economic stability in developed countries has attached a low risk premium therefore lower discount rate to investment. It can also be seen that STPR is the most widely used model in many counties (i.e., Germany, France, UK and Japan) because it attempts to cover all aspects of an appraisal (i.e., the public policy, social ethics and future economic conditions). The table also shows that in most developed economies STPR is around 3.5%–4.0% in real terms.

It can be seen that the discount rate used in the economic appraisal of the project is measured differently for different countries. Furthermore, many organizations have provided practical guidelines for choosing the discount rate as shown in table 2.5. Table 2.5 also provides a brief discussion on the use of discount rate in Thailand.

Organization	Guideline for estimating discount rate
ADB (1997)	The discount rate can be estimated by four methods: **i) The economic rate of return on alternative marginal projects or the economic opportunity cost of capital**: Project investments can be selected only if they show a minimum rate of return that is not exceeded by other possible investments. **ii) The real cost of foreign borrowing**: This method is used to ensure

Organization	Guideline for estimating discount rate
	that projects are committed to meeting the country's debt obligations, especially where investments are highly dependent on the inflow of foreign capitals. **iii) The real rate of return in the capital market**: This method determines the return that the projects must earn before investors will forego to more liquid types of investments. **iv) The overall demand and supply of investment funds**: Demand and supply of investment funds is a good indicator for estimating the economic price of the capital.
European Commission Guidelines (2008)	The European Commission specifies the choices of discount rates used in financial and economic appraisals as follows: **Financial appraisal**: **i) The weight average cost of capital (WACC)**: The project's weight concerning the average cost of capital of loans, bonds, and equity is used as the discount rate, for which the benchmark of WACC is: ▪ public project: the real return on government bonds (the marginal direct cost of public funds), ▪ private finance: the long-term real interest rate on commercial loans, ▪ or a weighted average of both. **ii) The return lost from the best investment alternative** (opportunity cost) **iii) The cut-off rate**, such as the interest rate or the rate of return from a listed issuer of securities **Economic appraisal (social –economic appraisal)**: **i) Traditional approach**: The marginal return on the public investment should equal the marginal rate of return on the private investment in that the public project can displace the private investment. **ii) The social time preference (STPR) approach** (consumption rate of interest):

Organization	Guideline for estimating discount rate
	STPR represents two major components: ▪ People's incomes grow at diminishing marginal utility. ▪ People have a pure time preference in that they prefer current utility rather than consuming in the future. This approach considers the rate of growth in economic (g) and the preference for current benefits over time. The formula for calculation is: $r = \mu g + \rho$ where: r = the social discount rate g = the growth rate of the public expenditure μ = the elasticity of the diminishing marginal utility of consumption p = a rate of pure time preference **iii) Multiple rates of return**: This method is applied to multiple discount rates that decline overtime.
The Green Book appraisal and evaluation in central government (U.K.)	The Green Book suggests the calculation for determining the discount rate as: **i) The social time preference approach** **ii) Long-term discount rate**: This approach uses the declining long-term discount rate as: Period of years: 0–30, 31–75, 76–125, 126–200, 201–300, and 301–more Discount rate: 3.5%, 3.0%, 2.5%, 2.0%, 1.5 %, and 1.0%
Circular A-94 (United States)	Circular A-94 suggests the calculation for determining the discount rate as: **i) The social opportunity cost rate** by approximating the marginal pre-tax rate of return on an average investment in the private sector in recent years **ii) Government borrowing rate** by using treasury notes and bonds on specified maturities
The World Bank	Uses 10 to 12% of the discount rate (the opportunity cost of capital method) for World Bank project financing.

Organization	Guideline for estimating discount rate
Thailand context	There is no precise and commonly accepted method of determining the discount rate for PPP project in Thailand. STPR is not easy to quantify accurately and STPR entails concepts that many people are unfamiliar with. WACC and government borrowing rate are the appropriate measures in Thailand context as they are available in the market and they reflect true borrowing cost. It is evident that there is no specific method when calculating the discount rate for economic appraisal, as every country, based on different assumptions, has its own policy and discount rate approach.

Table 2.5: Methods for estimating discount rates

Again, it can be seen that different organizations use different discount rates for evaluating investment projects. The discount rate used for calculating the discount cash flow in the economic appraisal of infrastructure projects should be used consistently by practitioners with an understanding of its limitations. It can be argued by many literatures that estimating discount rates for an investment project is one of the most challenging tasks, focusing especially on the disadvantages of each (see table 2.6). Table 2.6 presents the shortfall of each methodology when applied to the SES project which is a case study in this research.

Method for calculating discount rate	Shortcoming
WACC	It can be argued that there exists the theoretical difficulty for calculating the cost of equity in WACC. There are different methods for estimating the cost of equity, and each method uses different data sets. Practitioners introduce bias in their value estimates by making subjective adjustments. Therefore, it may lead to discrepancies between the different calculating methods. Though WACC is often used to estimate a project’s discount rate, it is more problematic. There are various factors that may affect the calculation of WACC:

Method for calculating discount rate	**Shortcoming**
	i) Using WACC as the discount rate in the project may not be adequate because the risks of the project and firm are normally not the same. **ii)** WACC is calculated assuming a constant variable that may not reflect reality. For example, the cost of debt (interest rate) may change over time due to economic change. Sources: Eschenbach and Cohen (2006), Mun (2006) The traditional approach adopted to evaluate the SES project (a case study in this research) regularly uses the WACC to estimate the discount rate. However, infrastructure projects including SES project are not actively traded in the secondary market, so estimating a discount rate, using WACC, for such projects is more difficult. However, determining variables in WACC such as the beta of the return on equity are not so difficult. An alternative approach is to identify proxies (i.e., beta of the similar company in stock market) for each variable used in calculating WACC.
STPR	STPR does not contain risk factors for calculating discount rate. STPR neglects potentially important risk factors such as uncertainty of future benefits and costs. For example, the uncertainty of traffic demand of the SES project may be neglected by STPR. Sources: Price and Nair (1985), Evans and Sezer (2002)
The government borrowing rate	In this method, the discount rate does not reflect the true cost of a project because most projects are financed by other sources, such as debt financing, not only government funding. Most projects including the

Method for calculating discount rate	Shortcoming
	SES project use a combination of debt and equity financing. Therefore, using the government borrowing rate may not reflect the true cost of project's fund. Source: SOAS (2009)
The market rate (the real rate of return in the capital market)	There are at least three major disadvantages of using the market rate as the discount rate: **i)** The market rate is highly volatile, which may lead to a wrong investment decision. **ii)** The market rate may be misled by market inefficiencies such as oligopolistic structures. **iii)** The market rate may not be appropriate for the public borrowing because it includes the risk premium of the private borrower. Source: SOAS (2009) As the market rate is quite volatile, it may not be appropriate for evaluating the long term project such as the SES project.
The economic opportunity cost of capital (social opportunity cost rate)	The return on private equity investment may be influenced by market imperfections, such as monopolies. Moreover, the use of alternative private investments may ignore externalities. Source: SOAS (2009)

Table 2.6: The shortfall of each discount rate methodology

Selecting the appropriate discount rate for project appraisal remains the subject of much debate for evaluators. Among the choices of discount rates are the opportunity costs of capital, STPR, the market rate, and the government borrowing rate.

2.7 Summary of Section I

There are two main methods to evaluate large-scale infrastructure projects: (i) economic appraisal, and (ii) financial appraisal. Economic appraisal is mainly used by governments to evaluate an infrastructure project in terms of the benefits and costs for society as a whole, while financial appraisal is mainly applied by the private sector to determine the financial viability and sustainability of an infrastructure project.

The main technique in economic appraisal is CBA, which estimates the benefit and cost of a project to determine whether or not the project is worthwhile for the community. While many techniques, such as NPV, IRR, and payback period, are used in financial appraisals, they have limitations for which a more careful analysis is required.

The economic appraisal of a transportation project was reviewed and addressed regarding its general framework and treatment, including the appraisal techniques of the major project impacts. This research attempted to consider key elements, such as appraisal techniques and the discount rate of the transport assessment. Comparative analysis was used with respect to effectiveness, simplicity, and accountability. The use of each technique may prove to be useful in transport project appraisals, subject to precaution.

Section II: Literature review: risk management in large-scale infrastructure projects

This section starts with a review of risk management in project finance. This section proposes the risk management framework used in this thesis. It also focuses on risk identification, risk analysis, and risk allocation in large-scale infrastructure projects.

2.8 Risk management in project finance

There are numerous possible definitions of project risk that could be used. The definition used in this thesis is that project risk refers to the probability of an event occurring that would make a project's circumstances different to those expected from forecasts (Partnerships Victoria, 2001). Risks always exist in infrastructure projects, and extreme risk can ultimately lead to the complete failure of a project. Risk is typically measured by the product of the probability and the size of the loss. To handle risks properly, it is essential to identify and properly manage them. Risk management can be defined as a process composed of three major components: (i) identifying risk, (ii) analysing risk, and (iii) responding to risk (Burke, 1999).

The risk management process for a project starts with risk identification. Risk identification should identify all the sources of risk and uncertainty that may impact a project. The purpose of risk identification is to identify a list of risk factors and then to rank their importance (Shen, 1997). Common methods used to identify risks are questionnaires, checklists, interviews, brainstorming sessions, and risk registers (Tanaka et al., 2005). The identification of risks prior to project development is critical in project evaluation for both public and private sectors (Roumboutsos and Anagnostopoulos, 2008).

The second task of risk management is to analyse and assess the risks. Risk analysis is the process that determines the possibility and impact of the various risks identified in the identification stage. Risk assessment can be done by quantitative and qualitative techniques, or the combination of both. In the qualitative approach, the likelihood (probability) and impact of the identified risks are focused to determine their magnitudes. The most popular qualitative techniques include probability impact matrices, top risk item tracking, interviewing, and the use of expert judgment. In contrast, under the quantitative approach, the assessment of risk is done by numerical measures. The most popular quantitative risk techniques include sensitivity analysis, probability analysis, decision trees, and Monte Carlo simulation.

Lastly, risk response is the process of mitigating or eliminating the potential impact of risks. Risk should be controlled in order to efficiently and effectively achieve a project's objectives (Merna and Njiru, 2002). Risk response can be classified into risk reduction, risk avoidance, risk elimination, risk transfer and allocation, and risk retention. The main focus of this research is risk response in order to determine the optimal risk allocations within the project. Real option is proposed in this research to allocate and mitigate the risks in the infrastructure project.

2.9 Risk management framework

Risk management is defined as a dynamic process rather than a static process in that it can identify feedback between the different processes of risk management (El-Amm, 2003). Though many research papers have proposed risk management frameworks, such as Turner (1993), Flanagan (2002), and El-Amm (2003), this thesis proposes the integrated risk management system and framework as shown in table 2.7.

The proposed risk management framework has been slightly modified from the original source by reorganizing the risk process into four parts: i) identification, ii) classification, iii) analysis, and iv) risk response and mitigation strategy. This framework was aimed to identify and classify the potential risks of the project, which can be assessed and quantified. The most common way to manage risk is risk transfer, reduction, retaining, and avoidance, respectively or in combination, in that risks should belong to the party best able to manage. In addition to these methods, many strategic tools, such as financial structures, diversifications, financial instruments, and support from the government or global multi-lateral institutions, are used to reduce and allocate the risks of a project. The selection criteria among these tools is dependent on the type of risks, the magnitude and severity of risk, the stakeholders' objective, and the strength and attitude toward risk (El-Amm, 2003).

The proposed risk management framework		
Risk identification	Identify the potential sources and types of risks.	- Design and construction risk - Procurement risk - Operation and maintenance risk - Economic risk - Environmental risk - Financial risk - Market risk - Technology risk - Force majeure risk - Others
Risk classification	Classify the types of risks that have affected the project, organization, and people.	- Project risk - Market risk - Country risk or - Systematic risk - Specific risk or - High-control risk - Low-control risk
Risk analysis	Assess the impact of risk using various risk measurements, both the quantitative and qualitative approach. Evaluate the impacts of a single risk or the combination of risks by using analytical techniques.	<u>Quantitative approach</u> - The expected value theory - The expected utility Theory - Sensitivity analysis, scenario analysis, and simulation - The decision tree analysis - the real option and valuation <u>Qualitative approach</u> - The risk factor analysis - The probability/impact matrix - Interview and expert judgment
Risk response/ Risk mitigation strategy	Consider different methods to manage risks (i.e., transferring to another party, avoiding, or retaining). Allocate risks to the appropriate parties.	- Financial structure - Diversification - Financial instruments - Incentive and contractual arrangement - Support from the government - Support from global multi-lateral institutions - Joint venture and unbundling - Option and flexibility

Table 2.7: The integrated risk management framework

Sources: adapted from Flanagan (2002) and El-Amm (2003)

2.10 Risk identification and classification in the large-scale infrastructure project

The first step in the process of risk management is to identify potential risks that may have a significant impact on the project. It is important to understand what risk characteristic is and what causes project failure. Shen (1997) suggested that risk identification is purposed not only to identify a list of risk factors but also to analyse the impacts of those risk factors. In general, risks in a project can be classified as completion, procurement, financial, operational, market, credit, political, legal, and environmental risks. Risk factors related to project finance are listed in table 2.8.

Major risks	**Sub-category risks**	**Mitigation strategy**
Completion risk		
	- Construction risk	- Payment and performance bond - Liquidated damage - Contractual arrangement and associated guarantees, such as fixed price and turnkey contract - Private insurance - Experienced and qualified contractors
	- Design risk	- Risk transferred from the government to the private sector by the design of an economically rational financing structure - Transferring risks to a subcontractor - A detailed architecture and engineering plan - Technical advisor
	- Commission risk	- An inspection and commissioning program backed by clauses in contracts - Appoint a high-quality project manager to manage the project.
Financial risk		
	- Foreign exchange risk	- Matching revenue and cost in the same currency - Adjustment provisions in contracts, such as foreign exchange index and revenue collection - Foreign exchange hedging

Major risks	Sub-category risks	Mitigation strategy
		- Government support and a guarantee for foreign exchange fluctuation - Use a derivative contract for hedging risk in the financial market. - Provide a contingent credit facility to cover higher than expected costs.
	- Inflation risk	- Provide an inflation index. - Long-term supply contract with a fixed price
	-Interest rate risk due to a limit to an existing financing source -Volatility risk of an interest rate	- Seek a low interest rate loan from an international financial institution or supranational bank. - Use a syndicated loan to finance large-scale infrastructure projects.
Market risk		
	- Demand risk such as the risk from lower than expected toll revenue, imprecise traffic forecasts, and others - Price risk such as price control by the government	- Contractual arrangement, such as a take or pay contract - Revenue guarantees from the government and price adjustment provision in a contract, such as toll adjustment - Early stage equity financing and refinancing debt at a lower interest rate - Set a lending structure by the front-end loading of debt payment and heavy repayment during fixed interest rates. - Provide the contingent credit facility to cover lower than expected revenue. - Cash trap to ensure that the lender continues to receive timely payment (e.g., no dividend payment would be permitted if DSCR cannot maintain) - Use tracking accounts (e.g., if the

Major risks	Sub-category risks	Mitigation strategy
		contract price exceeds spot market prices, the difference between the two would be tracked). - Set a debt service reserve fund.
Operating risk	- Higher than expected operating costs - Performance below project specifications	- Establish clear service standards. - Operating guarantees or performance bonds from the private company - Seek for the experienced operators. - Training program for the workforce - Employee participation program
Credit risk	- Counterparties' risks from suppliers, contractors, customers, or other parties that commit to meet a certain obligation in the future - Risk associated with the project's ability to repay debts	- Due diligence and credit rating process - Performance bond issued from counterparties - Counter guarantee/ standby LC issued by financial institution
Procurement risk	- Shortage of raw material - Increasing raw material cost	- Long-term fixed price or quantity supply contract - Contractual arrangement through put-or-pay or pass through structure
Political risk		
	- Political event (e.g., war, revolution)	- Government support and guarantee - Government participation in project - Seek participants from an international investor or international organization. - Government discloses policy as much as possible.
	- Changes in government policy, such as currency devaluation,	- Contract provision to pass the cost of any change to the customer in the form of a tariff increase

Major risks	Sub-category risks	Mitigation strategy
	taxes, foreign exchange control, export restriction, and fund transfer restriction - Government intervention on tariff structure - Political change and instability in the government	- Government support and guarantee for adverse change
Macro-economic risk	- Instability of economic and government policy - Country credit rating downgrade	- Provide a new mechanism to structure repayments under the economic downturn or crisis
Legal and environmental risk	- Change in environmental regulations - Change in regulatory framework - Property right clarity	- Put the consequence of adverse change in the initial pricing structure. - Pricing indexation adjusted for adverse change - Contract negotiation with the government to adjust tariffs in the event of adverse change
Force majeure	- Superior force such as earthquake and natural disaster - Political, such as civil riots and war	- Take insurance for business interruption and property damage.

Table 2.8: Risk factors of project finance

Sources: Kong et al. (2008), Leviakangas (2007), National Treasury/PPP Manual (2001), Obeng and Mokgohiwa (2002), Partnerships Victoria (2001), Ruster (1996), Schaufelberger and Wipadapisut (2003), Wibowo and Kochendorfer (2005).

There are various risk factors that may jeopardize the success of a project by causing cost overruns, schedule delays, and under specifications (Ghosh and Jintanapakanont, 2004). Due to the unique characteristics of a project, risk factors will be different between projects, and such different risks have different levels of impact. Successful project implementation is dependent on the effective management of critical risk factors.

Given the complexity, size and the time horizon of project finance, there are enormous ranges of potential risks that can affect the performance of the project. However, in general, risks can be classified into two main groups: systematic risk and non-systematic risk. Systematic risks, also known as market risk, are the risks that affect all projects within the economy. The factors that determine systematic risk include inflation, interest rate changes and recession which affect the whole market and cannot be avoided through diversification. The Capital asset pricing model (CAPM) developed by William Sharpe (noble laureate in economics) is commonly used model to calculate risk and return on investment. According to this model, project required returns should be determined based only on its systematic risk. The following is presented below:

$E(R_i) = R_f + \beta\ (R_m - R_f)$ where
$E(R_i)$ =expected return on asset, R_f = risk-free interest rate, β= beta of the security, R_m =the expected market return and $(R_m - R_f)$ = market risk premium

In CAPM model, beta is a measure of the volatility, or systematic risk, of an asset or a portfolio in comparison to the market. Beta is an important component of CAPM which is used to calculate the expected return.

Risks that are specific to a particular type of investment, company, business or projects are named as non-systematic risks. Examples of non-systematic risks in projects are construction completion, design change, and operational risks. Non-systematic risks can be mitigated through diversification, which consists of making investments in a variety of companies and projects.

In addition, long-term financing of infrastructure is subject to risks associated with debt financing. For project valuation using DCF method, it is common to use the weighted average cost of capital (WACC) as the discount rate. To calculate the debt capital cost (R_d) in WACC (see WACC's formula in page 76), it is normally assumed that cost of debt is not volatile. Hence, the WACC's assumption has been made that beta of debt is zero which is not necessarily the case for long term projects. Therefore, sensitivity analysis of the beta should be done on the discount rate (WACC) used in project evaluation.

2.10.1 *Specific risks in PPP large-scale infrastructure projects*

Due to the limitation on the use of public funds, governments are moving towards the private sector to invest in large-scale transportation projects. Investment amounts in transportation system projects, such as mass transit, are large-scale and long-term so that the success or failure of the project will have a large impact on its stakeholders. According to Ng and Loosemore (2007), large transport projects are generally long-term investments that typically involve various stakeholders and risks throughout the project lifecycle. The existence of a particular risk may adversely affect the success of the project.

Risk identification and risk analysis in large-scale infrastructure projects have been studied in many journals, scholarly works, country case studies, and reports. Wibowo and Kochendorfer (2005) performed a risk analysis of Indonesian toll road projects using a Latin hypercube simulation technique. The study concluded that the private investor and lender were exposed to cash flow uncertainty resulting from lower traffic volume and a delay in toll price adjustment. The study also found that some government support, such as a land acquisition process, can help mitigate land price risk and project completion risk.

Schaufelberger and Wipadapisut (2003) performed an analysis of 13 case studies on build operation transfer (BOT) projects, nine of which were transportation projects. The study found that political, financial, and market risks influenced the selection of a financial strategy. The result of the case study showed that to mitigate these risks, the project required strong government support and guarantees lent from strong financial institutions and flexible contract provisions, such as price escalation and a mechanism for foreign exchange and interest rate adjustment.

EL-Amm (2003) classified the risks of toll road projects into project risk, country risk, and market risk. Among the risk factors mentioned, project risk is a specific risk that is limited to the project itself. Project risk is found at all stages of the project life and impacts the profitability of the project. The market risk of the project is the risk that is subjected to demand and price volatilities, and the country risk is the risk occurred from government action, including political risk, economic risk, exchange rate risk, sovereign risk, and transfer risk.

2.11 Risk analysis and measurement

The second step of risk management is risk analysis and assessment. Risk analysis is a technique used to evaluate the project in terms of cash flow and the expected return on investment, with an assessment of the risks and uncertainties that threaten the project (El-Amm, 2003). The traditional approaches for evaluating project success are the expected NPV, the IRR, the project payback period, and the B/C ratio. The expected NPV is the most favourable method for evaluating a project because it can provide a fairly accurate assessment of the impact of risks on the investment project, taking into account the time value of money and the scale of investment. NPV is a method calculated to determine the present value of an investment by the discounted sum of net cash flow over the whole project life. The cash flow is discounted by the interest rate equal to the opportunity cost of capital, which is composed of the risk-free rate, the risk premium, and inflation (El-Amm, 2003). Though NPV is widely used for evaluating projects, the disadvantage of this method is the uncertainties of the cash flow prediction and the discount rate. One should be aware by the appraisers that the NPV can undervalue many projects (Lewis et al., 2004). There are other measures, such as the IRR, the real option, and simulation that can help overcome this weakness. Table 2.9 presents the risk assessment tool used for evaluating a project.

Risk analysis tools	**Criticize**
The expected NPV	- The discount rate is a critical component in the calculation of the expected NPV. In theory, the discount rate represents the expected return that is required to compensate investors for their exposure to risk factors. In reality, different investors have different attitudes towards risk (e.g., risk aversion, risk seeking, and risk-neutral), and attitudes towards risk change over time. Therefore, the use of a constant discount rate throughout the project lifecycle does not adequately reflect risks. For example, the use of a constant discount rate throughout the project lifecycle may not be appropriate, as a project is normally subjected to higher risks in earlier years of operation and lower risks when it reaches a steady stage of operation.

Risk analysis tools	Criticize
	- The NPV approach can capture the risks by doing a sensitivity and scenario analysis of the critical variables. A sensitivity analysis indicates the effect on NPV by changing one variable at a time whereas a scenario analysis considers the alternative possible outcomes. These two methods have a limitation in that they capture risks on the cash flow basis rather than adjust risks by using the different discount rates.
The expected utility theory	The expected utility theory explains the project investment decision by the investors' attitude to risk. For example, risk-averse investors will require a higher project NPV for the risky project to compensate for their risk-taking. Many empirical studies have revealed that most people express risk-averse behaviour when making investment decisions, especially people with low income (ADB, 2002). The drawback of the expected utility theory is the difficulties of estimating utility functions and quantifying the risk.
The decision tree analysis	The decision tree analysis is a path representation of the expected NPV. This method allows the project investors to factor in both the probability and the impact for each path of every decision under consideration. The major shortcoming of the decision tree analysis is the same as the NPV method in that it applies a constant discount rate for the whole path of the decision tree.
The simulation method	The simulation method is used to capture the uncertainty of the project cash flow. The Monte Carlo simulation method is one of the most widely used methods for project evaluation. It overcomes the traditional NPV by i) providing various risk factors in the simulation, ii) providing the probability function with repeated sampling, iii) simulating interrelation among variables, and iv) providing flexibility for simulating random events.

Risk analysis tools	Criticize
	There have been many criticisms of the simulation method from practitioners: - It is too complicated and contains too many variables. - It relies on a probability distribution. - It neglects managerial flexibility to embark on the investment decision.
Real option	Real option analysis is a useful tool for evaluating a project by including managerial flexibility in the investment decision. Real option applies the theory of financial option to evaluate investment options of real physical asset (Dixit and Pindyck, 1994). Real option exceeds the limitation of traditional project valuation by providing flexibility embedded into the investment decision (El-Amm, 2003). Real option has been used for evaluating projects in a variety of contexts, such as infrastructure, power generation, energy, and others. The nature of the real option approach, including its methodology, application, and limitation, will be treated in greater detail in the next chapter.

Table 2.9: The risk assessment tools

Sources: ADB (2002), Dixit and Pindyck (1994), El-Amm (2003)

2.12 Risks in a large-scale transportation system project in Thailand

Many transportation projects in Thailand have been traditionally financed by conventional procurements. In practice, transportation projects in Thailand are publicly funded and operated by a state-owned enterprise or the Department of Highway. Although investment in infrastructure projects is a core function of the government, it requires a lot from the government budget. As there is a limitation for the government investment budget and a high initial investment cost, the government tries to increase the role of the private sector in infrastructure investments by structuring a public procurement system to promote private investment. In the early 1990s, transportation system projects in Thailand were granted a concession by a government agency or state-owned enterprise under the Ministry of Transport.

PPP projects in Thailand are ruled under the framework of the Act on Private Participation in State Undertaking B.E. 2545 (1992). The act focused on the internal process of government's selection, approval, supervision, and monitoring to ensure that projects are properly executed. The act does not identify a method of project evaluation and procurement. In addition, the act does not provide the methodology for risk allocation between the public and private sectors when projects are not commercially viable (Susanggarn , 2007). The lack of a clear framework for project appraisal and risk allocation has been the issue and challenge for developing Thailand's large-scale infrastructure. Susanggarn (2007) suggested an improvement to the framework for PPP projects in the areas of PPP concept, rules for risk allocation and mitigation, and a guideline for project development and financial evaluation.

In Thailand, PPP concessions can be awarded in the form of either semi-public type or private type. For the semi-public type, the government may award the concession to a private company with public authority holding the majority of the shares in the project company or a special purpose vehicle (SPV). For the private type, the government may invite a short list of private companies to submit a bid, and the government authority may engage in the negotiation process to award a contract. The government can award a particular concession contract to a private company without a formal competition. Many of Thailand's large-scale transportation projects have been developed since the 1990s. A list of the major infrastructure projects in Thailand, including the identification of the project risks and mitigations, is provided in appendix B.

This thesis investigated the risk factors in large-scale transportation system projects in Thailand. It was found from the study that there are some common risk factors. The most common risks in Thailand infrastructure projects are lower than expected revenue and project delay leading to construction cost overrun. There is a considerable need to incorporate these risks into infrastructure development practices in order to mitigate or eliminate the risk consequences and to enhance the performance of projects.

2.13 Summary of Section II

Risk management is a key issue in transportation projects. The first step is to identify and classify risks. This includes recognizing potential risks and then classifying the risks. This section extended to propose a risk management framework and assessed the impacts of risks by various techniques. To assess risks in large-scale transportation projects, the case studies in

Thailand were presented. Numerous case studies were provided to assess impacts and the mitigations of project risks. The case studies showed that the infrastructure projects are dealing with many risk sources.

Section III: Risk allocation in large-scale infrastructure projects

The purpose of this section is to provide the background of effective risk allocation between the public and private sectors. Risk allocation is the process in which major risks are identified, and then each risk is appropriately allocated to one of the project's participants, such as the government, financers, or the project's sponsor (Hoffman, 1998). This section begins with the concept of risk allocation under different modes of PPP, and follows with past research studies on risk allocation and risk allocation strategies for key project stakeholders.

As mentioned in the previous section, the risk management process can be classified into four major components:

- Identification: identifying the potential sources and types of risks
- Classification: classifying the types of risks that have affected to the project, organization and people
- Analysis: assessing the impact of a risk using various risk measurements regarding both quantitative and qualitative approaches
- Risk response: considering different methods to manage risks, such as transferring to another party, avoiding or retaining

Risk response is the process that identifies, evaluates, selects, and implements strategies in order to reduce the likelihood risk events and to lower the impact of those risks to an acceptable level (Fan et al., 2008). In order to reduce risk events, a number of alternative actions are available under risk response strategies:

- Risk reduction: seeking to reduce the impacts of risks to below the acceptable threshold
- Risk avoidance: seeking to remove uncertainty
- Risk transfer: seeking the opportunity to transfer risks to a third party
- Risk allocation: seeking to allocate risks to the best party to manage it
- Risk retention: taking a risk as it is difficult to respond to the risk with other actions

Risk transfer and allocation are the main focuses in this thesis in that risks may be transferred from one party to a party that is able and willing to bear the risk. Obeng and Mokgohiwa (2002) suggested that risk allocation among the main stakeholders is a key factor of success in PPP infrastructure development. Finding an optimal risk allocation among the project's key stakeholders is essential. The next section will illustrate how risks are allocated among different modes of PPP.

2.14 Risk allocation between the public and private sectors in infrastructure projects

The purpose of this section is to address the literature gap and the knowledge base of risk allocation in PPP projects. This subsection begins with a discussion on the broad range of PPP models and later presents different strategies to allocate risks in PPP projects.

A broad range of infrastructure projects has been successfully implemented through the PPP, which encourages private sector participation. The objective of private participation in PPP projects is to obtain a good return on investment and to ensure that the future cash flow generated by a project can repay both capital expenditures and financial costs. Whilst the private sector focuses on the return generated from a project, the public sector's objective is to ensure a guarantee of service to a community, cost efficiency, an appropriate price charge, and a fair treatment of public service. The public sector invites the private sector to participate in the public project with the expectation that the PPP procurement can provide high-quality service to the community, lower cost, and less risk exposure. Therefore, it is important for the public and private sectors to balance the benefits and risks in order to ensure the viability and sustainability of PPP projects.

The challenge in the implementation of PPP projects is the misperception by the public sector that all the risks of a project should be transferred to the private sector. In fact, an efficient financing arrangement for PPP projects may require a certain degree of government support (Vega, 1997). Governments need to carefully assess the type of support provided to PPP projects. Instead of allocating all the risks to the private sector, the risks of PPP projects should be allocated optimally between the public and private sectors. Risk allocation in the project is proposed to minimise the project costs and risks by assigning a particular risk to the party which is best able to manage (Partnerships Victoria, 2001). By applying the risk allocation process in PPP projects, the government can determine whether risks should be: i) transferred to the private sector, ii) retained or taken back, or iii) shared with the private sector.

The broad range of PPP models in terms of the degree of public-private sector involvement is classified into outsourcing, management contract, leases, franchise, concession, build-own-operate (BOO), and divestiture (Shaw et al., 1996). These models range from the relatively short-term outsourcing contract through concession and BOO, which is a long-term agreement between the public and private sector.

It can also be argued that there are some common risks among PPP projects, which can be assigned to the responsible party. The key criteria in assigning risks are operational efficiency, capital investment, and asset ownership, which are parameters based on the concept of PPP. Table 2.10 shows how these key parameters are allocated between the public and private sectors for the different types of PPP procurement.

Key parameter/PPP type	**Service contract/ management contract**	**Lease**	**Concession (BOT, ROT, BOOT)**	**BOO**	**Divestiture**
Capital investment	Public	Public	Private	Private	Private
Operational efficiency	Shared	Private	Private	Private	Private
Asset ownership	Public	Public	Shared	Private	Private
Major risk					
Project risk[1]	Public	Public	Private	Private	Private
Operational risk	Shared	Private	Private	Private	Private
Market and financial risk[2]	Public	Shared	Shared	Shared	Private
Country risk[3]	Public	Public	Shared	Shared	Private

Table 2.10: Risk-sharing matrix for the different PPP procurements

Sources: Obeng and Mokgohiwa (2002)

[1]Project risk includes development, environmental, and construction risks.

[2]Market and financial risk includes demand, commercial, foreign exchange, interest rate, and inflation risks.
[3]Country risk includes social, political, legal, regulatory, economic, and force majeure risks.

According to the risk-sharing matrix in table 2.10, the private sector bears less risk in a service contract or a management contract. In a management contract, the government pays the management fee to the private company for the performance of project operation whilst both commercial, marketing, and investment decisions belong to the government. The private company takes over the responsibility for the operation and maintenance of a government-owned project for a specific period, whilst the government retains the ultimate ownership of the project. Also, risks such as demand and financial risks are retained by the government.

Another example of risk allocation in PPP procurement is a lease contract, which the private company, as the project's operator, uses to collect fees from customers. Then, in this PPP model, the financial risk is mainly allocated to the private company. In the lease contract, private companies pay a lease fee to the government. The private sector manages, operates, and maintains a public service, and they have to take some commercial risks and make important marketing decisions. The ownership of the asset belongs to the government.

A concession is a long-term type of collaboration between the government and the private sector for the development of large-scale infrastructure projects. In a concession, the public assets are managed by the private sector. There are various forms of concession commonly used in PPP procurements, which are franchising, the build-operate-and transfer (BOT), the build-own-operate (BOO), the rehabilitate-operate-and-transfer (ROT), and the build-own-operate-and-transfer (BOOT).

BOT and BOO are the most popular PPP methods in Thailand. Four large infrastructure projects (out of six) in Thailand used these schemes while the other two projects were operated by the government. BOT is normally used for the development of a green field project. In BOT, the private sector invests capital in the project and has the responsibility for providing a service at its own risk. Government grants the private sector the right for revenue collection to cover construction and operational costs for a certain period of time. Later, the ownership of assets is transferred to the government at the end of the concession period. Moreover, government is usually the purchaser of the services generated from the asset. The BOT contract normally specifies the minimum purchase quantity whether or not the quantity is consumed. Therefore, the demand risk is shared between the government and the private sector because the government provides a certain revenue guarantee. The other type of concession is the rehabilitate-operate-and-transfer (ROT), in which the private sector takes over responsibility for the operation, rehabilitation, and upgrading of an existing infrastructure.

BOO is quite similar to a concession in that the private sector has a responsibility to develop, finance, and operate a revenue-generating asset. The concession is very similar to the BOO contract, except that the government still retains the ownership of the project whereas for BOO, the government relinquishes all risks and ownership to the private sector.

On the other hand, divestiture may occur because the private company buys an equity share in a public project in the form of a direct asset sale, public offering, or mass privatization program. In divestiture, the private companies may either totally or partially own the assets. In the case of a totally owned asset, risk is fully transferred to the private sector.

From the above PPP models, it should be noticed that there could be a trend that governments have preferred to award concession to the private sector, in which risks are inappropriately allocated. This is because governments gain benefit as they can reduce their expenditures as well as receive the concession fee paid by the private company while all commercial risks are totally transferred to the private sector. This implies that the project may not provide good outcomes for the economic benefits, as the facility temporarily belongs (within the concession period) to the private sector whose objective is to maximize the shareholder's benefit. Furthermore, in the scenario of unexpected demand weakness, the government may take the risk of a project's default to operate, incurred by the private sector, whilst the private sector may refuse to participate in the risky projects. Therefore, in terms of creating economic efficiency, this research proposes to include option flexibility into the project development scheme in order to effectively allocate financial risks between the public sector and private sector. How financial risks are effectively allocated through real option will be presented in the next chapters of this thesis.

Risk allocation is the process wherein the major project risks are identified and allocated to the appropriate participants (Hoffman, 1998). The principle of risk allocation is to transfer risks to the party who manages them best. The suitable and effective allocation of risks among the parties is very essential. It can be seen that the levels of risks that are allocated among the public and private sectors, in any project, vary across the choice of procurement methods. Figure 2.1 describes the degree of risk allocation between the public and private sectors for the different types of procurement methods.

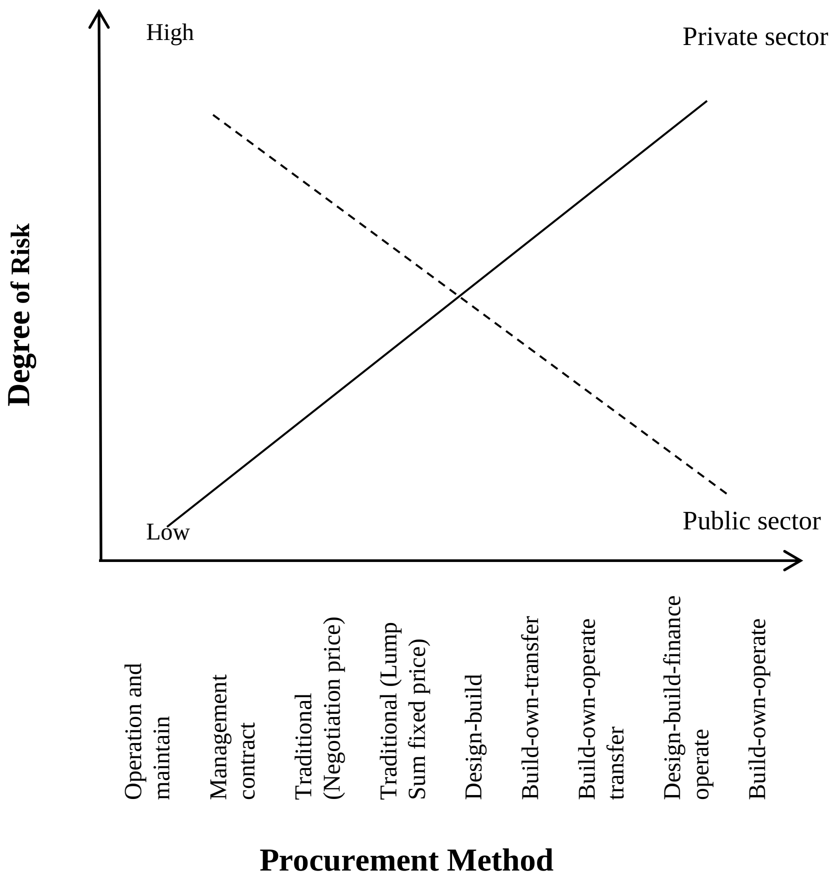


Figure 2.1: The degree of risk allocations for the different types of procurement methods
Source: Chege and Rwelamila (2001)

This figure was developed by Chege and Rwelamila (2001) based on a case study research of five Southern African Development Community (SADC) countries to review the relationship between risk management and the choice of procurement systems. The authors emphasized that risk allocation should be considered by the project developer before choosing the procurement model. However, it can be argued that their studies were based on the qualitative approach, in which the degree of risk is not quantified.

It can be seen in figure 2.1 that the level of risk allocation in the project is related to the types of the procurements. Figure 2.1 shows that when selecting the procurement method as it moves towards fully private participation, such as with build-own-operate (BOO), risk is mostly transferred from the public sector to the private sector (and vice versa for the operation and maintenance of facilities). However, the public sector has to ensure that risk is appropriately transferred. For example, in BOO, risks such as commercial risk and construction risk are passed to the private sector. If too much risk is transferred to the private sector, the project may become unaffordable. Chege and Rwelamila (2001) suggested for further study that a risk-sharing model of the project should be developed in order to optimize between the affordability and the value for money. The authors suggested that a quantitative model should be used to quantify the risk sharing.

There are other researches that have studied the risk identification and allocation in PPP projects. Obeng and Mokgohiwa (2002) provided the risk allocation matrix that defines the typical risks and allocation of each risk between the public and private sectors. They suggested for the risk type matching as follow: equity investor/project company—suited for economic risk and market risk; lenders/financial institution—suited for financial risks, such as interest rate risk and exchange rate risk; and government—suited for social political risk, regulatory risk, and legal risk. However, it can be argued that by assigning all commercial and financial risks to the private sector, the project may not always be financially viable. Governments should take or share some commercial risks of the PPP project with the private sector.

Ghosh and Jintanapakanont (2004) applied factor analysis to identify and assess the critical risk factors in an underground rail project in Thailand. It was shown that each project had different crucial risks because of the unique characteristics that made one project differs from another. However, the authors came to the same conclusion that the risks involved in infrastructure projects were significant and required a thorough analysis. Therefore, it can be argued that each individual project has its own unique set of risks. It is also noticeable from this study that support from the key stakeholders in the infrastructure development is essential.

2.15 Literature related to risk allocation in PPP projects

Numerous studies have been published on risk identifications, risk analysis, and risk allocation in infrastructure and transportation system projects. Songer et al. (1997) applied the Monte Carlo simulation to assess risks for toll road projects. Six risk factors were tested in the simulation: i) the number of toll transactions, ii) an average annual toll rate, iii) an annual operating expense, iv) the construction costs, v) a construction duration, and vi) interest rate.

The results of the simulation provided a flexible decision-making tool for assessing the feasibility of projects. Further exploration of risk allocation was required.

Malini (1999) applied the Monte Carlo simulation technique to analyse risks in the BOT transportation project. The author identified three types of risk parameters as the inputs for the simulation model: i) policy parameters, ii) macroeconomic indicators, and iii) stochastic input variables. The simulation model was performed to analyse the financial feasibility of the project. The main outputs from the simulation were the values of the key financial indicators, such as NPV, IRR, and payback period. A risk profile and risk allocation scheme between the government and the private sector can be constructed from the simulation results. However, risk was performed from the project owner's perspective in that it did not address the risks to the other stakeholders, such as the lender.

Ghosh and Jintanapakanont (2004) started research by applying factor analysis to assess the critical risks of a mass rapid-transit underground rail project, named the Chaloem Ratchamongkhon Line, in Thailand. The authors identified nine critical risk factors and ranked the selected risk factors in terms of an important index. The critical factors were confirmed by conducting interviews with senior management teams to assess their perceptions of the critical risk factors. The authors focused on identifying risks during the construction period. The top three risks were i) the delay risk, ii) financial and economic risks, and iii) the subcontractors' related risk. However, it can be argued that the method used for ranking risks was rather subjective. The authors did not provide suggestions on how to mitigate those critical risks, which were necessary.

Wibowo and Kochendorfer (2005) employed the Latin hypercube simulation approach to analyse risks of a toll road project in Indonesia. The authors evaluated three major financial risks associated with Indonesian toll projects from the perspectives of the sponsor and creditor: i) a delay in toll adjustment risk, ii) a new tariff regulation risk, and iii) a transfer of land acquisition risk. The results of the simulation showed that the project sponsor faced the highest risk because he or she had the lowest priority of all the claims. It has been argued that the project sponsors may reduce their risks, such as revenue risks, in the project by sharing such risks with other stakeholders, such as the government or lender. It can be also argued that the government as the project promoter may be exposed to the highest financial risk as the project has been discontinued. The authors did not address the issues of the risk allocations among the government, the private sector, and the financial institution.

Ng and Loosemore (2007) employed a descriptive case study for the New Southern Railway project in Sydney, Australia. The authors conducted semi-structured interviews with key stakeholders from the public and private sectors. Data was collected from contracts, reports, newspapers, articles, journals, and conference reports. This study explored the importance of effective risk allocation between the public and private sectors. The authors employed a case study to demonstrate the problem of an inappropriate risk allocation between the public and private sectors. The authors suggested that the criteria for the development of PPP projects should be considered in regard to the community needs for the service rather than solely considering the commercial viability. However, the optimal risk allocation was not employed in this research.

Leviakangas (2007) developed a project model and framework for the private finance of road infrastructure. The author demonstrated the model by using the case study of the Finnish shadow toll road project. The project model comprised of the cash flow model and the risk structure model. The project employed a multi-equation simulation technique in the empirical case. The author ranked the investor's risks by using the full project model, in which the most critical risks impacting project insolvency were:

- Risks in the capital structure: introducing debt capital increased the risk of insolvency situations.
- Inflation risk
- Interest rate risk
- Operating risk: the profitability of the project was impacted if the operating costs such as maintenance costs were more than the initial expectation.
- Traffic demand risk: demand risk occurred if the traffic volume was below the initial projection.

The risk mitigation strategies, such as i) a back end load debt finance strategy, ii) a minimum demand guarantee from the government, iii) the transfer of operating and construction cost to a subcontract or to the private sector, and iv) using inflation protective clauses, were recommended based on the result of the simulation. Also, the author focused on the transfer of risk from the public sector to the private company or investor, but did not provide the magnitude of risk or the degree of risk allocation.

Roumboutsos and Anagnostopoulos (2008) presented risk ranking and preferred risk allocation from the view of key project stakeholders in the Greek PPP market. The authors conducted a research survey in which the respondents were decision makers of public authorities, construction companies, and financial institutions. Respondents were requested to rank risk factors based on the probability of occurrences and impacts as well as to allocate their risk estimations to the public and private sectors or to be shared between both. The authors found that political, legal, and archaeological risks should be allocated to the public sector, while construction and operational risks were better belonging to the private sector. Lastly, macroeconomic risks, such as a poor financial market and influential economic events, were better shared between the public and private sector. However, it can be argued that the method used for ranking risks was highly subjective based on the risk perceptions of respondents. Another argument against this research finding was that their perceptions towards risks may change over time, depending on project phrases. Though this research focused on risk allocation, a quantitative approach, such as real option, would have helped determine the optimal risk allocation.

Yongjian et al. (2010) employed a survey research using a two-round Delphi method, which was done with experienced practitioners to identify the preference of risk allocation in China's PPP projects. A list of 34 potential risks was identified, and the authors used these risks to explore the perceptions of PPP participants towards risk allocation for construction projects in China. According to the study, the majority risks (14 risks) were allocated equally between the public and private sectors. Twelve risks were mostly allocated to the public sector. Though this research focused on risk allocation, the quantitative approach would have helped to determine the optimal risk allocation.

Ameyaw and Chan (2015) identified risk factors and evaluated the risk level of PPP water supply projects using a fuzzy synthetic evaluation approach. From the initial statistical analysis, 22 out of 40 risk factors were critical risks and were classified into three main factors: i) financial and commercial, ii) legal and socio-political, and iii) technical. It showed that the financial and commercial risk category was the most critical risk, followed by the legal and socio-political risk category and the technical risk category. The authors focused on the risk identification stage, which for PPP projects, risk allocation is essential for further study. In addition, financial and commercial risks are critical and should be allocated properly between the public sector and the private sector.

Though various authors have performed research studies on risk identification and analysis, the empirical research of risk allocations for transportation system projects has been scarce. Also, some authors have discussed the allocation of risk between the public and the private sector but have focused primarily on qualitative research. Few quantitative techniques have been presented. In addition, there has been relatively little empirical research on the real option theory and its application in the field of risk allocation in projects. The application of real options for allocating risk between the public and private sectors is rarely scarce.

2.16 Summary of Section III

The allocation of risk is one of the crucial factors for risk management and PPP projects. The essence of risk allocation in projects is that it helps the public and private sectors achieve a balanced distribution of responsibility and risk. However, the development of large infrastructure projects involves many stakeholders with their own interests and risk attitudes towards the project. In order to succeed and reconcile their objectives, a full risk analysis, including a risk management tool, is necessary.

Financing infrastructure projects, specifically in developing countries, entails a variety of crucial risks. It is the role of the government, the project sponsor, the lenders, and other participants to structure the financing in such a manner that mitigates these risks.
Lenders and the private company are always initially concerned about financing physical assets in distant, politically-risky areas in addition to construction cost overrun and lower than expected revenue collection. The government's role is to carve out the risks and assign them to the party best able to take responsibility. Therefore, the allocation of risks in a project is the main issue for its successful development and operation.

From the literature review, risk allocation between the public and private sectors can be implemented through the selection of different PPP models and options for key stakeholders. Different PPP models deliver different levels of risk allocated to the public and private sectors. The BOT scheme is frequently applied to allocate risks in PPP projects. The advantage of BOT is that it benefits the government to partially allocate risk to the private sector. However, it has been argued that the degree of risks allocated to private parties in BOT should be carefully determined. Lastly, it was found from the literature that real option was rarely proposed as the tool for risk allocation in PPP projects. The next chapter will propose and discuss the real option as a tool for managing the risks of a project.

Chapter 3. Real Option Methodology

This chapter provides a comprehensive review of the literature on real options, especially in the field of project finance. The chapter begins with an overview of real options theory, the types of real options and real option methodology. It then describes the roles and responsibility of the key project stakeholders, including the government, the private sector and financial institutions. The government support and options for the private company and financial institutions in the PPP project are also discussed. This chapter discusses the application of real options in the context of the project finance.

3.1 Options, real option theory and real option applications

This section introduces real options, including the commonalities and differences between real options and financial options. This section starts with the basic concepts of financial options. An option gives its holder the right, not the obligation, to buy or sell an asset at a pre-specified price on or before a given date. Financial markets have two basic types of options: call options and put options. The call option provides its holder the right to buy an asset at a specified price and date. A put option provides its holder the right to sell an asset at a specified price and date. There are two types of options regarding the allowable exercise dates before expiration. The option can be either American or European. The American option provides the option's holder the right to exercise the option at any time until the expiration date, whereas the European option can be exercised only at the expiration date. The value of an American option is normally higher or at least equal to that of an equivalent European option due to the greater number of opportunities to exercise the option (Cobb and Charnes, 2007).

The theory of financial options has been applied extensively in various areas, including applying option theory to value real physical assets. This application is called "real option" valuation. Examples of real options in practise are i) to value infrastructure investment (Zhao and Tseng, 2003; Pichayapan et al, 2003; Garvin and Cheah, 2004; Mathews, 2009), ii) to delay or abandon a project (Huang and Chou, 2006; He, 2007, Blank et al. (2009), iii) to expand and acquire (Kogut, 1991; Luehrman, 1998), iv) and to value growth opportunities (Kester, 1984; Tong et al, 2005). Details of each option type will be provided in the next section. In principle, real options are defined as the options embedded in real operational processes, activities or investment opportunities (Trigeorgis, 1996). Myers (1984) was among the pioneering researchers in applying financial options to real assets. His work illustrated the relationship established between financing and investment decisions in a contingent claim framework. Over the years, many academic papers have contributed significantly to explore the applications of real option theory. The application of real options has also been extended to infrastructure development. Examples of transportation projects with real options are given in a later section.

Real options apply financial option theory to value a real or physical asset. Although a real option, like a financial option, provides an owner the right, but not the obligation, to exercise an action, a real option is unlike a financial option in various ways. This research highlights the main differences between financial and real options. First, it is generally seen that real option valuation procedures may not necessarily follow the assumptions of financial option valuation. For example, the underlying asset values of financial options may not be negative, while real options may have negative values. In addition, information about real options is sometimes not available in the market, as opposed to information on financial options, which is easily obtained in the markets. Secondly, the maturity of real options is usually long (years), while financial options have short maturities, e.g., months (Mun, 2006; Triantis, 2005; and Brach, 2003). As a result of real options' long maturity, Brach (2003) argued that the volatility of real option is time-varying, usually with diminishing volatility, whilst the volatility of financial options is assumed to be stable. Researchers have also argued that the volatility of real options is not observable in the financial market. However, in infrastructure projects, the volatility of cash flows with constant value can be determined from the volatility of traffic volume, as historical traffic volumes can be observed in the market (Charoenpornpattana et al., 2003; Pichayapan et al, 2003; Blank et al., 2009).

Third, financial option valuation is usually simple, with single options, while real option valuation is more complex, with multiple options and their interactions (Trigeorgis, 1996; Rose, 1998; Copeland and Vladimir, 2001). Triantis (2005) argued that real option valuation is complicated to use and to explain in real practise. We argue against Triantis; although real option valuation is complex, real options can be used as a complement to the traditional discounted cash flow method. Understanding how options can be used to enhance a project's value is more important than its numerical accuracy. Lastly, questions have been raised regarding the precision of real option valuation, compared to financial option valuation (Haahtela, 2012). Haahtela (2012) argued that the precision of real option valuation depends on the quality of its input parameter. Table 3.1 provides an overview of the analogy between real and financial options.

	Financial options	**Real options**
Option price	A price is paid to acquire/sell stock or financial assets. The underlying value is the equity price or the other financial asset prices that reflect the firm's future cash flows.	A price is paid to acquire/sell a real or physical asset. The underlying value is the free cash flow, generated from the real asset. Therefore, in applying real option methodology to value physical assets, the underlying asset has to be known.
Underlying	Financial instruments such as stocks, bonds and FX	Real assets such as project cash flows and commodity prices
Exercise price	A fixed value defined in a contract. Note that this price is what the market (grantor) expects the future price to be (i.e., an expected value). The option pricing model assumes that the exercise of an option is instantaneous.	Actual cost of buying/selling the underlying real asset. This implies that the strike price may be stochastic. The exercise of a real option does not happen in an instant, i.e., the exercise may require a facility to be constructed.
Expiration time	- Clearly known in the contract - Short maturity, usually in months or within one year - Due to the short-term maturity of the financial option, the variance is known and constant.	-Clearly known in some cases, such as the period during which an investment opportunity is available. -Long maturity, usually in years; therefore, the variance is less likely to remain constant.
Timing of payoff	Immediately after the option is exercised. The option holder's decision to hold the asset is done to maximise the value of the option.	Over a long period of time after the option is exercised. Real projects are composed of sequenced investments that take time to build and to generate

	Financial options	Real options
		returns. For example, projects do not generate cash returns until they are completed.
Controllable	The option owner cannot control the option's value. Due to insider trading regulations, the option holder-in theory-cannot manipulate the stock price.	The option owner can control a real option's value through management decisions and flexibility. Management flexibility increases the option's value.
Option value over time, horizontal	The value increases over time. It is assumed that competition does not affect an option's valuation. The option value is known at exercise.	The value may or may not increase over time. For example, an option value will decrease when new competitors enter the market.
Option value as the function of asset's volatility	The value increases as the volatility increases. The option value would change as new information arrives on the market.	-The value increases as the volatility increases. -Time-varying maturity, but normally diminishing volatility. The volatility of long-term real options is unlikely to remain constant. New information such as market information may change the volatility.
Liquidity	Very liquid and tradable in financial markets	Neither liquid nor tradable. Normally, the underlying asset is not tradable and is not highly liquid.

Table 3.1: The comparison between the real option and the financial option

Source: Kodukula and Papudeso (2006), Majd and Pindyck (1987), Trigeorgis (1996)

3.1.1 *The key parameters used in financial and real options*

The basis inputs used to value any type of option and real option include the underlying asset value, option type, exercise price, volatility factor and others. Table 3.2 defines the similarities and differences between the parameters used in financial options versus typical real options. The similarities make it easier to understand and to implement option methods for real assets.

Variable	**Financial options**	**Real options**	**Symbol**
Underlying asset	Stock price	Net present value of the potential investment	S
Option Type	To buy (call) or sell (put)	Opportunity to invest (call) or divest (put)	c, p
Exercise date	Continuous right exists up to maturity (American) or right at the maturity date (European)	The same as financial options	C, P
Exercise price	Fixed price at which the option holder can buy (call) or sell (put) a unit of stock	Fixed price at which the option holder can invest or sell the asset	X
Expiry date	The last date of exercise (American) or the only date of exercise (European)	The last date for possible investment (American) or the only date for possible investment (European)	T
Volatility	Stock price volatility	Volatility of the underlying cash flow. Volatility may be time-varying, usually with diminishing volatility. However, if the underlying cash flow follows geometric Brownian motion (GBM), then the volatility can be estimated as constant.	σ
Dividend	Stock dividend	Project cash inflows or	D

Variable	Financial options	Real options	Symbol
		outflows. Dividends are considered to be leakages that can affect the project's cash flow, such as royalty income, royalty fees, storage costs and lost market share to competitors. Dividend yield is difficult to estimate with real options. Practitioners assume it to be zero.	
Delta	The change in the option's value, corresponding to the change of price in the underlying asset	The change in the option's value with a unit change in the present value of underlying cash flow series. Delta is defined mathematically as the partial differential of ∂π/∂S.	$\Delta\ (\frac{\partial \pi}{\partial S})$
Theta	The change in value of the option corresponding to the passage of time	The same definition as in the financial option. In projects, the time horizontal may involve years. Theta is defined mathematically by the partial differential ∂π/∂t.	$\Theta\ (\frac{\partial \pi}{\partial t})$
Gamma	The change in delta with respect to the price of an underlying asset	The change in delta with a unit change in the present value of the underlying cash flows series. It is defined mathematically by the	$\Gamma(\frac{\partial^2 \pi}{\partial S})$

Variable	Financial options	Real options	Symbol
		partial differential $(\partial^2 \pi)/\partial S$.	
Vega	The change in the value of an option corresponding to changes in the asset's volatility	The change in an option's value with a unit change in the volatility of the present value of the underlying cash flow series. It is defined mathematically by the partial differential $\partial\pi/\partial v$.	$v(\frac{\partial \pi}{\partial v})$
Rho	The change in the option's value corresponding to changes in interest rates	The change in the option's value of option corresponding to changes in the discount rate. It is defined mathematically by the partial differential $\partial\pi/\partial r$.	$Rho\ (\frac{\partial \pi}{\partial r})$
Xi	The change in the value of option with corresponding to the change in the value of strike price	The change in the value of option with corresponding to the change in the value of cost. It is defined by mathematical of partial differential $\partial\pi/\partial X$.	$Xi\ (\frac{\partial \pi}{\partial X})$

Table 3.2: The key parameters of financial and real options

Source: Howell et al. (2001)

Understanding the parameters in the model can help to understand real option problems and implement option methods on the real assets. The changes in option value relative to the changes in each parameter are defined by partial differential equations based on the Black–Scholes model. For example, delta is defined as the change in an option's value relative to each incremental change in the value of the underlying asset (S). However, although this sensitivity analysis is used extensively in financial options, it is rarely used in real option analysis.

In order to apply the method initially developed for financial options to real options, an appropriate underlying asset must first be identified. Most financial options refer to the underlying stock price, whereas the underlying asset of a real option can be an asset, the project cash flow and the commodity price. The fundamentals of both financial and real options are similar in that both are rights (explicit for one because there are two parties and implicit for the other) but not obligations. If we can find a financial option, such as a call option, that provides sufficiently similar characteristics to an investment opportunity of a real asset, the value of this option would tell us the value of the real asset. In fact, it is difficult to obtain such options because of the unique characteristics of any project. The other method for us to find an option is that we instead have to construct a real option. In real practise, one party can construct an option and give another party the right to do something. Real options, unlike financial options, are usually not bought or sold at capital markets. In the next section, this research will illustrate the concept of real options, including the methodology for constructing the real option.

3.2 Real option: performance and risk assessment methodology

In this section, this research describes in detail the real option methodology that can be applied to value the project. Real options provide the analysis framework with which to evaluate management flexibility in addressing the strategic aspects of a project's investment opportunities. Project evaluation practitioners can argue that traditional project evaluation (discount cash flow techniques; DCF), when applied improperly, often undervalues projects (Trigeorgis, 1993a). This method may undervalue projects with actual growth rates higher than the growth rate used in DCF. In practise, many project managers rely on net present value analysis, associated with their own adjustments, in an attempt to value managerial flexibility—which is subjective. Howell (2001) and Trigeorgis (1996) suggested using the real option technique to evaluate the managerial flexibility implicit in an investment opportunity. Trigeorgis (1993b) defined managerial flexibility as incorporating a set of real options, while real options offer a framework that can link value to risks. The risk concept of real options can be presented through the framework of financial theory.

According to Mun (2006), the real option methodology is a systematic approach that provides an integrated solution, using financial theories, economic analysis, management science, decision science, statistics and economic modelling to valuate real physical assets, as opposed to the narrower financial option, which is specifically used to value financial assets such as equity, bonds, futures and commodities. Real options are popularly used in the valuation of investment projects because this method is especially useful in dynamic and uncertain business environments (Mun, 2006). The real option process can be classified into 4 steps:

(i) Identifying different types of corporate and project investment decisions
(ii) Valuing each strategic decision in terms of financial viability and feasibility
(iii) Prioritising projects based on both qualitative and quantitative methods
(iv) Optimising the value of strategic investment decisions

Many researchers use real options to complement traditional analysis in determining the value of a project. Real options can help to improve the decision-making process under uncertain conditions. Traditionally, projects are evaluated using the NPV technique. Though NPV provides better decisions than other methods, the decision is often made under the assumption that management decisions to make any possible changes are limited during the whole life of the project. The NPV method often views a project as a set of decisions made once at the beginning that is unchanged for the whole life of the project. This perspective contrasts with the view of the real option approach, which frames the valuation process differently from the traditional approach regarding how managers can continually change their decisions in light of new information. By contrast, in NPV analysis, project cash flows are often adjusted and are usually subjective among decision makers. Real options analysis tries to estimate the value of the options that the managers may have and adds these values to the passive NPV. NPV analysis is a suitable starting point for project evaluation, while other methods such as real options, IRR and payback period are complementary. By applying a real option approach, the project can be managed to avoid bad outcomes or to take advantage of the appearance of a good outcome. Real options practically lead to higher expected value for the same project than the traditional method (passive method), which Neely and Neufville (2003) called the "expanded traditional net present value" (ENPV). Real options help to improve the NPV analysis by valuing the alternatives inherent in a project. Therefore, the expanded NPV is applied to consider the real option's value. The expanded NPV (ENPV) is calculated by:

ENPV = traditional NPV (passive/static NPV) + value of managerial flexibility

The expanded NPV (ENPV) can be decomposed into two parts: the traditional NPV and the value of managerial flexibility which can be either i) the sum of all strategic options' values or

ii) the maximum value of each strategic option for the mutually exclusive options (e.g. option to build or option to delay project). For mutually exclusive options, it means that exercising of one option does not depend on the other options. If all the strategic options embedded in the project are mutually exclusive, one may select the option that produces the highest value (Shil and Allada, 2007). The problems of choosing between mutually exclusive options have been addressed in the literatures; in particular by Rodrigues and Armada (2006) who use the Least Squares Monte Carlo Simulation method to value a mutually exclusive option between the expansions and abandon options and by (M.A.G) Dias et.al (2004) who examine mutually exclusive alternatives to develop an oilfield using numerical simulation.

The option's value is the value of the managers' flexibility to decide, but not the obligation, to employ the option. Options can enhance the expected value of passive NPV by introducing asymmetry or skewness in the probability distribution of the NPV. The asymmetry in the probability distribution increases the value of the passive NPV by defining the profit potential with the limitation of the downside risk (Trigeorgis, 1993a). This asymmetry feature in real options is the case with financial options, which have a buyer and a grantor. This relationship is absent in some real option situations, e.g., the option to explore or shut down.

The options may include managerial flexibility, which can take the form of either a single option or a set of multiple options. With a set of multiple options, the interactions among those multiple options exist and the interaction effects should be properly analysed. This is because the exercise of a prior option may affect the value of the underlying itself as well as the value of the subsequent options. Trigeorgis (1993a) identified four factors that may have effects on the level of option interactions: i) whether options are of the same type or different types, e.g., two puts, two calls or a put and a call; ii) the separation of their exercise times, such as a combination of European and American options; iii) whether options are in or out of the money; and iv) their orders or sequences, as the presence of the subsequent options will affect the value of the underlying asset of the former options. For example, at an extreme, the exercise of a prior abandon option (put option) on the asset may eliminate the value of the subsequent options.

The methodology of the real option approach is separated into two steps. The first step is a valuation approach that decomposes a complex real option problem into a sequence of simple options such as call or put options. In this step, a numerical method can be employed for valuing individual options. The second step is to combine the value of the individual option to construct option bundling. The value of the options and their combinations can be determined. Figure 3.1 presents the real option valuation model.

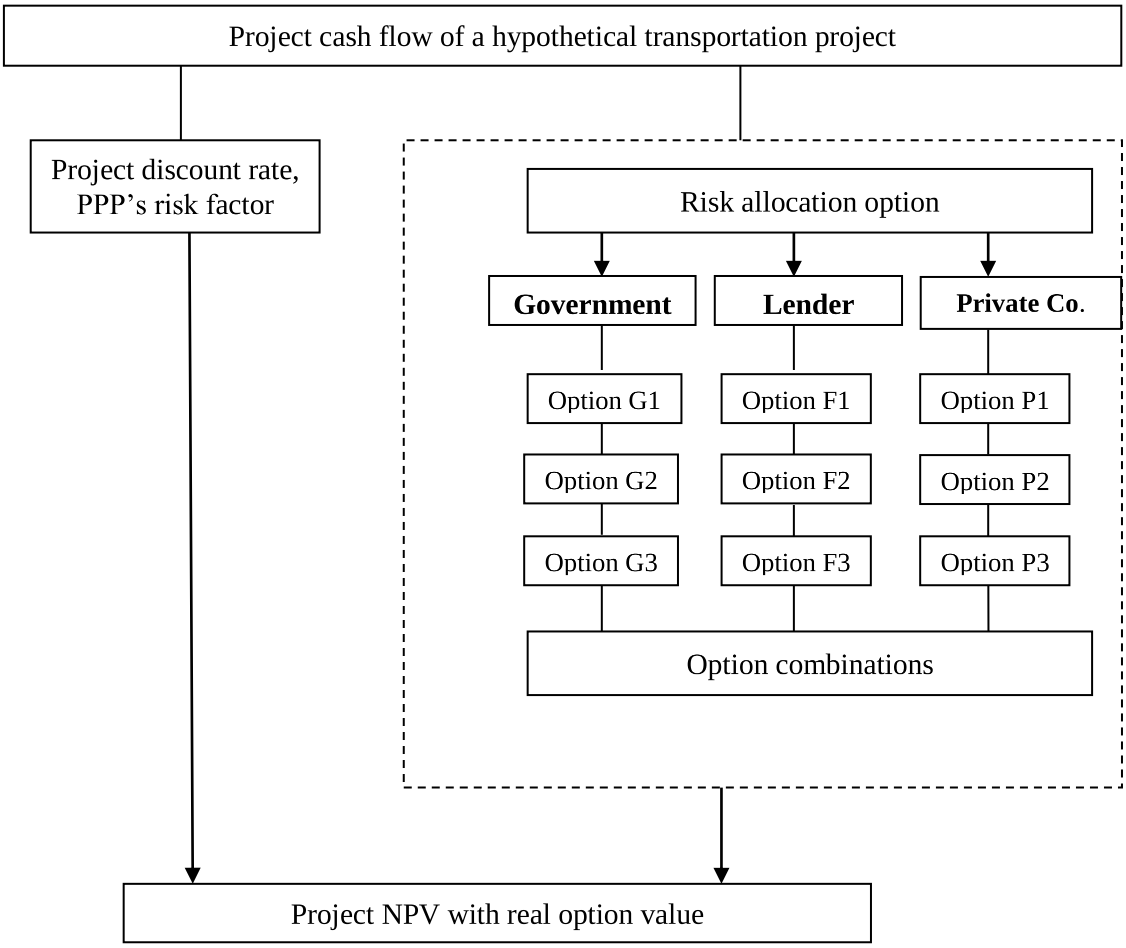


Figure 3.1: The real option valuation model

The next step is policy design and implementation. Policy design is the procedure to establish policies that can be implemented to improve a project's performance. The results of the real option valuation can be used to establish a project's development policy or guidelines for a large-scale infrastructure project. This research will propose strategies and options for allocating risks among the government, financial institutions and private companies to enhance the value of large-scale project development in Thailand.

3.3 The common types of real options

This section describes the most common types of real options. Various types of real options can be used to determine a project's financial viability. The most common forms of real options are presented in table 3.3, in addition to a list of relevant publications on real option valuation.

Option	**Definition**
Deferral option	The option to delay a decision until additional information is provided. For example, an investor may defer the decision to implement or execute a project. The deferral option is similar to the "European or American call option" on the project, except that, unlike "financial options", deferring an investment may create an additional risk that competition may not delay. Academic works: Bjerksund and Ekern (1990), Trigeorgis (1993b), Rose (1998), Casassus and Cortazar (1999), Garvin and Cheah C.(2004), Lewis et al. (2004), He (2007), Stout (2008)
Expansion option	The option to expand into different markets, products and strategies, or to increase current capacity. The expansion option is similar to the "European or American call option" as part of the project. Academic works: Kogut (1991), Trigeorgis (1993b), Luehrman (1998), Zhao and Tseng (2003), Zhao et al. (2004), Mayer and Kazakidis (2007), Guma (2008)
Contract option	The option to contract the existing operation. The contract option is similar to the "European or American put option" as part of a production project. Academic works: Trigeorgis (1993b)
Investment or time to invest option	The option to decide the timing of an investment in a project or product during the option's life. The investment option is similar to the "European call option" as part of the project. Academic works: Han and Park (2008)
Abandonment option	The option to terminate the existing project or product. The abandonment option can be constructed as the "American put option" on the existing project.

Option	Definition
	Academic works: Brennan and Schwartz (1985), Ross (1998), Bjerksund and Ekern (1990), Trigeorgis (1993b), Vandoros and Pantouvakis (2006), Huang and Chou (2006)
A switching option	The option to switch between different products, markets and technologies. The switching option is similar to the "American put option" on the project. Academic works: Carr (1988), Trigeorgis (1993b), Neely and Neufville (2003)
An option to choose	The option to choose between different strategies. For example, the company may decide whether to expand, contract or abandon in business operation. The option to choose can be either the "American call or put" option. Academic works: Neely and Neufville (2003)
A barrier option	The option to execute the strategy whether or not the underlying asset reached or exceeded a predetermined price. The underlying asset may be a commodity i.e., oil, gold or a cash flow of the project. A barrier option can be either the "American call or put" option. Academic works: Duong and Morel (2003), Buchen et al. (2009)
Simultaneous compound option	The value of the simultaneous compound option depends on the value of the other options. The compound option can be composed of a set of the "American call or put" option. Academic works: Trigeorgis (1993b)
Sequence compound (Multi-stage) option	Executing the sequence compound option is dependent on the previous option. The sequence compound option can be composed of a set of the "American call or put" options. Academic works: Panayi and Trigeorgis (1998), Casassus and Cortazar (1999), Perlitz et al. (1999), Neely and Neufville (2003), Mayer and Kazakidis (2007)

Option	Definition
Interaction among options	Managerial flexibility is a set of real options and option may interact with the other options. A project may have a collection of options and those options may interact. Academic works: Trigeorgis (1993a), Trigeorgis (1993b), Rose (1998), Huang and Chou (2006)

Table 3.3: Common types of real options, including a list of publications on real option valuation

3.4 The approaches to solving real option problems

In this section, this research presents a method for valuing real options. In principle, real option models can be classified into two categories: a continuous time model and a discrete time model. The continuous time model is the stochastic process in which the variables change continuously over time. The continuous time model assumes an infinitesimally short time with high-frequency transactions. The continuous time model is represented by the mathematics of a partial differential equation. The most popular application of the continuous time model is the Black–Scholes model, which is a specific-form analytical formula using a partial differential equation to solve for the value of an option, which is subject to a set of boundary conditions. This method is useful when the solution to a partial differential equation exists. If a partial differential equation does not exist, the modeller can move to the other continuous time model, i.e., a finite difference method and a Monte Carlo simulation

The other form of real option model is the discrete time model, which is an approximation of the continuous time model. The discrete time model assumes that transactions occur at any point in time. This method is powerful and flexible for valuing real options. The most discrete model frequently used in academic works to value options is a binomial model. This method sets an underlying asset path in a small time interval, in which the underlying asset may either move up or down. The underlying assumptions of both the discrete time model and the continuous time model are fundamentally the same, as they model variables that evolve over time, except they solve problems by applying different mathematical approaches.

Several methods are employed for valuing real options. The most well-known methods used to value real options are the binomial approach; a closed-form equation, e.g., the Black–Scholes model; a simulation; and a partial differential equation. Though some real option problems may initially be solved by the closed-form analytical method, other real option problems may not. Most real option problems cannot find a closed-form analytical solution, but the Black–Scholes model is not widely used to value real options. Instead of using an analytical approach to value real options, numerical methods such as the binomial lattice, simulation and finite difference methods can be applied. Figure 3.2 shows a summary of the real option models.

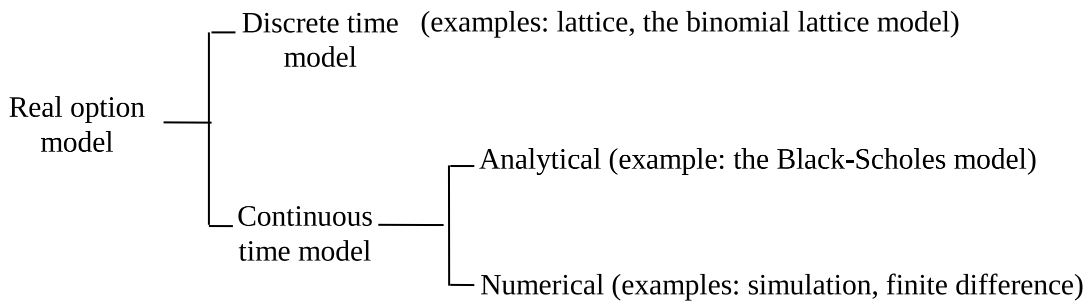


Figure 3.2: Summary of the real option models

3.4.1 *The binomial lattice and the binomial decision tree*

Cox's (1979) binomial lattice is a well-known discrete-time model representation of the behaviour of asset prices. A binomial model is used to approximate the continuous time model of a stochastic differential equation, i.e., the geometric Brownian motion (GBM). The binomial model assumes that the value of the underlying asset, e.g., the project's cash flow, follows a binomial distribution. The binomial distribution is the diagram of a different possible path that the stock (underlying asset) price might follow over the life of the option (Hull, 2009). The binomial model is a useful technique for pricing an option with simply discrete mathematics and a discrete formula (Cox et al., 1979). The method is accurate, remarkably robust and frequently used for valuing financial and real options (Hahn, 2005). This model involves constructing a path, which is called a binomial tree. The asset price (s) can move up (u) or down (d) by a certain amount and probability. Figure 3.3 shows a binomial lattice with three time steps.

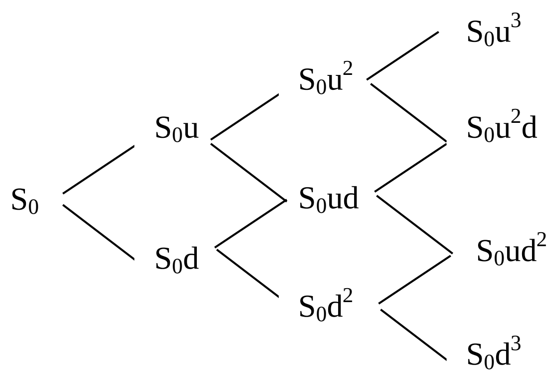


Figure 3.3: Example of the binomial lattice with three time steps

In a binomial lattice, the value of an option is computed under a risk-neutral probability equation. In a risk-neutral world, investors are indifferent about risk, so they do not require compensation for risk. The expected return on all securities is a risk-free interest rate, which is based on the assumption that one can construct a risk-free hedged portfolio. For example, a risk-free hedged portfolio could be constructed with the option to invest and a short position in a project. Also, the binomial lattice uses the notion of arbitrage in which the risk-adjusted probabilities can be computed if there is no arbitrage opportunity. This method adjusts the probability that leads to pay-outs and then discounts the cash flows by the risk-free interest rate, as risk is already adjusted at the cash flow. Using risk-neutral valuation and a no-arbitrage argument makes it more convenient to value options. It can be argued that this approach is beneficially grounded for valuing derivatives but it is highly susceptible to estimating the future value of derivatives. The probability "p" is used in the risk-neutral condition, in which risks have been accounted for. This method is very useful as it does not need to estimate project-specific discount rates at different nodes along the binomial. The neutral probability "p" is calculated by the following equation (Mun, 2006):

$$p = \frac{e^{rf(\Delta t)} - d}{u - d} = \text{a risk-neutral probability}$$

where

r_f = the risk-free interest rate (%)

Δt = the time step interval

u = the up factor

= $e^{\sigma\sqrt{\Delta t}}$

d = the down factor

= $e^{-\sigma\sqrt{\Delta t}}$

In the binomial lattice, the stock price changes in a small time interval (Δt), either by an uptick or a downtick. The observation time (t) starts from t_0 and increases with multiples of Δt. The changes in stock prices are independent of each other. When the time step (Δt) is small, the binomial lattice provides a good approximation of an option's value. The procedure starts with a forward movement of an underlying value (St) and determines an option's value at its expiration date. Then, using risk-adjusted probability, the option value can be determined by working backward with the lattice. The binomial model computes option values by assuming risk-neutral probability, so that we can discount project cash flows at the risk-free interest rate of return.

The binomial lattice is preferred for a real option analysis because it provides more flexibility for computing various option types, especially for exotic options, which are difficult to calculate using the closed-form analytical model, as it is quite a complex mathematical equation. The model is simple for implementing and easy for explanation. The advantage of the binomial model is its flexibility in analysing complex options such as American options or dividend-paying European options (Scaramozzino, 2010). Those option values can also be determined by solving the numerical method. The main advantage of binomial lattice over other methods (e.g., Black-Scholes model) is that it can be used to accurately price the American options. The Black-Scholes model cannot be used to accurately price American-style options as it only calculates the option price at one point while it is possible to check at every point in an option path for the possibility of early exercise in the binomial model. It also has an advantage because the mathematical formula is relatively easy compared to other methods. Moreover, the calculation is more accurate as the real market development can be inserted in the binomial model; therefore, the calculation can link with the actual market development.

The traditional valuation method normally uses WACC as a discount rate for an individual project without options. WACC is the hurdle rate or discount rate for evaluating projects, which is calculated using the following formula:

$$WACC = (E/V) * R_e) + [((D/V) * R_d)*(1-T)] \text{ where}$$

E = Market value of the company’s equity

D = Market value of the company’s debt

V = Total market value of the company (E + D)

R_e = Cost of equity

R_d = Cost of debt

T= Tax Rate

The disadvantage of WACC is its rigid assumptions without flexibility in the method of evaluation of new projects. The impractical assumption of an unchanged capital structure does not happen all the time. However, the existence of managerial flexibility of real options changes the risk of the project if the manager chooses to exercise real options to increase project value. Then WACC would not be the appropriate discount rate for the project with options. The binomial lattice overcomes the shortcoming of WACC by using the risk-free interest rate as the discount rate to calculate the option payoff. However, the main limitation of the binomial model is its relatively slow speed. The higher accuracy of the lattice model however comes at a cost. This method is more time-consuming than the other closed-form methods such as the Black-Scholes model.

Traditional option pricing methods require certain assumptions such as the complete market, which implies that there are marketable securities or portfolios of securities whose payoffs replicate the project's payoff in all states and periods (Brandao and Dyer, 2005). This assumption is important in the field of continuous-time real option valuation. Although this assumption is required for options on financial assets, for most of the real asset projects, no such replicating portfolio of securities exists and markets are said to be incomplete (Brandao and Dyer, 2005). With this limitation of the continuous-time real option, Copeland and Vladimir (2001) proposed an alternative discrete-time method (i.e., the binomial lattice model) based on the assumption that the present value of the project without options is the best unbiased estimator of the market value of the project. With this assumption, this option can be valued with traditional option pricing methods including the binomial lattice method.

The main assumptions of the binomial model (Cox et al., 1979) are that i) the constant risk-free interest rate is applied; ii) investors can borrow or lend as much as they want, and short selling is allowed; iii) there are no taxes, transaction costs or margin requirements, and no cash dividends are paid during the life of the option; iv) there are no arbitrage opportunities; v) stocks and options are traded in the perfect market with the same underlying uncertainties; and vi) the evaluation process is stationary over time.

The binomial model is the cornerstone of the option theory and it is the most widely used method for pricing the option and the real option. Although it can be argued that many assumptions seem restrictive, the binomial lattice has proven to be a solid and rigorous method for pricing both financial options and real options.

Table 3.4 lists previous research studies that apply the binomial lattice to real options.

Authors	**Title**	**Conclusion**
Brandao and Dyer (2005)	Decision Analysis and Real Options: A Discrete Time	The authors demonstrated that a binomial tree based on a binomial

Authors	Title	Conclusion
	Approach to Real Valuation	lattice can be used to evaluate real options. The authors used a hypothetical project to demonstrate that a binomial tree can be used to value real options, e.g., to abandon options. The authors conclude that the binomial tree method is computationally simpler and more intuitive than the traditional method. However, the authors argued that the use of the binomial tree for valuing projects with real options was not applicable for all situations.
Trigeorgis (1993a)	The Nature of Option Interactions and the Valuation of Investments with Multiple Real Options	This paper uses the binomial lattice to illustrate the interaction among multiple options (the option to defer, abandon, contract or expand, invest and switch use). The results show the incremental value of multiple options on individual options. Furthermore, multiple options tend to preserve a number of the familiar option's properties. The results of the study show that when adding an option to the other option, the incremental value is generally less than its value in isolation, and this value decreases if more options are added.
Trigeorgis (1993b)	Real Options and Interactions with Financial Flexibility	The author applied the binomial lattice to value several real options and to illustrate how option valuation can be extended to capture

Authors	Title	Conclusion
		interaction among options. The author illustrated how to value the various types of real options—e.g., option to defer, option to expand and option to abandon—in the investment capital. The author then extended real option analysis to the context of venture capital. The mix of the equity holders' option to default and the debtor's option to abandon the project was examined. The author concluded that option flexibility allows better financing terms in later stages of project financing and is therefore clearly more valuable than a passive alternative of financing terms that were irrevocably committed at the beginning of a project.

Table 3.4: Previous research studies using the binomial model on real option problems

Cox et al (1979) were the first researchers who applied the binomial lattice to approximate the underlying stochastic process and then calculate the option value through the use of risk-neutral pricing techniques. Their approximations to the underlying stochastic processes relied only on simple algebra and are therefore more transparent and computationally efficient. The binomial model has advantages over the Black-Scholes model in that it can be used to accurately price American options. With the binomial model it is possible to calculate the option value at every point in an option's life.

Although this method is widely used in pricing options, it has been argued that the binomial model is more cumbersome as the number of time periods increases. The increase in time periods requires intensive labour, especially handling problems involving multiple uncertainties, "path-dependent" uncertainties, and complex options (Tsui, 2005). The binomial model has the same limitations as those of the option pricing model. The method makes it difficult to find a replicating portfolio and consequently hinders the risk-neutral valuation. It also has practical problems with risk-neutral valuation when the inferred option pricing parameters are not applicable to the real world. For example, the probability of the real project's success or failure is different in the real and the risk-neutral world.

Emmanuel et al (2014) argued that the binomial model sometimes fails to value the managerial flexibility in many types of projects. The model is also difficult to adapt to more complex situations. In summary, Emmanuel et al (2014) argued that the binomial model is suitable and more accurate for pricing options with early exercise opportunities and that it is relatively easy to implement. However it can be quite difficult to adapt to more complex situations. Emmanuel et al (2014) argued that the model is much more capable of pricing early exercise because it considers the cash flow at each time period rather than just the cash flows at expiration.

Copeland and Vladimir (2001) were among the pioneers to apply the binomial lattice model to evaluate the real option problem. Their method assumed that the present value of the cash flows of the project without flexibility (traditional NPV) is the best unbiased estimator of the market value of the project. The traditional NPV is used as the value of the underlying asset for an option pricing model called the marketed asset disclaimer (MAD). In this method, the value of the project with flexibility is the value of the project without flexibility plus the value of the embedded options. Therefore, in the MAD approach, it requires an additivity argument, which can be proven in Williams (1938) or Schall (1972). The MAD approach proposes an alternative method to solve real option valuation problems based on the no arbitrage principle when the underlying asset is not traded in the capital market. Copeland and Vladimir (2001) proposed to build a binomial lattice model, with a binomial approximation to a geometric Brownian motion (gBm), to estimate the project value and real option value. However, it has been argued by Brandao and Dyer (2005) that the use of the MAD assumption to create a complete market for an asset that is usually not traded in the market may lead to significant errors. Moreover, it has been argued that the present value of the project is not readily observable but only approximated. Therefore, different analysts may receive various values of the underlying asset and recommend different exercise strategies.

For many researchers in infrastructure evaluations, the binomial model is the simplest method for real option pricing. The mathematics of the model is relatively easy to understand and it is not difficult to implement. The binomial model was recommended by Pichayapan et al (2003) for practical use in real option analysis. Compared with other methods, the binomial lattice is found to be most suitable for practitioners due to its lower complexity and efficiency in calculation (Pichayapan et al, 2003). The binomial model is used by many researchers i.e., Pichayapan et al (2003) and Charoenpornpattana et al (2003), in expressway evaluation for illustration to practitioners in real application. Infrastructure projects gain benefit from the use of the binomial model method for option valuation instead of traditional analysis, as the model can deal with projects with high risk and great uncertainty.

3.4.2 ***The Black-Scholes-Merton model***

The Black–Scholes model was developed by Fischer Black, Myron Scholes and Robert Merton in the early 1970s for pricing stock options. The model was the pioneer in option pricing and was fundamental to many subsequent academic studies. The Black–Scholes model was initially used to price the European option with the following assumptions (Black and Scholes, 1973):

a) The short-term interest rate is known and constant.
b) The stock price follows a continuous random work with a mean equal μ and constant variance (σ). A variance rate is proportional to the square of the stock price. The distribution of the stock price is lognormal.
c) There are no dividends or other distributions.
d) The option is a European option.
e) There are no transactions cost or taxes for buying or selling the stock or option.
f) Security trading is continuous. It is possible to borrow a fraction of a security at a short-term interest rate.
g) The short selling of a security is allowed.

The Black–Scholes model assumes that pricing a derivative is dependent on a non-dividend-paying underlying asset. The model assumes that the underlying asset price follows the geometric Brownian motion. The option value satisfies the Black–Scholes partial different equation subjected to a boundary condition. The Black–Scholes formulas for pricing a European call and put options on a non-dividend-paying stock are as follows:

$$c = S_0 N(d_1) - Ke^{-rT} N(d_2)$$

$$p = Ke^{-rT}N(-d_2) - S_0N(-d_1)$$

where

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

$N(x)$ = the cumulative probability distribution function for a standardised normal distribution

S_0 = the initial stock price

K = the strike price

r = the continuously compounded risk-free rate

σ = the volatility of the stock price

T = the time to maturity of the option

The Black–Scholes model can be adjusted to include a fixed dividend payment rate into the equation so that:

$$c = S_0e^{-qT}N(d_1) - Ke^{-rT}N(d_2)$$

$$p = Ke^{-rT}N(-d_2) - S_0e^{-qT}N(-d_1)$$

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r - q + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r - q - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

where, q = the dividend payment rate

The Black–Scholes model is a continuous function, whilst the binomial lattice model is a discrete function. The Black–Scholes model is an extension of the binomial model. The Black–Scholes model assumes a normal distribution, while the binomial model assumes a binomial probability distribution. Initially, the Black–Scholes model was limited to computing European options while the binomial lattice had more flexibility for computing both the European and American options. The strength of the Black–Scholes model is its closed-form solution, which provides computational simplicity. Later, the Black–Scholes model was also easily adapted to value American options. Also, the model can be used to perform a sensitivity analysis by using a partial derivative.

Although the Black–Scholes model is simple to use, the analysis should be done carefully when estimating the model's input variables, especially when estimating volatility. The disadvantage of the Black–Scholes model is that it is a very specific model, which limits the model's flexibility, as it is used to calculate the option price at a specific point of time. Some have argued that it is not adequate to price the American-type option (Nwozo and Fadugba, 2014). Furthermore, some of the Black–Scholes model's assumptions, e.g., the tradability of the underlying project asset, fail to hold in real assets, making the calculated number from the model less reliable. Previous studies using the Black–Scholes model are shown in table 3.5.

Authors	**Title**	**Conclusion**
Luehrman (1998)	Investment Opportunities as Real Options: Getting Started on the Number	The work is a good illustration of using the Black–Scholes model to value real options. The author illustrated the use of fundamental option-pricing variables to value a European-type real option. A hypothetical project involving a phrased expansion of manufacturing facilities was provided as an example for valuing real options. Then, the value associated with the option to expand the plant was calculated using the Black–Scholes formula. The author argued that real option pricing should complement, not be a substitute for, traditional capital budgeting analysis. Finally, the

Authors	Title	Conclusion
		author also argued that, although the assumptions of Black–Scholes fail to hold, its calculation provides qualitative insights. This study provides a good framework and steps for evaluating real options.
Benaroch and Kauffman (1999)	A Case for Using Real Options Pricing Analysis to Evaluate Information Technology Project Investment	The authors employed Black–Scholes option pricing for an information technology project. The case of "Yankee 24", an electronic banking network on New England, was used as an example for valuing American-style options using the Black–Scholes model. The authors found that the option of deferring entry into the point-of-sale (POS) debit market for a certain number of years supported the decision of Yankee's senior executive. The authors illustrated the use of the Black–Scholes model in a realistic and practical IT project. The authors concluded that the traditional financial option pricing models can be applied to capital budgeting decisions for non-traded information technology assets.
He (2007)	Real Options Application in Project Evaluation Practise	The author used the Black–Scholes model for valuing the "option to delay a project". This approach is a powerful tool to evaluate projects that have multiple investment

Authors	Title	Conclusion
		choices, such as a large multi-stage oil project. The author emphasised the key considerations when real options are applied to real projects: i) the project’s cash flows over time may not follow the price path assumed by the option pricing models; ii) the values of the key variables, e.g., the variance, may not be obtained easily because the project is not publicly traded; and iii) the expiration of the real option may not be during a specific period, as long as the company still has a right to the project.

Table 3.5: Previous studies using the Black–Scholes model on real option problems

3.4.3. *The Monte Carlo simulation*

A Monte Carlo simulation is simply defined as a method that generates a random number to determine the impact of an identified risk in a project (Mun, 2006). This method repeatedly selects random values from a pre-determined probability distribution to obtain numerous results. The Monte Carlo simulation is often used for analysing real options through simulating a path-dependent model that can simulate multiple future pathways using geometric Brownian motion. In general, the simulation provides more accurate results when the number of simulations and the number of steps in the simulation are increased. Also, the results depend on the accuracy of the assumed distribution functions of the input factors and their quality.

Boyle (1977) was among the pioneers who applied Monte Carlo simulation methods to valuing options on financial assets. His method was based on simulating future returns on asset price that could approximate the probability distributions of a terminal value of an underlying asset. Then, the simulation process generates a number of terminal stock values, which could be used to calculate the option’s value. The option cash flows are computed for each simulation, and then those cash flows are averaged. The average cash flow is discounted by the risk-free interest rate.

In recent years, several works have extended Monte Carlo simulations to option valuation. These include Charnes (2000) in valuing exotic options; Barraquand and Martineau (1995) in pricing American options with multiple sources of uncertainty; and Longstaff and Schwartz (2001) in valuing American options using the least squares regression technique. These efforts to improve the valuation of financial assets are also applicable in valuing real assets. Many studies have used Monte Carlo simulations to evaluate projects, as presented in table 3.6.

Authors	**Title**	**Conclusion**
Rose (1998)	Valuation of Interacting Real Options in a Tollroad Infrastructure Project	The author was the pioneer in using Monte Carlo simulation to value complex option interactions. The paper examines the value of two real options (the abandonment and deferral options) and their interactions in the Transurban City Link project, in Melbourne, Australia. The author illustrated the use of Monte Carlo simulation to value the abandonment and deferral options. Rose argued that ignoring embedded options and their interactions may underestimate the value of a project.
Cortazar (2001)	Simulation and Numerical Methods in Real Options Valuation, in Real Options and Investment under Uncertainty	This paper provides an overview of simulation and numerical methods, and their applicability for solving real option problems. The author discussed alternative approaches and presented that both forward- and backward-induction procedures have a place in real

Authors	Title	Conclusion
		option valuation. This research provides case studies.
Deng and Xia (2006)	A Real Options Approach for Pricing Electricity Tolling Agreements	This research was based on Monte Carlo simulation and used least squares regression to value an electricity tolling agreement. The real option model provided a fairly accurate approximation of a tolling agreement's market value.
Mayer and Kazakidis (2007)	Decision Making in Flexible Mine Production System Design Using Real Options	Real option valuation provided a strategic decision-making tool for mine managers to measure the value of managerial flexibility in a mine plan. Author presented flexibilities in mine production system design by using real option.
Samis and Davis (2014)	Using Monte Carlo Simulation with DCF and Real Options Risk Pricing Techniques to Analyse a Mine Financing Proposal	The authors applied the Monte Carlo simulation with DCF and the real option technique to evaluate an actual project-financing proposal for a small gold mine.

Table 3.6: Previous studies using Monte Carlo simulation for real option problems

The advantages of the Monte Carlo simulation are its ability to solve complex stochastic processes and find a complex option's payoff (Hull, 2009). This method is particularly useful when the underlying asset follows a path characterised by complex differential equations, which are difficult to solve analytically (Cobb and Charnes, 2007). Monte Carlo simulation may be used to simulate key inputs to obtain the full range of possible option values, as well as to solve real option problems (Mun, 2006). The drawback of this method is that its computation is more time-consuming.

3.4.4 *The finite difference method*

Schwartz (1997) first proposed the finite differences methodology (FDM) for solving valuation equations. The finite difference transforms the partial derivative into the form of the differential equations over a small interval. The finite difference assumes no arbitrage condition. The methodology can derive a partial differential equation for valuing real options.

With finite difference methods, the option price is obtained by approximating the differential equation that describes the option price evolving over time using a set of discrete-time difference equations. Then, such discrete difference equations are solved iteratively to calculate a price for the option. This method arises as the evolution by which option pricing can be computed by a partial differential equation (PDE) i.e., the Black–Scholes model. The Black–Scholes formula is obtained by the partial differential equation as a function of time and price of the underlying asset, with some assumptions regarding the variables (please see subsection 3.4.2), with which the option's value can be computed.

The limitation of the finite difference method is that it is difficult to implement when a project has many interacting options (Gamba, 2002). The applications of the finite difference method for solving real option problems are shown in the following table:

Authors	**Title**	**Conclusion**
Casassus and Cortazar (1999)	A Compound Option Model for Evaluating Multistage Natural Resource Investments	The implicit finite difference method was used to value a compound option of a commodity in a two-stage production and inventory problem. The critical first- and second-stage commodity prices were determined from this model, and the optimal operating policy could be defined as a function of state variables (the commodity spot price, available resources and intermediate inventory of the work in process). The output of the first stage was an intermediate inventory of a work in process, while the output of the second stage was the commodity spot price. The finite different model with boundary

Authors	Title	Conclusion
		conditions could be formulated. The author illustrated a numerical implementation of the two-stage inventory and production model using a copper mine's production as an example. The value of a storage option as a function of commodity prices and reserves was obtained by the finite different model. With the authors' model, the optimal operating policy—which presents the optimal level of resources and the intermediate inventory—could be obtained, which was the main contribution of this research. However, the extension of the model to n-stages production could add more complexity to the model.
Cortazar (2001)	Simulation and Numerical Methods in Real Options Valuation, in Real Options and Investment under Uncertainty	The author provides an overview of simulation and numerical methods, and their applicability for solving real option problems. This study used various methods including the binomial lattice, the Black–Scholes model, the finite difference method and simulation to value a European real option. The results of the study showed that the four methods provided the same results when valuing a project's investment opportunities. The author also addressed the drawback of the standard simulation method: it is a

Authors	Title	Conclusion
		forward induction procedure that is not adequate for valuing American-style options.
Cortazar and Schwartz (1997)	Implementing a Real Option Model for Valuing an Undeveloped Oil Field	The authors presented the real option model using the finite difference method to evaluate an undeveloped oil field. The model presented the oil field as having a contingent claim on the oil price, for which the spot price was uncertain. The oil field was modelled with a three-stage model involving the investment decision, investment time and extraction. The three-stage model was then formulated with a partial differential equation with boundary conditions. Finally, the values of the undeveloped oil field were obtained. With the numerical calculation, the model defined the critical price that was optimal to develop the oil field, which was the main contribution of this research. Also, the results of the study showed that real options provided the managerial flexibility to delay investment. However such a sophisticated real model of an undeveloped oil field may provide little practical relevance.

Table 3.7: Previous studies using the finite difference method for real option problems

3.4.5 *The interaction between real options*

The flexibility of real options is seldom in the form of a single option but is instead presented as a combination of options that are likely to interact. This is shown by Trigeorgis (1996), who argued that the presence of subsequent options on the same project can increase the underlying value of the effect for earlier options, while the exercise of prior real options may alter the underlying asset itself. Thereby, the value of the subsequent option depends on the exercise of prior options and therefore, the combined value of a collection of real options may differ from the sum of the separately analysed real option values.

For a pair of two options combined, in theory, the exercise of the first option may alter the underlying asset itself and hence the value of the second option on the same underlying, thus causing a second order interaction. For example the option to expand would increase while the option to contract would decrease the underlying project's value and therefore affect the value of subsequent options on it. In theory, the conditional probability of exercising a second option in the presence of the first option would be higher or lower than the marginal probability of its exercise as a separate option depending on whether the first option is the same type (same call or put) or a different type. The degrees of the interaction may vary depending on the probability of their joint exercise during the investment life.

The principle of real option interaction is that the value of an option in the presence of option combination may differ from its value in isolation. In theory, the degree of interaction and the probability of joint exercise between two options are dependent on (Trigeogis, 1993a):

- whether the two options are the same type or are opposites
- the separation of their exercise times
- whether the options are in or out of the money
- their order or sequence

For two options combined, the value of the first option would be changed if followed by the subsequent option because the presence of the second option increases the value of the effective underlying asset for the first option. The value of the prior option is affected by the sign of the interaction as well as its magnitude. In addition, the degree of interaction between two options may be proportional to the probability of a joint exercise. For a combination of two options, there are three possible outcomes of the option interaction:

- Whether the two options are call options (with different maturities): The interaction may be positive if the first option and the second option are a call option (e.g., option to expand the project scale). Thus, the value of the combination of two options would be greater than their separate values. In this case, the conditional probability of exercising the second option given prior exercise of the first option ($P_{S/F}$) may be high. Therefore, the degree of the interaction may be large.
- The two options are put options (with different maturities): the value of the first option would be lower relative to its value as a separate option. The effective underlying asset for a second option may be lower conditional on prior exercise of the first put option (e.g., to contract the project scale) than if the first option was not exercised (e.g., to maintain the project scale). As the options would be the same type, which is the case for case both puts, their exercise region may overlap significantly and then the conditional probability of exercising second put, given earlier exercise of the first put ($P_{S/F}$), would be high. Therefore, there is a sign of negative interaction.
- The two options are of opposite types; for instance, a pair of a put (first option) and a call option (second option) with different maturities. With this combination, the options are optimally exercisable under opposite circumstances. The conditional probability of exercising the second option given prior exercise of the first option ($P_{S/F}$) may be smaller than the marginal probability of exercising the second option alone. The degree of the interaction may be small which the options are approximately additive. The value of option combination is purely additive in the case that both options are mature at the same time. Their interactions would be zero.

In principle, the lower (higher) the conditional joint probability of exercise, the lower (higher) the degree of interaction between two options. The interaction between two options may be approximate as shown in the following table:

Interactions between two options with different maturities		Second option	
		Call	Put
First option	Call	High	Small
	Put	Small	high

Table 3.8: Value of interactions between two options

Source: Trigeorgis (1993a)

The value of two options will be approximately additive when there is small or no interaction between them. Thus, the conditional probability of exercising both options would be low or zero. In contrast, the interaction may be high if it is very likely that both options will be exercised jointly, and then the conditional probability of a joint exercise ($P_{S/F}$) is 1. The interaction may be positive if the first option is a call and negative if it is a put. For negative interaction, the combined option value is the higher of the separate individual values.

The mathematical equation of option interaction is provided and proven by Trigeorgis (1996). If the underlying asset follows a continuous-time diffusion process, as in the following equation, the joint cumulative probability of a pair of real options will be exercised (Trigeorgis, 1996).

$$\frac{dV}{V} = (\alpha - \delta)dt + \sigma\, dz,$$

Where: V= the project's value, α = instantaneous actual expected return on the project, σ = the instantaneous standard deviation of the project value, dz = a standard wiener process, and δ= the rate of return shortfall between the equilibrium and total expected return required of an equivalent-risk traded asset (Trigeorgis, 1996).

Trigeorgis (1996) expressed the degree of option interaction as a mathematical function of the bivariate cumulative probability of a joint option exercise as follows:

$$P(x_1 x_2) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \exp\left(-\frac{z}{2(1-\rho^2)}\right), \text{ where}$$

$$z = \frac{(x-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2}, and\ \rho = cor(x_1, x_2) = \frac{V_{12}}{\sigma_1\sigma_2}$$

The bivariate cumulative standard normal distribution is in the form of B(a,b;ρ), evaluated at "a" and "b" (as upper and lower integral limits) with ρ, a correlation coefficient, = $\sqrt[2]{\tau_1/\tau_2}$ (where τ_1 and τ_2 are the times to maturity of the two options).

- For a pair of the opposite type options (a put option and a call option), the conditional probability of a joint exercise (P) takes the form B(-d*,d;-ρ) with ρ =$\sqrt{(\tau_1/\tau_2}$. If the separation between the exercising times of the pair of options is as large as (τ_2/τ_1)~∞, then ρ ~ 0 with B(-d*,d;0) = N(-d*) N(d), where N(d) is the (univariate) cumulative standard normal distribution function with d as the upper integral limit, establishing the stochastic independent condition ($P_{F/S} = P_F P_S$). When the finite separation between opposite types is a low (negative or zero) correlation, B(-d*,d;-ρ) ≤ N(-d*) N(d), this verifies that $P_{F,S} \leq P_F P_S$ or $P_{S/F} \leq P_S$ then the interaction effect is relatively small.

For the case of two options that have fully overlapped ($\tau_1 = \tau_2$), ρ = $-\sqrt{(\tau_1/\tau_2} = -1$ with B(-d*,d;-1), since $P_{F,S} = P_{S/F} = 0$, the interaction effect is zero leading to a pure option value additive. In this case, the option exercise is mutually exclusive.

- For a pair of options of the same type (two calls or two puts), $P_{S/F}$ is relatively high and the interaction effect is large. In this case, the conditional probability of a joint exercise (P) takes the form of B(-d*,d; ρ) with ρ =$\sqrt{(\tau_1/\tau_2}$. If the separation between the exercising times of the pair of options is as large as (τ_2/τ_1) ~∞, then ρ ~ 0 with B(-d*,d;0) = N(-d*) N(d). With finite separation, ρ>0 and then B(-d*,d;ρ) ≥ N(-d*) N(d), thus verifying that $P_{F,S} \geq P_F P_S$ leads to a large value for the bivariate probability and to a large value, for the interaction effect. In the case of ρ=1 and B(d*,d;1) = N(d) with $P_{F,S} = P_F$ or $P_{S/F} = 1$, the interaction effect is highest.

The mathematical proof of real option interactions is given by Rossella's work (2007). His paper attempts to provide a mathematical proof of real option interactions in multiple investment projects, focussing on the combination of the option to expand and the option to contract. The detail of the mathematical proof can be found in Rossella's paper (2007). The result of his study confirmed the interaction effect found in Trigeorgis (1993a) based on a different mathematical methodology. Rossella (2007) confirmed the Trigeorgis study by numerical valuation. The result of his study shows that the combined value of two real options may differ greatly from the sum of their individual values. In other words, option interactions are generally nonadditive.

The value of interaction "Interaction effect" (IE) will be used extensively to develop the findings in chapter 4, 5 and 6. Trigeorgis (1993a) and Ross (1998) defined the mathematical formula for the value of interaction effect simply as the option value with the interaction effect, less the option value without the effect (the formula is also referred to in chapter 4 and 5). Their studies assume that in each small time interval, the interactions may be linear. The value of option (equation in section 3.2) and option combination (OC) in their studies are defined as the difference between the Expanded NPV and the Passive NPV (Traditional NPV). Although a mathematical proof of the interaction effect was rarely addressed in the literature, Trigeorgis (1993a) investigated the nature of option interactions. Trigeorgis (1993a) presented the numerical valuation results for the generic project's multiple real options, in which he concludes that the interaction between real options does maintain a number of the usual option properties. In addition, the mathematic formula of IE and OC (in subsection 4.5.6 page 148 and subsection 5.2.4 page 166) is a simple additive function that can be proven as shown by Williams (1938) or Schall (1972). In the Trigeorgis study, the properties of the interaction effect have been analysed and proven in the following cases:

- The interaction effect would be large and positive if a call follows another call option
- The interaction effect would be large and negative if a put precedes another put option and there are extensively overlapping exercise regions.
- The interaction would be zero and two options are purely additive if the options are of opposite types, are exercisable at exactly the same time and are out of the money.

Ross (1998) used a straightforward formula to value the interaction effect. In order to test the validity of the interacting embedded model (interaction effect formula), Ross conducted a sensitivity analysis of the model for each input parameter. The outcome of his study showed that the sensitivity of the input did not pose any threats to the model's validity and reliability.

Blank et al (2009) applied Trigeorgis and Ross's formula to value the interaction effect for the combination of a minimum traffic guarantee and an abandon option in a toll road highway concession in Brazil. Different scenarios were proposed to analyse and validate how options interact. When two options were combined the guarantee option had a strategic importance and it is possible to design a level of guarantee that minimises the probability of abandonment. Trigeorgis and Ross's formula has also been used by Huang and Chou (2006). In their studies, the High-Speed Rail Project in Taiwan was selected as a numerical case to apply the formulas. The study confirmed Blank's result in that increasing the minimum guaranteed level would decrease the value of the option to abandon, and, at a certain guaranteed level, the option to abandon was worthless.

3.4.6 *A comparison of alternative option valuation techniques*

This subsection aims to compare various models used for pricing options. The methods used to price options can be divided into two groups. The first group is the analytical approaches that use formulas to obtain risk-neutral prices with some assumptions. An example of this approach is the Black–Scholes model. The second group is numerical approaches, which provide numerical processes for pricing options. The members of this group include the binomial lattice, simulation and finite difference methods. In theory, various option-pricing models are based on the same mathematical foundations and assumptions e.g., geometric Brownian motion, the theory of underlying asset movement and risk-neutral valuation.

The two most common models for pricing options are the Black–Scholes model and the binomial lattice model. Both are based on the same theoretical backgrounds and assumptions i.e., risk-neutral valuation and geometric Brownian motion. The binomial model converges to the Black–Scholes formula when the number of binomial steps is infinitesimal. Both methods assume different processes: the Black–Scholes model assumes a normal distribution while the binomial assumes a binomial probability distribution. Also, the Black–Scholes model is a specific case of the binomial model. It has been argued that the binomial model can be used to accurately price American options, compared with using the Black–Scholes model. This is because in the binomial model, it is possible to check along the binomial tree at every point of the early exercise. The main disadvantage of the binomial model is its relatively slow speed, as it requires a number of time steps for computing, while an advantage of the Black–Scholes model is its speed. It can calculate a large number of the option prices in a short time.

Tsui (2005) argued that the Black-Scholes model is too simple and is not efficient to reflect the complexity involved in the real project. However, a more complex model might require many assumptions and computation effort to reflect reality. The computation could become cumbersome for the modelers. Compared to Black-Scholes model and to other methods (i.e., finite difference), the binomial lattice is more intuitive and requires less mathematics and complexity background to develop and use. This quality is considered suitable for practitioners. However, it also shares the same limitations as those of the Black-Sholes model. Practitioners should, therefore, understand those limitations and indeed tradeoff when choosing a valuation method.

Monte Carlo simulation uses a numerical method to price an option's value, which is different from the analytical approach of the Black–Scholes model. Monte Carlo simulation is a mathematical process with a large number of asset paths. The underlying asset paths are evolved with respect to stochastic differential equations. The option price using Monte Carlo simulation converges to the value obtained from the Black–Scholes model as the number of simulations increases. The Monte Carlo simulation is more reliable when enough sample paths are taken. Therefore, the accuracy of Monte Carlo simulation comes at a large computational cost. The other disadvantage of Monte Carlo simulation the difficulty of valuing American-style options, as the binomial lattice and finite differential methods are more accurate to price these types of contracts. The general simulation process uses forward algorithms, whereas American-style options require backward algorithms. This creates the inconsistent process of applying an inherently forward-based mechanism to a problem that requires a backwards procedure to solve (Fu et al., 2001).

Finite difference methods are also classified in the numerical class, as they are used to approximate solutions using certain ordinary and partial differential equations. With finite difference methods, options would satisfy the Black–Scholes PDE, which differs from the Black–Scholes model in determining the different boundary conditions. When using the Black–Scholes model, an analytical closed-form solution exists under certain assumptions that may not easy to obtain from more advanced and complex options. Therefore, it is better to adopt numerical approaches in some cases e.g., for American-style and exotic options. Table 3.9 summarises the advantages and disadvantages of the option models.

Methodology	**Advantages**	**Disadvantages**
Black and Scholes Model	- The model has simplicity and speed for computing. - It is easy to use through a closed-form solution. - The model uses risk-free interest rate and it does not require estimating the risk adjusted discount rate.	-It has limited accuracy in pricing American-style options. -Analytical solutions may not exist in many real situations. For example, it is difficult to derive an analytical formula for pricing stock follow a jump process or multiple interacting options. - The method is simple and it is not sufficient to reflect the complexity involved in real projects. For example, the method may not accurately price the complex real options and their interactions.
Binomial Lattice	-The binomial model offers simplicity and flexibility that allows for a broader range of applications. The method is more suitable for	-The binomial lattice model is fundamentally based on a discrete process rather than a continuous process. -This method consumes time when many paths are set.

Methodology	Advantages	Disadvantages
	approximating values of options when Black - Scholes model is not applicable. -It is used to price both European and American options with a high degree of accuracy. With the binomial model, it is possible to check American-style options for early exercise opportunities at every step in the binomial tree. The binomial lattice model gives greater flexibility in modelling real, complex problems, e.g., options with complex payoff characteristics. -This method is useful when the stochastic process of the underlying asset cannot be represented or when it is difficult to derive a closed-form analytical formula using the partial differential equation. - The model uses risk-free interest rate and it does not need to estimate risk adjusted discount rate. - It is more appropriate for	- It is difficult to find a replicating portfolio. - Another weakness is whether or not the assumptions of binomial model are likely to be true in a real project. - The model is sometimes hard to adapt to more complex project.

Methodology	Advantages	Disadvantages
	valuing complex projects with a set of sequential options and multiple embedded real options and option interactions. - The model is good for path dependent options.	
Monte Carlo Simulation	- The implementation of this method is simple when price uncertainty is computed with a multi-factor model. - This method can be used to value path-dependent options.	-This method presents problems in valuing American-type options. -This method has a high computation cost. The method requires a lot of modelling effort. - It is difficult to verify and validate complex models.
Finite Difference	- It is suitable for valuing both European and American options.	-This method is time consuming.

Table 3.9: A comparison of option pricing models

Sources: Perlitz et al. (1999), Cortazar (2000), Wang (2003), Garvin and Cheah (2004), Trigeorgis (1993a,b), Buchen et al. (2009), Tsui (2005), Emmanuel et al (2014)

Each option-pricing method has its advantages and disadvantages. The main challenge regarding the option-pricing method is whether the standard option method, e.g., the binomial lattice or the Black–Scholes model, or the complex method, e.g., the numerical method should be applied (Perlitz et al., 1999). Perlitz et al. (1999) suggested that a standard method such as the binomial lattice is suited to valuing general investment decisions using real options. The binomial lattice is more flexible and can be applied to a broader range of option categories. It is frequently used because the model makes it easy to solve the problem. However, Copeland and Tufano (2004) argued that such standard methods are ideally suited to real option analysis, as they assume more simplicity than options in the real world presents.

3.5 Limitations of the real option methodology

This section aims to provide the limitations of real options. It is essential to understand the limitations of real options in evaluating projects to correctly analyse the results of a study. The following are the main limitations of the real option methodology:

- The traditional options, such as calls or puts, contain too few variables, which makes modelling all of a project's circumstances too difficult to be efficient. The model may oversimplify by using the simple call or put options. Several types of real options can be embedded in the projects. However, compound options involving call and put options play a pivotal role in valuing investment decisions within projects.
- Although real options perform well under uncertain conditions (Lewis et al., 2004), this approach is difficult to apply because of no justifiable volatility (Wang, 2003). An option's value relies on estimated variables, such as the volatility of project's return, which is difficult to forecast. Real options are similar to financial options, in that the parameters required in pricing real options, e.g., volatility, are often difficult to estimate. Often, the volatility of a real asset cannot be found in the financial market due to a lack of historical data. Parameter estimations may be more challenging for projects that require sufficient and adequate data.
- It is important for real option practitioners to understand the limitation of applying assumptions used for valuing financial options to real assets (El-Amm, 2003). Tallon et al (2002) argued that some assumptions of financial options, such as their tradability and liquidity, are inappropriate for the valuing real options.
- This thesis argues that real options have no added value for irreversible investments. If the management has to commit to the original investment plan, then adding management flexibility is not necessary. This means that option flexibility adds no value if the future is certain.
- The mathematical complexity of real option models, e.g., the Black-Scholes and finite difference models, gives them limited accessibility to investment decision makers. However, their complexity provides qualitative insights into each option strategy.

3.6. The real option process

This part presents a real option process framework for evaluating an option. Various research papers have identified the real option process. For example, Copeland and Vladimir (2001) identified four steps to carrying out a real option analysis: i) calculate the present value under certain conditions using a standard discount cash-flow method; ii) define the uncertainty using an event tree; iii) identify and incorporate managerial flexibility, and identify possible options; and iv) perform the real option analysis. After reviewing many studies on the real option process, i.e., Mun (2006), El-Amm (2003), Wang (2003) and Copeland and Vladimir (2001), this research proposes a simple real option process framework that can be classified into three phases, as shown in figure 3.4.

I. Problem formulation

- Formulate the problem framework.
- Identify key risks and options.
- Perform historical data analysis and forecasting.
- Formulate the cash flow model.
- Evaluate: NPV (base case).
- Perform a sensitivity analysis

II. Modeling and analysis

- Identify and determine the key variables: S, X, σ, T, ΔT, and r.
- Select the option valuation method (For example e.g., the binomial, the Black and Scholes, the Monte Carlo simulation).
- Value the options and option bundling.

III. Strategic decision

- Select the real option solution.
- Design the optimum strategic decision.
- Report, monitor and redesign.

Figure 3.4: The real option process framework

The real option process starts with a problem formulation stage, during which a set of critical risks and options is identified. Defining alternatives for a risky project is more difficult than for financial options, for which flexibility is identified up front by a contract (Neely and Neufville, 2003). Before going forward to the analysis phase, relevant data such as costs and benefits must be collected to formulate the base-cash-flow model. The base-cash-flow is defined as the cash flow before the flexibilities are embedded. Sensitivity analysis is sometimes necessary because cash flow value is calculated based on many assumptions and approximations. The appropriate option valuation method among the binomial model, the Black and Scholes model and Monte Carlo simulation must be selected and applied to compute the option's value in the second step.

Lastly, after comparing the options, those with the highest estimated net NPV are selected and a set of optimal strategies and decisions can be designed. Reporting, monitoring and redesign are necessary because real options always exist throughout the project life.

The real option methodology is proposed in this study as a more effective approach to evaluating a project's risk. The most appropriate method among the analytical methods—e.g., the Black–Scholes model—and the numerical methods—e.g., the binomial model and simulation—is selected and will be applied to obtain the value of the options. This thesis uses the binomial lattice method, as it is more flexible and can be applied to a broader range of option categories. Then, the options among the main project's stakeholders will be obtained. Such options are presented through the selected case of a large transportation project (the SES project) in Bangkok, Thailand.

3.7 The application of real options for valuing infrastructure projects

This section provides the background of real option theory and applies it to value managerial flexibility in a large-scale infrastructure project. Also, this section presents the relevant literature involving the application of real options for valuing projects. The selected literature focuses more on the application of the valuation methodology than its theory.

Infrastructure projects with real options can be modelled using a continuous time model or a discrete time model. A continuous time model can be computed for valuing real options in which the variables behave randomly. Discount cash flow analysis is widely used in traditional project evaluation. In general, if a project's cash flows are stochastic, then they are assumed to follow geometric Brownian motion.

Valuing options in a project requires the mathematics of a partial differential equation (PDE) with boundary conditions. The Black–Scholes model is one of the most famous partial differential equations and was initially used to value financial options. Later, many academic researchers applied the Black–Scholes model to value option flexibility in real assets, especially for investment projects. Among them were Benaroch and Kauffman (1999), in evaluating information technology project investment; He (2007), in valuing the option to delay a project; and Vandoros and Pantouvakis (2006), in using real options to evaluate a toll road project. Table 3.10 provides the findings of their studies. Although the Black–Scholes model is useful, its limitations have been clearly stated. It provides an industry-standard methodology to assess the value of a financial derivative, for which a specific equation of the model may not exist in many realistic situations. Many researchers, i.e., Rose (1998), Lewis et al. (2004), Charles and Liu (2006), and Zhao et al. (2004), have moved to using numerical methods—including the binomial lattice method, the finite difference method and Monte Carlo simulation—for option pricing.

One of the most popular discrete time models is the binomial lattice model, which creates two sets of cash flows: one up and one down. It is generally used to price the value of an option assuming a risk-neutral probability. The main assumption of risk neutrality is that the market is complete, and therefore, a replicating portfolio can be found (Garvin and Cheah, 2004). When a risk-neutral probability outcome is defined, the project's cash flows can be discounted at the risk-free rate. In this research, the binomial lattice method was selected for valuing real options because of its flexibility, matched with the characteristics of the project's cash flows.

The assumption of geometric Brownian motion (GBM) with constant volatility is common when valuing real options. If the changes in the value of a project's cash flows follow GBM, then the real option can be valued by the traditional option pricing method (Brandao and Dyer, 2005). Then, the binomial lattice method in a risk-neutral world can be applied to the option's valuation. However, when the project's cash flows are discounted by a risk-adjusted discount rate to value the base NPV, the option payoff is discounted by a risk-free rate, assuming risk-neutral valuation.

Many practitioners including Myers (1987) and Trigeorgis (1993a) have suggested implementing real options in practise by trying to value the inherent managerial flexibility in an investment project. Trigeorgis (1993a) defined the meaning of managerial flexibility as a set of real options, i.e., the option to defer, abandon, contract or invest in the project. In addition, the managerial flexibility embedded in an investment project traditionally takes the form of the collection of real options, in that the combined values of these operating options can have a large impact on the project's value (Trigeorgis, 1993a).

Real options theory has specifically been applied to deal with the uncertainty and flexibility inherit in an investment project (Trigeorgis, 1996). Substantial evidence indicates that the infrastructure projects are key areas for using the application of real options. Many researchers have used real options for valuing infrastructure projects. Blank et al. (2009)

valued a government's options to guarantee minimum and maximum traffic to mitigate the demand risk of a toll road in Brazil using analytical and simulation methods. Charoenpornpattana et al. (2003) analysed build–operate–transfer (BOT) projects focussing on the real options of minimum traffic guarantee and shadow tolls. Zhao et al (2004) developed a real option model for the development and operation phase of a highway. The model focussed on three risk types: traffic demand, land prices and highway deterioration. Other authors have applied real options for valuing infrastructure projects, including Chiara et al. (2007), in valuing the multiple exercise of real options in a toll road project; Ford et al. (2002), in measuring the strategic flexibility of a toll road; Ho and Liu (2002), in evaluating the financial viability of privatised infrastructure project; and Rose (1998), in valuing option interactions in a toll road infrastructure project. A detailed analysis of these studies has already been provided in this section.

Typically, real options in a project are more complex, in that the project incorporates a set of multiple real options. When options are combined, their interactions exist and the valuation of those options becomes more complicated. Trigeorgis (1993a) researched the interactions between two options or among more than two options. His study concluded that the combined value of two options in the presence of each other may differ from the sum of the separate value of each option. Literature related to the interaction among options in infrastructure projects is rare. There are Huang and Chou (2006) on the interaction between a minimum revenue guarantee and an abandon option, Rose (1998) on the interaction between abandonment and deferral options.

Valuing an investment project is difficult due to its substantial uncertainty and complexity, which make it necessary to use sophisticated tools to evaluate opportunities and risks. Real option analysis offers a framework for assessing the risks in a project. Real options are used to capture the managerial flexibility under uncertainty and to simplify complex problems. The real option approach has recently gained growing attention in the project evaluation field. Many authors have illustrated the applicability of the real option methodology for evaluating infrastructure and R&D projects. The next table lists previous works on the application of real options to project evaluation.

Authors	**Project type**	**Finding on the study**
Blank et. al. (2009)	Toll road	The authors proposed three real options in their study: a minimum traffic guarantee, a

Authors	Project type	Finding on the study
		maximum traffic ceiling and the abandon option. In the minimum traffic guarantee, the government subsidises demand that is lower than the lower bound level, whereas in a maximum traffic ceiling, the concessionaires pay the government if demand exceeds the upper level. In addition, the implicit abandon option was considered to influence the government's decision about the guarantee option. The analytical approach and the Monte Carlo simulation approach were proposed to evaluate the real options for the toll project. Their study showed that the government's guarantee option had two benefits: i) the guarantee could reduce the probability of project's default and ii) the government could design a level of guarantee to minimise the probability of abandonment from the concessionaires. It can be argued that adopting the abandon option in a project should be carefully reviewed, as doing so may create unfavourable consequences, such as social and political problems, for governments. This research agrees with the authors that three objectives should be carefully considered: the concession scheme should be attractive to private capital; the probability of abandonment should be limited; and the overall risks of the project should be minimised.
Charles and Liu (2006)	Infrastructure and transportation	The authors used a Monte Carlo simulation of cash flow to value the government's support and the repayment option in an infrastructure

Authors	Project type	Finding on the study
	project	project. The case study of the Malaysia–Singapore Second Crossing project was used in their study. The simulation showed that the value of the government support, in the form of subsidy payments, may be substantial, relative to the base net present value. In addition, a repayment option can be designed to set a limit on the concessionaire's return. The value of a government guarantee may be significant and create significant government expenses. Hence, the appropriate level of government guarantee should be determined.
Vandoros and Pantouvakis (2006)	PPP Project (toll road project)	The author evaluated "the option to abandon" a hypothetical toll road project. The hypothetical toll road project was used to evaluate and compare both traditional NPV and real option analysis using the Black and Scholes method. The authors concluded that real options incorporate managerial flexibility in decision making for evaluating projects at the appraisal stage. The study is limited to a hypothetical project, in that the use of a case study could provide more realistic results. The authors argued that the advantage of real option analysis over NPV is its flexibility to deal with uncertainty in the decision making process. The authors did not analyse the limitations of the Black–Scholes model.
Lewis et. al (2004)	Research and development project	The authors presented a method for evaluating research and development projects. The authors determined the value of a deferral option and defined five variables that would impact the

Authors	Project type	Finding on the study
		option's value: -Future cash flow -The investment cost -The interest rate -Time -The volatility of the future cash flows The authors used the binomial lattice and Black–Scholes models to price an option's value. The authors defined the deferral option as the call option. The dividend payment was considered to be the cost of deferral. The study showed that the deferral option provided the value of managerial flexibility. In a sensitivity analysis of the independent variables, the present values of the future cash flows and their volatilities were the most sensitive factors in the option's value and should be forecasted with great care. It can be argued that the cost of the deferral option should be considered, as it may have significant impacts on the deferral option's value. The lender in the project can apply the deferral option, as the lender may have the option to delay long-term funding and may wish to see the progress of the construction.
Zhao et. al (2004)	Highway project	The authors presented a real option model for decision making in highway development. The study focusses on three real options: land acquiring, expansion and rehabilitation. The model focusses on three risk types: traffic demand, land prices and highway deterioration. The uncertainties were simulated using Monte

Authors	Project type	Finding on the study
		Carlo simulation. The authors proposed optimal decision making for highway expansion and rehabilitation. However, they did not address the limitations of applying Monte Carlo simulation, especially in valuing American options.
Charoenpornpattana et. al (2003)	BOT highway project	The authors presented the role of government support in BOT projects. The authors focussed on two types of government support: the minimum traffic guarantee and the shadow toll. The project's cash flows were divided into two parts to evaluate the value of the government support: the cash flow without support and the support component. The support component could be valued by the real option approach, with the support component composed of a set of multiple options. To evaluate the real options, the authors used the binomial lattice with a risk-neutral approach. The case study of the M2 toll road project in Australia was selected for illustration. The level of the minimum traffic guarantee and the level of toll rates were determined using the binomial model. However, the minimum traffic guarantee may not be the best strategic choice for governments, as it may create significant future liabilities for governments. This research can be extended to investigate the other types of government support. The study did not conclude which types of support the government should incorporate into the project.

Authors	Project type	Finding on the study
Pichayapan et al (2003)	Expressway project	The authors evaluated an expressway project with the option to delay an investment decision. The paper showed that as long as the project could be delayed without any additional cost, the longer delaying time provided higher NPV. The value of delay options is more valuable for financially unfeasible projects with low volatility. However, economic NPV should be analysed for public transportation projects for which a delay decision is worthless. The authors suggested that a social loss due to delaying the project should be included into the calculation of an option's value; otherwise, the option's value will seem to be overestimated.

Table 3.10: Previous literature associated with using real options in project evaluation

The approach in this research differs from that of Charoenpornpattana (2003), Blank (2009) and Charles and Liu (2006), in that their studies focus on the government's options in the development of infrastructure projects. This research extends the application of real options to a project's other main stakeholders, not only the government but also financial institutions and private companies. In addition, this study proposes a real option interaction model among the government, the financial institution and the private company. This research begins with the financial institution's options in infrastructure development (Chapter 4) and then defines and determines the government's options in infrastructure projects (Chapter 5). Next, the options for the private company in the project are valued (Chapter 5). Lastly, this study will determine the value of the option interactions among the government, the private company and the financial institution (Chapter 6).

3.8 The options for governments, private companies and financial institutions in infrastructure projects

This section presents the options for main stakeholders in the development of infrastructure projects. These main stakeholders are the government, the private sector and the financial institution. Examples of each stakeholder's real options will be presented in this subsection.

There is a global trend for many governments to engage in public-private partnerships (PPPs) to provide infrastructures services. Most of these engagements are done through a contractual concession. Concession is a type of Public Private Partnership (PPP) of which a PPP is an association, agreement or cooperation between a government and a private company oriented to pursue and accomplish a project. Such concessions can be awarded through direct negotiation between the government and the concessionaire.

The negotiation process may be facilitated by various valuation techniques which may range from a simple rule-of-thumb, as learning from past project's experiences, to sophisticated methodologies, such as Monte Carlo simulation and real option analysis (Razgaitis, 2003). Real option in infrastructure development is initially about risk negotiation between two parties, the grantor (government) and the concessionaire (private company), and the subsequent allocation of risk. All value and risks are negotiated in order to allocate to the appropriate party. For example, when the private company can negotiate with the government to provide a revenue guarantee of the project for a certain level, the revenue risk is partially allocated to the government.

The negotiation table between the government and the private company can be extended to the other parties such as financial institution (FI). In the negotiation, the government may give the option to defer the concession fee to the private company as well as provide the option to abandon the project to FI. With the option arrangement, one party either private company or FI can optimize the value of the option. The private company can earn benefit (which will be a cost to the government) by exercising a deferral option, while the FI can benefit by exercising the abandon option. Though the real option is extended to three parties (government, FI and private company), the option agreement is still between two parties such as the deferral option between the government and the private company and the abandon option between the government and the FI.

As stated in the previous chapter, infrastructure projects usually face substantial risks, such as cost overrun and revenue risk, during the construction and operation phases. To mitigate such risks, the concessionaire (the private company) often negotiates with the government and financial institutions for some support. The presence of such support will increase the concessionaire's flexibility in investment decisions and thus increase the project's value. On the other hand, financial institutions will request the option flexibility to defer or abandon to provide funding for projects until circumstances become favourable. In addition, risk allocation among the main stakeholders is also critical for the success of a large project's development (Khan and Parra, 2003). Jin and Doloi (2008) and Roumboutsos and Anagnostopoulos (2008) suggested a research study on this topic using a quantitative approach to identify appropriate risk allocation in PPP infrastructure projects. Next, in chapters 4–6, this research will apply real options to help determine the appropriate amount of risk allocation among the government, private company and financial institution.

Khan and Parra (2003) and Zhang (2005) listed some typical interests of the major parties in the development of large-scale infrastructure projects related to key risk factors, i.e., financial and market risk:

- Government: Governments look for an appropriate toll -charge for public services, as well as public affordability, the lowest total life cycle cost of for a project and a project's completion within its budget.
- Private sponsor: Private companies look to optimize of their investments by allocating more capital in profitable projects, as well as a low- equity injections in projects, the protection of private investments from market risk and currency's conversions or transfers to mitigate the market risk.
- Financial institution: Financial institutions look for certainty in the project's cash flow, the project's ability to service debt and a credit enhancement from the reliable parties.

The complexity and obscurity of the risks facing a project's stakeholders make it difficult to distribute the risks appropriately. Before distributing such risks, it is essential to understand the real options for key stakeholders, which will help to mitigate and allocate risks in PPP projects.

3.8.1 *Government support in projects*

Risk identification, risk analysis, risk mitigation, risk sharing and government support are crucial to the success of infrastructure projects. Risk identification and risk analysis have been discussed in Chapter 2. This subsection will provide information on risk sharing by the government.

Fishbein and Babbar (1996) defined eight levels of government financial support (presented in figure 3.5) to project sponsors, ranked by government financial exposure from low to high: 1) concession extensions, 2) revenue enhancement, 3) minimum traffic guarantees, 4) shadow tolls, 5) grants and subordinated loans, 6) exchange rate guarantees; 7) debt guarantees and 8) equity guarantees. In addition, governments can help to mitigate political risk through providing support, guarantees or financing (Schaufelberger and Wipadapisul, 2003).

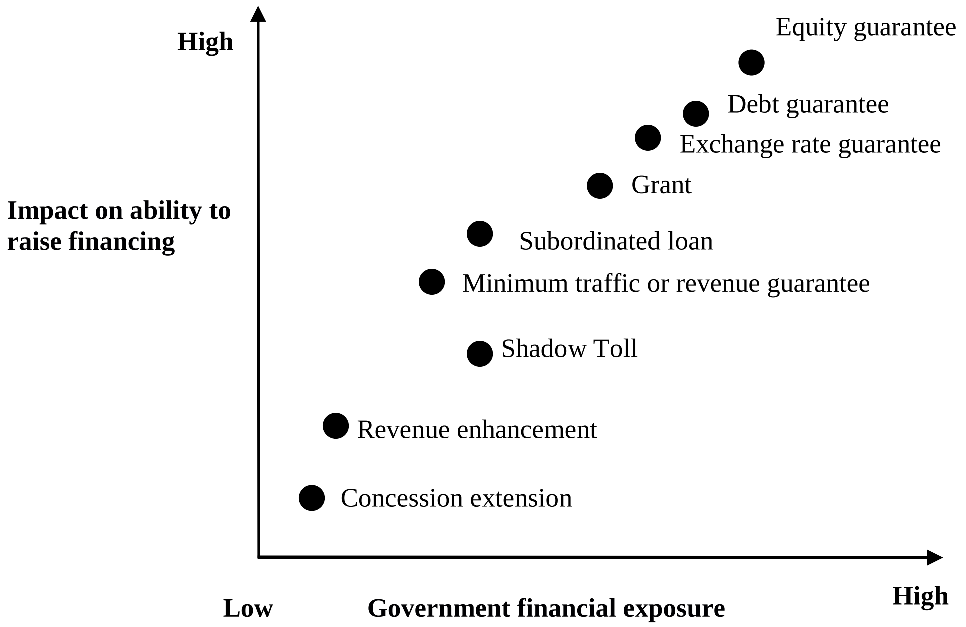


Figure 3.5: Level of government support in BOT projects
Source: Fishbein and Babbar (1996)

In figure 3.5, the risk allocation mechanisms range from concession extensions to equity guarantees. Concession extensions involve limited government risk, in that the private company still takes the project’s main risks i.e., revenue shortfall risk. A minimum traffic guarantee is a common type of government support in which governments compensate the concessionaire if the project’s revenue falls below the guarantee level. With a minimum traffic guarantee, the government holds the option and determines the appropriate level of guarantee. Revenue risk is partly shared between the public and private sectors. Charoenpornpattana et al. (2003), Huang and Chou (2006), Brandao and Saraiva (2008), and

Blank et al. (2009) developed real option models to determine the value of revenue guarantees. Charoenpornpattana et al. (2003) determined the value of projects with minimum traffic guarantees using the real option approach. Their research found that the value of support was important for the success of PPP projects, as it helps to make projects more attractive for private investors. Huang, and Chou, (2006) studied the interaction between the minimum guarantee option and the abandon option using Taiwan high-speed rail as a project case. They applied derived option pricing formulas to value the options. They concluded that the value of the abandon option was worthless when the guarantee level was high enough e.g., at 350% of revenue. Brandao and Saraiva (2008) used a real option model with Monte Carlo simulation to assess the value of a government guarantee. They applied their model to the BR-163 toll road in Brazil. They found that a minimum traffic guarantee with a cap on total government expenditures for the project increased the project's value and reduced the revenue risk for the private investor. However, a minimum traffic guarantee may not be the best option for the government to support a project, as the revenue risk is mostly transferred to the public sector, creating significant exposure for the government in the future. This research will explore the different types of government options to define the appropriate level of government support in PPP projects.

Example of PPP projects that applied revenue guarantees include the 4th Line of the Sao Paulo Metro in Brazil, the El Cortijo–El Vino toll road in Colombia and the Santiago–Valparaiso–Vifia del Mar Toll Road in Chile. In these projects, the government provided a guarantee to help reduce the risks for the private sector and lender in the PPP project. This research differs from Charoenpornpattana et al. (2003) and Blank, et al. (2009), in that it extends the model's scope to study the interaction among the government options as well as the option interactions among the main stakeholders in PPP projects.

Among the various types of government support, an equity guarantee is the highest degree of government support (Fishbein and Babbar, 1996). A government gives a private company the option to sell (put option) the project to the government at a specific price that guarantees a minimum rate of return. This equity guarantee option can be exercised in very specific conditions, which are defined in the concession agreement. The other government guarantees are debt and exchange rate guarantees. In a debt guarantee, the government promises to pay the lender the principal and interest in case of financial default. A government provides an exchange rate guarantee to mitigate exchange rate volatility.

Debt guarantees which the risk of repayment are frequently used by governments to pursue policy objectives for supporting PPP infrastructure projects in financial distress. A guarantee is valuable to prevent the lender or bondholder in the event of payment default with a cost to government. With lending guarantee, the incentives of the debt holders (financial institutions or bondholders) in monitoring the performance of the project company may fall. Therefore, government's guarantee should preserve project companies' incentive to management risk they can manage. To create the incentive for continued project monitoring or to discourage private companies which may reluctant to repay debt, government may set the guarantee mechanism i.e. limited guarantee for a portion of debt or limited guarantee only for unexpected lower revenue. The government may require the borrower to provide any securities such as assignment of future earning for any recourse. Furthermore, the government may set control account to make sure that the project's revenues are actually used to repay the FI loans or bondholders and any cash deficiencies are covered by properly exercising debt guarantee. Equity and debt guarantees enhance a project's cash flow while limiting the downside, similar to the hedging feature of options. This research will apply real option methodology to examine the value of these options.

In addition, governments can provide other forms of support to enhance a project's economic feasibility, such as by granting subordinated loans and guarantees for traffic revenue (minimum traffic guarantees and shadow tolls). A subordinate loan serves to increase a project's debt leverage and to decrease the cost of equity funding (El-Amm, 2003). A shadow toll is a payment structure for the number of vehicles using the road that uses the government instead of toll users. Fishbein and Babbar (1996) argued that it may not be efficient for the government to provide shadow tolls to protect private investors from revenue risks. In this option, the government's contribution is proportionate to the traffic volume. Therefore, the support may not be adequate if traffic flow is lower than expected, as the revenue risk is wholly owned by the government. Charoenpornpattana et al. (2003) argued that shadow tolls contribute to projects if the government defines a suitable set of support variables, such as toll rate and traffic levels. Therefore, the government's revenue risk is limited.

Governments in many countries support projects through revenue enhancement and concession extensions. Governments help to enhance project revenue by limiting competitors, increasing demands by providing interconnections with other transport projects or allowing the development of ancillary facilities (Charoenpornpattana et al., 2003). A government may extend the concession period for a private company to earn a reasonable return if revenue falls below a specified level, such as in the Mexico City Toluca Toll road project. By giving revenue enhancements and concession extensions, a government can limit its financial exposure to projects. Fishbein and Babbar (1996) argued that, although these two options limit a government's liability in projects, they do not protect the private investor's risks regarding traffic or revenue shortfalls, as these risks still belong to the private sector.

3.8.2 *Private-sector options in a project's development*

Private partnership is becoming an essential tool in developing infrastructure projects. Governments in many countries may set up support mechanisms to stimulate private investment into projects. Project finance is a typical tool used to fund large-scale infrastructure projects and bring private capital into the provision of infrastructure projects. A private company may participate in projects in different ways, e.g., as advisors, insurers, project developers, operators and investors. Private investors normally attempt to not participate in high-risk projects. They may require a higher rate of return to compensate for a project's risk. It is essential for private companies to ensure that their investments are at an optimal level.

Private investors can employ various means to mitigate project risks, such as an abandonment option, project extension or debt rescheduling. In an abandonment option, a private company can withdraw from a project if the project's cash flow is negative (Pollio, 1998). Podhraski (2014) argued that the abandonment option is difficult for the private sector to apply in PPP projects due to the protection of public interests. This is because the abandonment option allows private companies to stop a project if it turns out to be loss-making. The abandonment option may interrupt the service to the public, which is usually not acceptable for the government. However, an abandonment option can be awarded to the private sector within a short period of time, i.e., within the construction period or early in the operating years. An example of the abandonment option involves the 345-km Taiwan High-Speed Rail project, which links Taipei and Kaohsiung. In this project, a private company had the option to abandon the project within a specific short-term period after signing the contract. This research will investigate the best time for a private company to abandon a project.

A project's investors may require the option to reschedule or to extend repayment in the contract obligations if the project experiences low traffic (Schaufelberger and Wipadapisul 2003). Rose (1998) studied the private companies' option to defer the concession fee to the government. The value of this option is similar to the value of the company's call option to defer payment to the government. Ross found that the value of the deferral option was significant relative to the project's value (about 30% of the total concession fees). However, the deferral option may not be preferable as a policy choice under the government is experiencing budget constraints, as the government will receive less revenue.

3.8.3 *Financial institutions' options in project development*

Large infrastructure projects in global markets are usually funded using project finance arrangements. According to S&P, global project finance origination reached a record peak of around 680 projects in 2007 but sharply declined to approximately 250 projects in 2013 after the financial crisis. In addition, referring to Thomson OneBanker data, global project finance loans reached its highest level of USD $247 billion in 2008 but decreased sharply in 2009 and recovered to USD $204 billion in 2013. Financial institutions are a primary source of project financing. Normally, financial institutions are not comfortable with funding long-term projects; therefore, they will attempt to limit their funding risks by allocating the risks to the other project participants, such as by requiring a government guarantee and equity injections from the project company. The project company, on the other hand, may require support mechanisms from the lender in the form of some equity injections, prolonged debt service and bank guarantees.

Multilateral finance institutions such as the World Bank, the International Finance Corporation and the International Monetary Fund, as well as regional development banks often act as lenders or co-financiers in developing infrastructure projects within developing countries. The World Bank has funded approximately 12,300 projects in 173 countries from 1947 to 2015. In addition to direct funding, they may provide full or partial guarantees for insuring infrastructure development in developing countries. The partial guarantees mainly cover country risks such as political risk and force majeure, and may be extended to cover foreign exchange risks. The guarantees are triggered when credit default occurs due to government non-compliance with its contract obligations.

Based on the literature review, real options for financial institutions (FIs) have been neglected, which has inspired the author to continue working in this area. Details on applying real options to FIs will be explored in the next chapter.

3.9 Summary

This section starts by reviewing the similarities and differences between financial options and real options. The most important difference is that the former is actively traded in the market, with shorter maturity compared to real options. Real option models, including the binomial lattice model, the Black–Scholes model and Monte Carlo simulation, are also introduced as important approaches for valuing real options. Previous studies have widely applied real options to evaluate projects, although there are some limitations. Among the various real option models, the binomial model's advantages are its ability to find solutions for the valuation of American options, its flexibility to value more compound options and its mathematical simplicity for interpretation in real projects. The application of the binomial model to a project's valuation problems looks natural because the binomial model is commonly used to model project flexibility. This research applies a binomial lattice model with risk-neutral probabilities to estimate the value of option flexibility with the changes in a project's value over time.

This section also provides reverent literature reviews on applying real options in project evaluation. The presence of options in the project can be shown by real option theory. The literature motivates me to further study real option valuing and the interactions among real options in the context of project finance.

Chapter 4: SES Case Study: Financial-Institution Option

This chapter presents the approach this study used in order to answer the research questions addressed in the literature review. In this chapter, the real-option valuation model is presented in which the binomial lattice is used for valuing the real option for the financial institution. This research then formulates a set of multiple options for financial institutions and determines the values of the option interactions.

This research study began with a review of project-evaluation method, risk identification, risk analysis, the risk allocation in the large-scale infrastructure project (Chapter 2) and the real-option methodology (Chapter 3). The main finding from the literature review is that traditional project evaluation techniques (i.e., NPV, IRR) tend to understate the value of the project and neglect managerial flexibility in the analysis.

The literature also showed that a typical project finance is mainly subject to financial risks (e.g., lower than expected revenue due to the uncertainty of traffic demand and the construction cost overrun). Furthermore, to explore the critical risks in a practical context, this thesis uses a qualitative method to collect data from a selection of 6 large infrastructure projects in Thailand. The analysis of case studies allowed the identification of three main risk factors: i) an underestimated project demand ii) construction cost overrun, and iii) large amounts of debt. The traditional project evaluation (i.e., NPV, IRR) falls to capture the investment decision regarding these risks and therefore, an additional, flexible tool to handle such risks is required. In addition, based on the result of the literature review on risk factors in infrastructure projects, this thesis found that the risk allocation between the main project's parties is essential for a successful project.

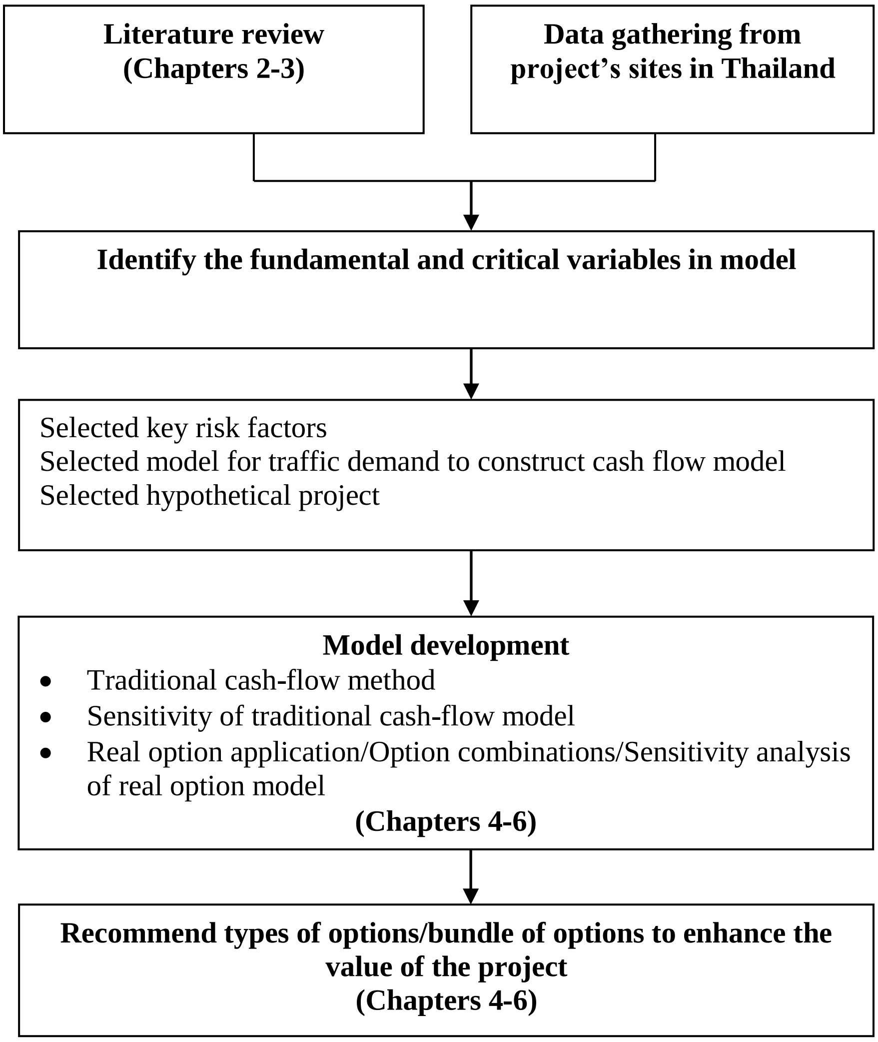


Figure 4.1: The schematic representation of study methodology

The data collected from large infrastructure projects were then used to identify fundamental and critical variables in the model. The selected hypothetical project was used to develop the traditional cash-flow model. The appropriate real options were selected from the literature. Then, this study used the real-option model with the binomial lattice to simulate cash-flow behaviour and to analyse the impacts of the financial risk of projects. This research used Excel spreadsheet for all numerical simulations and calculations. Finally, the value of real options and their combinations in the context of project finance are investigated in order to enhance the value of the project. The results will be used as a guideline for policy design and implementation. Figure 4.1 is a representation of the methodology adopted in this DBA thesis.

This research selected the second-stage expressway system (SES) project for real-option analysis because of the availability and completeness of the project's information in the time that data were collected. The SES project is the first example of a public–private participants (PPP) implementation in Thailand.

The traffic flow is assumed to follow the geometric Brownian motion (GBM) with a constant volatility. For real-option analysis, the NPV of the SES project is initially determined by the traditional discount cash-flow method. The binomial lattice of the selected real options is determined, and the real-option value can be computed.

4.1 An introduction to financial institution option

This section will discuss the real option for a financial institution in the PPP infrastructure project. The primary aim of this section is to study the implementation of a real option in the infrastructure projects.

One of the major concerns when a financial institution provides financial support to large infrastructure projects is the uncertainty of the project's cash flows, which is a main source for repaying its debt obligation. A lender is looking for the risk-mitigation mechanism which can help reduce project risk. The credit quality of the project can be improved if the lender is sufficiently shielded from the repayment risk. This section presents the application of the real option to value and investment project in the context of a financial-institution option. Real options for financial institutions are identified and evaluated. The option interaction in the form of multiple real options is also investigated in this section. This section aims to demonstrate the application of the real-option method to value investment projects and show how the real options can mitigate risks for the financial institution.

This chapter provides practical insight into financial-institution risks for a large-scale infrastructure project. This research proposes the application of financial-institution options in the case study of toll-road concession. The financial-institution options and their interactions are evaluated, interpreted, and designed for policy implementation. The finding of this part would facilitate the risk-analysis and risk-mitigation processes that can be conducted by the financial institution prior to the development of the infrastructure project.

For large-scale infrastructure development, the project is normally initiated by the government. Governments from many countries, specifically in developing countries, stimulated private-sector participation in large-scale infrastructure project because of their limited resources and budgets. From there, many public infrastructure projects have been privatised worldwide; benefits and risks are substantially distributed between the public and private sectors. Large infrastructure projects typically involve various risk factors. Thus, the successful implementation of those projects depends on an effective management of the key project risks. Government benefits from private-sector participation in a project are that the appropriate risks can be transferred to the private sector. On the contrary, the private sector and financial institution encounter a number of project risks, such as cost overrun risk, market risk, and financial risk. To ensure the project's financial viability, the private company and lender demand some support from governments. The government may provide support to the project in the forms of equity guarantee, debt guarantee, minimum-traffic guarantee, grant, and concession extension, which will be studied in the next chapter. Additionally, the lender may guard against the risks of the project (e.g., cost overrun and lower than expected revenue) by extracting the deferral or abandon options from the government and project company.

The main focus of this chapter is the lender's options in the PPP infrastructure project. In traditional project finance, the types of loan facilities supported by lenders are revolving credit, term loan, standby letter of credit, and a bridge loan and guarantee (Finnerty, 1996). The lenders will need some mechanisms to manage risks if the project fails to perform when compared to its anticipated performance. Although there are many types of financing options, a lender still requires some form of security in case the borrower defaults on the loan. This kind of security can be in the form of individual option or a bundle of options. This study evaluates the lender options in the project and will illustrate the use and value of real options in the transportation project. This study will provide illustrations through the case study, focussing on valuing individual options and interactions among the options (option to defer, and abandon option). This study will apply the real-option valuation theory in the context of project finance in order to enhance the project's value. In general, the real options in the project are often more complex, which makes them difficult to value using the general close-form analytical solution. In order to value such complex options, the numerical approach (i.e., the binomial lattice and the simulation approach) can be applied.

The rest of this chapter is organised as follows. It starts by reviewing the risks financial institutes face in infrastructure projects. Next, this chapter introduces types of options for financial institutions. The chapter also provides a brief overview of the case study used in this research. The option-valuation technique is illustrated through a retrospective case study of a transport-development project in Thailand. Lastly, this research provides a conclusion and recommends the appropriate options for the financial institution.

4.2. Financial institution's risks in the PPP infrastructure project

This section examines the project risks primarily from the perspective of the lender. This section will illustrate how the lender's risks are mitigated. Financial-institution risks in the project can be mitigated and reallocated through the implementation of a real option. Before moving forward to the analysis of the lender's risks in the PPP project, the risk factors of the PPP infrastructure project are worth to understand.

A review of the literature showed that much attention has been given to identifying the general risks of the PPP infrastructure project (Schaufelberger and Wipadapisut, 2003; EL-Amm, 2003; and Wibowo and Kochendorfer, 2005). Those studies found that inadequate revenue is the most significant risk during the project's operational phrase whilst construction cost overrun is one of the major risks in the construction phrase. This study will employ real-option methodology to mitigate these two risks. The project's specific risk for the lender will be explored in the next section.

4.2.1 *Risks of financial institution in PPP infrastructure project*

This subsection provides the project's specifics for the financial institution. Whilst research has attempted to identify risks in the infrastructure project, it is also useful to consider the specific risks associated with financial institutions (FIs). There are several types of risks that potentially affect the lender in infrastructure projects. These risks are listed in table 4.1.

Risks	**Definition**	**Risk to FI**
Credit risk	The risk related to the sponsor or project-company's creditworthiness	Lender is exposed to the risks of principal and interest losses.
Completion risk	The risks of cost overrun or time delay	The lender may have to reschedule or allow refinancing of his loan. Furthermore, the lender may have to provide additional funding to the

Risks	Definition	Risk to FI
		project company when the project has incurred cost overruns.
Market risk	The risk of traffic demand falls below expectations.	Revenue generation is below projection, affecting the ability to repay debt declines.
Financial risk	Risks of foreign exchange, interest rate, labour cost, and price of the project's inputs and outputs	The cash flow can be affected in a way that forces the lender to reschedule or refinance its loan.
Economic risk	Risk of economic downturn	Revenue falls more than expected because traffic volume reduces. As a result, the ability to repay debt for the project is declined.
Political and country risk	The risk from unexpected changes in regulations or a failure by the government to implement tariff adjustments. These risks are inherited by a lender who provides a cross-border loan to the project company.	Host country is not in an economic position to accept a transferrable currency to repay foreign debt. Political party interrupts the project, causing the project's delay and cost overrun.

Table 4.1: FI risks in infrastructure project

Source: Kreydieh (1996)

The FI's problem in the case of project finance is to assure that the revenues generated from the project's assets will be sufficient to repay the loan. Table 4.1 showed that there are numerous key risks for lenders that may affect a project's cash flow. The lenders will need some mechanisms to manage or mitigate such risks. Tools such as real options provide the lender with flexibility to cope with those risks, therefore making lending more attractive to the lender.

4.3. Evaluation of the transportation-investment project

The standard technique for evaluating projects is the net present value of the expected cash flow from the investment project, discounted by an appropriate rate. In financial theory, the capital asset pricing model (CAPM) is used to determine a theoretically appropriate discount rate of an asset, though the drawback of this approach is widely acknowledged. One disadvantage of this approach is that it neglects the stochastic nature of the project's cash flows. Although CAPM appears as the simplest technique to use, the high volatility of traffic demand induces some fundamental uncertainties which are difficult to solve using this traditional discount cash-flow method. The traffic demand is quite uncertain in the transportation project because the traffic volume may swing 10–20% per year. Under such conditions, the valuation model for the transport project proposed by this research considers the traffic demand as a stochastic variable in which certain price is assumed to be non-stochastic.

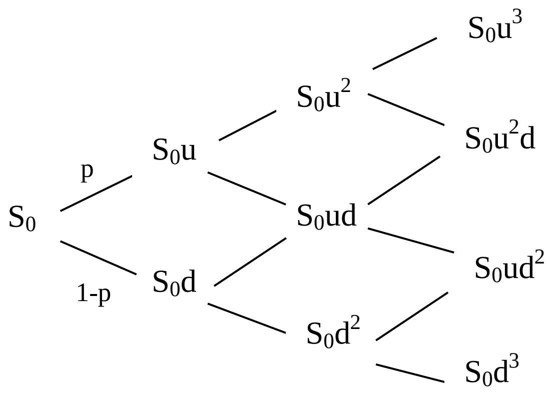
The binomial lattice discrete-time valuation model can be used to accurately approximate solutions from the continuous-time valuation model. The application of the binomial model is widely used by researchers and practitioners for transportation project evaluation. Among them are Blank et al (2009), Pichayapan et al (2003) and Charoenpornpattana et al (2003). In their studies, traffic flow is considered to be a stochastic variable in the model. This research focuses on a transportation system valuation in which traffic flow is a critical parameter. As traffic flows evolve stochastically overtime, the value of the project will also vary in the same manner. The volatility of the traffic demand also increases the option value of the project. For transportation project evaluation, the traffic flow is assumed to follow the geometric Brownian motion (GBM). This assumption is often adopted by many researchers such as Ho and Liu (2002), Garvin and Cheah (2004), Brandao and Saraiva (2008) and Blank et al (2009). This research starts with the general model for predicting traffic volume. In general, traffic volume is uncertain which means the traffic flow is a stochastic process. GBM represents an uncertainty in traffic flow as follow;

$$dV/V = \mu\, dt + \sigma\, dz$$

Where V is the monthly or yearly traffic volume and μ is a traffic volume growth rate which is assumed to be constant, σ is the volatility of traffic equaled to $\sqrt{\frac{\sum(V_t-\bar{V})^2}{n-1}}$ and dz is incremental to a geometric Brownian motion (GBM) which is equal to $\epsilon\sqrt{t}$ where ϵ is a normally distributed random variable whose mean is 0 and variance is 1. It is observed that the traffic flow is dependent on volatility (σ) and trend (μ). A small volatility and drift rate may have a major impact on the range of possible future outcomes. The assumption of a GBM means that traffic flow is normally distributed, which implies that future traffic is log-normally distributed as follow:

$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(\ln(x)-\mu)^2}{2\sigma^2}}\ if\ x \geq 0, or = 0\ if\ x < 0$ and denotes a lognormal μ, σ^2 by $x \sim$ lognorm (μ,σ^2)

Since the traffic flows follow a GBM, they may apply a binomial tree to represent a traffic path (Blank et. al., 2009). The traffic volume is assumed to follow a GBM which for each node, the traffic 'S' in the period 'i' and state 's' can be increased to uS^s_i or decreased to dS^s_i. By performing backward calculation, the investment decision can be exercised in each node (figure 4.2).



$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = e^{-\sigma\sqrt{\Delta t}}$$

$$p = \frac{e^{r\Delta t} - d}{u - d}$$

where p is the risk-neutral probability of traffic demand

r is a risk-free interest rate

σ is traffic volatility = $\sqrt{\frac{\sum(V_t-\bar{V})^2}{n-1}}$

Figure 4.2: The binomial tree of the traffic volume in the project

The simple binomial model is presented to simulate the traffic demand for the infrastructure project. This model used a binomial model with risk-neutral probabilities, representing a discrete time characteristic to approximate the uncertainty associated with the changes in the value of a traffic demand (or project's cash flow) over time. This model rather explicitly recognises the volatility of demand for an infrastructure asset. Figure 4.2 illustrated the binomial path set up in the risk-neutral world.

The main assumption of the binomial lattice used in transport project valuation is that the traffic flow or the present value of the project fluctuates randomly in a complete, efficient market. Under the random walk assumption, the traffic volume jump is characterised by a normal or lognormal probability distribution. This means that the logarithm of the change of traffic volume [Log (V_2/ V_1)] follows a normal or bell-shaped curve. The statistical test of the proof that the change of traffic volume follows a lognormal distribution is given in appendix C. The result of the statistical test shows that annual traffic volume is well described by a lognormal distribution.

Volatility is the critical parameter for option pricing in which the option values are sensitive to change in volatility. The estimation of the option's volatility is ambiguous and has an effect on the option's value. It is known that greater uncertainty (volatility) increases real option value. Volatility of the financial option can be implied by the current market price. However for real asset trading, implied volatility is difficult to observe from the current market price. An alternative is to estimate it using historical data. Since volatility is a sensitive parameter, this research has completed the sensitivity test for different values of traffic volatilities (see section 4.6, 5.3, 5.8 and 6.5).

It is expected to have different outcomes of real option valuation from a discrete-time model and a continuous-time model with yearly or monthly time intervals. It is generally known that the binomial model converges to the continuous-time model (Black-Scholes model) when the number of time periods increases and the length of each time period is infinitesimally short. This proof was given by Cox, Ross and Rubinstein (1979). The binomial model that calculates option values for the SES project is checked against values from a Black-Scholes model in appendix D.

To apply the binomial model for the SES project, it is important to expand on the understanding of risk neutrality, the complete market and a replicating portfolio in the case of an infrastructure project. It has been argued that while many practitioners have applied real option analysis on an infrastructure investment problem using a standard financial option valuation model,(e.g., binomial lattice, Black-Scholes), the strict assumptions are rarely satisfied for real infrastructure projects, including the SES project. The assumption of risk neutrality is crucial in real option work. What discount rate should be used is the most critical task and the discount rate can also change over time which is a shortfall for the traditional discounted cash flow method. The assumption of risk neutrality resolves this shortfall by transforming the real world into a risk-neutral world. In a risk-neutral world, all assets are evaluated at the risk-free interest rate and the project uncertainty is captured in the evaluation process by the volatility measure (Garvin and Ford, 2012).

The main assumption behind risk neutrality is that the underlying asset is traded in a complete market. Financial options use a strong relation between the underlying asset and the option to replicate the results of a riskless asset portfolio, and the value of option is obtained from the observation of the capital market. This standard option valuation uses the known price of an underlying asset to estimate the relevant price of the derivative asset. Therefore, it seems that the use of a replicating portfolio requires that the markets where assets are traded be complete. In a complete market, a replicating portfolio can be found among traded assets and the price resulting from when the replicating portfolio and derivative price are the same (no arbitrage principle). Indeed, these characteristics of the complete market are relatively rare for an infrastructure project including the SES project. Copeland and Antikarov (2001) proposed the use of the present value of the project as the best market value for the asset. With this method, it allows to use the project itself as the basic asset in the replicating portfolio with the assumption that a project without flexibility is highly correlated with the value of the project with options (a form of the marketed asset disclaimer: MAD). Therefore, cash flows/NPVs from the SES project can be used as trade proxies in the market. Moreover, cash flows/NPVs from the SES project can still be reasonably tracked through the infrequency of real asset trading in the market. Therefore, these assumptions of risk neutrality and the complete market are reasonable in the case of the SES project.

4.4. Case illustration: the SES in Bangkok, Thailand

The SES is selected as a case study to illustrate the application of real options. Information about this case was gathered from corporate prospectus, presentations, news articles, and field data collection.

4.4.1 *Project background*

The SES project was a pioneer amongst toll-road projects in Thailand to be delivered by private financing concessions beginning in the 1980s, when the Thai government started to persuade private sectors towards infrastructure development. SES was built to connect the outer areas of Bangkok (including Nonthaburi and Pathum Thani provinces and the southern area of Bangkok) to the central area of Bangkok. The project awarded a 30-year build-transfer-operate (BTO) concession from the Expressway Authority of Thailand (EXAT), a government agency, to a private company named ‘Bangkok Expressway Public Company Limited’ (BECL). In this project, BECL invested in all construction and operation costs, worth approximately 37 billion baht to construct a 6-lane elevated road with a total distance of 38.5 kilometres. BECL took responsible for the design, construction, operation, and management of the toll road. BECL connected their path with the first-stage expressway system (FES) to form the network that covered the Bangkok area.

In 1996, Northern Bangkok Expressway Company Limited: NECL, a company in which BECL holds a 53% stake, was established to operate the Udon Ratthaya expressway (URE) from 1996 to 2026. NECL is an extension of the existing SES which faces high competition from local and alternative toll roads. As a result, NECL’s traffic volume was far below original projections, which resulted in operating losses.

4.4.2 *Unit root analysis of traffic time series in the SES project*

In this research, it is assumed that variations of traffic volume follow a GBM. Therefore, assuming that traffic volume evolves according to a GBM process, then it follows the random walk. The GBM process, which is sometimes called a lognormal growth process, has gained wide acceptance as a valid model for the growth in traffic volume overtime. It also means that the change in traffic volume (log ratios of traffic volume) is normally distributed over any time interval (Δt) and that the change in traffic volume is independent of previous data (log ratios independent of their past values).

In this research, a test is performed for the hypothesis of a GBM for the evaluation of traffic volume on the SES project. Series available for SES project have been used, that cover a 12-year period. In this research, traffic statistics on a monthly and annual basis have been tested for the GBM assumptions. The results of the testing of GBM assumptions are shown in appendix C.

Using the statistical analysis of the monthly data of the traffic flow, the p-value for the Augmented Dickey-Fuller (ADF) test of the random walk with drift is more than 0.05; hence, the null hypothesis cannot be rejected that the traffic follows a GBM. On the other hand, the p-value for the Shapiro-Wilk test of normality is less than 0.05; therefore the null hypothesis that natural logs of traffic are normal is rejected. In addition, the significant value of the Box Ljung statistic is less than 0.05; hence, the null hypothesis that the natural logs of traffic values are independent is rejected. This outcome is due to the seasonality of the monthly data. With the unit root test, we cannot reject the hypothesis that traffic volume follows a GBM. Therefore, we can still conclude that the monthly data is modelled as a GBM process.

For the statistical analysis of the annual data, the problem of the seasonality in traffic volume is avoided. According to the results obtained in the t-statistic of the ADF test described in appendix C, the GBM hypothesis cannot be rejected. However, it should be emphasised that the number of annual data is only 12. Furthermore, we found that the lognormal ratios are normally distributed and independent. Hence, we can conclude that the annual data are consistent with the GBM process. Therefore, we rely on the annual value for the real option evaluation.

4.4.3 *The SES traffic-demand model*

With the binomial model and the Brownian motion of traffic flow, the expected high and low demands of the SES project were assigned. For example, the current demand starts at 138 million trips per year, so the expected high and low demands were assigned values of 168.6 (138 x $e^{0.2}$) million trips per year and 113 (138 x $e^{-0.2}$) million trips per year, respectively, as shown in figure 4.3. Risk-neutral probabilities, p and 1 − p, were calculated, as referenced in the 'boxed' formula in figure 4.2. In this case study, the risk-neutral probabilities were 0.60 for the high initial traffic volume and 0.40 for the low initial traffic volume. The binomial model is then calculated until the end of the project life, at which point the traffic demand is capped with the maximum capacity of the expressway. A slight modification in the binomial lattice model is required to ensure that infeasible traffic demand is not generated. In the binomial model of the SES project, the traffic demand of some of the paths hits the upper capacity boundary at year 7 which will have the effect on the underlying value (project cash flow) of the option valuation. This would limit the value of the project net cash flow and the value of the option; especially a call option which can never be worth more than the underlying cash flow. However, the binomial lattice has an advantage since the model could take into account the road maximum traffic capacity. This maximum capacity can be used as the cap for annual traffic values in the binomial lattice. Thus, in this binomial lattice model, the annual traffic volume is limited to the maximum traffic capacity.

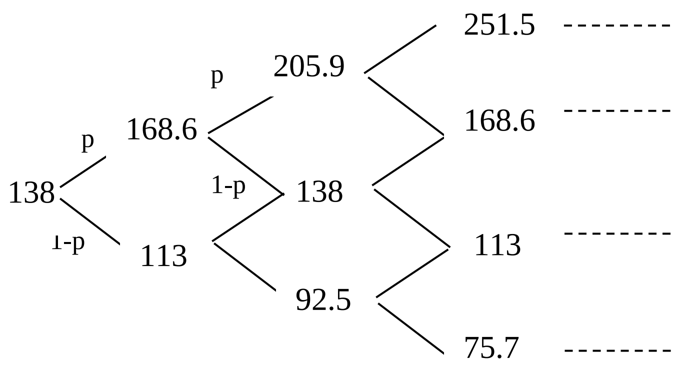


Figure 4.3: The binomial lattice of the SES traffic demand (million trips per year)

The traffic demand is then used to calculate the project's net cash flow. The project's net cash flow is represented by the present value of the earnings before interest and taxes (EBIT) over the concession period. The next section will present the base case model of the SES project.

4.4.4 *The cash-flow model of the SES project*

The cash flow analysis for the SES project is evaluated from an ex ante perspective using revenue and cost estimating from a project feasibility study submitted by the project consultant to the government agency.

The revenue structure is designed to combine all tolls from the first stage expressway (FES) and the SES. Then, the combined revenue is shared between the government and BECL (project owner). The EXAT is responsible for the collection of all tolls and shares revenue (with the exception of certain suburban routes of the SES). The proportion of revenue sharing is represented in table 4.2.

Expressway	**Aspects**	**Distance (Km)**	**Revenue Share**		
			Period	**Government's share of toll revenue (%)**	**BECL's share of toll revenue (%)**
FES	Urban	27.1	1. The first 9-years period (02/09/93 – 01/09/02)	40	60
SES*	Urban and Suburban	38.5	2. The last 9-year Period (01/03/11 – 28/02/20)	60	40

Expressway	Aspects	Distance (Km)	Revenue Share		
			Period	**Government's share of toll revenue (%)**	**BECL's share of toll revenue (%)**
URE**	Suburban	32	3. The 9-year period between Periods 1 and 2 (02/09/02 – 8/02/11)	50	50

***** The revenue of SES is shared for only Sections A and B. For Sections C and, D, BECL owns 100% of revenue.

** NECL owns 100% of URE revenue.

Table 4.2: The revenue- sharing scheme between the FES and the SES

The revenue of the SES project can be determined by the following equation;

Operating income = Average daily traffic (V_t) x Average toll rate (X_t) x 365 days
= {Average daily traffic (inbound areas) x Average toll rate (inbound areas) + Average daily traffic (outbound areas) x Average toll rate (outbound areas)} x 365

*Remark: The SES project divided into two parts, inbound and outbound.

Toll rates are subject to adjustment every 5 years using the consumer price index (CPI) for the Bangkok metropolis issued by the Ministry of Commerce.

The total construction and development costs were estimated at 25.147 billion baht, which was assumed to be split evenly over 3-year construction periods. To value the SES project, the operating cash flow, which is represented by earnings before interest and taxes (EBIT) is used. The operating cash flow is subtracted by capital expenditures in a certain year during the concession period. The cash flow of the project is computed as follows:

Cash flow (Cf_t) = Operating income – Operating Expense – Capital expenditure

$$= \sum V_t X_t - E_t - C_t \qquad (1)$$

Where

V_t = the expected traffic volume at year t

V_t = Average daily traffic (inbound and outbound) x 365 days

X_t = the average toll rate (inbound and outbound) at year t

C_t = the capital expenditure at year t

E_t = the operating expenses at year t

The volatility of traffic volume is estimated by using historical data:

$$\text{Volatility of traffic volume } (\sigma_{\text{traffic}}) = \sqrt{\frac{\sum(V_t - \bar{V})^2}{n-1}} \quad (2)$$

$\bar{V}$ = the average traffic volume

The average daily traffic demand is assumed to increase 2% annually on average for an operational period of 27 years. The demand is expected to reach full capacity during the operational period. The schedule of average annual toll rates started at 30 baht and gradually rose to 80 baht by the 27th year of operation. The schedule of average annual toll rate is shown in table 4.3. The operating expenses include operation and maintenance costs and other expenses. The operating cost was estimated to begin at 262 million baht and predicted to grow, as shown in table 4.4. The capital expenditure includes land acquisition. To estimate the discount rate, the weighted average cost of capital (WACC) is used:

$$\text{WACC} = R_e{*}\, w_e + R_d\, w_d\, (1\text{-}t) \quad (3)$$

where R_e is the required return on equity, R_d is the cost of debt and w_e and w_d are a proportion of the equity and debt financings. R_e is estimated by the capital asset pricing model (CAPM):

$$R_e = R_f + \beta_e\, (R_m - R_f) \quad (4)$$

where R_f is a risk-free interest rate that is normally determined from treasury yield (6% for 10-year treasury yield) and R_m-R_f is the equity-risk premium , which is historically 5–12% in Thailand. In this case, it is reasonable to select the conservative value of 12%. The last parameter is β_e which compares the sensitivity of the expected excess asset returns to the expected excess market returns. In the SES project, this research assumed that project return is moderately relative to the economic condition of Thailand. For this reason, it estimated that $\beta_e = 0.6$ for the project company (BECL). By substituting the estimated value of key parameters, the discount rate for the SES project is estimated at 12.23%, which is reasonable for an infrastructure project in Thailand. The summary of parameter estimations and the project information are given in table 4.3.

Concession period	Total concession period: 30 years Construction period: 3 years Operation period: 27 years
Project cost	Construction cost: 25.147 billion baht, estimated to be equally distributed over 3 years. Land acquisition cost: 10 billion baht (land cost was supported by government). This research includes land cost as a part of total project cost.
Traffic volume	Initial traffic volume starts from 121 million trips per year for inbound areas and 17 million trips per year for outbound areas. Year / Inbound areas (million trips per year) / Outbound areas (million trips per year) 4 / 121 / 17 5 / 130 / 19 6 / 164 / 23 7 / 186 / 24 8 / 208 / 25 9 / 197 / 23 10 / 204 / 23 11 / 210 / 24 12 / 214 / 24 . . . 30 / 214 / 24 Volatility of traffic volume: 20% (based on historical data)
Toll rate	Toll rate starts from 30 baht per trip and increases 10 baht every 5 years for inbound areas and 10 baht for outbound areas (increases 5baht for every 5 years).

		Inbound areas (baht per trip)	Outbound areas (baht per trip)
	Years 4-8 :	30	10
	Years 9-13 :	40	15
	Years 14-18:	50	20
	Years 19-23:	60	25
	Years 24-28:	70	30
	Years 29-30:	80	35
Yearly operating expense	Shown in table 4.4		
Tax rate	30%		
Discount rate	Using the weighted average cost of capital where WACC $= R_e * (E/V) + R_d (D/V) (1-t)$ R_d = 12% (from historical data) R_e = 13.4% (calculating from Equation 4) t = 30% (corporate tax)		
Risk-free interest rate	Assume using treasury yield for 10-year period = 6% (based on historical data)		

Table 4.3: The parameter estimation of the SES project

4.4.5 *The base case of cash-flow analysis for the SES project*

The base case analysis follows the original expectation in which all parameters are set as described previously in table 4.3. The SES valuation model is presented in table 4.4. Under assumptions in the base case, the project's NPV is at negative -7,749 million baht. Without managerial flexibility, the passive NPV would reject the SES project based on negative NPV.

Time	Average daily traffic (Inbound areas) (Trip/day)	Toll rate per vehicle (Inbound areas) (Baht)	Average daily traffic (Outbound areas) (Trip/day)	Toll rate per vehicle (Outbound areas) (Baht	Operating Income (Million baht)	Operating expense (Million baht)	Construction Cost (Million baht)	Net Cash flow (Million baht)*
0							-10,000	-10,000
1							-8,382	-8,382
2							-8,382	-8,382
3							-8,382	-8,382
4	331,507	30	46,575	10	2,348	262		2,086
5	356,164	30	52,055	10	2,530	254		2,276
6	449,315	30	63,014	10	3,182	319		2,863
7	509,589	30	65,753	10	3,588	347		3,241
8	569,863	30	68,493	10	3,994	322		3,672
9	539,726	40	63,014	15	5,073	338		4,735

Time	Average daily traffic (Inbound areas) (Trip/day)	Toll rate per vehicle (Inbound areas) (Baht)	Average daily traffic (Outbound areas) (Trip/day)	Toll rate per vehicle (Outbound areas) (Baht	Operating Income (Million baht)	Operating expense (Million baht)	Construction Cost (Million baht)	Net Cash flow (Million baht)*
10	558,904	40	63,014	15	5,241	344		4,897
11	575,342	40	65,753	15	5,400	416		4,984
12	589,041	40	65,753	15	5,520	377		5,143
13	586,301	40	68,493	15	4,655	948		3,707
14	583,562	50	60,274	20	5,765	415		5,350
15	586,301	50	63,014	20	5,810	777		5,033
16	586,301	50	63,014	20	5,810	457		5,353
17	586,301	50	65,753	20	5,830	480		5,350
18	586,301	50	65,753	20	5,830	647		5,183
19	586,301	60	60,274	25	6,970	611		6,359
20	586,301	60	63,014	25	6,995	625		6,370
21	586,301	60	63,014	25	6,995	581		6,414
22	586,301	60	65,753	25	5,736	610		5,126
23	586,301	60	65,753	25	5,736	1687		4,049
24	586,301	70	63,014	30	6,682	673		6,009
25	586,301	70	63,014	30	6,682	1197		5,485
26	586,301	70	65,753	30	6,712	741		5,971
27	586,301	70	65,753	30	6,712	900		5,812
28	586,301	70	65,753	30	6,712	817		5,895
29	586,301	80	65,753	35	7,688	858		6,830
30	586,301	80	65,753	35	7,688	3,498		4,190

***** Net cash flow of the SES portion

Table 4.4: The SES valuation model

Source: EXAT

Next, the sensitivity analysis of the key parameters was done with the following: a) the average daily traffic volume, ranging from -20% to 20% of original forecasting, b) discount-rate ranges from 8% to 20%, c) construction cost, ranging from -20% to 20% of the original cost, d) beta ranging from -20% to 20% of original forecasting and e) risk-free interest rate ranging from -20% to 20% of original forecasting. The results of the sensitive analysis of key parameters were presented in figure 4.4. The result showed that the project's NPV is sensitive to the discount rate, the average daily traffic volume, construction cost, beta and risk-free interest rate respectively, ranking the observed values from high to low impacts (Figure 4.4).

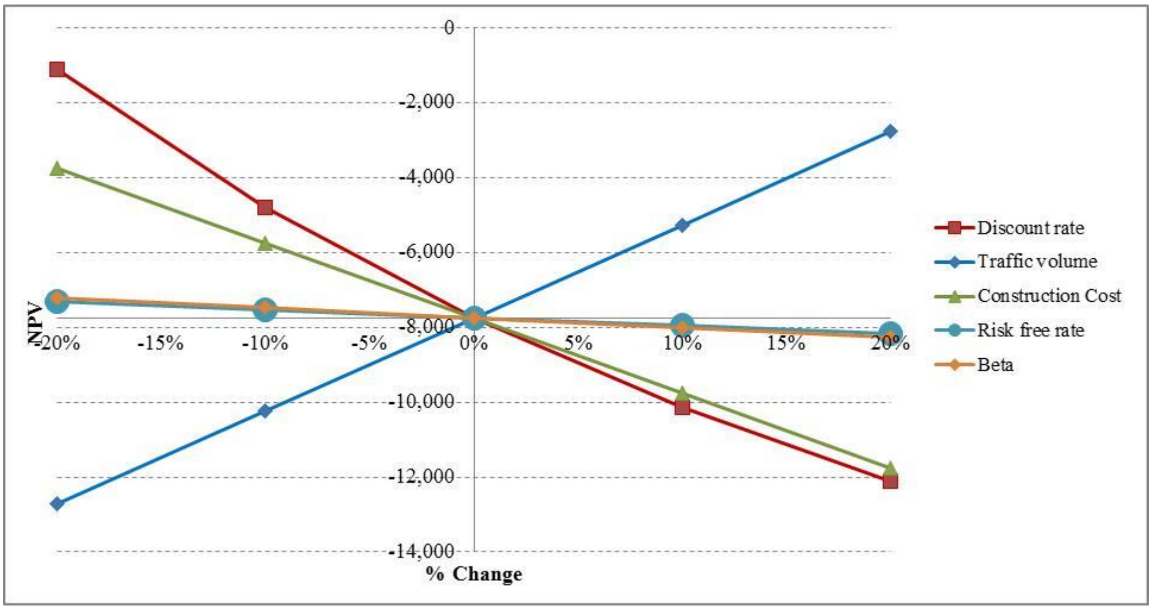


Figure 4.4: The sensitivity of key parameters for the SES project

4.5 The FI's options in the SES project

This section presents the real options for the FI in the large-scale infrastructure project. Large infrastructure has been typically financed on the basis of the cash flows of the project. In project finance structure, lenders normally have limited recourse to the project sponsor's assets other than the project itself. Lenders have recourse based on the cash flow generated from the project and the assets of the project. In project finance, lenders have to look to a specific asset or pool of assets for their debt services. In case of project default, the lenders' opportunities for principal recovery are much more limited (Finnerty, 1996). The consequences of project default would fall heavily on the lender. The lender is subjected to project-specific risk which is non-diversified (Sorge, 2004).

Evaluating the financial viability of a large infrastructure project is complex and challenging for an FI. This is mainly because of the uncertainties involved: the project's size, a long period of time, and the project complexity. The project company may make the project viable for an FI by offering a support mechanism to create a condition so that the FI can participate in financing the project. The FI options are necessary tools for project development, otherwise the project company may not be able to achieve a financial close due to an unfavourable result of the financial projections. For example, a lender may refuse to provide loan because the traditional project-valuation method will result in an underestimated project NPV. The use of options-based project-valuation methods is required to improve the feasibility of the infrastructure project.

Whilst most literature has focussed on an analysis of options the government support in infrastructure projects, little effort has been given to analyse the needs of the FI option. The FI options in the project finance can be valued using real-option methodology. Types of flexibilities embedded in a transportation project by an FI may include the following.

4.5.1 *Option to defer long-term project financing*

In traditional project funding, lenders normally take the risks of construction delay and cost overrun, in which the lender may have to reschedule or refinance his existing loan. Lenders may mitigate the risks associated with construction and start-up by delaying their funding decisions until the commencement of operations (Loke, 1998). Deferment could allow the lender to gather better information and observe project development. If the project is delayed with a total cost overrun, the lender may choose to forego any long-term financing.

The deferral option is the option between the financial institution and the private company. With the deferral option, the lending contract is developed into two parts; i) the bridging loan contract (three-year terms for the SES project) with deferral option and ii) the long-term financing contract. If the existing lender decides not to exercise the deferral option and to continue to support the project, the bridging loan is replaced by the long-term financing. If the deferral option is exercised a new lender can come in to fund the continuing operation of project (long-term financing part) and the existing collaterals are transferred to the new lender.

The deferral option is formulated under a funding option held by the lender. The deferral option defines the value of keeping the project funded whilst lenders defer the decision to finance the project. The deferral option is viewed as a European call option, with the expiration date at the date of commencement of project's operations. Figure 4.5 shows the concession schedule of the SES project that began with the construction phase at time $t = 0$ and ended the construction phase at $t = 3$ when the operational period starts. During the construction stage, the lender may provide a 3-year medium-term bridging loan. This option enables lenders to defer funding for up to 3 years, and the lender gains benefits until more information is known before funding.

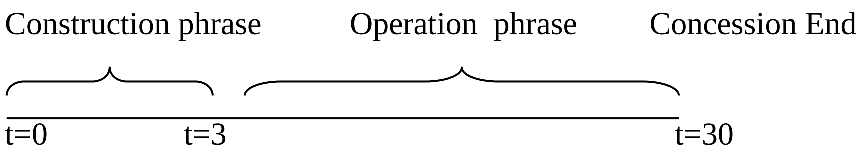


Figure 4.5: Concession period of the SES project

The lender may decide to walk away from providing funds at any time during the construction phase, but this research assumes the final decision can only be made at the date of commencement of the project's operations (t = 3). The construction phase was assumed to be the specific period stipulated in a contract by which the contractor must complete construction. Based on key assumptions, the option was formulated under a deferral option held by the lender at t = 0 and set to expire at t = 3. Let C denote the project's construction costs. Suppose C were a random variable, and suppose C were modelled by the binomial lattice.

In the deferral option, three stages of future construction costs are identified, which were the expected construction cost, the higher than expected cost, and the lower than expected cost. Flyvbjerg et al (2003) found that the construction cost of the transportation project was on average 28% higher than the estimated project cost, and cost overruns of 40 to 120 percent above the estimated cost were common. For simple illustration, the construction costs during 3-year construction period were assumed a value of 1.0 (the expected cost), 1.30 (high cost), and 0.9 (low cost) times of the projected construction cost. Figure 4.6 shows the binomial model of the construction cost in the risk-neutral world.

The option to defer is then viewed as a European call option on the net present value of the project's construction cost, with the exercise price equal to the expected project revenue. If construction cost is higher than the project's revenue, meaning negative net cash flows, the call option is then exercised.

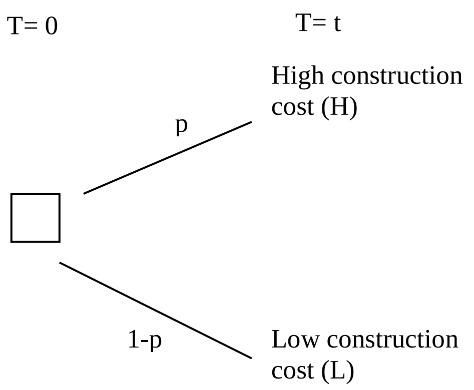


Figure 4.6: The binomial lattice model of construction cost

The expected construction cost = $\frac{[p(H)+(1-p)L]}{(1+r_f)^t}$ where *p* equals a risk-neutral probability, r_f equals the risk-free interest rate, and *t* equals a time interval. The real-option value can be computed using a backwards risk-neutral valuation process. In a risk-neutral world, the value of a real option can be obtained from its expected future value, calculating from the risk-neutral probability, *p*, and then discounting at the risk-free interest rate (6%). The risk-neutral probability, *p*, can be computed as follows:

$$p = \frac{e^{rf}(\text{the expected construction cost}) - L}{H - L}$$

For the SES project: $p = \frac{e^{0.06(1)}(1-0.97)}{1.1-0.97} = 0.71$

Figure 4.7 presents the binomial path of the construction cost of the SES project

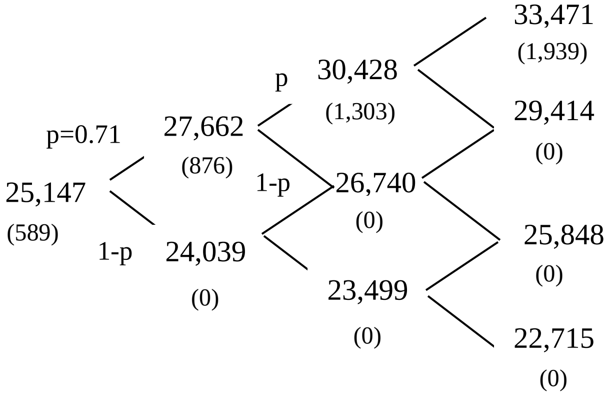


Figure 4.7: The binomial path of the construction cost of the SES project

The deferral option is a call option with the strike price of the Expected $\sum_3^{30}$ PV of the project income at year 3 (31,532 million baht, calculated from the binomial model of the project's cash flows from the 3rd year to the 30th year). The call option will be exercised when the construction cost is greater than $\sum_3^{30}$ PV of project income. The value of the call option for each node in the path is presented in figure 4.7 in parentheses. Therefore, the deferral option is valued at 589 million baht by backwards calculation.

It is known from the literature review that construction delay is a major risk in infrastructure project and it can affect the present value of the future cash flow. Because construction delay has significant effect on completion cost, this thesis performs sensitivity analysis of the deferral-option values for different periods of construction i.e., 3 years, 4 years, 5 years, 6 years and 7 years. The results of the analysis are shown in the table 4.5. The results of the sensitivity analysis show that the value of the deferral option increases as the construction period increases.

Construction period	**Value of deferral option (Million baht)**
3-year construction period - no delay	589
4-year construction period - delay for 1 year	1,147
5-year construction period - delay for 2 years	2,624
6-year construction period - delay for 3 years	3,990
7-year construction period - delay for 4 years	5,368

Table 4.5: Sensitivity analysis of the option values for different periods of construction

4.5.2 *The abandon option*

An FI that provides a loan to the project sponsor may cancel funding if the project's cash flow or a traffic volume falls below a certain debt level (Buchen et. al., 2009) at any time during the operational stage. The abandon option can be represented by a put option in figure 4.8-c.

The value of the abandon option is then equal to the following:

V_t = Max (X_t-S_t, 0), where

X_t = the exercise price of a put option (Threshold level: the outstanding debt) at time t

S_t = the project's value (the NPV of EBIT) at time t

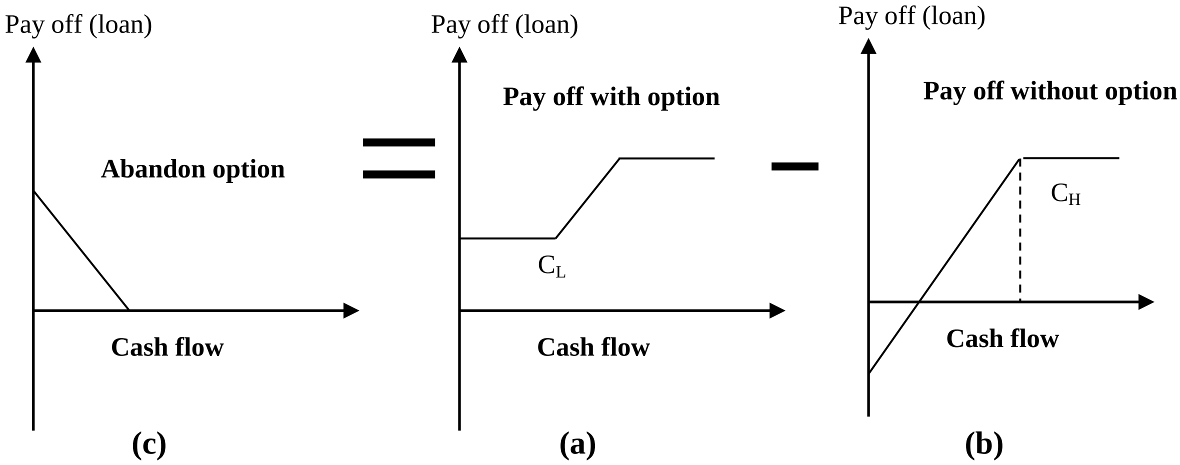


Figure 4.8: The payoff for the abandon option

Without the option case, if the cash flow lies above a certain (C_H) level, the lender still receives loan repayment, whereas the project's ability to repay its debt will decrease if the cash flow decreases below the C_H level. The loan payoff to the lender in a without-option case is shown in Figure 4.8-b. The mechanism used to mitigate the cash-flow risk of the project is based on the threshold (lower floor) level of the cash flow. The lender will exercise the option if the cash flow of the project lies below a certain specified level (C_L). The threshold level represents the maximum acceptable risk level for the lender. This level may be the minimum cash flow that can repay i) both principal and interest to a lender (without threshold) or ii) the principal and minimum interest at a bank financial cost (with threshold case). The lender grants the project company the option to issue the notice in satisfaction of their obligation to pay the lower interest fee to the lender. The lender could decide whether to continue providing lending. The abandon option provides lenders the flexibility to withdraw from the project under a worse scenario. Figure 4.8-a represents the diagram of the loan's pay off with the abandon option.

Traditionally if a lender does not receive the monthly payment the lenders have to exercise their right to dispose of the assets and repay the debt. The financial institution may suffer a large loss by selling asset at distressed prices. In order to alleviate such project risks the government may offer the financial institution the possibility of abandoning the project funding. In this structure, the financial institution has an additional flexibility given by option of abandonment at each repayment date. The financial institution may liquidate the project when the "the exercise price (total outstanding debt) is greater than the present value of cash flow before debt in case FI remain funding the project. Whenever the net cash flow is negative, the FI could decide whether or not to fund the project. This means that the embedded option increases project value. If the financial institution exercises the abandonment option and withdraws from lending, government or the state-owned banks has a legal liability to pay the debt. With this financing option structure, lenders do not need to foreclose, force the project into bankruptcy and take over the project.

To understand the abandon option, it is useful to demonstrate the theory using numerical data. The abandon option without threshold is used for demonstration. The abandon option without threshold is the American put option, which is exercised when the project NPV is less than the outstanding debt ending balance.

The equation of the abandon option without threshold is shown in the following:

$AO_{(t-i)} = Max\ (TD_{(t-i)} – NPV_{(t-i)}, \{p(AO_{(t-i+1)u}+(1-p)AO_{(t-i+1)d}\}e^{-rt}\},0)$

where	$AO_{(t-i)}$	= the abandon option without threshold at intermediate state t-i
	$AO_{(t-i+1)u}$	= the abandon option value at state t-i+1 with up state u
	$AO_{(t-i+1)d}$	= the abandon option value at state t-i+1 with down state d
	$TD_{(t-i)}$	= the ending outstanding debt at stage t-1
	$NPV_{(t-i)}$	= the NPV before debt at stage t-1
	p	= the risk-neutral probability (%)
	r	= the risk-free interest rate

The example of a 2-period binomial model is presented in figure 4.9.

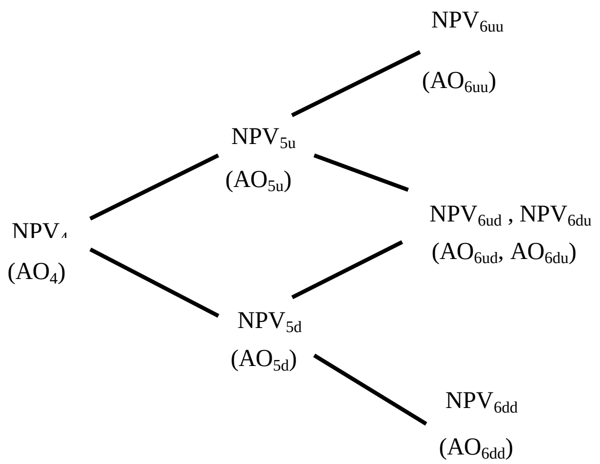


Figure 4.9: The abandon-option calculation of the 2 operation years

Table 4.6 presents the numerical data of 2 periods for the abandon option without threshold.

Year	4*	5	6
$TD_{(t-i)}$	19,995	18,943	17,890
$NPV_{(t-i)}$	19,416	26,172[1]	32,374[3]
		1,5983[2]	22,987[4]
			12,261[5]
$AO_{(t-i)}$	1,156	91	10
		2,960	228
			5630

* the SES project started operation in year 4

1= NPV_{5u} , 2= NPV_{5d} , 3= NPV_{6uu}, 4= NPV_{6ud} , NPV_{6du}, 5= NPV_{6dd}

Table 4.6: The numerical data for the abandon option without threshold (Million baht)

4.5.3 *The option to expand*

An FI may have an option to expand the scale of the project by providing an additional loan amount. The lender provides an additional loan when the project's performance is beyond the expectation. For an option to expand when traffic level grows beyond the maximum capacity, the lender may consider providing additional or top-up loans to expand the project's capacity. However, for the elevated toll-road project (i.e., the SES project), which was not designed for the capacity expansion, this research omitted the option to expand in its analysis.

4.5.4 *Investment option*

The task of constructing a project requires nontrivial investments. Thus, it is often beyond the resources of a single company to invest in the large-scale project. Cooperation, especially cooperation which brings the requisite capital and skills, may be sought to share the costs of meeting the anticipation of the future project's opportunity. The investment option can be constituted for use by the FI to share the project's risk. The assignment of the right for lenders to buy equity in a project is a common feature of many agreements. Pure risk sharing arises in the agreement if lenders have to commit capital inflows that are dependent upon the uncertainty of a future demand. This obligation should not be judged to be favourable to the FI. The lender faces a difficult decision to invest in such projects. Under such circumstances, the lender may prefer that the terms of the agreement provide a call option, not an obligation, for the lender to invest in the ownership of the project.

The opportunity to invest in equity sharing in the infrastructure project has worthwhile value, since lenders would invest only if the traffic volume rises significantly, making the project interesting, whereas they are not obligated to invest under unfavourable conditions. With investment options, the results indicate that unexpected growth in traffic demand increases the likelihood of lender acquisition.

An FI may hold the option to invest in the equity share of the project after the commencement of commercial operation. The investment decision is based on the opportunity-cost concept, which is defined as a comparison between the expected future option value and the expected future profit earned by estimating investment timing of real options' early action. The option to wait to invest is analogous to a call option on the project value with the exercise price equal to an investment outlay. The main criterion for the lender's decision to invest in project is only if:

a. The project is completed on schedule and well under budget. The estimation of time for the completion of construction is essential in situations in which completion delay could result in higher financing costs and future revenue losses (Sing, 2002). When the information regarding total construction investments is revealed, the option to acquire a stake in a project is likely to be exercised. The project is still financially feasible when the project is ready to operate. The decision is also based on accurate traffic-volume predictions. In this option, the investment opportunity is assumed to expire at time T when T is the length of time from beginning construction to completion. The investment decision is made if the present value of the expected cash inflow exceeds the investment cost or the total construction cost. The value of construction cost follows a discrete time (binomial lattice) model in which the construction cost moves to one of the two possible directions: 'up' or 'down'. The probability of 'up' and 'down' direction is defined as 'p' and '1-p', respectively, as previously mentioned in the deferral option. We may assume a specific time at which the lenders can make an equity investment in the project. The time to exercise the option is decided when the value of exercising is higher than the value of waiting for the option until its expiration date.

b. A fundamental problem facing the decision maker's decision to invest and expand into new transportation projects is characterised by uncertain traffic demand. Lenders may exercise options to invest in the project if the project cash flow or the traffic volume is above a certain level. The value to wait, before proven market demand, has to be traded off with the benefit of investing today. The exercise of an investment option is accompanied by an acquisition of equity share. This option gives the lender the opportunity to take ownership of the project. It is assumed that timing the acquisition should be triggered by a market signal indicating an increase in the project's cash-flow valuation. The lender may delay investing until the net benefit from the real investment project is higher than the option value for delaying an investment decision (Net benefit – Option value > 0). With the investment option, the lender may delay the decision to invest in the project within the maximum allowable period of n years after the commencement of commercial operation. The investment option can be done at one specific due date. This research defines the designated date as the 5th anniversary after the commencement of the commercial operation, which seems suitable for the SES project. When the traffic demand is proven, the option to invest is likely to be exercised.

Investment option provides FI opportunity for a stock share purchased from the original project's shareholder at a later stage. This new equity investment does not increase cash flow or expand the project. The capital structure and the project's cost of fund still remain the same. However, FI can enhance its overall yield with a higher return on equity.

The investment option will be exercised if the project's value for the investor (lender), *S* is greater than the exercise price, *X:* the liability of the project (outstanding debt). The investment option is calculated with the following equation:

IV_t = MAX (S_t-X_t, 0), IV = the value of the investment option at time t

S_t-X_t is the value shareholder equity during the life of the option. The lender could decide whether to invest if the cash flow is negative. The lender's investment decision is viewed as a call option. The value of a call option can be used by working backwards through the binomial tree. The binomial tree can be built to represent the traffic movement, as shown in figure 4.2. For the SES project, the investment decision is assumed at the end of the 5th year after the commencement of the commercial operation, of which the value of the option is the following:

$IV_5 = \text{Max}(NPV_5 + [p\, NPV_{6u} + (1-p)\, NPV_{6d}]e^{-rf(1)} - TD_{(5)}, 0)$, where:

$TD_{(t)}$ = the outstanding debt ending at stage t

$NPV_{(t)}$ = the NPV at stage t

IV(t) = the value of investment option at stage t p = the risk-neutral probability (%)

r_f = the risk-free interest rate

4.5.5 *Result and discussion*

Using the binomial lattice model with the risk-neutral probability, the NPV and the real-option value for the SES project could be determined. Real-option value is calculated with the binomial model with 27 time steps (total concession year minus construction period). The values of the deferral, abandon, and investment options are determined with the backwards calculation of the binomial path. The option value is the difference between the NPV with option and the base NPV (without option). The results of the numerical calculation for the SES project are shown in table 4.7.

Type of options	**Base NPV (Million baht)**	**NPV with option (Million baht)**	**Value of option (Million baht)**
Traditional cash flow calculation	-7,749		
F1) Deferral option	-7,749	-7,160	589
F2) Abandon option without threshold *	-7,749	-7,040	709
F3) Abandon option with threshold **	-7,749	-7,506	243
F4) Investment option (limit investment within 5 years after the commencement of commercial operation)	-7,749	-7,576	172

* The normal debt service level that is equal to principal plus bank normal interest rate

** The threshold amount is set at minimum debt service level that is required by lender (principal and minimum interest at bank financial cost)

Table 4.7: The value of real options (FI) calculated from the binomial lattice model

The result of traditional project evaluation methods, such as NPV analysis, has an unfavourable outcome with a large negative NPV (-7,749 million baht). The traditional NPV represents a shortfall in the project's cash flow, reflecting the uncertain characteristics of the transportation project and the risks involved in the investment project. Furthermore, academic researchers such as Trigeorgis (1996) and Ye and Tiong (2000) pointed out the inadequacy of the traditional NPV method, and they suggested that the project NPV can be improved by employing the real-option methodology.

The value of passive NPV, based on the net cash-flow analysis, is -7,749 million baht; thus, the lender may neglect to support the project either in the form of project funding or investing in the project's shares. Based on the NPV with real-option calculation for the FI, the SES project still has a negative NPV, though it shows a sign of improvement.

In addition, it could be seen that the 'abandon option without threshold' has the highest option value (709 million baht), followed by the 'deferral option', 'the abandon option with threshold', and 'investment option', respectively. However, if the project with FI option is still unfeasible, then the FI may ask for some support mechanisms from other stakeholders (e.g., government).

4.5.6 *Interactions amongst multiple options*

Most real-option literature to date has tended to value individual options. Options embedded in large-scale infrastructure projects typically take the form of a set of real options. For large and more complex projects, there exists a set of multiple options, and interaction amongst them is typical. The combined value of real options can have a large impact on the value of a project. Simon Rose (1998) was one of the pioneers to evaluate the interaction among real options. He demonstrated how the two options were interacting in the Trans-Urban City Link project in Melbourne, Australia by applying the Monte Carlo simulation. His paper illustrates the importance of properly valuing the interaction between the government's options to defer and abandon options. Two and multiple interacting options were identified in the hypothetical project.

Next, this research gives an illustration of how the combination of real options and their interactions are evaluated. In general, the exercise of prior options may alter not only the underlying asset itself but also the value of the subsequent option, causing the option interaction. For example, an option to invest would increase project scale and may decrease the opportunity for the option to abandon. The level of interaction effect is dependent on the type of real options (call or put), its exercise time (European or American options), whether being in or out of the money, and its order or sequence (Trigeorgis, 1993a).

To illustrate the nature of option interaction, this research provides the example of interacting real options between the abandon and investment options. The FI may abandon (i.e., the first option) the project funding if the project cash flow is negative. This option is a put option. The value of the abandon option can be enhanced by adding the investment option, the second option. The second option, giving the right to the FI to assume the ownership of the project, can be priced by finding the equity value (the asset value represented by net operating cash flows minus the liability represented by total debt outstanding). The second option is the European call option, which can be exercised at the specific date in the contract. The exercise of the investment option will enhance the FI return. The value of combined options is the FI's call option to invest in the project plus the value of FI's put option to abandon the project. Thus, one can imply that after the FI chooses to exercise the investment option, the FI's return is the combination of return on equity and return on debt. The investment option increases the project's value and then decreases the opportunity to exercise the abandon option. In order to explicitly measure the interaction effect, both options are valued simultaneously.

The value of simultaneous multiple options may differ from their values in isolation. For example, the combined value of two options may differ from evaluating each option separately and adding the results (Trigeorgis, 1993a). The option can be valued with and without interaction, and the value of the interaction effect can be calculated by the value of combined options (with the interaction effect) minus the value of the first option minus the value of the second option. The combined value of two options in the presence of each other may differ from the sum of the separate value of each option due to i) whether options are of the same type or different types; ii) the separation of their exercise times; iii) whether options are in or out of money; and iv) their orders or sequences. The interaction effect (IE) for two combined options is calculated with the following formula:

IE = the value of combined options – the value of the first option – the value of the second option

The value of the interaction effect is shown in the following table:

Option value (million baht)	**Project NPV with options**	**Interaction**	**No interaction (value isolation)**	**Interaction effect**
F1, F2	-3,209	4,540	1,298	3,242
F1, F3	-5,119	2,630	832	1,798
F1, F4	-3,173	4,576	761	3,815
F2, F4	-7,216	533	881	-348

Option value (million baht)	Project NPV with options	Interaction	No interaction (value isolation)	Interaction effect
F3, F4	-7,327	422	415	7
F1,F2,F4	-1,912	5,837	1,470	4,367
F1,F3,F4	-2,003	5,746	1,470	4,276

F1= the deferral option

F2= the abandon option without threshold

F3= the abandon option with threshold

F4= the investment option

Table 4.8: The value of the interaction effect for the SES project

The interaction effect can be large and have a positive or negative value. Table 4.7 and table 4.8 showed the value of the individual option and the value of the combined options. For example, the value of the SES project slightly increases from -7,749 million baht to -7,160 million baht with the value of the option to defer (F1), to -3,209 million baht with the option to defer and option to abandon without threshold (F1, F2), to -1,912 million baht with the option to defer, option to abandon without threshold, and investment option (F1, F2, F4). The change in option value of a combined option of F1, F2, and F4 by adding each option is 589 million baht when adding the deferral option (F1), 3,951 million baht when adding option F2 to F1, and 1,297 million baht when adding F4 to a combined option of F1 and F2. The illustration shows that by adding more options to the existing option, with more options combined, the incremental value of adding options tend to be lower. Furthermore, some options, when combined, showed a negative interaction, such as the combination of the abandon option without threshold (F2) and the investment option (F4).

The practical illustrations can be described in the following. For the combination of options F1, F2, and F4, the FI engages in the project by providing financial support to the project. However, the FI has the option to defer (option F1) providing long-term financing in order to avoid the completion risk. The FI can delay up to the time the construction completed. The FI will re-evaluate the impact of the construction time and cost on the feasibility of the project. If the project is still feasible, the FI may consider long-term financing. After a certain year of operation, if the traffic flow is more than expected, then the FI may select to invest in the project and gains the combination return-on-investment and the return-on-debt financing. However, if the project value is lower than estimated, FI can permanently abandon the project, and the private company has to pay back the loan. By adding the value of the combined investment and abandon options to the first option, the interaction effect increased the value of first option (i.e., the deferral option). For example, even though the project experienced cost overrun compared to the original estimated, FIs may consider providing a loan by introducing the abandon option, because they still have the option to exit the project later. The timeline and formula for the combination of deferral, abandonment, and investment options are presented as follows:

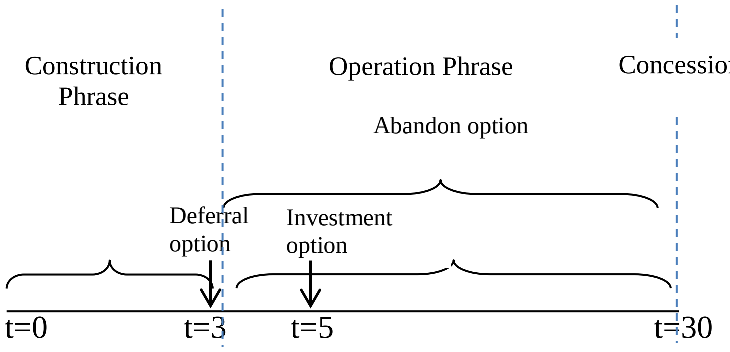


Figure 4.10: Timeline for the combination of the deferral, abandon, and investment options

The value of the option interaction and the interaction effect can be calculated by the following equation:

OC = the Expanded NPV – the Passive NPV

IE = OC – DO-AO-IV

where,

Expand NPV = the NPV with option

Passive NPV = the NPV without option

OC = the combination of deferral, abandon and investment options

DO = the deferral option

AO = the abandon option

IV = the investment option

IE = the interaction effect among deferral, abandon and investment options

For the combination of deferral, abandon and investment options, if the Expand NPV and the Passive NPV are equal to -1,912 million baht and -7,749 million baht, respectively, then the option value is 5,837 million baht (-1912-[-7,749]). The interaction effect is 4,346 million baht (5,837-589-709-172).

Among all FI options, the combination of deferral, abandon, and investment options is the most valuable, with the highest project NPV. The combined option tends to be more additive when a) the options involved are different types: two calls and one put, combined with no overlap between their exercise regions (see figure 4.10) and b) three options interact with each other, indicating high interaction effect at 4,367 million baht. However, if the project is not feasible under FI options, then additional support from other main stakeholders, such as the government and the private company, is required.

4.6 Volatility and seasonality analysis: Financial institution option

In this subsection, the analysis of the option value is conducted based on systematic seasonal variations of the traffic flow. For this study, a typical monthly period of traffic flow was selected from January 2004 to April 2015. To account for seasonal effects of traffic flow, an analysis explores the volatility for annual traffic data from 2004 to 2015. Based on year-to-year growth rates (see table A5 in appendix A) as well as seasonal adjustments for traffic volume (see table A6 in appendix A), traffic volatility is valued at approximately 4% and the risk-free rate in the model is valued at 3%. The deferral option, the abandon option and their combinations are selected for sensitivity analysis.

The most important parameter for the option value is the volatility of traffic volume. It is generally known that option values increase (decrease) with an increase (decrease) in volatility. However, the result shows that the deferral option is less sensitive to changes in traffic volatility. Table 4.9 shows the relationship of various options, calculated using binomial lattice, to changes in volatility. The approach accounted for the seasonality effect of traffic flow.

Option type for the SES project	**Option value (million baht) at 20% of volatility and 3% of risk-free interest rate**	**Option value (million baht) at 4% of volatility and 3% of risk-free interest rate, account for seasonality**
The deferral option	56.5	56.5
The abandon option (without threshold)	962	0
The combination of deferral option and abandon option	3,625	54.8

Table 4.9: The value of FI option at different volatility levels

4.7 Sensitivity to other parameters: Financial institution option

The second most important parameter in estimating option value using the binomial lattice is the risk-free interest rate. Therefore, the effect of the risk-free rate on the value of real options is explored in this subsection. The deferral option, the abandon option and their combinations are selected for sensitivity analysis. In general, the interest rate of the project is often increased to compensate for risk. In the binomial lattice, the project's cash flows will move up or down by an amount calculated using volatility and time to expiration, while the interest rate used in real options is a risk-free interest rate.

The option value increases with decreases in the risk-free interest rate for the put option (the abandon option) while it decreases with decreases in the risk-free interest rate for call option (the deferral option). The relationship is shown in Table 4.10.

Option type for the SES project	**Option value (million baht) at 6% of risk free rate (20% of volatility)**	**Option value (million baht) at 3% of risk-free interest rate (20% of volatility)**
The deferral option	589	56
The abandon option (without threshold)	709	962
The combination of deferral option and abandon option	4,540	3,625

Table 4.10: The value of FI option at different risk-free interest rates

4.8 Summary

This research has introduced a practical way of using real options to evaluate managerial flexibility for FIs involved in the investment project. The project contains both internal and external risks, which can affect the traffic demand and the profitability of the project. Some risks (e.g. demand risks, cost overrun) are partially mitigated by formulating the real option. This chapter provided an example of the valuation of a real option in the context of a large-scale infrastructure project. This research used the binomial lattice model to evaluate a large-scale transportation project.

This research has demonstrated how the large-scale transportation project is evaluated along with the value of the deferral, abandon, and investment options from the FI perspective. This research has presented a numerical method to solve the real-option problem. The real-option model has several advantages over the traditional net cash-flow evaluation. The model evaluates the managerial flexibilities of being able to optimise the FI supports in investment projects. The model is simple to use and does not require the estimation of risk premiums because it uses the risk-free interest rate. Finally, the model is useful for designing and formulating a set of more complex options in which the optimal structure can be determined. The FI can design and construct options in order to achieve the desired value.

The real-option mechanism for lenders in a large-scale infrastructure can be demonstrated. Options such as the investment option are flexible, providing firms and FIs with the discretion to expand into favourable environments while avoiding some of the losses from the downside risk. Real-option methodology presented a way to formulate the trial and learning aspect to lenders. This instrument, when applied by the FI, can add to the project's value, reallocate risks, reduce risks, and increase the project's attractiveness.

The results indicated that the number of options has some values, and values have improved the result of project performance. However, it seems that the individual FI option is not enough to make the project more attractive for the provision of financial funding. The project still needs some support from other stakeholders, such as the government and private companies. However, by applying the real-option approach, the FI can rationally determine the value of support it needs. The FI can design and formulate the type of real options to achieve the desirable level.

The result of the study also shows that the value of the option is significantly affected by the interaction between options. By adding more options, the value of the combined option is generally different from the sum of its value in isolation. The result of study supports Trigeorgis (1993a) in that the greater the number of options combined, the lower the incremental value of adding options tends to be. Furthermore, by simple summing, a separated option value may miscalculate the value of the project. These interactions are more likely useful by designing a proper financial package. Real-option-based valuation can be a particularly useful tool for FIs to reduce risks and make the project more attractive.

Furthermore, the sensitivities show the effect on option value as single variable (volatility and risk-free interest rate) changes. Option value is related to the volatility and risk-free interest rate. The volatility decreases will decrease the option value. Risk-free interest rate increases will increase the value of deferral (call) option and decrease the value of the abandon (put) option. It is also found that the impact of volatility and interest rate on the value of the combination of options is more complex. For example, an increase in the interest rate will increase the magnitude of the payoff on the call option component (the deferral option) but lower the payoff on the put option component (the abandon option).

Chapter 5: SES Case Study: Government and Private Company Options

This chapter begins with government support for the SES project. The real options model is proposed as a methodology for the design and formulation of government support. The real options methodology allows the government to analyse the benefits and costs of each level of support and options. Real options also propose alternatives for governments to limit their financial cost, while still maintaining benefits to the other main stakeholders: the financial institution and the private investor.

The second part of this chapter involves the options of the project's sponsor (the private company) in the SES project. Regarding the various risks such as cost overrun and demand risks in transport projects, different options for the private company have been proposed. Three real options of the private company are proposed and analysed: i) the deferral option ii) the abandon option and iii) the grant option. Finally, sensitivity analysis on the two variables, the volatility and risk-free interest rate is performed for government and private company options and the results are discussed.

Section I: Government options in the SES project

This section focuses on government support for the SES project. It begins with the roles and types of the government's financial support for the project. Three types of support are formulated as the real options. This section then presents the different interactions between the government options. Furthermore, sensitivity analysis on key variables is performed and the results are discussed.

It is recognized that risks in infrastructure development may impact enormously on the success of the project. In these cases, governments normally provide support in order to alleviate such risks. The support schemes are often offered in the concession agreement between the government and the private sector. Government needs to play a crucial role in making the project development successful. The government may act as the owner, regulator, financier, manager or operator of the transport infrastructure project (Hasselgren, 2013).

5.1 Government role in the development of infrastructure projects

The role of governments in the development of infrastructure projects is presented in this subsection. Infrastructure projects around the world involve a large amount of investments and private participations in the project are required. The governments of many countries, with budget constraints, have been forced to limit their spending on new infrastructure projects despite a country's demand for new infrastructures. Therefore, governments have advocated the private sector to fulfill the infrastructure requirement through the public-private partnership (PPP) framework. Normally, the private sector is concerned with a project's viability and profitability, whereas the public sector focuses mainly on social benefit. To attract private investment in the project, it is essential for the government to ensure that the project is not only socially and economically viable but also financially feasible. In order to invest in a risky project or a financially unviable project, a government may have to offer various incentives or support, such as revenue guarantee, equity guarantee, grants or subordinate loans, to attract private investment.

The use of these instruments makes such projects viable and attracts private investment in the project. Nevertheless, such mechanisms are difficult to quantify. Government support for public projects is rather subjective and requires an appropriate valuation method. This research proposes the real option methodology for evaluating the value of support from the government perspective.

5.2 Types of government support for infrastructure projects

This subsection illustrates the types of government support in the forms of real options. Much of the literature – Charoenpornpattana et al (2003), Fishbein and Babbar (1996), Schaufelberger and Wipadapisul (2003) – defines the types of government support for infrastructure projects which are summarised in table 5.1. These studies indicate that support from the government is necessary for the success of the project development.

Type	**Definition**
Equity guarantee	Government provides the private company a guaranteed minimum return on equity in the investment project, or the government gives the project company the option to sell the project to government with a guaranteed minimum return on equity.
Debt guarantee	Government provides support in case the cash flow generated from the project is insufficient to service its debt obligation. The

Type	Definition
	support amounts should be at least enough to service the debt.
Exchange rate guarantee	Government protects the project company from the risk of an exchange rate fluctuation.
Grant and subordinated loan	Government provides support in the form of a grant and sub-debt to promote the project economics. The subordinated loan will be serviced after all debt obligations have been settled.
Shadow toll	Government pays the toll, instead of users, to the project company. The toll rate can be adjusted, depending on the demand level.
Minimum traffic guarantee	Government pays the project company if the project cash flow/revenue falls below the specific guarantee level.
Concession extension	Government gives the project company the right to extend the concession period, in case the project's revenue is below expectation.
Revenue enhancement	Government enhances the project's revenue by limiting competitors, facilitating demands or allowing the development of ancillary facilities.

Table 5.1: Type of government supports

Out of all the types of government support, the minimum traffic guarantee, the debt guarantee and the equity guarantee have the ability to capture the upside potential and limit the downside risk of the project. These features are similar to the payoff diagram for the long call or put option on the project. Therefore, these support mechanisms by the government for the project can be evaluated through the real option methodology.

5.2.1 *The minimum traffic/revenue guarantee*

Large infrastructure projects usually face substantial revenue risks, with the allocation of revenue risk as crucial in the development of a PPP project. To mitigate the downside risks of revenues, the project company often negotiates with the government to provide a minimum revenue guarantee. The main approach widely adopted around the world to mitigate the revenue risk is the revenue or traffic guarantee, whereby risks are distributed between the government and the concessionaire. Based on the minimum guarantee mechanism, a government supports the revenue shortfall at a certain level to guarantee the concessionaire's income. The guarantee level should be at least enough to cover the debt obligation in which the lender's risk is also mitigated. Among the different types of support from governments, the minimum traffic guarantee provides the cash flow with a downside risk protection. This cash flow feature is similar to the option feature.

In the minimum traffic guarantee, the government may grant the private company a contract to compensate the revenue shortfall during the operation phase. The government will pay the private sector the revenue shortfall equal to:

K = a minimum revenue guarantee

The minimum guarantee option is similar to a 'European put option' whereby the exercise price is the minimum guarantee level (K). If the guarantee covers the whole operation period, then the option can be exercised every years (Δt =1 year) when the net revenue falls below the guarantee level. This means that the guarantee option value increases if the revenue or traffic volume decreases below a certain level. The level of revenue or traffic guarantee is shown in figure 5.1.

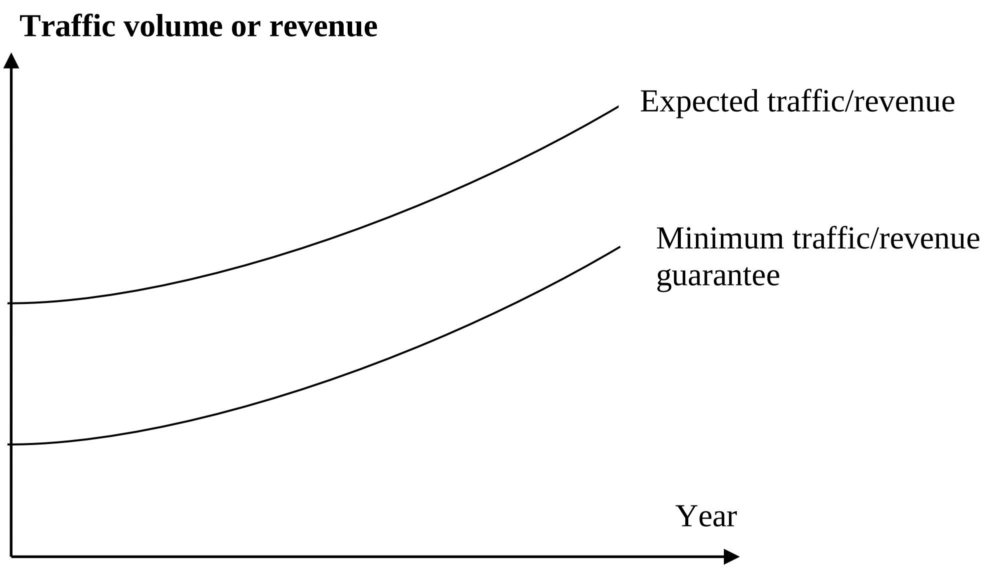


Figure 5.1: The expected traffic flow & the Min. traffic guarantee

The payoff for the minimum traffic guarantee (MTG) can be seen in figure 5.2.

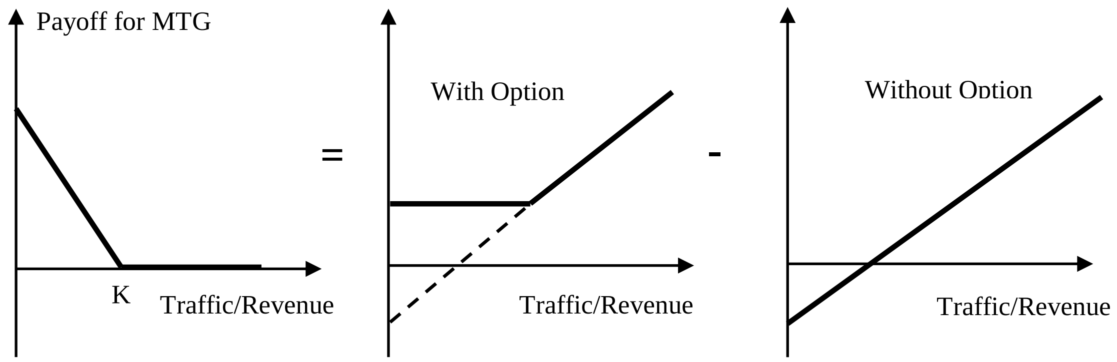


Figure 5.2: The payoff for the minimum traffic/revenue guarantee (million baht)

The guarantee option will be exercised if the actual toll revenue or the actual traffic volume in each year is below the guarantee level. The government would then have to compensate for the revenue shortfall.

Revenue or traffic guarantee is the mechanism to reallocate the traffic demand risk or the revenue risk, based on the range of traffic volume or revenue level. In this way, a government offers the minimum level of traffic or revenue. For example, if the guarantee revenue was set at 90% of the projected traffic volume, and actual traffic volume lay between 90% and 100% of the projected volume, then there would be no need for subsidy by the government. When traffic demand has fallen below 90%, support would be necessary. For the SES project, the guarantee period is 27 years, apart from three years of the construction phase. The valuation of the government guarantees can be modelled as a series of independent European put options with their maturity specified at the end of the fourth to the thirtieth years of the project operation phase. This option can be valued by the binomial model, given the assumption of the evolution of traffic volume as the geometric Brownian motion. The value of the guarantee option can be determined by the possibility of exercising the option when the traffic/revenue falls below the minimum guarantee level (K_i). The option value is calculated backward with the discounted rate at the risk-free interest rate, and the value of the project with the revenue guarantee can be then obtained by a simple sum of 27 option values along the paths on the binomial tree. The revenue received by the concessionaire in each period t, given that the revenue is limited with the maximum toll capacity, is therefore equal to:

RG_t = $\text{Max}\{\text{Min}(R_t, R_{maxt}), G_t\}$, where

RG_t = the revenue with the minimum guarantee at year t

R_t = the observed revenue at time t

R_{maxt} = the revenue at the maximum capacity at time t

G_t = the level of revenue at the floor at time t

The minimum traffic guarantee option allows governments to minimise the risk of a project's abandonment by the project owner or the lender. For the SES project, the guarantee value can be evaluated by the binomial lattice, as shown in table 5.2. This research selects the guarantee level at 80% and 90% which is widely used in the real project.

Level of minimum guarantee	**NPV w/o guarantee**	**NPV with guarantee**	**Value of option**
80%	-7,749	5,603	13,352
90%	-7,749	7,209	14,958

Table 5.2: Value of the real option for government minimum guarantee at 80% and 90% (million baht)

Table 5.2 shows the value of project net present value (NPV) with the guarantee level at 80% and 90%. We can see that the contractual guarantee at 80% increases the project value by 13,352 million baht, and this option value increases when the guarantee level increases to 90% (14,958 million baht). The result of the real option model showed that the total value added by the minimum guarantee traffic options to the original NPV can be very high. The guarantee level (80% or 90%) represents the revenue floor that is set to reduce the risk of the project to the project company. The value of the option increases as the guarantee level increases. For example, at 90% guarantee level, the government has to pay an additional amount of 1,606 million baht or an increase of 12%, compared with the guarantee level at 80%. It can be seen that at the high levels of guarantee, the minimum guarantee option helps the private company to reduce or even eliminate risks, meaning that the project becomes a nearly risk-free project. To implement effective government policy, the government may select to provide the guarantee level at 80%, which the government can negotiate with the project owner and lender. It should be noted that granting guarantees at high level may create future liability for the government.

5.2.2 *Debt guarantee option*

The government provides a debt guarantee when the project's cash flow is insufficient to service debt obligation. This is a full guarantee or a cash flow deficiency guarantee to repay the lender's debt. The credit risk of the project company is transferred to the credit of the government. Furthermore, the debt guarantee provides more opportunity to finance the project at a lower cost of capital, as the credit risk becomes the risk of a government unable to meet its commitment. The debt guarantee option makes lenders more comfortable to provide financial support to the project company.

In a debt guarantee, the government reduces the project risk by setting the condition to repay a principal debt and interest when default occurs. In this type of guarantee, the government legally has an obligation to pay back the principal and interest to the loan issuers on a defined repayment schedule. Therefore, the government takes a risk on the amount of principal guarantee, and the benefit to itself is difficult to identify (e.g., potential tax paid, job creation). Such benefits, however, are beyond the scope of this study.

The debt guarantee option can be valued as the put option on the project's cash flow, where the put option has maturity equal to the loan's maturity and its exercise price equals the interest and principal payment to the debt holder or lender. With the debt guarantee, the debt amount is safe as the loan obligation can be transferred to the government, while without the guarantee the debt is the obligation of the project company.

The debt guarantee option is analogous to the European put option, whereby the value of the debt guarantee equals the value of the put option on the project's cash flow before debt, and the exercise price of each option is the amount of debt obligation due each year. The debt guarantee option will be exercised if the net cash flow (before debt service) in each year is insufficient to service its debt obligation. The government has to subsidize the cash shortfall. The payoff for the debt guarantee option can be viewed in figure 5.3.

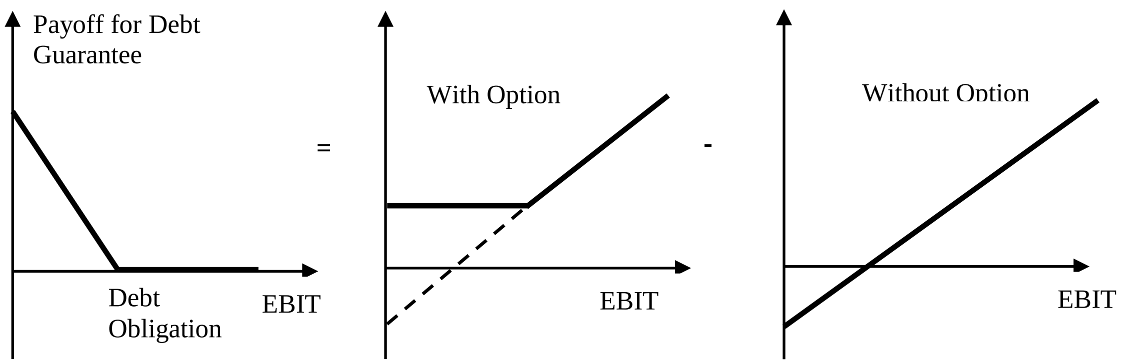


Figure 5.3: The payoff for debt guarantee option (million baht)

With the debt guarantee option, the project's free cash flow (after debt) received by the concessionaire in each period t, given that the project's cash flow is limited with the maximum toll capacity, is:

Rd_t = Max [Max {Min (Cb_t, C_{maxt}), 0,}, D_t] where

Rd_t = the project's free cash flow with debt guarantee at time t

Cb_t = the observed project's free cash flow (before debt) at time t

C_{maxt} = the project's free cash flow at maximum capacity at time t

D_t = the amount of debt (principal and interest) that has to be serviced by the project company at time t

The payoff for the debt guarantee option is then equal to:

Vd_t = Max (-(Cb_t-D_t), 0), where;

Vd_t = Value of the debt guarantee option

The value of the debt guarantee option can be determined by the possibility of exercising an option when the net cash flow of the project falls below the level of debt obligation. The option value is calculated backward, so that the discounted rate at the risk-free interest rate and the value of the project with the debt guarantee can be then obtained by a simple sum of the value of each option. The value of the debt guarantee option is presented in table 5.3.

Type of guarantee	**NPV w/o guarantee**	**NPV with guarantee**	**Real option value**
Debt guarantee	-7,749	-4,637	3,112

Table 5.3: Real option value of debt guarantee (million baht)

It should be noted that the value of the debt guarantee increases the project's NPV. However, a project with an individual debt guarantee option is insufficient for the SES project. The NPV of the SES project is still negative which requires more options. The debt guarantee option was found to be more valuable if this option was combined with other types of government support to enhance project financial viability.

5.2.3 *Equity guarantee with caps (maximum guarantee at return on equity)*

The last type of government support is the equity guarantee, whereby the government guarantees the return to the project owner at least equal to the pre-specified amount (return on equity). For the equity guarantee, government exposure can be limited by setting guarantee caps, so that government support is stopped once the pre-established ceiling is reached. The caps may limit either the aggregate value of options or each option individually. For the individual limit, the value of guarantee can be shown as:

Value of guarantee for each year = Min {Value of Option, Cap} or

For the aggregate limit applied:

Value of guarantee = Min $\{\sum_1^n$ PV (Value of option), Cap$\}$

The cap can be the value of a guarantee minimum return equal to a pre-specified amount. The equity guarantee feature is similar to the debt guarantee. If the cash flow of the project in each year cannot generate enough return to the project owner, its deficit will be guaranteed at the pre-specified return on equity. For example, if the equity injected into the SES project is 4,100 million baht and the cost of equity is 13%, the annual free cash flow (FCF) of the project is then guaranteed at 4,100 x 13% = 551 million baht. The equity guarantee option is viewed as a European put option with the strike price at 551 million baht. The payoff of the equity guarantee option can be viewed as follows:

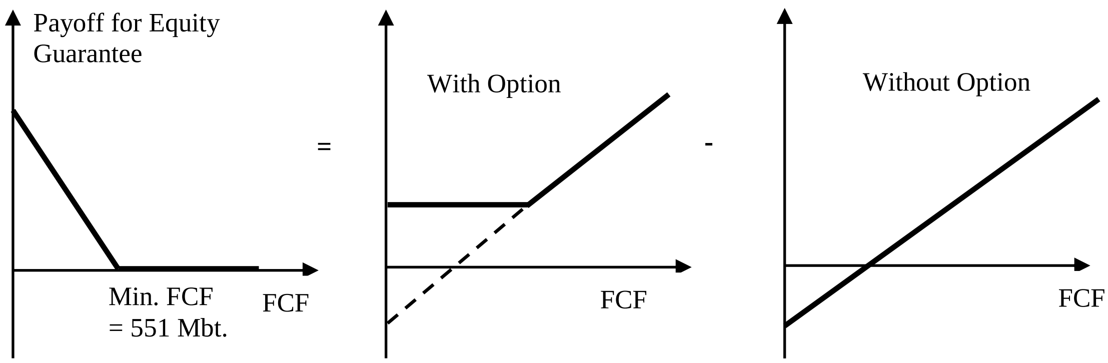


Figure 5.4: The payoff for equity guarantee option (million baht)

With the equity guarantee option, the project's free cash flow (after debt) received by the concessionaire in each period t, given that the project's cash flow is limited with the maximum toll capacity, is calculated by the following equation:

Re_t = Max [Max { Min (C_t, C_{maxt}), 0,}, E_t] where

Re_t = the project's free cash flow with equity guarantee option at time t

C_t = the observed project's free cash flow (after debt) at time t

C_{maxt} = the project's free cash flow at maximum capacity at time t

E_t = the level of the project's free cash flow that generates return equal to cost of equity at time t

The payoff for the equity guarantee option at time t is determined by:

Ve_t = Max (E_t-C_t, 0) where

Ve_t = the value of the equity guarantee option at time t

The binomial lattice is used to value the equity guarantee option (V_e). The value of the equity guarantee option can be determined by the value of the exercised option when the free cash flow falls below the guarantee level. The option value is calculated backward, whereby the discount rate at the risk-free interest rate and the value of the project with the equity guarantee option can be then obtained by a simple sum of the NPV of each option. The value of the equity guarantee option is shown in table 5.4.

Type of guarantee	**NPV w/o guarantee**	**NPV with guarantee**	**Value of equity guarantee**
Equity guarantee	-7,749	-2,788	4,961

Table 5.4: Real option value of equity guarantee with cap (million baht)

Based on the equity guarantee option, the project NPV was improved, although the project was not financially feasible. As a result, the project with an equity guarantee option does not attract the private sector to invest in the SES project. Therefore, more support from government was required and the government may consider adding more options to the project in order to make the project attractive.

5.2.4 *The combination of government options*

This part considers government support for the project as the combination of options (a 'bundle of options'). The value of options for each combination can be seen in table 5.5. The more presents of the subsequence options increased the value of the project. The value of the combined option may differ from the value of the summation of each individual option, reflecting the interaction affect. This means that the exercise of the prior option may change the value of project's cash flow and then the value of the subsequent option, especially for the same option types.

Option type	Project NPV with option	Interaction	No interaction (value isolation)	Interaction effect
G1, G3	7,712	15,461	16,464	-1,003
G2, G3	9,021	16,770	18,070	-1,300
G1, G4	9,080	16,829	18,313	-1,484
G2, G4	10,305	18,054	19,919	-1,865
G3, G4	-2,788	4,961	8,073	-3,112
G1, G3, G4	9,080	16,829	21,425	-4,596
G2, G3, G4	10,305	18,054	23,031	-4,977

G1= the minimum traffic guarantee at 80%, G2= the minimum traffic guarantee at 90%, G3= the debt guarantee G4= the equity guarantee

Table 5.5: Value of option combinations for government support (million baht)

Table 5.5 shows the results of the numerical valuation for valuing the project's multiple real options. It is clear that the value of a combined option may differ from its value in isolation and the interaction effect is large and negative. Also, it shows that the option values in the presence of each other were not simply additive. For example, the value of revenue guarantee at 80% was 13,352 million baht and the value of equity guarantee was 4,961 million baht, while the value of both option combinations were presented at 16,829 million baht, showing negative interaction. With the single minimum traffic guarantee option, the project is feasible. However, the single debt guarantee and equity guarantee is insufficient and needs an additional option for the project.

Adding the minimum traffic guarantee to the individual debt guarantee option or the equity guarantee option, even if the project is feasible, means that the interaction effect is negative. This is because options have the same exercise region and same type (see figure 5.5), and because the first option (minimum traffic guarantee) dominates the other options.

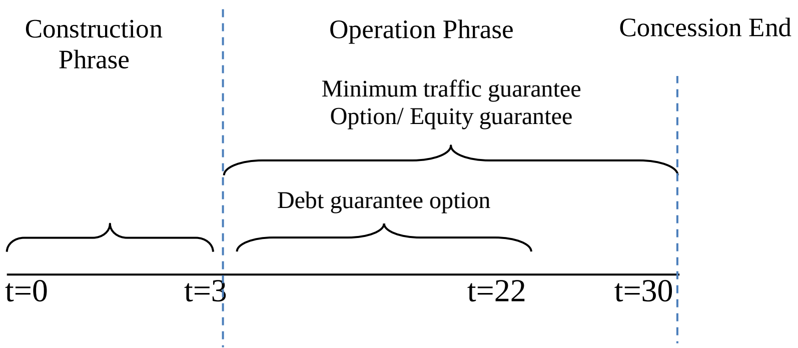


Figure 5.5: Exercise regions of government options

The combination of options for the government can be calculated with the following (See page 92-95 for mathematic proof):

OC = Expanded NPV – Passive NPV
IE = OC-MTG-DG-EG, where
Expand NPV = the NPV with option combinations
Passive NPV = the NPV without option combinations
OC = the option combinations of the minimum traffic guarantee, debt and equity guarantees
MTG = the minimum traffic guarantee option
DG = the debt guarantee option
EG = the equity guarantee option
IE = the interaction effect between the minimum traffic guarantee, debt and equity guarantee

Each government option feature is summarised in table 5.6.

	Minimum traffic guarantee	**Debt guarantee**	**Equity guarantee**
Type of option	Put	Put	Put
Underlying asset	Underlying cash flow	Underlying cash flow	Underlying cash flow
Exercise price	Cash flow at minimum traffic guarantee (80% or 90%)	Total debt obligation in each year	Cash flow at return on equity
Maturity time	1 year	1 year	1 year
Discount rate	Risk-free interest rate	Risk-free interest rate	Risk-free interest rate

Table 5.6: Summary of government options

The combined value of all three options (the minimum traffic guarantee at 90%, debt guarantee, and equity guarantee option) means that the expanded NPV and the passive NPV are equal to 10,305 million baht and -7,749 million baht respectively. In this case, the option value is 18,054 million baht [10,305 - (-7,749)]. The interaction effect is - 4,977 million baht [18,054 - 14,958 - 3,112 - 4,961].

Based on the evaluation of government options in the SES projects, the results show that the combination of the minimum traffic guarantee at 90% and equity guarantee provided the highest value of support to the project company. Adding the debt guarantee option to this combination is useless, because the exercise area of debt guarantee option fully overlaps with the minimum traffic guarantee at 90% and the equity guarantee.

The SES project is feasible with an individual minimum traffic guarantee option. Adding more options help to make the project more attractive. The minimum traffic guarantee may not be the best option for the government because it spends lot of government money, creating future contingent liability. The government may consider another type of support that helps to reduce its expenditure. It should be noted that the more support provided by the government, the larger the expense to its budget.

5.3 Volatility and seasonality analysis: Government option

In this subsection, the government option is analysed for the seasonality of the traffic flow. The volatility of the underlying cash flow is determined from the volatility of traffic volume. To account for the seasonal effects of traffic flow, an analysis explores the volatility for annual traffic data from 2004 to 2015. Based on year-to-year growth rates as well as seasonal adjustment for traffic volume (monthly data), traffic volatility is valued at approximately 4% (see table A5 and table A6 in appendix A) and the risk-free interest rate in the model is valued at 3%.

Table 5.7 shows the relationship of various options, calculated using the binomial lattice, to changes in volatility. The approach accounted for the seasonality effect of traffic flow. It is found from the analysis that option value increases (decreases) with increases (decreases) in volatility except for the minimum traffic guarantee option. This is because i) the minimum traffic guarantee is modelled as a put option, in which any upward movement in underlying (traffic flow) would not benefit the put option and ii) a low risk-free interest rate (3%) is used for “low-volatility traffic” which would increase the value of the put option (the minimum traffic guarantee) because of the discount effect on the exercise price.

Option Type for the SES project	Option value (million baht) at 20% of volatility and 3% of risk-free interest rate	Option value (million baht) at 4% of volatility and 3% of risk-free interest rate account for seasonality
The minimum traffic guarantee at 90%	24,897	24,902
The debt guarantee option	4,332	3,003
The equity guarantee option	6,350	4,326
The combination of debt guarantee and equity guarantee options	6,350	4,326

Table 5.7: The value of government option at different volatility levels

The result of the study shows that the minimum traffic guarantee is still the most valuable for "low volatility", followed by the equity guarantee and the debt guarantee, respectively.

5.4 Sensitivity to other parameters: Government option

The effect of risk-free interest rate on the value of real option for the government is explored in this subsection. In general, the interest rate of the project is often increased to compensate for risk. In binomial lattice, the project's cash flows will move up or down by an amount calculated using volatility and time to expiration while the interest rate used in real option is a risk-free interest rate.

The option value increases with decreases in the risk-free interest rate for put option (the minimum traffic guarantee, the debt guarantee option and the equity guarantee option) while it decreases with decreases in the risk-free interest rate for call option. The relationship is shown in table 5.8.

Option Type for the SES project	Option value (million baht) at 6% of risk-free interest rate (20% of volatility)	Option value (million baht) at 3% of risk-free interest rate (20% of volatility)
The minimum traffic guarantee	14,958	24,897

Option Type for the SES project	Option value (million baht) at 6% of risk-free interest rate (20% of volatility)	Option value (million baht) at 3% of risk-free interest rate (20% of volatility)
at 90%		
The debt guarantee option	3,112	4,332
The equity guarantee option	4,961	6,350
The combination of debt guarantee and equity guarantee options	4,961	6,350

Table 5.8: The value of government option at different risk-free interest rates

It is seen that the minimum traffic guarantee is still the most valuable for "low-risk free interest rate", followed by the equity guarantee and the debt guarantee, respectively.

5.5 Section summary: government options in the SES project

This study found that government support for the SES project is necessary and would help to improve the project's value. However, the government has to determine the optimal level of its support. The research presents a real option with the binomial lattice that can be used to assess the value of government options, and allows the government to analyse the benefits and risks of each type of support. The study also proposes the alternatives for the government to value its appropriate types of support and limit its exposure, but still maintain the benefits of the other project's stakeholders such as the project owner and financial institution.

Three types of government guarantees were selected to value the amount of government support. The value of government guarantee can be modelled on the series of independent European options. These options can be valued directly by the binomial lattice model. Based on the binomial model, this research can determine the value of guarantees which it cannot do by the traditional evaluation method. The method proposed by this research can be applied in real projects to evaluate the type of guarantee being offered in a large PPP infrastructure project. However, guarantees can create significant future liabilities for the government. Specifying the level of guarantee would help the government to limit its liability and would be acceptable to all stakeholders involved.

From this study, the minimum revenue guarantee or traffic is found to be the most beneficial to the project company. The other types of support – the debt guarantee whereby lender's debt is secured by government subsidy and the equity guarantee whereby the project owner can ensure the project return – also improved the project performance, but were still insufficient for the SES project. The option of the equity guarantee has more value to the project company than the debt guarantee option, as the government provides a return guarantee to the project company not only to cover all debt obligation but also to secure the project company with some specified return.

Based on the numerical calculation, it found that government support in terms of combined options has strongly affected the NPV of the project. The better combination of types of support, the higher the resulting NPV. The value of a combination of the minimum traffic guarantee at 90% and the equity guarantee options provided the maximum option value to the project. However, the more government guarantees, the higher the government expense. The level or type of government support should be discussed to establish a clear government guideline or policy. Furthermore, the sensitivity of government option value to volatility and risk-free interest rate is performed in this section. In general, it is found that option's value increases with an increase in volatility. While, a decrease in risk-free interest rate will increase put option value because it increases the present value of the exercise price.

Section II: Private company options in the SES project

This section firstly defines the roles of the private company in the infrastructure development. Later, the categories of private company options are defined and formulated. The values of each option and their interactions are calculated with the binomial lattice model.

5.6 The role of private companies in developing infrastructure projects

This section considers opportunities with specific real options for private participants in the large-scale transport infrastructure. Numbers of transport infrastructure projects have been awarded concessions in which governments retain ownership of the project's physical assets, but grant exploitation rights to a concessionaire. The financial analysis of a privatized infrastructure project is more complex and uncertain, due mainly to the project's size, contract duration, nonrecourse financing, and various project participants. Traditional financial analysis techniques such as NPV, IRR, and payback period have limitations and are insufficient to deal with risks and uncertainties in the project. To make the project attractive for the private company, firms in an infrastructure development business have applied the real option theory as potentially offering an improvement over the traditional decision analysis approach.

The success of a privatization project requires the effective risk management of major risks, such as demand and construction risks, and the usage of real options to explore financial opportunities. The latter will increase the private company's flexibility in an investment decision. The main focus of this section, therefore, is the analysis of private company options which can help the project company to mitigate financial risks. The following sections will present various options for private companies in large-scale infrastructure projects.

5.7 Types of real options for private companies in large-scale infrastructure projects

This section highlights the option flexibility for the project company in the development of infrastructure projects. It is generally well known that project complexity, as well as economic, financial and market risks, have increased frustration and diminished incentives for the private sector to invest in the infrastructure project. The academic literature proposes that this research applies real options to reduce risks in public infrastructure projects. Real options are the financial instrument that can help to improve the viability of infrastructure project. They are well-established tools that help to make the project more attractive to the private company, which normally invests in projects that are profitable, with a low level of equity investment, to ensure good risk management and mitigation.

A large-scale infrastructure project may have a real option embedded in the contract agreement between the private company and the government. In the past, it was difficult to explicitly value the embedded options. This section presents a straightforward methodology to evaluate the options for the private company. Three options – deferral, abandon and grant options – are the main focus. These options limit the risk of the project and make it more attractive for private investors. These options and their interactions are valued with the binomial lattice model.

Type of private company option	Definition
Deferral option	The private company may defer delivering the concession fee to the government when the project is underperforming. The deferred delivery date is pre-specified in the concession contract. Benefit to the project company is the time value of money of the deferred amounts.
Abandon option	With permanent revenue decline, management can abandon the current project's operation and may return the project to the government or resell the project in the secondary market at a value pre-specified in the concession contract.
Grant option	Government promotes private investment by providing non-refundable grants to the private company. Projects can be relieved of financial obligation with a grant option. Government sacrifices its income in order to make the project more attractive.
Concession extension	Government provides the right to project company to prolong the concession term when the project's revenue falls below a specified level. Such support means less financial cost to government, but is less effective at easing financial status of project.

Table 5.9: Type of private company option in infrastructure projects

5.7.1 *The deferral option*

This option allows the project company to defer payment of the concession fee to the government (Rose, 1998). For the SES project, the option is the deferral of revenue sharing to the government which normally pays at the end of each year. The private company is required to share 40% of total revenue with the government for the first nine years, 50% of total revenue for the next nine years, and 60% of total revenue for the last nine years (the total concession collection period = 27 years). The total revenue sharing is estimated at the very considerable sum of 154,081 million baht during the whole concession period. These amounts have a significant impact on the project return. In order to make the project more attractive to a private company, the government may grant the company to issue a concession notification to delay payment in case of financial loss. The concession notifications are non-interest charged and due for payment at the end of the concession period. This deferral option is viewed as the European put option which can be exercised at the end of each year during the concession period.

The option payoff to the project company is the time value gained in the payment of the concession fee, which is equal to the difference between the face value of the notification and the present value of its eventual repayment. The payoff for the deferral option can be expressed as the following equation:

Option payoff $= \max(0, FV_t - PV(FV_t))$

$= \max(0, FV_t - \frac{FV_t}{(1+r_{t,T})^{T-t}})$ where:

FV_t	=	the face value of notification issued in the period of t (value of revenue sharing in each year which is predetermined, based on the project cash flow of base case scenario). The payment will be paid at the end of the concession.
$PV(FV_t)_{T-t}$	=	the present value of a payment FV_t at time t
T	=	the total concession period
$r_{a,b}$	=	the average risk-free interest rate between time a and time b

The deferral option is triggered when the net NPV for each year is negative. The option payoff should be discounted from the time the notification is issued. The present value of payoff is given by:

PV payoff $= PV(FV_t - PV(FV_t))_t$

$= \frac{1}{(1+r_{0,t})^t}[FV_t - \frac{FV_t}{(1+r_{t,T})^{T-t}}]$

$= \frac{FV_t}{(1+r_{0,t})^t} - \frac{FV_t}{(1+r_{0,t})^t(1+r_{t,T})^{T-t}}$

It is simplified to:

$= FV_t[(1+r_{0,t})^{-t} - [(1+r_{0,T})^{-T}]$

The payoff of the deferral option is similar to the payoff of the European put option with the strike price starting to trigger when the project NPV is less than zero (see figure 5.6).

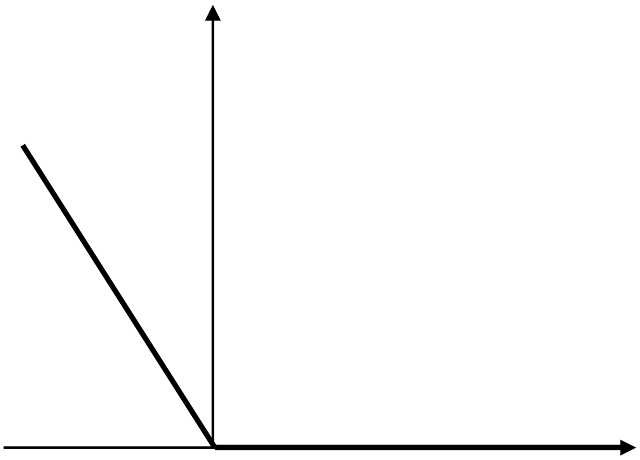


Figure 5.6: The payoff for the deferral option (million baht)

The case study is taken from the SES project in Bangkok, Thailand. The project feature is given in chapter 4. The project NPV with the deferred option is determined by the binomial lattice model. This research provides an example of the deferral option calculation. The predetermined deferral amount for the SES project is presented in table 5.10.

Year	4	5	6	7	8	9	10	11
Deferral amount	1,452	1,560	1,968	2,232	2,496	3,152	3,264	3,360
Year	12	13	14	15	16	17	18	19
Deferral amount	3,440	4,280	5,325	5,350	5,350	5,350	5,350	6,420
Year	20	21	22	23	24	25	26	27
Deferral amount	6,420	6,420	7,704	7,704	8,988	8,988	8,988	8,988
Year	28	29	30					
Deferral amount	8,988	10,272	10,272					

Note: the project started its operation in year 4 and the proportion of revenue sharing is 40–60%; the predetermined deferral amount is the amount of revenue sharing, paid to the government each year during the operation phrase

Table 5.10: Predetermined deferred amount of the SES project (million baht)

The predetermined deferral amount from table 5.10 is the amount of revenue sharing to the government during the operation phase of the SES project. The private company (the concessionaire) can delay a payment to the government if the project's cash flow is negative. For example, the predetermined revenue sharing of the SES project to the government in year 10 is 3,264 million baht. The deferred benefit at year 10 is equal to 2,940 million baht [3,264 – $3{,}264/(1+0.1223)^{30-10}$] at the discount rate of 12.23%. If the net cash flow on the binomial path is negative at year 10, the deferral option is triggered. The payoff of the option to defer is 2,940 million baht. The total deferral amounts are the sum of all individual deferral options for each year, discounted at the risk-free interest rate. Table 5.11 presents the value of the deferral option for the SES project.

Type of guarantee	**NPV w/o deferral option**	**NPV with deferral option**	**Value of deferral option**
Deferral option	-7,749	-1,431	6,317.6

Table 5.11: Value of the deferral option for the SES project (million baht)

The deferral option gives the right to the private company to postpone the concession fee in the year that the project performs poorly. The deferment of concession payment is viewed as the European put option for the private company. In order to value the deferral option, it is necessary to determine "t", the time that each concession fee will be paid. In the SES project, this research assumed that the repaid amount will be at the end of the concession (thirtieth year). The private company will exercise the deferral option if the project's net cash flow after debt in each year during the operation phase is negative.

Granting the private company the right to defer the payment of the concession fee has a significant value of approximately 6,318 million baht for the SES project. The value is quite high relative to the total project value (~25% of the project investment cost). This value is contributed from the time value of the deferred payment. Clearly, the deferral option contributes significantly to the value of the project. However, the project with the deferral option is still financially unfeasible for the private investor, indicating a negative project NPV. Thus, the project sponsor may need to more support to make the project more attractive.

5.7.2 ***The abandon option (private company option)***

The second option for a private company is the option to abandon the project when the project cash flow does not measure up to expectations. In the worst case scenario, the private company has the option to abandon the infrastructure project at a specific time, in exchange for its salvage value or a value pre-specified in the concession contract. The private company may exercise the option to abandon the project if the private company does not feel comfortable with the actual revenue collection. If the traffic volume suffers a substantial decline, the management makes a decision to abandon the project. The private company may abandon the project permanently in exchange for the exit value (i.e., the value of pre-negotiation in the contract or the terminated value). The abandon option is written in the concession at the contract-signing date, and is set to expire before a specific date (i.e., the pre-construction completion date). The abandon option can be valued as a European or an American option on the current project value (net NPV) with the exercise price equal to the exit value.

In this option, the project company has been given the right to abandon a project at a specific repayment date. Its payoff can be determined as:

Max (L –E, 0), where

E = is the expected remaining NPV on a project if it continues to the end of its life
L = the liquidation or abandonment value (the pre-estimated NPV) for the same project at the same point in time.

Following is an illustration of the option to abandon for the SES project. A private company has an abandon option at the fifth year of the operation phase. The pre-estimated project NPV at the fifth year is 23,518 million baht. The binomial path of the project's net cash flow at the fifth year is 15,169 million baht, which means the observed cash flow is lower than estimated. Then the abandon option of private company is:

Abandon option at year 5 = Max (L_5-E_5,0)
= Max (23,518-15,169,0)
= 8,349 million baht

The abandon option is analogous to a European put option. The project company will exercise the option when the expected project NPV is less than the pre-estimated value (see figure 5.7). The firm can abandon a project with the possibility of reselling the physical project's asset at salvage value or predetermined value (pre-agreed project NPV). This option allows the private company to sell the asset back to the government or the public agency. The sellback agreement may specify at the initial stage of contract signing or are negotiated ex post. The concessionaire may decide to walk away at a specific time during the concession. The project ownership is transferred to the government. The government can recover the project's cash flow either by collecting it itself or by providing a new concession to a new private company.

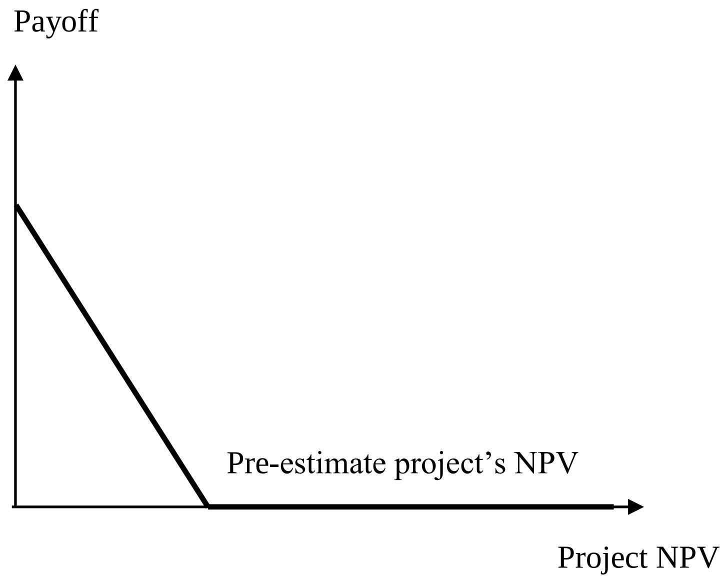


Figure 5.7: The payoff for the abandon option (million baht)

In this option, we can assume that the exercise price is the liquidation or abandon value (the value of the pre-estimated project NPV). The option will be exercised when the remaining project value (the revised NPV) is less than the abandon value. The remaining project cash flow in the abandon option is equivalent to the revised net present value of the project's cash flow in the binomial lattice model. As time passes since the project started commercial operation, the uncertainty about the project cash flow is resolved. However, if the actual cash flow is substantially lower than the expected ex ante, it will lead to a revised NPV that is lower than the exercise price. The private company may consider executing a put option. One of the main challenges is to solve the optimal stopping time (time to abandon the project) which is not the scope of this study.

With the abandon option, the private company (the buyer) has the right to exercise the option at a set number of times, i.e., years 5, 10 and 20. The abandon option with the binomial lattice model is calculated in table 5.12.

Type of guarantee	**NPV w/o guarantee**	**NPV with guarantee**	**Real option value**
Abandon option at year 5 of operation	-7,749	-6,949	825
Abandon option at year 10 of operation	-7,749	-6,896	853
Abandon option at year 20 of operation	-7,749	-7,310	439

Table 5.12: Value of the abandon option of the private company (million baht)

The option to abandon creates the value to the private company. The value of the abandon option is 825 million baht, 853 million baht and 439 million baht at the fifth, tenth and twentieth years since the operation started respectively. The abandon option at year 10 of operation is the most valuable. It assumes that a clearer picture of project demand would be developed within ten years since commencement of the operation phrase. Thus, the decision to abandon is likely to depend on whether additional time will improve the traffic volume prediction. (This is a reasonable timeframe which gives the project owner enough information about the project.) Over 10 years, the abandon option provides a lower value for the private company. With the abandon option, the project's NPV is still negative. The project is therefore not attractive to the private company.

5.7.3 *The grant option*

The private company has an option to receive a grant from the government, making the project more attractive. The government can help to enhance the project performance by providing the private company with an irrevocable grant. In order to receive a grant, the project should meet certain qualifications. As the project has a high probability of a negative NPV, the private company could qualify to receive a grant from the government. The grant option is the multiple exercise option which the project company receives payment from the government each year.

In the SES project, the grant amount is set at the amount of the estimated revenue sharing in each year to the government (between 40% and 60% for the SES project). When the net project's cash flow is negative, the private company can claim the amount that has been paid to the government. The private company can waive all or a portion of revenue sharing to the government in the year of inferior performance. With the grant option, the private companies hold yearly European put options throughout the project operation period. The payoff of the grant option can be written as:

i) If $NCF_i \geq 0 = 0$

ii) If $NCF_i < 0 = \text{Min}(-NCF_i, G_i)$, as

NCF_i = the Net Cash flow in each year

G_i = the level of government grant each year (the amount of revenue sharing in table 5.10)

The payoff of the grant option is similar to the payoff of the one-year European put option. The put option is exercised when the project NPV is less than zero (shown in figure 5.8).

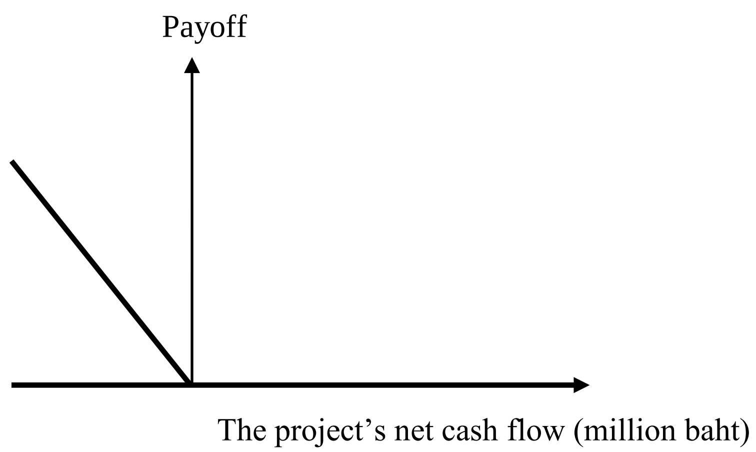


Figure 5.8: The payoff for the grant option (million baht)

To give a simple example: suppose the project net cash flow in the fifth year of operation is -2,033 million baht, and the portion of the revenue sharing to government is 2,496 million baht, then:

Grant option value = $\text{Min}(-NCF_i, G_i)$

= Min. (-(-2,033), 2,496)

= 2,033 million baht

The value of the grant option is calculated by summation of the individual options in the binomial path. The value of the grant option for the SES project is presented in table 5.13.

Type of guarantee	**NPV w/o guarantee**	**NPV with guarantee**	**Value of grant option**
Grant option	-7,749	-4,660	3,089

Table 5.13: Value of the grant option (million baht)

The value of the grant option using the binomial model for the SES project is worth 3,089 million baht. The project NPV with a grant option is still negative. In the real option analysis with a single grant option, the project is financially not feasible, and therefore the project does not attract private funding. In this case, more options are required to make the project more attractive to a private company

5.7.4 *The other options: options to extend concession period*

In the concession contract, the key issue is to set the duration of the concession as well as the degree of managerial flexibility, whether or not the concession extension is allowed. The project company may be granted the option from the government to extend the concession term in case the revenue falls below a certain level.

This research does not consider how the concession is lengthened. That evaluation needs more complex mathematical/financial techniques beyond the scope of this study. However, this research initially found that the option to extend concession affects the concession value, in which more revenue will be collected by the concessionaire. It is generally argued that the extension option is privately valuable as it allows a concessionaire to increase its overall project returns. For the SES project, the private company did not have the option to extend its concession.

5.7.5 *The combination of options for the private company*

The last part of this section is considered the private company options as the option combinations (the bundle of options)**.** When the options are combined, they will interact with each other. The option combinations allow the private company to combine two or more options. The values for each option combination and the timeline of the option can be seen in table 5.14 and figure 5.9 respectively.

Option value	Project NPV with option	Interaction	No interaction (value isolation)	Interaction effect
P1, P2	-1,431	6,318	7,171	-853
P1, P3	-1,381	6,368	9,407	-3,039
P2, P3	-3,971	3,778	3,942	-164
P1, P2, P3	-1,381	6,368	10,260	-3,892

P1 = the deferral option

P2 = the abandon option at year 10 of operation period

P3 = the grant option

Table 5.14: The value of option combinations for private company (million baht)

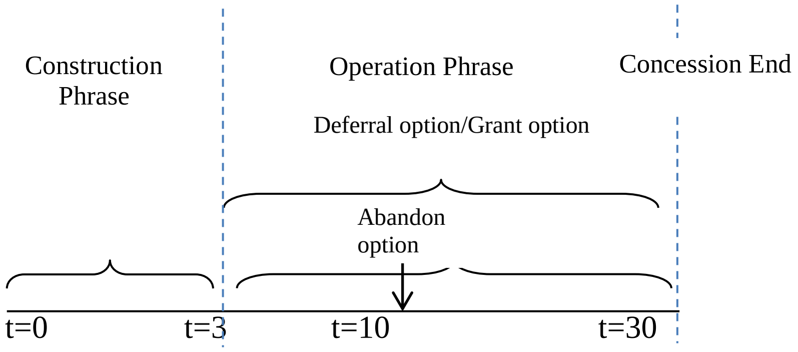


Figure 5.9: Timeline of deferral, abandon and grant options for the SES project

Considering the combination of two options, the combination of deferral option and grant option is the most valuable option. Though the value is highest, the interaction effect is large and negative (-3,039 million baht). This is because the exercised region of the deferral and grant options fully overlaps (see figure 5.9) and both options are put options. The result shows that adding the second option (grant option) to the first option (deferral option) seems inefficient.

As we can see in table 5.14, the combined value of real options is different from the sum of the separate option values. It can be seen that the interaction effect has negative value for the combination of two and three options. The combined value of three options (deferral, abandon, grant) is the same as the combined value of the grant and deferral options, and is not significantly different from a combined value of the abandon and deferral options. This can conclude that the combination of options within the private company is inefficient.

The results indicated that the abandon option when combined with other options could create more option value, while the most favourable for the private company is the deferral option. However, adding the second option to the deferral option seems worthless. When the study looks at the option bundle, it seems that the project is still financially not feasible. The combination of options within the private company is impractical. As a result, the projects with only the private company option are not attractive for investment. The project needs more support from the government and financial institutions in order to make the project feasible and more attractive.

5.8 Volatility and Seasonality Analysis: Private company option

In this subsection, the private company option is conducted based on systematic seasonal variations of the traffic flow. In this case, the volatility of the underlying cash flow is determined from the volatility of traffic volume. The volatility of traffic volume is calculated on historical data during 2004-2015. Based on year-to-year growth rates (see table A5 in appendix A) as well as seasonal adjustments for (monthly) traffic volume (see table A6 in appendix A), traffic volatility is valued at around 4% and the risk-free interest rate in the model is valued at 3%.

The option value is most sensitive to volatility changes. It is generally known that option value increases (decreases) with an increase (decrease) in volatility. Table 5.15 shows the relationship of selected private company options, calculated using binomial lattice, to changes in volatility which the approach accounted for the seasonality effect of traffic flow.

Option Type for the SES project	**Option value (million baht) at 20% of volatility and 3% of risk-free interest rate**	**Option value (million baht) at 4% of volatility and 3% of risk-free interest rate, account for seasonality**
The deferral option	10,367	5,331
The grant option	4,302	3,003
The combination of the deferral option and the grant option	10,433	5,367

Table 5.15: The value of private company option at different volatility levels

An option's value of the deferral option and the grant option decreases with a decrease in volatility of the traffic flow. The result of the study shows that the combination of the deferral option and the grant option is still the most valuable for "low volatility", followed by the deferral option and the grant option, respectively.

5.9 Sensitivity to other parameters: Private company option

The effect of risk-free interest rate on the value of real options for private company is explored in this subsection. In general, the interest rate of the project is often increased to compensate for risk. In the binomial lattice, the project's cash flows will move up or down by an amount calculated using volatility and time to expiration, while the interest rate used in real options is a risk-free interest rate.

The option value increases with a decrease in the risk-free interest rate for the put option (the deferral option and the grant option). The relationship is shown in table 5.16.

Option Type for the SES project	**Option value (million baht) at 6%-risk free interest rate (20%-volatility)**	**Option value (million baht) at 3%-risk free interest rate (20%-volatility)**
The deferral option	6,318	10,367
The grant option	3,089	4,302
The combination of deferral option and grant option	6,368	10,433

Table 5.16: The value of selected private company option at different risk-free interest rates

The result of the study shows that the combination of the deferral option and the grant option is still the most valuable for "low interest rate", followed by the deferral option and the grant option, respectively.

5.10 Section summary: the private company option in the SES project

The major finding of this study was that the private company found a diverse range of potential uncertainties which formulated risks associated with the project. The main risk was the uncertainty of the future market condition (traffic condition). To mitigate such risk, the options for potential courses of action can be formulated. These options were based on looking at the major risks and selecting options and combinations of options which were most suitable to reduce downside exposure.

From the result of this analysis, the option to defer is a preferable policy choice under government support to the private company, and its justification is more straightforward. Granting the private company the option to defer payment of the concession fee gains a significant amount. This value is quite high compared with project value. Furthermore, the sensitivity analysis shows that the option values decrease with decreases in volatility and the option to defer remains a preferable option for the private company.

After traffic volatility, the other significant risk factor is risk-free interest rates. A decrease in interest rate will improve the value of the option because the payoff on the option is the NPV of the project cash flow then both the payoff and its NPV will raise when interest rates decrease. For the combination of two options, the combination of the deferral option and the grant option is still the most valuable option under both low volatility and interest rate.

Overall, the private company's options in the selected project look promising. When the options were combined, they supported each other and their values were increased. The interaction increases the value for the first option, especially for the abandon option. In contrast, the interaction is insignificant for the deferral option. Furthermore, although the option bundle increases the project's value, it seems insufficient to attract private investors. The study should extend further to capture the more complex option combinations between the government, the financial institution and the private company.

Chapter 6. SES Case Study: Option Combinations

This chapter deals with the nature of the option interactions among the government, the financial institution and the private company as well as the valuation of the project flexibility in the context of multiple real options. Interaction between options reflects the type, the order of option involved, whether in the money or not, and the separation of exercise time. This chapter will illustrate through a case-study example the importance of properly accounting for interactions among the government, the financial institution and the private company.

6.1 Introduction of the option interaction in the project

This section deals with the option interactions in the project. The multiple options are formulated, and the values of option interactions are determined. As explained in the previous chapters, it seems that the single option from the financial institution and the private company, except for the government, is insufficient to make a project feasible. This chapter illustrates the importance of proper option combinations for the government, the financial institution and the private company. Myers (1987), Trigeorgis (1993a,b) and Ross (1998), the pioneers in the field of real option application, attempted to value option bundling and demonstrated the interaction among options. The results of their studies indicated that some option combinations had a very significant value partially as a result of the interaction between the options. The implication of their analyses is that the value of options in the presence of combination may differ from its value in isolation. The combined value of two or more options therefore may differ from the values of each option separately and of simply adding the results.

The main point of this research study is to design and formulate the real option as a package for the private investor, the government and the financial institution. The option package is provided for mitigating all financial risks such as revenue and construction overrun risks related to project. The previous study in chapter 4 and 5 showed that the various support options from the government, the financial institution or the private company, though valuable, may not be enough to make project financially attractive. Valuing the option combinations among the government, the financial institution and the private company is required. It is generally known that real-life projects are often more complicate and involve a set of multiple options.

The option combinations can be considered in the form of the package of two or more options from i) the government and the financial institution, ii) the government and the private company and iii) the financial institution and the private company. This study applied the binomial lattice approach which is a very flexible technique to evaluate option combinations. The SES project in Bangkok Thailand is used to illustrate the application of option combinations.

6.2 Combination of the government and the financial institution options

This section focuses on option combinations involving the government and financial institution. As mentioned before, each party has its own interests, and they involve a collection of multiple real options in the project. When their options are proposed at the same time in the project, it is essential to understand the interaction effect. Generally, the cash flow of the project with options is divided into three components: the cash flow without option support, the option support component and the option interaction. The support component actually contains the combination of options. It consists of several option elements, called "bundle of options". Options can be valued simultaneously and the bundle of options is broken down into the value of individual option elements and the interaction effect. Therefore, the value of project NPV without support plus the value of the option bundle is the value of the project NPV with option support.

The following is the bundle of the selected individual options from the government and the financial institution. The selective criterions are the individual option value and its implication to the project. The value of the project's NPV with option and option interaction are shown as follows:

Option value (million baht)	**Project NPV with option**	**Interaction**	**No interaction (value isolation)**	**Interaction effect**
G1, F1	16,269	24,018	15,546	8,472
G2, F1	-1,324	6,424	3,701	2,723
G3, F1	1,268	9,016	5,550	3,466

<u>Government support</u>

G1 = Minimum traffic/revenue guarantee option at 90% level of guarantee

G2 = Debt guarantee option

G3 = Equity guarantee option

Financial institution option

F1 = Deferral option

Table 6.1: The value of the government and the financial institution option combinations and their interaction effects (million baht)

When more than two options from the government and financial institution are embedded in the project, they interact. Each option combination is valued by the binomial lattice model, and the interpretation is presented as follows:

6.2.1 *Combination of the minimum traffic guarantee option (government) and the deferral option (financial institution)*

When the minimum traffic guarantee is combined with the deferral option under concession package, they will interact with each other. Both options are of opposite types—the prior call option (the deferral option) and the latter put option (the minimum traffic guarantee). They interact with each other with non-overlapping exercise region; therefore, the project performance is enhanced (see figure 6.1).

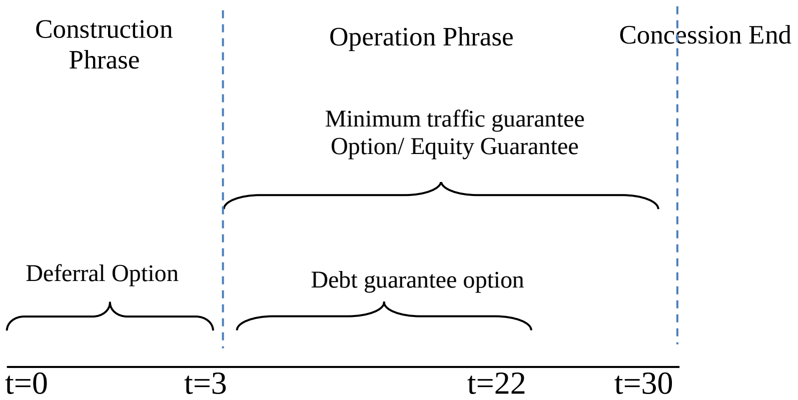


Figure 6.1: The exercise region of the government and the financial institution options

In general, the exercise of the prior option will alter the underline asset and hence the value of subsequent option. For example, the lender has an option to defer funding for the project until the operating commencement date. Lender gains the benefit in case of the project cost overruns, which decreases the ability to pay debt, by cancelling the project funds. By adding the minimum traffic guarantee option, the probability of the lender to exercise the deferral option is lower as the lender foresees the future cash flow with guarantee. This is because the project cash flow under the minimum guarantee (at 90% level) is strong enough to repay debt in some project cash flow scenarios, though the project cost is overrun. By adding both options together, the project NPV turns out to be 16,269 million baht, and the SES project is financially feasible. In addition, the result showed that the value of the interaction effect is at large 8,472 million baht as the option has no overlapped portion in the exercise areas and the exercise of the prior option may destroy the latter option in some paths of the binomial lattice model.

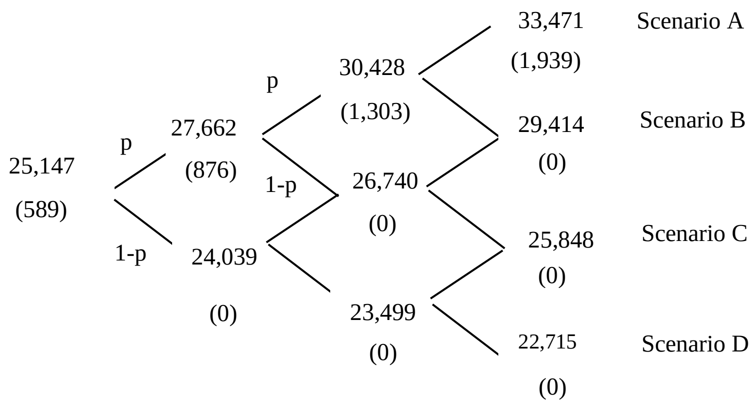


Figure 6.2: The 3-year binomial path of total construction cost and the value of the deferral option (in parenthesis) in million baht

Suppose the construction cost is higher than the expectation at 33,471 million baht (see Scenario A in figure 6.2). With a single deferral option, the financial institution may decide to forego financing project, then the value of the deferral option is 589 million baht (in figure 6.2 and referred to Chapter 4 for detail). By adding the minimum traffic guarantee, the value of the minimum traffic guarantees the option at the 3rd year will increase to 15,840 million baht (table 6.2) under 33,471 million baht of total construction cost, compared to 1,939 million baht of the single deferral option (Scenario A in figure 6.2). Therefore, the lender, with the combination of the deferral option and the minimum traffic guarantee options, still continues to support the project. The values of the minimum traffic guarantee under various construction costs are presented in the following table:

Scenario	**Total construction cost at 3rd year (million baht)**	**Value (NPV) of the minimum traffic guarantee option at 3rd year (million baht)**
A	33,471	15,840
B	29,414	20,227
C	25,848	24,083

Scenario	Total construction cost at 3rd year (million baht)	Value (NPV) of the minimum traffic guarantee option at 3rd year (million baht)
D	22,715	27,471

Table 6.2: The value of the minimum traffic guarantee at the end of the 3rd year of the binomial path for various construction costs (million baht)

The project's NPVs of the combined deferral option and the minimum traffic guarantee option along the binomial path are presented in figure 6.3. Finally, going backwards through the tree until the value of option today is calculated, the NPV value of combined options is 16,269 million baht [e $^{(0.06*1)}$ (16,238x0.71+19,864x (1-0.71)); with p=0.71, r_f =6%]. The binomial path of the combined deferral and the minimum traffic guarantee option is shown in figure 6.3. Therefore, it can potentially create improvements in the project's value through the combined deferral and the minimum traffic guarantee option.

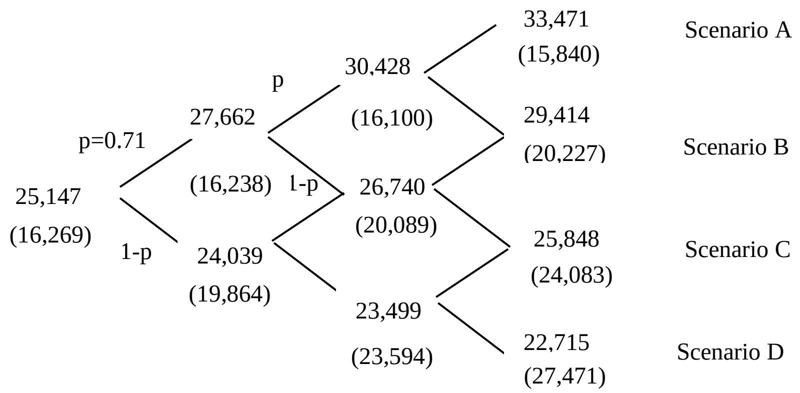


Figure 6.3: The 3-year binomial path of total construction cost and the value of the combined deferral and minimum traffic guarantee options (in parenthesis) in million baht

6.2.2 *Combination of the debt guarantee option (government) and the deferral option (financial institution)*

Previously, the debt guarantee option by the government itself was not enough to make the project attractive for investment. However, when the debt guarantee from the government was combined with the deferral option from the financial institution, the project's NPV is improved. Both options are different; one call option (the deferral option) and one put option (the debt guarantee option). Both options are in a sequential order which affects the conditions of the first; the deferral option will impact the second option, the debt guarantee option (see figure 6.1). When both options are of different type, they are exercisable under negatively correlated conditions. The effective underlying asset for the latter option may be highly conditional on prior exercise of an earlier deferral option (e.g., at higher construction cost in the prior option), then the option value of exercising the latter (the debt guarantee) option, given the condition of the former, would be large.

For example, at the higher construction cost of 33,471 million baht (see figure 6.2), with a single deferral option, the financial institution may decide to forego funding the project. By adding the debt guarantee option, the value of the debt guarantee option at the 3rd year will be 9,684 million baht, improving the project's NPV. Therefore, the lender may decide to fund the project with the combination of the deferral option and the debt guarantee option. The values of debt guarantee under various construction costs are presented in the following table 6.3:

Scenario	**Total construction cost at 3rd year (million baht)**	**Value of the debt guarantee option at t=3 (million baht)**
A	33,471	9,684
B	29,414	7,403
C	25,848	4,875
D	22,715	3,231

Table 6.3: The value of the debt guarantee option at the end of the 3rd year of the binomial path for various construction costs (million baht)

The project's NPVs of the combined deferral option and the debt guarantee options along the binomial path are presented in figure 6.4. Using a backward calculation, the value of the combined option is 6,424 million baht [$e^{(0.06*1)}$ (7,413x0.71+5,347x (1-0.71))]. The option values of the combined deferral and the debt guarantee options are shown (in parenthesis) in figure 6.4. The value of project is improved by the combined deferral and the debt guarantee option.

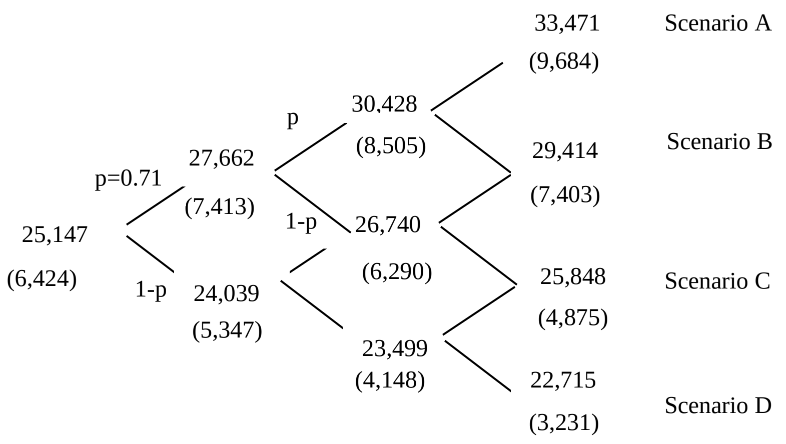


Figure 6.4: The 3-year binomial path of total construction cost and the value of the combined deferral and debt guarantee options (in parenthesis) in million baht

The interaction effect is relatively high at 2,723 million baht (shown in table 6.1). Interaction increased the value of the debt guarantee option. In the worst scenario of project's cost overrun, the debt guarantee option from the government is exercised and helps to increase the project's value. The opportunity to exercise the deferral option decreases when it was combined with the debt-guarantee option. It is implied that the project generates sufficient cash flow to service debt obligations. However, the option combinations are still insufficient, and the project is financially infeasible. More options are required. The project NPV is slightly negative at 1,324 million baht, and the government may consider providing other supports as the project is nearly feasible.

6.2.3 *Combination of the equity guarantee option (government) and the deferral option (financial institution)*

The project becomes more attractive when the equity guarantee option (government) and the deferral option (financial institution) are combined. Both options are of opposite types: one call option (the deferral option) and one put option (the equity guarantee option). In addition, the condition on the first (the deferral option) will alter the value of the subsequence (the equity guarantee) option. There is no overlap between the two options (see figure 6.1). The conditional probability of exercising the second option (the equity guarantee) given prior exercise of the first option (the deferral option) would be small. Both are optimally exercised, represented by the high interaction value at 3,466 million baht. The interaction is high when i) there is no overlap in the exercise region and ii) options are in the money.

Under the scenario of the high construction cost, the individual deferral option is normally exercised by financial institutions to refuse to fund the project. With the option combination, the risk of construction cost overrun is protected by the equity guarantee option from the government. In the case of high construction cost, the conditional probability of exercising the equity guarantee option would be higher and also the option would have a larger value. The values of the equity guarantee under various construction costs are presented in the following table:

Scenario	**Total construction cost at t=3 (million baht)**	**Value of the equity guarantee option at t=3 (million baht)**
A	33,471	13,015
B	29,414	10,498
C	25,848	7,619
D	22,715	5,640

Table 6.4: The value of the equity guarantee option at the end of the 3rd year of the binomial path for various construction costs (million baht)

The 3-year binomial path of the combined deferral and the equity guarantee option is presented in figure 6.5. The value of the project is enhanced by the combined deferral and the equity guarantee option.

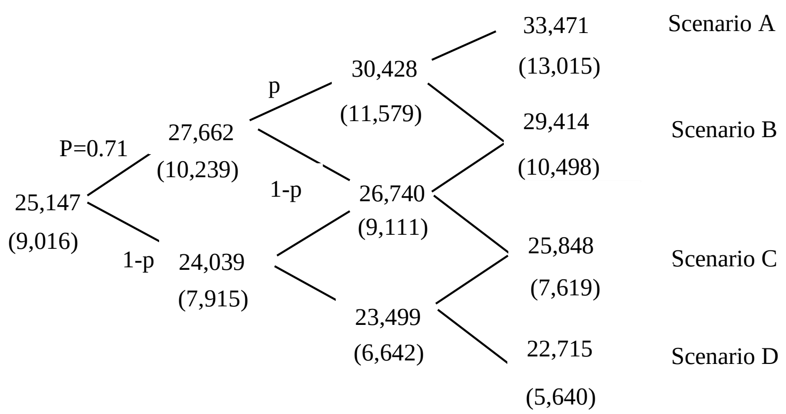


Figure 6.5: The 3-year binomial path of total construction cost and the value of the combined deferral and equity guarantee options (in parenthesis) in million baht

The combination of the deferral option and the equity guarantee option is valued at 9,016 million baht [$e^{(0.06*1)}$ (10,239x0.71+7,915x(1-0.71))]. The project is feasible with these two option combinations, worth at 1,268 million baht (-7,749+9,016). This option may be considered a good choice for the government to support as it does not spend a large government budget with equity guarantees and the project is still feasible. For policy design, the project is recommended to propose the combination of the deferral and the equity guarantee option in the project's scheme.

6.3 Combination of government and private company options

This section focuses on the option combinations involving the government and private company. The values of the SES project with various option combinations and their interactions are shown in the following table:

Option value (million baht)	**Project NPV with option**	**Option interaction**	**No interaction (value isolation)**	**Interaction effect**
G1, P1	12,549	20,298	21,275	-977
G2, P1	-1,357	6,391	9,430	-3,039
G1,G3,P2	11,469	19,218	23,008	-3,709

<u>Government support</u>

G1 = Minimum traffic/revenue guarantee option at 90% level of guarantee
G2 = Debt guarantee option
G3 = Equity guarantee option
<u>Private company option</u>
P1 = Deferral option
P2 = Grant option

Table 6.5: The value of option involving the government and private company and their interaction effects

When options of the government and private company are combined in the project, there is an interaction effect. Overall, the project value is enhanced. Option combinations are valued by the binomial lattice model as follows:

6.3.1 ***Combination of the minimum traffic guarantee option at 90% (government) and the deferral option (private company)***

When the minimum traffic guarantee option is combined with the deferral option under a concession package, there is an interaction effect. Both options are a European put option. The degree of interaction depends on the option sequences and whether the latter option is in the money or out of the money when the first option is exercised. The investment project with its collection of real options for the government and private companies is summarised in figure 6.6.

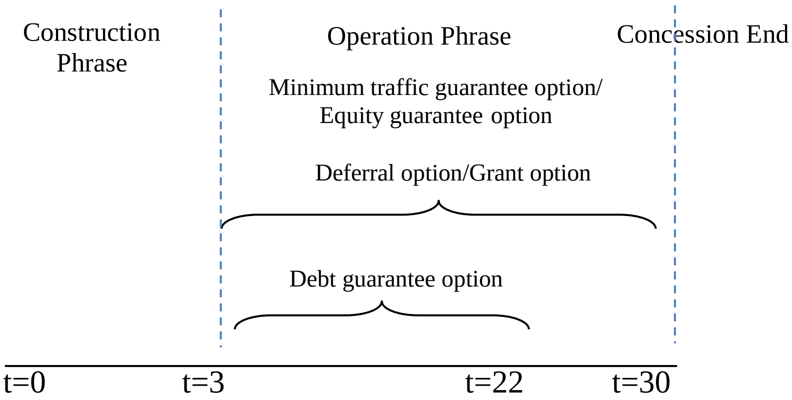


Figure 6.6: The exercise region of the government and private company options

To determine the values of the option combination and its interaction effect, they are valued simultaneously. The payoff for this option combination can be determined in the following ways.

i) The project's revenue with minimum traffic guarantee is:

RG_t = Max {Min (R_t, R_{maxt}), G_t}, where

RG_t = the revenue with the minimum guarantee at year t

R_t = the observed revenue at time t

R_{maxt} = the revenue at the maximum capacity at time t

G_t = the level of revenue at the floor at time t

ii) The deferral option payoff of private company (Vd_t) is:

Vd_t = Max (0, FV_t-PV(FV_t)$_{T-t}$) if $C_t < 0$

= Max (0, $FV_t - \frac{FV_t}{(1+r_{t,T})^{T-t}}$)), or

= 0 if C_t > or equal 0, where

FV_t	=	the face value of notification issued in the period of t (the value of revenue sharing in each year which is predetermined, based on the projected cash flow of a base case scenario). The payment will be paid at the end of the concession.
$PV(FV_t)_{T-t}$	=	the present value of a payment FV_t at time t
C_t	=	the observed project's free cash flow (after debt) at time t
T	=	the total concession period

The deferral option is triggered when the project's NPV in each year is negative, then the private company can delay the concession payment. The deferred amount can be seen in table 5.10 in Chapter 5. The payoff (cash flow) for the combined minimum traffic guarantee and the deferral option (Vdmt) is:

Vdm_t	=	Max (0, FV_t-$PV(FV_t)_{T-t}$) if Sm_t <0, or
	=	Vm_t if Sm_t > or equal 0
Sm_t	=	the project's NPV with the minimum traffic guarantee
Vm_t	=	the option value of the minimum traffic guarantee at time t

Tables 6.6 provides the example of the payoff calculating for the combination of the minimum traffic guarantee option and the deferral option.

a) The binomial path of the projected cash flow after debt at t=8	= -1,552 million baht
a.1) the binomial path of the projected cash flow after debt with the minimum traffic guarantee at 90% at t=8	= 295 million baht
a.2) the value of the minimum traffic guarantee (Vm_t)	= a.1-a =295--(1,552) =1,847 million baht
b) the predetermine deferred amount at t=8	= 2,496 million baht
c) the deferral option payoff max (0, FV_t-$PV(FV_t)_{T-t}$) t= 8 T=30	= max (0, FV_t-$PV(FV_t)$) = max(0, 2,496-PV(2,496)) = max(0, 2,299)) = 2,299 million baht
d) the payoff (cash flow) for the combined minimum traffic guarantee and the deferral	= Vm_t if Sm_t > or equal 0 = 1,847 million baht

option = max (0, FV_t-PV(FV_t)) if Sm_t <0 = Sm_t if Sm_t > or equal 0	
e) Result	By including the minimum traffic guarantee, the deferral option is out of the money. This case is an example of a situation where that the first option may eliminate the latter option.

Table 6.6: Calculating sheet for valuing the combination of the minimum traffic guarantee option and the deferral option

In this combination, the interaction effect is negative at 977 million baht. The sum of the value of each separate option is higher than the combined value of the two options which represents a case of negative interaction. Therefore, measuring the value of option combination by simply adding the individual option value would be a slight overstatement. However, the combination of the minimum traffic guarantee option and the deferral option enhances the project's value, making the project feasible. The NPV of the SES project is high at 12,549 million baht. This combined option may not be worth it as it contains potential future liability to the government for the whole life of the project.

6.3.2 *Combination of the debt guarantee option (government) and the deferral option (private company)*

When the debt guarantee option and the deferral option are combined, the interaction effect is -3,039 million baht, signalling overlap in exercise region (presented in figure 6.6). As a result of the negative interaction, the combined value of options is less than the sum of the value of each separate option. This is because the exercise of the debt guarantee option will reduce the opportunity to exercise the deferral option or vice versa. These two options are the same type and are fully overlapped in the exercise areas. The value of this combined option can be determined as follows.

i) The payoff of the debt guarantee option is:

V_{Dt} = Max (-(Cb_t-D_t), 0) and the project's free cash flow with debt guarantee is

Rd_t = Max [Max { Min (Cb_t, C_{maxt}), 0,}, D_t], where

Rd_t = the project's free cash flow with debt guarantee at time t

Cb_t = the observed project's free cash flow (before debt) at time t

C_{maxt} = the project's free cash flow at maximum capacity at time t

D_t = the amount of debt (principal and interest) that has to be serviced by the project company at time t

ii) The deferral option payoff for private company is:

Vd_t = Max (0, FV_t-$PV(FV_t)_{T-t}$) if $C_t < 0$

= Max (0, $FV_t - \frac{FV_t}{(1+r_{t,T})^{T-t}}$)), or

= 0 if C_t > or equal 0 where

FV_t = the face value of notification issued in the period of t (value of revenue sharing in each year which is predetermined, based on the project cash flow of a base case scenario). The payment will be paid at the end of the concession.

$PV(FV_t)_{T-t}$ = the present value of a payment FV_t at time t

C_t = the observed project's free cash flow (after debt)

T = the total concession period

Therefore, the payoff for the combination of the debt guarantee option and the deferral option (Vdd_t) is:

Vdd_t = Max (-C_t ,max (0, FV_t-$PV(FV_t)_{T-t}$) if C_t <0, or

= 0 if C_t > or equal 0

C_t = the observed project's free cash flow (after debt)

= Cb_t-D_t

Table 6.7 provides an example of the payoff calculation for the combination of the debt guarantee option and the deferral option.

a) The binomial path of projected cash flow after debt at t=8	= -1,552 million baht
a.1) the binomial path of the project cash flow after debt with debt guarantee at t=8	= -(a) = 1,552 million baht
b) the predetermine deferred amount at t=8	= 2,496 million baht
c) the deferral option payoff max (0, FV_t-$PV(FV_t)_{T-t}$) at t=8	= max (0, FV_t-$PV(FV_t)_{T-t}$) = max(0, 2,496-PV(2,496)) = max(0, 2,299))

	= 2,299 million baht
d) the payoff for the combination of the debt guarantee and the deferral option Max (C_t ,max (0, FV_t-PV(FV_t) $_{T-t}$)) if C_t <0	= Max (-C_t ,max (0, FV_t-PV(FV_t) $_{T-t}$)) if C_t <0 = Max (-(-1,552),2,299) = 2,299 million baht
e) Result	The option value is equal to the value of the stand-alone deferral option. Though the debt guarantee option is in the money it is worthless when combined with the deferral option.

Table 6.7: Calculating sheet for valuing the combination of the debt guarantee option and the deferral option

The stand-alone deferral option is valued at 6,318 million baht which is slightly less than the combined value (6,391 million baht). This combination is an example of the two put options with almost full overlap in the exercise area, and the first option (the deferral option) can eliminate the second option (the debt guarantee option). It is implied that the combination of these two options may not be effective and that the project is still not financially feasible with negative NPV of -1,357 million baht. The project needs additional options to enhance the project's NPV.

6.3.3 *Combination of the minimum traffic guarantee option, the equity guarantee option (government) and the grant option (private company)*

The combination of three options—two options from the government (the minimum traffic guarantee and the equity guarantee) and one option from the private company (grant option) —are combined. The value of this option combination can be calculated as the following:

i) The project's revenue with minimum traffic guarantee option is:

RG_t = Max {Min (R_t, R_{maxt}), G_t}, where

RG_t = the revenue with the minimum guarantee at year t

R_t = the observed revenue at time t

R_{maxt} = the revenue at the maximum capacity at time t

G_t = the level of revenue at the floor at time t

ii) The payoff for the equity guarantee option (Ve_t) at time t is:

Ve_t = Max (E_t-C_t, 0), and

The project's free cash flow with the equity guarantee option is:

Re_t = Max [Max { Min (C_t, C_{maxt}), 0,},E_t] , where

Re_t = the project's free cash flow with equity guarantee at time t

C_t = the observed project's free cash flow (after debt) at time t

C_{maxt} = the project's free cash flow at maximum capacity at time t

E_t = the level of the project's free cash flow that generates return equal to a required return on equity at time t

iii) The payoff of the grant option (Vg_t) is:

In case

$C_t \geq 0$ = 0

$C_t < 0$ = Min (-C_t, G_t), where

C_t = the observed project's free cash flow (after debt) at time t

G_t = the amounts of government grant for each year (the amount of revenue sharing in table 5.10) at time t

Therefore the payoff for the combination of the minimum traffic guarantee option, the equity guarantee option and grant option is:

V_{meg} = Max (E_t-C_{mt},Vg_t) if C_{mt} <0, or

= E_t-C_{mt} if 0<C_{mt}<E_t, or

= 0 if C_{mt} > E_t, where

C_{mt} = the observed project's free cash flow (after debt) with the minimum traffic guarantee

Vg_t = the value of the grant option at time t

Table 6.8 presents the example of the payoff calculation for the combination of the minimum traffic guarantee option, the equity guarantee option and grant option.

a) The binomial path of the projected cash flow after debt at t=8 of project operation	= -1,552 million baht
a.1) the binomial path of the projected cash flow after debt with the minimum traffic guarantee at 90% at t=8	= 295 million baht
b) the equity guarantee amount at t=8	= 551 million baht

c) the max grant amount at t=8	= 2,496 million baht
d) the single equity guarantee option payoff = Max (E_t-C_t, 0)	= max (E_t-C_t, 0) = max (551-(-1,552),0) = 2,103 million baht
e) the single grant option payoff =Min (-C_t, G_i)	= Min (-C_t, G_i) = Min (-(-1,552), 2,496) = 1,552 million baht
f) the payoff for the combination of the minimum traffic guarantee option, the equity guarantee option and grant option =max (0,E_t-C_{mt},G_i) if C_{mt} <0 = max (E_t-C_{mt}, 0) if 0<C_{mt}<E_t = 0 if C_{mt} > E_t	= max (E_t-C_{mt}, 0) if 0<C_{mt}<E_t = max (0,551-295,0) = 256 million baht
g) Result	By including the minimum traffic guarantee, the project NPV is improved. The grant option is out of the money. Adding the minimum traffic guarantee decreased the opportunity to exercise the grant option. Typically, if put options are overlapped, the combined option value will exhibit negative interaction. The interaction effect is moderately negative.

Table 6.8: Calculating sheet for valuing the combination of the minimum traffic guarantee option, the equity guarantee option and grant option

The combination of these three options enhances the project's NPV without option from -7,749 million baht to 11,469 million baht. This combination combines three put options that overlap in exercise regions; therefore, the interaction effect is negative at -3,709 million baht. The minimum traffic guarantee option increases the value of the underlying asset (the project's cash flow). Then, the value of the equity guarantee option (put option) and grant option (put option) decreased as the value of the underlying asset (the project's cash flow) increases. However, this option combination is recommended as it spends a smaller amount of the government support.

6.4 Combination of financial institution option and private company option

This section focuses on option combinations involving financial institution and private company. In typical project financing, the project company borrows funds from the financial institution for the development and operation of the project whilst cash flows that are generated by the project are used to make principal and interest payments on the loan. Therefore the uncertainty of the project's cash flow exists with financial institutions. To mitigate such risks, the managerial flexibility in the project is required by the financial institution.

As shown in the previous section, managerial flexibility embedded in investment projects typically takes the form of a collection of real options. This part focuses mainly on valuing the combination of the financial institution option and the private company option. The values of the SES project with the combination of financial institution option and private company option and their interactions are shown in the following table:

Option value (million baht)	**Project NPV with option**	**Option interaction**	**No interaction (value isolation)**	**Interaction effect**
F1,P1	1,916	9,664	6,906	2,758
F1,P2	2,973	10,721	3,678	7,044
F1,F2,P1	2,598	10,347	7,615	2,731

Financial institution option

F1 = the Deferral option

F2 = the Abandon option without threshold

Private company option

P1 = the Deferral option

P2 = the Grant option

Table 6.9: The values of the combination of the financial institution option and private company option and their interaction effects (million baht)

The investment project with combination of financial institution option and private company option is summarised in figure 6.7.

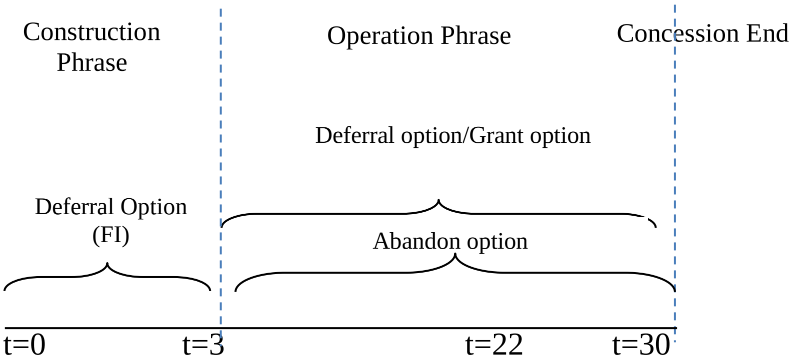


Figure 6.7: The exercise region of the financial institution option and private company option

When the financial institution option is combined with private company option, there is an interaction effect. Each option combination is valued by the binomial lattice model as follows:

6.4.1 *Combination of the deferral option (financial institution) and the deferral option (private company)*

When the first deferral option of financial institution and the second deferral option of the private company are combined, the project value is enhanced. With the combined option, the probability of the lender to exercise its first deferral option is less as the project's NPV with the second deferral option (private company) is enhanced as seen in table 6.10:

Scenario	Total construction cost at year 3 (million baht)	Value of deferral option for financial institution without the deferral option (private company) at the 3rd year (million baht)	Value of deferral option for financial institution with the deferral option (private company) at the 3rd year (million baht)
A	33,471	1,939	13,122
B	29,414	0	11,447
C	25,848	0	9,149
D	22,715	0	7,921

Table 6.10: The value of the deferral option (FI) at the end of the 3rd year for various construction costs (million baht)

The binomial path of the combined option is presented in figure 6.8. The value of the project is enhanced by combined both deferral options (financial institution and the private company).

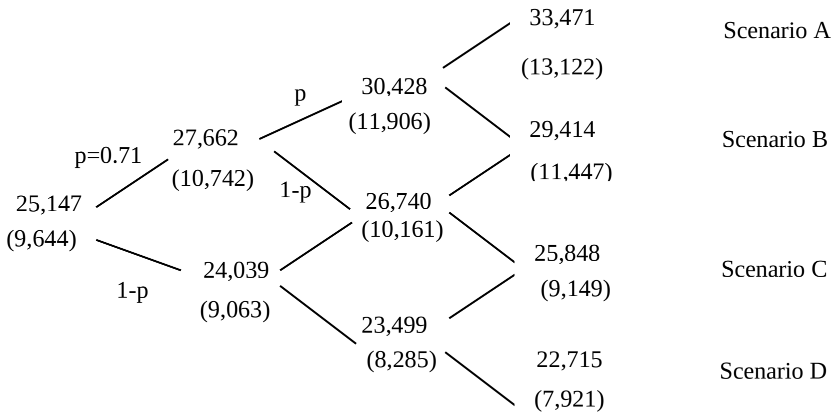


Figure 6.8: The 3-year binomial path of total construction cost and the value of the combination of both deferral options (in parenthesis) in million baht

The project's NPV of the SES project is improved from -7,749 million baht to 1,916 million baht with the value of the combined deferral options at 9,644 million baht. Therefore, the project is feasible. Though both options are put options, their exercise regions do not overlap, and one option supports the other option. Furthermore, two options have a different expiration date. The deferral option of the financial institution can be exercised during construction period whilst the deferral option of the private company can be exercised during the project operation phase. Because there is no overlapping in the exercise, the interaction effect is high at 2,758 million baht. This type of option combination is recommended for policy implementation.

6.4.2 *Combination of the deferral option (financial institution) and the grant option (private company)*

When the deferral option is combined with the grant option, there is an interaction effect. Valuing this option combination can be determined in the following ways.

i) The payoff of the grant option (Vg_t) of the private company is computed by the following:

Vg_t = 0 if $C_t \geq 0$ or

= Min ($-C_t$, G_i), if $C_t < 0$, where;

Vg_t = the value of grant option at time t

C_t = the observed project's free cash flow (after debt)

G_i = the amount of government grant each year (the amount of revenue sharing in table 5.10)

In this financial scheme, the private company foresees the amount of grant that the government must pay to the concessionaire under the pre-agreed condition in the concession contract. The value of the project's NPV is enhanced with grant options, and therefore the likelihood to exercise the deferral option of the financial institution is decreased. The value of the deferral option at the end of year 3 for various construction costs is provided in table 6.11.

Scenario	**Total construction cost at 3rd year (million baht)**	**Value of the deferral option for financial institution without grant option (private company) at 3rd (million baht)**	**Value of the deferral option for financial institution with grant option at 3rd year (million baht)**
A	33,471	1,939	14,737
B	29,414	0	12,562
C	25,848	0	10,127
D	22,715	0	8,731

Table 6.11: The value of the deferral option (FI) with/without grant option at the end of the 3rd year for various construction costs

The binomial path of the combination of the deferral option (financial institution) and the grant option (private company) is presented in figure 6.9. The value of project is enhanced by the combination of the deferral option and the grant option. The value of this combined option at each node on the 3-year binomial path is shown in the parenthesis in figure 6.9.

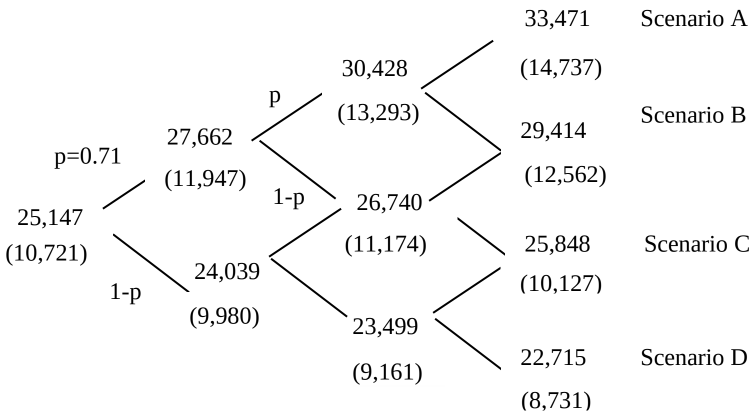


Figure 6.9: The 3-year binomial path of total construction cost and the value of the combination of the deferral option (financial institution) and the grant option (private company): million baht

Though the project's NPV improves from -7,749 million baht to 2,973 million baht, then, the SES project is financially feasible. The interaction effect is 7,044 million baht because there is no overlap in the exercise areas and the grant option has significant values under the cost overrun scenario (Scenario A in table 6.11). Therefore, the project does not require the additional options to increase its NPV.

6.4.3 *Combination of the deferral option and the abandon option without threshold (financial institution) with the deferral option (private company)*

Three options—two options from financial institution (the deferral and the abandon option without threshold) and one option from the private company (the deferral option)—are combined. Also, two put options (the abandon option without threshold of the financial institution and the deferral option of the private company) and one call option (the deferral option of the financial institution) are combined. The value of this option combination is calculated with the following steps.

Step 1: Calculating the value of the combination of abandon option (financial institution) and the deferral option (private company).

1.1) the payoff for the abandon option is:

Va_t = Max (X_t-S_t, 0), where

X_t = the exercise price of a put option (threshold level: outstanding debt) at time t

S_t = the project's value (the NPV of EBITDA) at time t

1.2) the payoff for the deferral (Vd_t) option is:

Vd_t = Max (0, FV_t-$PV(FV_t)_{T-t}$) if $C_t < 0$

= Max (0, $FV_t - \frac{FV_t}{(1+r_{t,T})^{T-t}}$)), or

= 0 if C_t > or equal 0 where

FV_t = the face value of notification issued in the period of t (value of revenue sharing each year which is predetermined, based on the project cash flow of a base case scenario). The payment will be paid at the end of the concession.

$PV(FV_t)_{T-t}$ = the present value of a payment FV_t at time t

C_t = the observed project's free cash flow (after debt)

T = the total concession period

Step 2: The next step is to combine the abandon option (financial institution) and the deferral option (the private company) with the deferral option (financial institution). The probability of the financial institution to exercise its deferral option is less as the future cash flow (with the abandon option of financial institution and the deferral option of the private company) is enhanced as seen in table 6.12.

Scenario	**Total construction cost at 3rd year (million baht)**	**Value of the combined abandon option of financial institution with the deferral option of the private company at 3rd year (million baht)**
A	33,471	15,369
B	29,414	11,447
C	25,848	9,149
D	22,715	7,921

Table 6.12: The value of the combined abandon option (financial institution) and deferral option (the private company) at the end of the 3rd year of the binomial path for various construction costs

The binomial path of the combination of deferral option (financial institution) and the abandon (financial institution) and the deferral option (private company) is presented in figure 6.10.

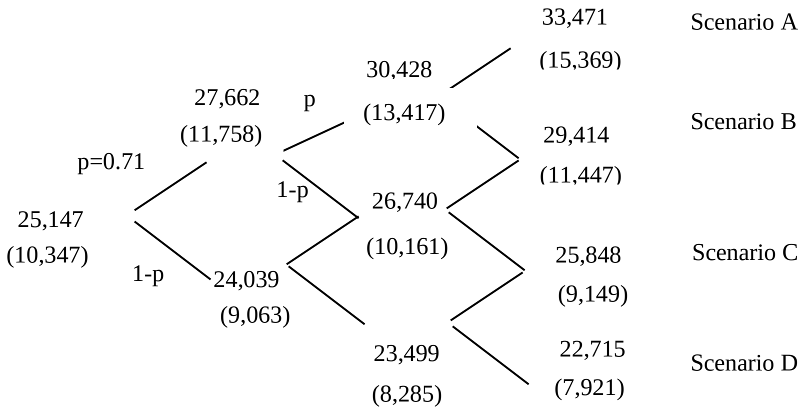


Figure 6.10: The first 3-year binomial path of the combination of the deferral option and the abandon option (financial institution) and the deferral option (private company) in million baht

The interaction effect of this combination is quite high, valued at 2,731 million baht. It also shows that the first option (the deferral option from the private company) eliminates the second and third option. When the deferral option from the private company is exercised, the abandon-without-threshold (financial institution) and the deferral option (financial institution) are out of money. In addition, the project does not need the additional options from either the financial institution or the private company to increase the project's NPV. It is noted that even though more options are applied, the option combination may not be worthwhile.

6.5 Volatility and Seasonality Analysis: Option combinations

In this subsection, the analysis of the option value for various option combinations value is conducted based on systematic seasonal variations of the traffic flow. In this case, the volatility of the underlying cash flow is determined from the volatility of traffic volume. The volatility of traffic volume is calculated on historical data during 2004-2015. To account for seasonal effects of traffic flow, an analysis explores volatility for annual traffic data from 2004 to 2015. Based on year-to-year growth rates (see table A5 in appendix A) as well as seasonal adjustments for (monthly) traffic volume (see table A6 in appendix A), traffic volatility is valued at approximately 4% and the risk-free interest rate in the model is valued at 3%.

For all combinations of options, except the combination of options with the minimum traffic guarantee (government), the value of option combination decreases with a decrease in volatility of the traffic flow (from 20% to 4%). It is generally known that option value increase (decrease) with an increase (decrease) in volatility. Table 6.13 shows the relationship of various option combinations, calculated using binomial lattice, to changes in volatility, which the approach accounted for the seasonality effect of traffic flow.

Option combinations for the SES project	**Option value (million baht) at 20%-volatility and 3%-risk-free interest rate**	**Option value (million baht) at 4%-volatility and 3%-risk-free interest rate, account for seasonality**
The deferral option (FI) and the minimum traffic guarantee (government)	27,246	27,252
The deferral option (FI) and the debt guarantee option (government)	7,543	5,200
The deferral option (FI) and the equity guarantee option (government)	10,378	7,203
The minimum traffic guarantee (government) and the deferral option (private company option)	30,680	31,059
The debt guarantee option (government) and the deferral option (private company option)	10,463	5,367
The minimum traffic guarantee and the equity guarantee (government) and the grant option (private company option)	29,380	29,566
The deferral option (FI) and the deferral option (private company)	15,232	8,278
The deferral option (FI) and the	17,503	9,013

Option combinations for the SES project	Option value (million baht) at 20%-volatility and 3%-risk-free interest rate	Option value (million baht) at 4%-volatility and 3%-risk-free interest rate, account for seasonality
grant option (private company)		
The deferral option (FI), the abandon option without threshold (FI) and the deferral option (private company)	15,232	8,278

Table 6.13: The value of option combinations at different volatility levels

For the pair of options, the most valuable option is the combination of the minimum traffic guarantee option (government) and the deferral option (private company), regardless of how volatility of traffic is.

6.6 Sensitivity to other parameters: Option combinations

The effect of risk-free interest rate on the value of real option for option combinations is explored in this subsection. In general, the interest rate of the project is often increased to compensate for risk. In binomial lattice, how much the underlying asset moves up or down is determined by its volatility while the interest rate used in real options is a risk-free interest rate.

It is shown from the analysis that the value of option combinations increases with the decrease in risk-free interest rate for all option combinations. The relationship is shown in table 6.14.

Option combinations for the SES project	Option value (million baht) at 6% of risk-free interest rate (20%-volatility)	Option value (million baht) at 3% of risk-free interest rate (20%-volatility)
The deferral option (FI) and the minimum traffic guarantee (government)	24,018	27,246
The deferral option (FI) and the	6,424	7,543

Option combinations for the SES project	Option value (million baht) at 6% of risk-free interest rate (20%-volatility)	Option value (million baht) at 3% of risk-free interest rate (20%-volatility)
debt guarantee option (government)		
The deferral option (FI) and the equity guarantee option (government)	9,016	10,378
The minimum traffic guarantee (government) and the deferral option (private company option)	20,298	30,680
The debt guarantee option (government) and the deferral option (private company option)	6,391	10,463
The minimum traffic guarantee and the equity guarantee (government) and the grant option (private company option)	19,218	29,380
The deferral option (FI) and the deferral option (Private company)	9,664	15,232
The deferral option (FI) and the grant option (private company)	10,721	17,503
The deferral option (FI), the abandon option without threshold (FI) and the deferral option (private company)	10,347	15,232

Table 6.14: The value of option combinations at different risk-free interest rates

For the pair of options, the most valuable option is the combination of the deferral option (financial institution) and the minimum traffic guarantee option (government) for 6% of risk-free interest rate and the combination of the minimum traffic guarantee (government) and the deferral option (private company) for 3% of risk-free interest rate respectively.

6.7 Summary

This chapter gives an example of the combined options from the government, financial institution and the private company in a large-scale infrastructure project. The option combination can be valued by the binomial option pricing.

The results present that the combined options have a very meaningful value for the policy design and implementation. The option values are significantly influenced by the interaction between the options. Interactions may be small or large. Interactions are dependent upon type, being in or out of money, and the order of the options. In terms of numerical calculation, 1) the combination of the minimum traffic guarantee (government) and the deferral option (financial institution) provides the highest option value but scarifies a lot of government budgets; and 2) the combination of the deferral option (financial institution) and the debt guarantee of government or the combination of the deferral option (financial institution) and the equity guarantee option of government or the combination of the deferral option (financial institution) and the grant option of the private company or the combination of the deferral option (financial institution) and the deferral option of the private company are recommended to apply to the project. This is because when these options are combined, the interaction effect is large.

Chapter 7: Conclusion and Recommendation

This chapter summarises the research findings related to the application of real options and option interactions among the key project stakeholders in large scale infrastructure projects. Referring to the purpose of this research, an attempt to minimise the knowledge gap between risk sharing between the public and private sector in PPP projects has been made. This chapter concludes and illustrates the achievements of the research. Limitations of this research and recommendations for further research explorations are also provided in this chapter.

This study has applied the real option theory in large-scale infrastructure projects and the case study of the Second Stage Expressway System (SES) project in Bangkok, Thailand. This study has provided an analysis of the risk allocations among the three main stakeholders in the project; the government, the financial institution and the private company (project sponsor). This research demonstrates the complexity and the obscurity of risks and of appropriate and inappropriate risk allocation. It is concluded that the risks incurred in a large-scale infrastructure project need to be thoroughly analysed, managed and allocated. The study also concurred with much of the academic literature and previous research studies that large-scale infrastructure projects are subject to a high probability of project failure, requiring supports and commitments from the stakeholders in the project development. However, the degrees of appropriate support are doubted and require quantitative analysis to evaluate. The gap of the past research studies has inspired the author to continue research studies in the field of risk allocation in the context of project finance.

This research noted the following lessons and findings from the past literature. The large infrastructure projects themselves without support are subject to the risk of project failure. The literature addresses the importance of the support from the main stakeholders, especially from the government, in the project development. Governments can make such projects feasible by offering support such as guarantees or grants under certain conditions. However, the government has to scarify the project success with its spending and such risks are solely transferred to the government. To mitigate the government risk, Public Private Partnerships (PPPs) are being applied. Private participation in infrastructure projects has been sought by governments in order to allocate project risks and to provide an additional source of funds in the project investments. The literature also mentions that the success of PPPs depends on reasonable support or risk sharing between the private sector and the government.

Determining the optimal level of government support and risk allocation may not be done by traditional project evaluation methods and the shortfall of such methods then requires the use of option pricing techniques. Real options are introduced as the tool to quantify the support of governments in investment projects. Much of the literature also refers to the notion that real options are suitable to determine the optimal decision for project investment. Typical project options include the option to abandon a project that is performing poorly or to provide the guarantee level when the project revenue is below plan. However, most of the literature focused on government support in the project. Options from other stakeholders such as financial institutions and the private company are missing in the studies. Furthermore, a quantitative tool to measure the risk allocations between the private companies and government is required. The risk allocations among them are somehow subjective. The designs of such support are somehow subjective and irrational. This is because of the lack of a suitable quantitative tool for evaluation, while the irrationality is derived from inefficiencies of the traditional method. In this research, the design and formulation of the option combinations among the government, financial institution and private company in large infrastructure projects are explored.

Real options with the binomial lattice model are applied in this study to use for evaluating investment projects. This is because the model is simplified, flexible and efficient in the calculation. The study applied the real options in a real world project, the expressway project in Thailand. Initially, the study found that the project was infeasible, mainly due to the uncertainty of traffic revenue. Also, due to the government budget constraints, the project needed private participants. However, the project alone was not sufficiently attractive for the private sector to engage in the project. To decrease the risks of the project, concessionaires normally negotiate with the government and financial institutions to provide some support or options such as revenue guarantees or an abandonment option. The presence of the options will increase the main stakeholder flexibility in taking the investment decision and thus increase the project's value.

The option combination among the main stakeholders, the government, financial institution and private company are developed in this study. The major contribution of this research study is to provide a theoretical and quantitative tool for evaluating the financial viability and risk allocations of large infrastructure projects from the perspectives of the government, financial institution and private company. The results of the study can be summarised in the following:

7.1 The project's value without options

The hypothetical project (the SES project) when evaluated by the traditional method, seems financially infeasible. The project's NPV of the SES project shows negative value. The project features may not be sufficiently attractive for the private sector to invest and for the financial institution to lend in this project. Therefore, the additional support or options are needed to make the project more attractive. A typical infrastructure project, especially in Thailand, is normally financially infeasible because the support of the government in the project is limited. To attract private investors and financial institutions to the project, governments may create the incentives, support or option features to enhance the project's value.

7.2 The real options of the financial institution

One of the major concerns of financial institutions about any project is the probability and impact of the revenue shortfall and cost over estimate. From the financial model, the risk of the financial institution has been decreased by adding real options in the contract. Although the value of the project with options improved, the improvement was not significant. From the numerical model, it is found that the real options of financial institutions have a small impact upon the project's performance. The main findings from the hypothetical project are summarised as follows:

7.2.1 Considering a single option, it is found that the abandonment option without a threshold provides the greater benefit to the project though the project is still not financially feasible. Normally, the financial institution (lender) will exercise the abandonment option, at the expense of the government (project sponsor) and the project owner, when the project cannot service all of its debt obligations. The government provides the needed financing, funds for cash-flow deficiency, guarantees for repayment of the existing debt and allows the project company to operate the project. The project company has to find alternative lenders for the replacement of a defaulting lender. The numerical model shows that the lender will exercise the option and gains considerable benefit when the revenue is greatly underestimated. The benefit of the abandonment option is small because the loan is normally a structured periodic payment and the probability to trigger the option is decreased as the time passes. The abandon option will have greater value in the early years because the amount of the outstanding debt is large. However, in the real world the lenders normally do not utilize the option in the initial year of the project operation. Lenders may decide to wait and see. It should be noted that the values of other lenders' options such as the deferral option, are quite small and insignificant relative to the project's value.

7.2.2 The value of the interaction effect is presented in the context of financial institution options. This research found that the combination of the deferral option, the abandonment option without threshold and the investment option provides the largest interaction effect. This combination shows no overlapping in the exercise areas between the abandonment option/the investment option and the deferral option. The abandonment option can be exercised at the project's operation phrase while the deferral option is applied during the project pre-operation stage. The option to defer is formulated under a lending option held by the financial institution at the contract signing and expires before operation commencement. Furthermore from the model, the abandonment option during the project's operation reduces the probability of deferment. This is because the abandonment option increases the project's value and then reduces the probability of the lender deferring the financing of the project.

7.2.3 Though the research study found that real options and their combinations are very useful tools for financial institutions, the project is still financially infeasible in the context of the SES project. An individual option of a financial institution is nevertheless limited in its practical value. Real life projects are financially structured in that they involve the collections of multiple real options from main stakeholders such as the government and the private company. The provision of supports or options from the government and the private company are required.

7.3 The real options of the government

It is generally learned from the literature that large infrastructure projects are subject to substantial market risks such as the revenue risk during the operation phase. To avoid the downside revenue risks, the project owner usually requires the government to provide support mechanisms. Government supports in the projects have option-like characteristics, and the option pricing model is used to determine the appropriate level of government support, which cannot be achieved through the traditional project analysis methods such as NPV or IRR. Such government supports include the revenue guarantee, the grant, the debt guarantee, the exchange rate guarantee and others. In revenue guarantee, the government is obligated to compensate for a revenue shortfall between a pre-specified revenue level and actual revenue collection. Governments can make the project feasible by providing supports and subsidies to the project under certain conditions. Such supports can increase the credit capability of Public Private Partnership (PPP) projects that face high risks. However, the appropriate support level should be specified since such supports extend the government cost and budget. From the model calculation the following were found:

7.3.1 Based on valuing the individual option for the government, the results show that a single option such as the minimum traffic guarantee option, the debt guarantee option or the equity guarantee option can create value to the project. Among these options, the minimum traffic guarantee option provides the greatest promise. The project is attractive for an investment decision with government support in the form of a minimum traffic guarantee. The model also showed that the suitable guarantee level is around 80-90% of the revenue guarantee. However, the minimum traffic guarantee is valuable in the view of the private investors and financial institutions, but it requires substantial budgetary commitment from the government. If the project performs poorly due to high revenue risks, the lender or the private company may ask the government to provide the minimum traffic guarantee at the expense of the government. The other government supports may be a preferable policy choice under budgetary constraints, and their justification is straightforward. The single guarantee option may not be a good choice for the government. The minimum traffic guarantee option involves large government budgetary commitments, therefore its benefits and costs should be carefully reviewed. The other options, or option bundling, may be considered as an alternative for the government. The government can design an appropriate level of guarantee and type of guarantee which attracts private participation in the project as well as permitting an affordable government budget.

7.3.2 It can be seen from the real option model that the support of the government in the form of the minimum guarantee may not be appropriate. Though this option increases the value of the project, it requires a large proportion of the government budget. In addition, other options from the government, such as debt guarantees and equity guarantees are insufficient to make the project attractive for investment, and therefore the option bundling is required.

7.3.3 The government support can be seen as the combination of options. For the option combinations of two or more options, the combination of the minimum traffic guarantee at 90% and the equity guarantee provided the most value to the investment decision. It can be seen that the project is made more valuable by adding more options. Also, this option combination needs a substantial government budget commitment. With various types of option strategies, governments can choose a suitable set of options to optimize the relationship between the benefits and the cost. For example, governments can select the combination of the minimum traffic guarantee at 90% and the debt guarantee option under which the project is still valuable with a smaller government budget.

7.3.3 The interactions among the options of the government support are quite significant. The interaction is likely to have an impact upon projects which are large, long and uncertain in terms of revenue collection. The positive interaction increases the project value but also raises spending on government costs. The negative interactions are likely to benefit the government as the value of the support decreases. Understanding these interactions and designing proper option combinations provides the government with the flexibility to manage the project to achieve the desired result. It is found that within the government bundle of options, the negative interactions are more prevalent within a given project. The negative interaction decreases the value of the project as well as the expenses of the government. It also found that the more options are combined, the greater the negative interaction.

7.4 The real options of the private company (concessionaire)

The private company (sponsor) needs supports from the government and the lender to increase the project creditworthiness as well as to mitigate risks. The results of this study have delivered an interesting result. The project that is solely developed by the private company, either with or without options, is insufficient. The private company normally requires the risk allocation and mitigation in the project. Risks should be effectively shared and allocated to the lender and government. To allocate risks, the private company needs the strategic tools to properly evaluate an infrastructure project’s potential for non-recourse project financing. Assessing a project’s financial viability gives the private company the opportunity to explicitly consider whether i) to continue investing in the project without any request for support, or ii) to continue participating in the project with the additional supports from the government or the lender, or iii) to abandon the project by pushing the project back to the government after the project performs poorly. In such circumstances, this research proposes to present and to discuss the real option method for valuing private investments in public infrastructure. The real option model exams are based on the flexibility of the private company in the project at each stage of the project development, in the pre-operation, post construction and operation phrases. The highlight has been concentrated on the benefits of the options and their interactions adding to the project's value. Major findings are presented as follows:

7.4.1 The private company prefers to have option flexibility throughout the whole project cycle. This study showed that the option to defer the concession fee payment to the government provides the most benefit to the private company. The study found that the time value of the option is significant. Private companies have the flexibility to defer the concession fee to the government until the project can generate sufficient revenue. It is found that the deferral amount of the project case-study is large, valued at approximately 25% of the project investment cost. However, with the arrangement of the single option, the project is still not financially feasible.

7.4.2 One of the important findings in real options of the private company is determining the optimal timing of the irreversible investment during the life of the option. Considering the abandonment option, the private company can abandon the project, pushing the cost to the government and the lender when the project value has decreased to a level much lower than expected. The result of the model calculation with a hypothetical project indicates that the suggested time to abandon, in the case preferred by the private company, is between 5-10 years of the operation period. Late exercising of real options on time significantly reduces the project's value. The study implied that the private company should carefully review the project viability during that period, thus deciding whether to remain in the project or to leave.

7.4.3 Considering the option combination, the model demonstrates that the option interaction is small and negative. In the case of the small interaction, the additive is a good approximation. For negative interaction, it means that adding more options may be worthless or reduce the opportunity to exercise the prior option, thus the project's value remains the same as it would have been without adding the option. The main reason for small interaction is because options for private companies are of the same types, with most of the exercising areas overlapping.

7.4.4 The single option and option combinations within the private company are found insufficient for the success of the project development. The supports or options across the private company are required. The model also found that a single deferral option almost makes the project feasible. Adding a few options from the government such as a debt guarantee, an equity guarantee or from the lender, i.e., the deferral option, may turn the project to become financially feasible. Furthermore, the grant option is the second ranked option of the private company which can be combined with the government or the financial institution options to increase the project's value.

7.5 Option combinations among the financial institution, government and private company

Risk allocation between the financial institution, government, and private company is the critical success factor for PPP infrastructure projects. The quantitative method to quantify risk allocation is sophisticated. With real options, this research study can select the option combination, and compare and design a suitable policy. It is generally found that interactions among the options are dependent on the type, separation, whether or not the option is in or out of the money, and the option's sequence.

Individual options applied to the project represent: i) insufficient to make the project feasible; ii) overload the risk exposures for specific stakeholders, i.e., government, and iii) spending a large budget in the case of government guarantees. Formulating option interactions among the financial institution, government and private company is inevitable. For example, the lender commits a loan based on the strong participation of the government and private company whereby the benefits of the lender are protected. The research study pairs the option interactions among the financial institution, government and private company. The main findings of the option interactions are as follows:

7.5.1 In terms of policy design and implementation in the project, based on the real option model, the following option-combination structures are ranked by project NPV:

Rank	Government	Financial Institution	Private company
1.	The minimum traffic guarantee at 90%	Deferral option	-
2.	The minimum traffic guarantee at 90%		Deferral option
3.	The minimum traffic guarantee at 90% and the equity option		Grant option
4.		Deferral option	Grant option

Rank	Government	Financial Institution	Private company
5.		Deferral option and the abandon option without threshold	Deferral option

Table 7.1: Ranking of the option combinations among the government, financial institution and private company by the project NPV

Based on the real option model, it can be shown that the government has an important role in establishing the financial structure for the large-scale infrastructure development. Without the government's support, the project may not be attractive for investment. However, though these option combinations enhance the project's value, making the project more attractive for private companies to invest and for financial institutions to provide funding, it is necessary to commit a large government budget. To provide support, the government has to carefully review the optimal financial structure tradeoff between government spending and the other economic and social benefits.

7.5.2 For the pair of financial institution and government options, the most valuable option is the combination of the minimum traffic guarantee option (government) and the deferral option (financial institution). Though this combination is worth the most, it creates a substantial cost for the government. The degree of option interaction for this option is large, so that simple option addition does not provide a good approximation. This study also found that the combination of the equity guarantee of the government and the deferral option of the financial institution had a large interaction effect. This is because there is no overlapping in the exercise areas. This research also found that the degree of interaction was related to the option type and the areas of overlap in the exercise regions. Considering the combination of the equity guarantee option and the deferral option, the project is financially viable with suitable support from the government. This option combination is recommended for the policy design and implementation.

7.5.3 For the pair of the financial institution and private company options, the most valuable option is the combination of the grant option (private company) and the deferral option (financial institution). This study found that the existence of a prior call option (deferral option of the financial institution) may alter the value of the project cash flow (underlying asset) and, then, the value of subsequent put options (grant option of the private company), making for a large interaction effect. For example, the first deferral option (financial institution) under the construction cost overrun scenario will decrease the project cash flow and hence increase the value of the second grant option (private company). This option combination is suitable and recommended in that the project is financially feasible and does not require any additional option from the government. The government, in terms of policy design, may consider designing and structuring the project with this option combination. The financial institution has the benefit of being able to leave the project at an early stage while the private company has the option to receive a grant payment until the project cash flow is sufficient.

7.5.4 For the pair of the government and the private company options, the most valuable option is the combination of the minimum traffic guarantee option (government) and the deferral option (private company). The computational model presents a slightly negative interaction effect for this option combination. With this option combination, the government supplies a lot of support, and therefore this option combination may not be worthwhile for the government. The second ranked option combination is the combination of the minimum traffic guarantee option (government), the equity guarantee option (government) and the grant option (private company). With this combination, the interaction effect is largely negative, thereby decreasing the government spending. Without the participation of a financial institution option, the combination of the minimum traffic guarantee option and the equity guarantee option of the government, and the grant option of the private company may be recommended for policy implementation. This study noted that the minimum traffic guarantee option is essential for the financial structure under the combination of the government and the private company options.

7.5.5 For the three option combinations, the most optimal option is the combination of the deferral option and the abandon option without threshold (financial institution) and the deferral option (private company). With three options combined, the option value is large and accounts for around 40% of the project investment cost. The project turns financially feasible for the private entity and FI with support from the government. The presence of the deferral option (financial institution) will increase the flexibility of the investment decision and thus the project NPV. The deferral option of the financial institution under the worst case scenario (construction cost overrun) will increase the probability of the second (the abandon option without threshold) and the third options (the deferral option) to be exercised, thus increasing the value of the option. However, there exists an overlap in the exercise areas between the abandon option without threshold and the deferral option, resulting in a large interaction effect. In terms of the policy design and implementation, this option combination may be considered as the options increase the value of the project, proper allocation of risks among the private company, financial institution and government. Therefore, the combination of the deferral option (financial institution), the abandonment option (financial institution) and the deferral option (private company) may be recommended as the project is still financially feasible with less government support.

7.5.6 In terms of the value of the interaction effect across main stakeholders, the following option combinations are ranked:

Rank	Government	Financial Institution	Private company
1.	The minimum traffic guarantee at 90%	Deferral option	
2.		Deferral option	Grant option
3.	The minimum traffic guarantee at 90% and the equity guarantee option		Grant option
4.	The equity guarantee option	Deferral option	
5.	The debt guarantee option		Deferral option

Table 7.2: Ranking of the value of the interaction effect (million baht) among the government, financial institution and the private company

Valuing the interaction effect is beneficial because: i) it can increase the project's value; ii) option interaction may have a negative value which helps to reduce the incremental value of certain options such as the minimum traffic guarantee or equity guarantee option. Therefore, the government's future liability is limited with the interaction effects, and iii) it enhances the project valuation accuracy.

Based on model simulations, the combination of the minimum traffic guarantee option and the deferral option (financial institution) gives the highest interaction effect. This combined option helps to enhance the project's value. It also was found that the option interaction within the financial institution options is large. Meanwhile, the option bundling within government and the private company exhibits a negative interaction. Lastly, this research emphasizes the finding that ignoring interactions among options in the project's valuation process may result in a significant underestimation of the value of the project.

7.6 Sensitivity testing and model validation

Unlike financial options, the variables used in real option valuation are not directly observable in the market. For example, traffic volatility is an unknown input and requires estimation. In order to test the validity of the real option model, sensitivity analysis on the significant parameters is performed and the results are summarised as follows:

7.6.1. The most significant parameter is traffic volatility, which has the most impact on the option value. In this study, it is found that an increase in volatility will increase the value of real options, bundle of real options and interaction effect (IE). For the SES project, traffic volatility is estimated using monthly data on traffic volume. However, it is observed that using monthly traffic data without accounting for systematic seasonal variations may affect the calculation of the option values. Therefore, annual traffic data that attempt to remove seasonal variations in the data are used to calculate annual traffic volatility. In this study, annual traffic volatility (4%) is compared to monthly volatility (20%) in the sensitivity analysis. The results indicate that option values increase with increases in volatility.

7.6.2 The following option combinations are ranked by project NPV and option value due to the apparent lower project volatility (4% of traffic volatility):

Rank	**Government**	**Financial Institution**	**Private company**
1.	The minimum traffic guarantee at 90%		Deferral option
2.	The minimum traffic guarantee at 90% and the equity option		Grant option
3.	The minimum traffic guarantee at 90%	Deferral option	
4.		Deferral option	Grant option
5.		Deferral option and the	Deferral option

Rank	Government	Financial Institution	Private company
		abandon option without threshold	

Table 7.3: Ranking of the option combinations by the project NPV due to the apparent lower project volatility

At low traffic volatility, it also found that the government maintains an important role in establishing the financial structure for the large-scale infrastructure development. Without the government's support, the project may not be attractive for investment.

7.6.3 The second most significant parameter is interest rate. The results showed that an increase in the risk-free interest rate will increase the value of call option and decrease the value of the put option. An increase in the risk-free interest rate would decrease the present value of the exercise price therefore increasing the value of call option and decreasing the value of the put option.

7.6.4 In order to test the validity and the accuracy of the binomial model, the value of real options is measured against the equivalent value from a Black-Scholes model. It can be seen in this study that the option values that are calculated by the binomial lattice are close to those calculated by the Black-Scholes option pricing model.

7.7 Summary

Overall, the application of the real option approach in PPP infrastructure projects is promising. The real option approach applied to value the infrastructure project is complicated but the mechanism helps to design and implement government policy. In this study, the researcher considers various forms of government, financial institution and private company supports and options in large-scale infrastructure projects. Through this research study and model analysis, it can be demonstrated that the government plays a crucial role in the risk allocation in large-scale infrastructure projects. The most powerful individual option is the minimum traffic guarantee which is provided by the government. The government takes an active role as the guarantor to assist in the project's success. The level of revenue guarantee is the option for the government which should consider the balance between project's revenue and government costs. However, the government should properly evaluate the economic viability of such arrangements prior to offering optimal option proposals to the private company. The inclusion of a single minimum traffic guarantee in the financial scheme may not be worthwhile for the government in that it creates future contingent liability. This research found that other government options such as the equity guarantee option, when combined with options from the financial institution, may be selected to implement in the project finance scheme.

The relationship among the financial institution, government, and private company is significant. The lender is concerned about whether the loan will be repaid according to the original schedule in the contract. It is also a crucial role of the lender to investigate the creditworthiness of the project and the private company. It is found that project development undertaken solely by the private company is insufficient. To increase the project creditworthiness, the government plays the critical role. Governments can support projects by providing supports such as guarantees to create the project benefit, but these create costs to the government budget. Then the project is strengthened and the lenders feel confident to provide project funding.

Interactions among the options are a critical consideration for policy design and implementation. Real options may interact for various reasons and with different degrees, depending on the probability of their joint exercise, areas of the interaction, and the type of the option during the infrastructure project lifecycle. Governments may consider the interaction effect among options in order to relieve their budgets. Great option combinations may be worthwhile for governments. Looking for the optimal approach with a balance between the project’s value to be attractive for investors and the level of government subsidy required is essential. It is found that some option combinations are recommended: i) the combination of the equity guarantee option (government) and the deferral option (financial institution); ii) the combination of the deferral option (financial institution) and the grant option (private company) iii) the combination of the deferral option (financial institution) and the deferral option (private company) and iv) the combination of the deferral option (financial institution), the abandonment option (financial institution) and the deferral option (private company). The project is financially feasible with these options and the government expense is arranged at the appropriate level.

The research methodology applies real options as an innovative tool in policy analysis. The application of real options enables modelling of individual risk factors, such as revenue risk and construction risk, before informing a comparison of the relative influence of uncertainty.

With real options, this research can critically compare the effects of different policy designs in order to solicit structured public financing schemes. However, policy makers should understand the model limitations and carefully consider the assumptions underlying the valuation methods, particularly traffic flow and the binomial option method. Properly appraised project variables will provide good sources for investment decisions as well as policy design and implementation. Inappropriate applications can mislead and conclude improper policies.

7.7 Recommendations

Recommendations for future research studies have been identified during the progress of this research. The following areas are related to the valuation methodology for PPP infrastructure projects and real option modeling issues that can be explored for further research:

7.7.1 Future research may be to apply other approaches using the real option model such as finite difference, or Monte Carlo simulations to value government, lender and private company supports in large infrastructure projects. In addition, extending this approach to another type of infrastructure project such as mass transit, or water pipe systems will be also very beneficial.

7.7.2 This study found that if the variables in the model such as the traffic volatility change over time, the investment decision may be changed. The policy should be structured in such a manner as to allow its later revision.

7.7.3 The limitations of the real option model should be understood by the policymakers and applicants. For example, the most pertinent limitation is the access to information since the development period. The information required for model simulation and computation is often confidential. In addition, the study suggested that the real option approach should be considered for the valuation of projects with option-like characteristics only after a careful review of the main assumptions in the context of specific applications, because the method may not be applicable to all situations.

7.7.4 There are various other PPP infrastructure assets such as power plant projects, with likely option characteristics. The kinds of informational economies, insights, and policies discussed here in relation to valuing infrastructure projects may be applied in accessing the economic value of other real assets as well.

7.7.5 The main focus of this study is on the stochastic behavior, i.e., Brownian motion of the traffic revenue. Other factors such as macroeconomic data may be considered for project valuation to improve the benefits of the model.

7.7.6 The social benefit may be added to value real options in large-scale infrastructure projects. This social benefit may either increase or decrease the real option value. For example, social losses due to delaying the project may decrease the value of the deferral option, whereas the social benefit may increase the value of the project as well as the value of the real option.

Appendix A Data Sources of the Second Stage Expressway System Project (SES Project)

A1 General project information

Project type	An elevated 6-traffic lane expressway for a total length of approximately 38.5 kilometers
Concession type	30-year Build-transfer-operate (BTO)
Project owner	Bangkok Expressway Public Company Limited (BECL), a listed company in Thailand Stock Exchange
Project sponsor	The Expressway Authority of Thailand (EXAT)
Concession period	Total concession periods : 30 years Construction periods : 3 years Operating periods: 27 years
Land acquisition and construction cost	Construction cost: 25,147 million baht, estimated to be equally distributed over 3 years. Land acquisition cost: 10,000 million baht.

Table A1: General project information

Source: the BECL website (http://www.bemplc.co.th/)

A2 Traffic volume and toll rate

A2.1 *Traffic volume (Million trips per year)*

Year of operation	**4**	**5**	**6**	**7**	**8**	**9**	**10**
- Inbound areas	121	130	164	186	208	197	204
- Outbound areas	17	19	23	24	25	23	23
Year of operation	**11**	**12**	**13**	**14**	**15**	**16**	**17**
- Inbound areas	210	215	214	213	214	214	214
- Outbound areas	24	24	25	22	23	23	24
Year of operation	**18**	**19**	**20**	**21**	**22**	**23**	**24**
- Inbound areas	214	214	214	214	214	214	214
- Outbound areas	24	22	23	23	24	24	23
Year of operation	**25**	**26**	**27**	**28**	**29**	**30**	
- Inbound areas	214	214	214	214	214	214	
- Outbound areas	23	24	24	24	24	24	

*The maximum toll capacity is 214 million trips per year.

Table A2: Traffic volumes of the SES project

Source: The project feasibility study submitted by project consultant to the government agency (EXAT)

A2.2 *Toll rate (Baht per trip)*

Year of operation*	**4**	**5**	**6**	**7**	**8**	**9**	**10**
- Inbound areas	30	30	30	30	30	40	40
- Outbound areas	10	10	10	10	10	15	15
Year of operation	**11**	**12**	**13**	**14**	**15**	**16**	**17**
- Inbound areas	40	40	40	50	50	50	50
- Outbound areas	15	15	15	20	20	20	20
Year of operation	**18**	**19**	**20**	**21**	**22**	**23**	**24**
- Inbound areas	50	60	60	60	60	60	70
- Outbound areas	20	25	25	25	25	25	30
Year of operation	**25**	**26**	**27**	**28**	**29**	**30**	
- Inbound areas	70	70	70	70	80	80	
- Outbound areas	30	30	30	30	35	35	

* The first 3-year was the construction period.

Table A3: Toll rates of the SES project

Source: The project feasibility study submitted by project consultant to the government agency (EXAT)

A3 Traffic growth volatility

The traffic volatility is calculated as follow:

A3.1 *Traffic volatility (Monthly basis)*

The traffic volatility was estimated from the standard deviation of the traffic volume. Data was available on monthly basis (from year 2004-2015).

Year	**Month**	**Traffic Volume (1000 trip/day)**	**Traffic Growth (%)**
2004	Jan.	816.73	
	Feb.	857.28	4.96%
	Mar.	862.39	0.60%
	Apr.	789.01	-8.51%

Year	Month	Traffic Volume (1000 trip/day)	Traffic Growth (%)
	May.	816.54	3.49%
	Jun.	837.58	2.58%
	Jul.	851.48	1.66%
	Aug.	822.66	-3.38%
	Sep.	851.75	3.54%
	Oct.	842.61	-1.07%
	Nov	883.22	4.82%
	Dec.	879.73	-0.40%
2005	Jan.	849.84	-3.40%
	Feb.	879.81	3.53%
	Mar.	897.04	1.96%
	Apr.	801.13	-10.69%
	May.	834.14	4.12%
	Jun.	873.46	4.71%
	Jul.	832.93	-4.64%
	Aug.	867.8	4.19%
	Sep.	873.63	0.67%
	Oct.	858.87	-1.69%
	Nov	903.26	5.17%
	Dec.	894.5	-0.97%
2006	Jan.	874.09	-2.28%
	Feb.	897.56	2.69%
	Mar.	925.08	3.07%
	Apr.	819.19	-11.45%
	May.	862.79	5.32%
	Jun.	877.06	1.65%
	Jul.	858.21	-2.15%
	Aug.	895.43	4.34%
	Sep.	891.56	-0.43%
	Oct.	906.28	1.65%
	Nov	958.48	5.76%
	Dec.	927.2	-3.26%

Year	**Month**	**Traffic Volume (1000 trip/day)**	**Traffic Growth (%)**
2007	Jan.	913.04	-1.53%
	Feb.	954.81	4.57%
	Mar.	961.11	0.66%
	Apr.	870.3	-9.45%
	May.	906.2	4.13%
	Jun.	944.81	4.26%
	Jul.	922.55	-2.36%
	Aug.	940.99	2.00%
	Sep.	941.65	0.07%
	Oct.	943.15	0.16%
	Nov	959.82	1.77%
	Dec.	875.96	-8.74%
2008	Jan.	888.45	1.43%
	Feb.	915.07	3.00%
	Mar.	921.8	0.74%
	Apr.	839.61	-8.92%
	May.	855.38	1.88%
	Jun.	865.59	1.19%
	Jul.	854.69	-1.26%
	Aug.	875.67	2.45%
	Sep.	849	-3.05%
	Oct.	871.9	2.70%
	Nov	877.07	0.59%
	Dec.	861.34	-1.79%
2009	Jan.	865.83	0.52%
	Feb.	909.43	5.04%
	Mar.	930.37	2.30%
	Apr.	824.25	-11.41%
	May.	854.61	3.68%
	Jun.	914.85	7.05%
	Jul.	880.2	-3.79%
	Aug.	904.94	2.81%

Year	Month	Traffic Volume (1000 trip/day)	Traffic Growth (%)
	Sep.	923.16	2.01%
	Oct.	922.84	-0.03%
	Nov	942.63	2.14%
	Dec.	929.62	-1.38%
2010	Jan.	905.35	-2.61%
	Feb.	957.24	5.73%
	Mar.	919.57	-3.94%
	Apr.	821.87	-10.62%
	May.	785.76	-4.39%
	Jun.	950.89	21.02%
	Jul.	953.78	0.30%
	Aug.	925.02	-3.02%
	Sep.	952.55	2.98%
	Oct.	990.72	4.01%
	Nov	1048.64	5.85%
	Dec.	1023.95	-2.35%
2011	Jan.	995.6	-2.77%
	Feb.	1033.4	3.80%
	Mar.	1065.36	3.09%
	Apr.	960	-9.89%
	May.	999.94	4.16%
	Jun.	1053.24	5.33%
	Jul.	1036.88	-1.55%
	Aug.	1054.36	1.69%
	Sep.	1077.17	2.16%
	Oct.	903.29	-16.14%
	Nov	1032.59	14.31%
	Dec.	1088.16	5.38%
2012	Jan.	1069.13	-1.75%
	Feb.	1115.75	4.36%
	Mar.	1116.6	0.08%
	Apr.	1012.94	-9.28%

Year	Month	Traffic Volume (1000 trip/day)	Traffic Growth (%)
	May.	1065.71	5.21%
	Jun.	1079.8	1.32%
	Jul.	1089.18	0.87%
	Aug.	1079.71	-0.87%
	Sep.	1080.32	0.06%
	Oct.	1080.88	0.05%
	Nov	1136.63	5.16%
	Dec.	1089.37	-4.16%
2013	Jan.	1096.67	0.67%
	Feb.	1118.06	1.95%
	Mar.	1154.52	3.26%
	Apr.	1040.52	-9.87%
	May.	1093.29	5.07%
	Jun.	1115.48	2.03%
	Jul.	1102.26	-1.19%
	Aug.	1124.83	2.05%
	Sep.	1099.62	-2.24%
	Oct.	1103.68	0.37%
	Nov	1116.6	1.17%
	Dec.	1032.07	-7.57%
2014	Jan.	1031.7	-0.04%
	Feb.	1087.94	5.45%
	Mar.	1119.93	2.94%
	Apr.	1042.91	-6.88%
	May.	1065.67	2.18%
	Jun.	1098.37	3.07%
	Jul.	1099.77	0.13%
	Aug.	1123.07	2.12%
	Sep.	1137.47	1.28%
	Oct.	1139.18	0.15%
	Nov	1166.66	2.41%
	Dec.	1130.11	-3.13%

Year	Month	Traffic Volume (1000 trip/day)	Traffic Growth (%)
2015	Jan.	1111.19	-1.67%
	Feb.	1176	5.83%
	Mar.	1176.01	0.00%
	Apr.	1071.98	-8.85%
Monthly Standard Deviation			4.94%
Yearly Standard Deviation			17.10%

Table A4: Traffic growth volatility (monthly data)

Source: The traffic flow report: BEM company report at http://www.bemplc.co.th/

To avoid seasonality, the traffic volatility on annual basis was estimated as following table:

Year	Annual Traffic Volume (trip per year)	Traffic Growth (%)
2004	303329.4	
2005	310992.3	2.5%
2006	320787.9	3.1%
2007	334031.7	4.1%
2008	314267.1	-5.9%
2009	324081.9	3.1%
2010	337060.2	4.0%
2011	368999.7	9.5%
2012	390480.6	5.8%
2013	395928.0	1.4%
2014	397283.4	0.3%
2015	408166.2	2.7%
Yearly Standard Deviation		3.76%

Table A5: Traffic growth volatility (Annual data)

Source: The traffic flow report: BEM company report at http://www.bemplc.co.th/

A3.2 *Traffic volume (Monthly basis) with seasonal adjustment*

Traffic of the SES project is typically affected by the seasons of the year with it being low during the month with long holidays i.e., April and May and high for the year ending

December. Seasonal adjustment is used for removing the seasonal component of time by using the data for each month i.e., log of January data to compute standard deviation (do for all months) and take average and then annualise. The traffic volatility with seasonal adjustment is estimated as following table:

Year	**Month**	**Traffic Volume (1000 trip/day)**	**Log (Traffic)**	**Δ Log (traffic) (Log_t-Log_{t-1})**
2004	Jan.	816.73	2.912078508	
	Feb.	857.28	2.933122692	0.02104418
	Mar.	862.39	2.935703712	0.00258102
	Apr.	789.01	2.897082508	-0.03862120
	May.	816.54	2.911977464	0.01489496
	Jun.	837.58	2.923026299	0.01104883
	Jul.	851.48	2.930174451	0.00714815
	Aug.	822.66	2.915220381	-0.01495407
	Sep.	851.75	2.930312142	0.01509176
	Oct.	842.61	2.925626609	-0.00468553
	Nov	883.22	2.946068895	0.02044229
	Dec.	879.73	2.944349402	-0.00171949
2005	Jan.	849.84	2.929337168	-0.01501223
	Feb.	879.81	2.944388894	0.01505173
	Mar.	897.04	2.952811809	0.00842292
	Apr.	801.13	2.903702995	-0.04910881
	May.	834.14	2.921238948	0.01753595
	Jun.	873.46	2.941243021	0.02000407
	Jul.	832.93	2.920608505	-0.02063452
	Aug.	867.8	2.938419646	0.01781114
	Sep.	873.63	2.941327539	0.00290789
	Oct.	858.87	2.933927433	-0.00740011
	Nov	903.26	2.955812778	0.02188535
	Dec.	894.5	2.951580345	-0.00423243
2006	Jan.	874.09	2.941556152	-0.01002419
	Feb.	897.56	2.953063490	0.01150734
	Mar.	925.08	2.966179292	0.01311580
	Apr.	819.19	2.913384642	-0.05279465

Year	Month	Traffic Volume (1000 trip/day)	Log (Traffic)	Δ Log (traffic) (Log_t-Log_{t-1})
	May.	862.79	2.935905103	0.02252046
	Jun.	877.06	2.943029305	0.00712420
	Jul.	858.21	2.933593571	-0.00943573
	Aug.	895.43	2.952031641	0.01843807
	Sep.	891.56	2.950150576	-0.00188107
	Oct.	906.28	2.957262396	0.00711182
	Nov	958.48	2.981583055	0.02432066
	Dec.	927.2	2.967173423	-0.01440963
2007	Jan.	913.04	2.960489804	-0.00668362
	Feb.	954.81	2.979916959	0.01942715
	Mar.	961.11	2.982773096	0.00285614
	Apr.	870.3	2.939668984	-0.04310411
	May.	906.2	2.957224058	0.01755507
	Jun.	944.81	2.975344481	0.01812042
	Jul.	922.55	2.964989913	-0.01035457
	Aug.	940.99	2.973585008	0.00859509
	Sep.	941.65	2.973889511	0.00030450
	Oct.	943.15	2.974580769	0.00069126
	Nov	959.82	2.982189795	0.00760903
	Dec.	875.96	2.942484275	-0.03970552
2008	Jan.	888.45	2.948632992	0.00614872
	Feb.	915.07	2.961454318	0.01282133
	Mar.	921.8	2.964636704	0.00318239
	Apr.	839.61	2.924077603	-0.04055910
	May.	855.38	2.932159092	0.00808149
	Jun.	865.59	2.937312230	0.00515314
	Jul.	854.69	2.931808623	-0.00550361
	Aug.	875.67	2.942340471	0.01053185
	Sep.	849	2.928907690	-0.01343278
	Oct.	871.9	2.940466678	0.01155899
	Nov	877.07	2.943034256	0.00256758
	Dec.	861.34	2.935174616	-0.00785964

Year	Month	Traffic Volume (1000 trip/day)	Log (Traffic)	Δ Log (traffic) (Log_t-Log_{t-1})
2009	Jan.	865.83	2.937432630	0.00225801
	Feb.	909.43	2.958769276	0.02133665
	Mar.	930.37	2.968655698	0.00988642
	Apr.	824.25	2.916058956	-0.05259674
	May.	854.61	2.931767970	0.01570901
	Jun.	914.85	2.961349892	0.02958192
	Jul.	880.2	2.944581364	-0.01676853
	Aug.	904.94	2.956619785	0.01203842
	Sep.	923.16	2.965276978	0.00865719
	Oct.	922.84	2.965126411	-0.00015057
	Nov	942.63	2.974341257	0.00921485
	Dec.	929.62	2.968305459	-0.00603580
2010	Jan.	905.35	2.956816506	-0.01148895
	Feb.	957.24	2.981020838	0.02420433
	Mar.	919.57	2.963584794	-0.01743604
	Apr.	821.87	2.914803128	-0.04878167
	May.	785.76	2.895289917	-0.01951321
	Jun.	950.89	2.978130280	0.08284036
	Jul.	953.78	2.979448211	0.00131793
	Aug.	925.02	2.966151123	-0.01329709
	Sep.	952.55	2.978887781	0.01273666
	Oct.	990.72	2.995950930	0.01706315
	Nov	1048.64	3.020626420	0.02467549
	Dec.	1023.95	3.010278750	-0.01034767
2011	Jan.	995.6	2.998084888	-0.01219386
	Feb.	1033.4	3.014268457	0.01618357
	Mar.	1065.36	3.027496387	0.01322793
	Apr.	960	2.982271233	-0.04522515
	May.	999.94	2.999973942	0.01770271
	Jun.	1053.24	3.022527344	0.02255340
	Jul.	1036.88	3.015728498	-0.00679885
	Aug.	1054.36	3.022988921	0.00726042

Year	Month	Traffic Volume (1000 trip/day)	Log (Traffic)	Δ Log (traffic) (Log_t-Log_{t-1})
	Sep.	1077.17	3.032284249	0.00929533
	Oct.	903.29	2.955827202	-0.07645705
	Nov	1032.59	3.013927915	0.05810071
	Dec.	1088.16	3.036692758	0.02276484
2012	Jan.	1069.13	3.029030516	-0.00766224
	Feb.	1115.75	3.047566896	0.01853638
	Mar.	1116.6	3.047897624	0.00033073
	Apr.	1012.94	3.005583721	-0.04231390
	May.	1065.71	3.027639041	0.02205532
	Jun.	1079.8	3.033343323	0.00570428
	Jul.	1089.18	3.037099658	0.00375633
	Aug.	1079.71	3.033307124	-0.00379253
	Sep.	1080.32	3.033552416	0.00024529
	Oct.	1080.88	3.033777481	0.00022506
	Nov	1136.63	3.055619115	0.02184163
	Dec.	1089.37	3.037175411	-0.01844370
2013	Jan.	1096.67	3.040075963	0.00290055
	Feb.	1118.06	3.048465110	0.00838915
	Mar.	1154.52	3.062401461	0.01393635
	Apr.	1040.52	3.017250432	-0.04515103
	May.	1093.29	3.038735376	0.02148494
	Jun.	1115.48	3.047461788	0.00872641
	Jul.	1102.26	3.042284048	-0.00517774
	Aug.	1124.83	3.051086891	0.00880284
	Sep.	1099.62	3.041242630	-0.00984426
	Oct.	1103.68	3.042843173	0.00160054
	Nov	1116.6	3.047897624	0.00505445
	Dec.	1032.07	3.013709154	-0.03418847
2014	Jan.	1031.7	3.013553431	-0.00015572
	Feb.	1087.94	3.036604945	0.02305151
	Mar.	1119.93	3.049190878	0.01258593
	Apr.	1042.91	3.018246832	-0.03094405

Year	Month	Traffic Volume (1000 trip/day)	Log (Traffic)	Δ Log (traffic) (Log_t-Log_{t-1})
	May.	1065.67	3.027622740	0.00937591
	Jun.	1098.37	3.040748662	0.01312592
	Jul.	1099.77	3.041301869	0.00055321
	Aug.	1123.07	3.050406826	0.00910496
	Sep.	1137.47	3.055939951	0.00553312
	Oct.	1139.18	3.056592352	0.00065240
	Nov	1166.66	3.066944308	0.01035196
	Dec.	1130.11	3.053120718	-0.01382359
2015	Jan.	1111.19	3.045788324	-0.00733239
	Feb.	1176	3.070407322	0.02461900
	Mar.	1176.01	3.070411015	0.00000369
	Apr.	1071.98	3.030186683	-0.04022433

Traffic volatility (Standard deviation of Δ log: Monthly) adjusted for seasonality

Month	Standard Deviation (SD)	Detail Calculation
January	0.006714483	SD of Δ log of January data
February	0.005032217	SD of Δ log of February data
March	0.008513966	SD of Δ log of March data
April	0.006000008	SD of Δ log of April data
May	0.011328458	SD of Δ log of May data
June	0.021093705	SD of Δ log of June data
July	0.008121153	SD of Δ log of July data
August	0.010794199	SD of Δ log of August data
September	0.008483787	SD of Δ log of September data
October	0.023694851	SD of Δ log of October data
November	0.014684184	SD of Δ log of November data
December	0.015780270	SD of Δ log of December data
Average Monthly Standard Deviation	1.1687%	Average SD (Jan, Feb…….,Dec)
Yearly Standard Deviation	4.0484%	

Table A6 Seasonal adjustment for traffic volume (monthly data)

A4 Operating expense (Million baht)

Year of operation	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Operating expense	262	254	319	347	322	338	344
Year of operation	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Operating expense	416	377	948	415	777	457	480
Year of operation	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Operating expense	647	611	625	581	610	1,687	673
Year of operation	**25**	**26**	**27**	**28**	**29**	**30**	
Operating expense	1,197	741	900	817	858	3,498	

Table A7 Operating expense of the SES project

Source: The project feasibility study submitted by project consultant to the government agency (EXAT)

A5 Key financial parameters

Parameter	**Unit**	**Value**	**Source**
Government bond yield (10 Y)	%	6%	Bank of Thailand (Year 1993)
Cost of debt	%	12%	Bangkok of Thailand (Year 1993)
Beta (BECL)	time	0.6	Router
Risk premium	%	5-12%	The Stock Exchange of Thailand, Bank of Thailand

Table A8 Key financial parameters of the SES project

Appendix B Lists of Transportation System Projects in Thailand

B1 The Don Muang Tollway Project

The Don Muang Tollway Project was developed from 1994 to 1998 under the National Intercity Motorway Network Master Plan, which was implemented by the Department of Highways. The Don Muang Tollway was granted concession by the Department of Highways, a government agent, in a build-transfer-operate (BTO) form. The project is 28 km in length with a 6-lane elevated road linked from central Bangkok to the Don Muang International Airport and North Bangkok. The total project cost was 12,000 million baht, of which 7,400 million baht was funded from both local and foreign financial institutions. Forty-five percent of the total loan was funded by foreign currency denominations.

The Department of Highways granted a 25-year concession to the Don Muang Tollway Company LTD., which was a joint between DYWIDAG (a German company), Delta Construction (a Thai construction company) and GMI (a French contracting company). Table B1 shows the risks and impacts of the Don Muang Tollway Project.

Project's specific risks	**Impacts on project**	**Mitigation**
- Toll revenue was less than expectation by 30% because of new road competition and the opening of the Suvarnabhumi Airport, which redirected a lot of traffic from the Don Muang area.* - The project was unable to increase tolls due to government ordering. - The government has not abided by the project's concession terms, including rules limiting the	- The project went bankrupt. - The project accumulated operating losses of approximately 5.6 billion baht between 1996 and 2006. - The funding cost was increased due to a Thai baht devaluation.	- The Department of Highways extended the Don Muang Tollway Project's 25-year concession by 11 years to help the company make up for the lower revenue.

Project's specific risks	Impacts on project	Mitigation
construction of local roads competing with the tollway as well as delaying the construction of new flyovers allowing radial movements. - Foreign exchange risk		

* The Don Muang area was formerly the first Bangkok International Airport, but in 2005 all international services were moved to the new international airport, Suvarnabhumi International Airport, in the opposite direction.

Table B1: Risk factors and their impacts on the Don Muang Tollway Project

Sources: Bangkok Post (2009), Bangkok Post (2005), ADB (2000)

B2 The Bangkok Mass Transit System (BTS) Project

The Bangkok Mass Transit System (BTS) Project was Thailand's first mass transit system and was implemented through a public-private partnership (PPP) scheme. The BTS was awarded a 30-year build-operate-transfer concession by the Bangkok Metropolitan Authority (BMA). The project is solely, privately financed in Thailand and is operated by the Bangkok Mass Transit System Public Company LTD. The project initially had 25 stations with 25 km of operation track. The BTS line is connected with the underground rail system (the BMT project) at three stations (Asok, Sala Daeng and Mor-chit). Later, between 2009 and 2013, the line was extended by an additional 12.7 km under 13 stations. The ridership has increased from 200,000 passenger trips per day in 1999 to 650,000 passenger trips per day in 2013.

The BTS has had financial difficulties since its first operation in December 1999. The revenue was lower than expected because ridership projections tend to be overestimated. The project faced foreign exchange risks after the Thai baht depreciated in 1997. The BTS entered its debt rehabilitation process in January 2007 after the court approved the plan. Table B2 provides a list of risk factors and their impacts regarding the BTS Project.

Project's specific risks	Impacts on project	Mitigation
- The traffic was	- The project was subject	- Expanded the mass transit

Project's specific risks	Impacts on project	Mitigation
underestimated. - It initially had lower than predicted ridership, with 200,000 passenger trips per day at the beginning. - There was a foreign exchange risk due to a devaluation of Thai baht.	to operating losses. - The debt principal (in Thai baht notional) increases.	network to attack new traffic. - The project restructured its capital by reducing its paid-up capital to par value and injected new issued share. - Converted debts to equity.

Table B2: Risk factors and their impacts on the BTS Project

Source: Credit News TRIS Rating (17 July 2009)

B3 The MRT Project

The MRT Project was Thailand's first underground mass transit project that was awarded a 25-year acquire-operate-transfer (AOT) concession. The project was procured through a PPP scheme between Thailand's Mass Rapid Transit Authority (MRTA), a state-owned enterprise, and a private company named the Bangkok Metro Public Company LTD. (BMCL). BMCL operated a 20 km underground mass transit system that began commercial operation in 2004.

The government supported the MRT Project by providing investments in land acquisition and infrastructure cost while the private company invested in mechanical and electrical systems, including trains and other equipment. The total construction cost was 115,812 million baht, 91,249 million of which was infrastructure cost, and the rest involved mechanical and electrical (M&E) work. BMCL has a 25-year concession with a right to collect fares and undertake activities and commercial developments, including advertising and leasing spaces in the project area. BMCL has an obligation to make remuneration from fares and commercial developments to the MRTA at the agreed rates set forth in the concession agreement. The project's revenue is mainly from two sources: revenue from fares, which accounts for nearly 90% of the total revenue, and revenue from commercial development. Under the concession agreement, BMCL can adjust the fare rate every 2 years based on actual changes in the Bangkok Non-Food Consumer Price Index. However, the adjustment should obtain prior approval from the MRTA before the toll level can be increased. There may be delays in adjustment. The project's revenue growth has expected to increase the volume of passengers by extending and offering new lines in the system. However, implementation delay concerning the Mass Rapid Transit Master Plan in Bangkok Metropolitan has impacted the traffic flow to the project. Since its first operation year, the company has faced net losses far from expectation. Table B3 provides a list of risk factors and their impacts on the MRT Project. Ridership in 2014 was around 240,000 per day on weekdays, lower than projections of over 400,000.

Project's specific risks	**Impacts on project**	**Mitigation**
- The ridership is far from the forecast. - The project's ability to repay debt has declined.	- The project's revenue is underestimated. - The project may default.	- The company tried to promote a marketing campaign to increase ridership. - The project company negotiated with the lender to extend the debt or require more capital injection from the shareholders.

Table B3: Risk factors and their impacts on the MRT project

Source: The Bangkok Metro Public Company Limited (BMCL) Annual Report (2009)

B4 The Second Stage Expressway System (SES) Project

The Second Stage Expressway System (SES) Project was the first expressway project to be developed through a PPP scheme. The project was awarded a 30-year build-transfer-operate (BTO) concession from the Expressway Authority of Thailand (EXAT). The concession was granted to the Bangkok Expressway Company LTD. (BECL), which carried out the construction and operated the project. The project was built as a 6-lane elevated expressway with 38.5 km in length. The total project cost was approximately $1.1 billion. The project has four sectors linked to the first stage expressway (FES), which was constructed and has been operated by the EXAT. BECL completed construction on schedule and started operation in 1993.

The 30-year concession was separated into a 3-year construction period and 27 years of BECL's operation of facility. Over that 27-year operating period, revenue collection is shared between FES and SES. SES received 60% of the revenue collected during the first 9 years of the operating period. FES and SES shared 50% of the revenue in the second 9-year period.

For the last 9 years of the concession period, FES receives 60% of the total revenue, and the remaining 40% belongs to SES.

In the earlier years of operation, income flows from users were more than the initial projection. The project was profitable and self-sustaining after a certain period of operation. In 1995, BECL was successfully listed on the stock exchange of Thailand. However, with economic hits in 1997, traffic volume and toll revenue decreased, which impacted its ability to repay debt.

In 1996, NECL was established to operate a new expressway, called the Udon Ratthaya Expressway (URE), under a 30-year BTO concession agreement awarded by the EXAT from 1996 to 2026. BECL holds 53.33% of NECL. URE is the extension phase of SES. Table B4 provides a list of risk factors and their impacts on the SES Project.

Project's specific risks	**Impacts on project**	**Mitigation**
- SES's traffic volume and revenue were lower than expected due to the economic crisis in 1997. - Traffic declined due to the opening of toll-free roads and new expressways. - NECL's traffic volume was far below projections due to competition from alternate roads.	- Traffic would not be able to generate enough revenue to provide an adequate return, or it was not sufficient to service the debt. - NECL faced operating losses.	- The company has negotiated with syndicated lenders to reschedule its loans. - It has proposed a new revenue-sharing scheme between FES and SES (by combining the revenue collected from both projects) over the 27-year operating period of the concession.

Table B4: Risk factors and their impacts on the SES Project

Source: Credit News TRIS Rating (29 April 2009)

B5 The Airport Rail Link Project

The Airport Rail Link Project (ARL) is the mass transit system that links the new Suvarnabhumi Airport to city areas. The project was built as an elevated mass transit with 28 km in length. The total project cost was approximately 20,000 million baht, including civil and M&E work. The project cost was funded by a combination of government budget and loans from Thai banks. The State Railway of Thailand (SRT) is the owner of the line and the rolling stock. The project has two lines: the express line linked directly to the airport, and the city line. The government is still reviewing the PPP options for operation and management. Table B5 provides a list of risk factors and their impacts on the Airport Rail Link Project.

Project's specific risks	**Impacts on project**	**Mitigation**
- Construction was delayed for 2 years because clearance of the construction land, under the responsibility of the SRT, was slower than planned. - The ridership was far from forecasted.	- The project was delayed to generate revenue. - The project's cost was overrun due to an increase in raw material prices, such as steel and oil. - Operating losses have occurred since the first launch on 23 August 2010.	- The project company negotiated with the government to compensate for higher construction costs.

Table B5: Risk factors and their impacts on the Airport Rail Link Project
Source: Bangkok Post (2010)

B6 The Bangna Bangpi Bangpakong Expressway Project

The Bangna Bangpi Bangpakong Expressway (BBBE) Project is an expressway connecting Bangkok, Bang Na and Bang Pakong by means of a 55 km, 6-lane elevated road. Construction work was award to a joint venture named BBCD with a turnkey contract. The project cost was initially estimated at 25,193 million baht, but was subject to cost overrun by 6,300 million baht. The Expressway and Rapid Transit Authority of Thailand (ETA; currently changed to Expressway Authority of Thailand: EXAT) is the owner of the project and takes responsibility for collecting the toll. The private sector participated in the project's overall design, procurement and construction. No concession was provided in this project, and the ETA is still the operator. Table B6 provides the risk factors and their impacts on the BBBE Project.

Project’s specific risks	Impacts on project	Mitigation
- The traffic was lower than the estimation due to local road competition. - Construction was delayed by about 11 months because of design change and a delay of land delivery by the owner.	- The project was delayed, leading to lower revenues than projected. - Delays caused the project’s cost to overrun by 15-20%.	- The contractor was claimed for the cost overrun.

Table B6: Risk factors and their impacts on the BBBE Project

Source: Chritamara and Ogunlana (2001)

Appendix C Testing for Geometric Brownian Motion (GBM) process

In this thesis, the methodology for the valuation of the large infrastructure project is based on the real option approach. This methodology is generally constructed on the assumption of the flow of traffic volume as a geometric Brownian motion (GBM) which is the hypothesis analysed in this section.

C1 Testing for geometric Brownian motion (GBM) process fit

In general, if a stochastic process of the traffic flow {*x(t), t*>0} follows a Brownian motion process, it presents the following two properties (Marathe and Ryan, 2005);

- The change in the value of x, Δx, over a time interval of Δt is proportional to the square root of Δt $\{\Delta x = x(t+\Delta t) - x(t) = \varepsilon\sqrt{\Delta t}\}$, where ε is a standard normal random variable. Then value of Δx follows a normal distribution with mean 0 and variance equals to the change in time (Δt) over which Δx is measured.
- The changes in the value of *x(t)* for any two non-overlapping in intervals of time are independent.

Assuming traffic volume evolves according to a geometric Brownian motion process then it follows the random walk. In addition, the traffic volume should be tested for the properties of GBM which there are two assumptions to be satisfied; 1) Normality of the log ratios with constant mean and variance 2) Independence from the past data. This thesis does statistically validate the assumption of GBM from the historical monthly and yearly data. The following statistical tests will be done;

i) Test for A random walk with drift using Augmented Dickey-Fuller t-statistic

ii) Test for normality with Shapiro-Wilk Statistic and

iii) Test for autocorrelation with Box-Ljung Statistic

C1.1 *Validating geometric Brownian motion (GBM) assumption with monthly traffic data*

1) Test for a random walk with drift: Using log traffic

The Unit Root test (ADF test) is used for detecting a random walk with drift. It can specify the null and alternative hypothesis as:

H_0 : x_t (the natural log of traffic level) is a random walk with drift, against

H_1 : x_t is trend stationary

The *Eviews* output for the Unit Root test is given below:

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.942757	0.1527
Test critical values	1% level	-4.028496	
	5% level	-3.443961	
	10% level	-3.146755	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable:	D(LOG_TRAFFIC)			
Method:	Least Square			
Include observations	133 after adjustment			
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_TRAFFIC(-1)	-0.239832	0.081499	-2.942757	0.0039
D(LOG_TRAFFIC(-1))	-0.279067	0.089562	-3.115912	0.0023
D(LOG_TRAFFIC(-2)	-0.424303	0.080939	-5.242274	0.0000
C	0.698515	0.237024	2.947027	0.0038
@TREND("2004")	0.000263	9.49E-05	2.775161	0.0063
R-squared	0.362394		Mean dependent var	0.000710
Adjusted R-squared	0.342469		S.D. dependent var	0.021803
S.E. of regression	0.017679		Akaike info criterion	-5.195955
Sum squared resid	0.040008		Schwarz criterion	-5.087295
Log likelihood	350.5310		Hannan-Quinn criter.	-5.151799
F-statistic	18.18775		Durbin-Watson stat	1.964644
Prob (F-statistic)	0.000000			

The ADF test statistic is -2.942757 which is greater than the 0.05 critical value of -3.443961 and so the null hypothesis that the natural log of traffic is a random walk with drift is not rejected. **Thus it cannot reject the hypothesis that traffic follows a geometric Brownian motion.**

2) Test for normality: Using the change of log (traffic)

The Shapiro-Wilk test is the most widely used test of normality. It can specify the null and alternative hypothesis as:

H_0 : The distribution is normal, against

H_1 : The distribution is not normal

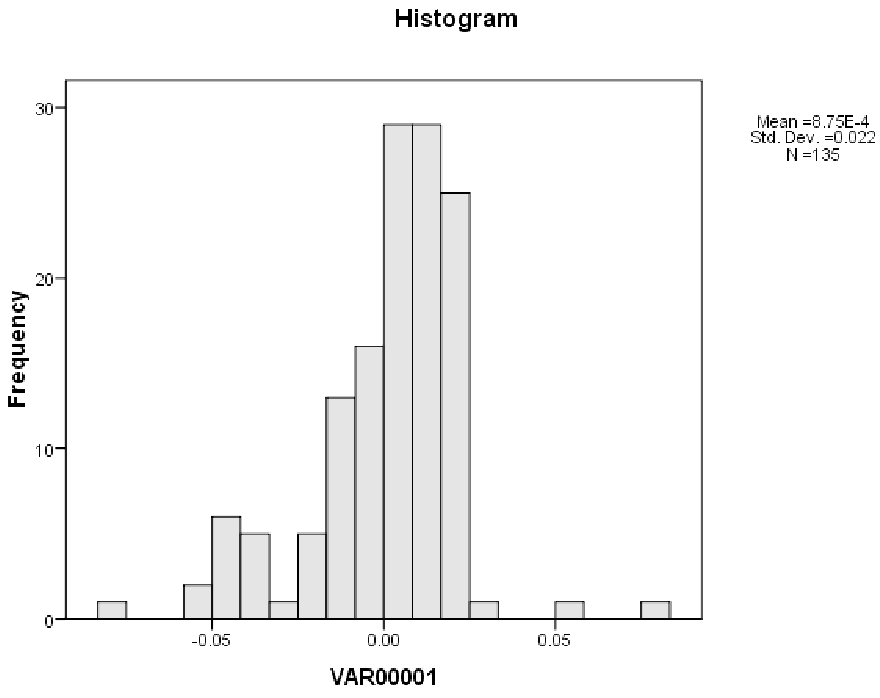
SPSS generates the following output for the test of normality:

Case Processing Summary						
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
VAR00001: the change of log (traffic)-Monthly	135	100.0%	0	.0%	135	100.0%

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00001: the change of log (traffic)-Monthly	.133	135	.000	.914	135	.000

a. Lilliefors Significance Correction



The calculated value of the test statistic is .914 which is greater than the 0.05 critical value. **The series (the change of log (traffic)) is not normal**.

3) Test for autocorrelation: Using the change of log (traffic)

The Box-Ljung Statistic is used to detect the autocorrelation. The null and alternative hypothesis can be expressed as:

H_0 : There is no serial correlation (there is no association between the variables), against

H_1 : Some correlation does exist

The output from the SPSS autocorrelation test is shown as follow.

Case Processing Summary

		VAR00001 (the change of log (traffic))-Monthly
Series Length		135
Number of Missing Values	User-Missing	0
	System-Missing	0
Number of Valid Values		135
Number of Computable First Lags		134

Autocorrelations

Series:VAR00001: the change of log (traffic)-Monthly

Lag	Autocorrelation	Std. Error[a]	Box-Ljung Statistic Value	df	Sig.[b]
1	-.270	.085	10.047	1	.002
2	-.390	.085	31.178	2	.000
3	.247	.084	39.753	3	.000
4	.044	.084	40.021	4	.000
5	-.137	.084	42.711	5	.000
6	.141	.084	45.564	6	.000
7	-.223	.083	52.750	7	.000
8	.072	.083	53.502	8	.000
9	.243	.083	62.171	9	.000
10	-.331	.082	78.378	10	.000
11	-.165	.082	82.446	11	.000
12	.595	.082	135.731	12	.000
13	-.179	.081	140.566	13	.000
14	-.274	.081	152.079	14	.000
15	.195	.081	157.968	15	.000
16	-.043	.080	158.258	16	.000

a. The underlying process assumed is independence (white noise).

b. Based on the asymptotic chi-square approximation.

Box-Ljung test statistic is 10.047 which is greater than the critical value (0.05) and the null hypothesis that there is no serial correlation, is rejected. **Then it means that some correlation does exist**.

C1.2 ***Validating geometric Brownian motion (GBM) assumption with yearly traffic data***

1) Test for a random walk with drift: Using log traffic

The Unit Root test (ADF test) is used for detecting a random walk with drift. It can specify the null and alternative hypothesis as:

H_0 : x_t (the natural log of traffic level) is a random walk with drift, against

H_1 : x_t is trend stationary

The *Eviews* output for the Unit Root test is given below:

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.128623	0.4720
Test critical values	1% level	-5.295384	
	5% level	-4.008157	
	10% level	3.460791	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation

Dependent Variable: D(LOG_TRAFFIC_YEAR_)

Method: Least Square

Include observations 10 after adjustment

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_TRAFFIC_YEAR(-1)	-0.759736	0.356914	-2.128623	0.0774
D(LOG_TRAFFIC_YEAR(-1))	0.438321	0.351879	1.245658	0.2593
C	4.150109	1.946104	2.132522	0.0769
@TREND("2004")	0.010238	0.004888	2.094456	0.0811
R-squared	0.438806		Mean dependent var	0.011809
Adjusted R-squared	0.158209		S.D. dependent var	0.016972
S.E. of regression	0.015572		Akaike info criterion	-5.197564
Sum squared resid	0.001455		Schwarz criterion	-5.076530
Log likelihood	29.98782		Hannan-Quinn criter.	-5.330338
F-statistic	1.563831		Durbin-Watson stat	2.374166
Prob (F-statistic)	0.292989			

The ADF test statistic is -2.128623which is greater than the 0.05 critical value of -4.008157 and so the null hypothesis that the natural log of traffic is a random walk with drift is not rejected. **Thus, it cannot reject the hypothesis that traffic follows a geometric Brownian motion.**

2) Test for normality: Using the change of log (traffic) on annual basis

The Shapiro-Wilk statistic is used to detect normality. The null and alternative hypothesis can be expressed as:

H_0 : The distribution is normal, against

H_1 : The distribution is not normal

SPSS generates the following output for the test of normality:

Case Processing Summary

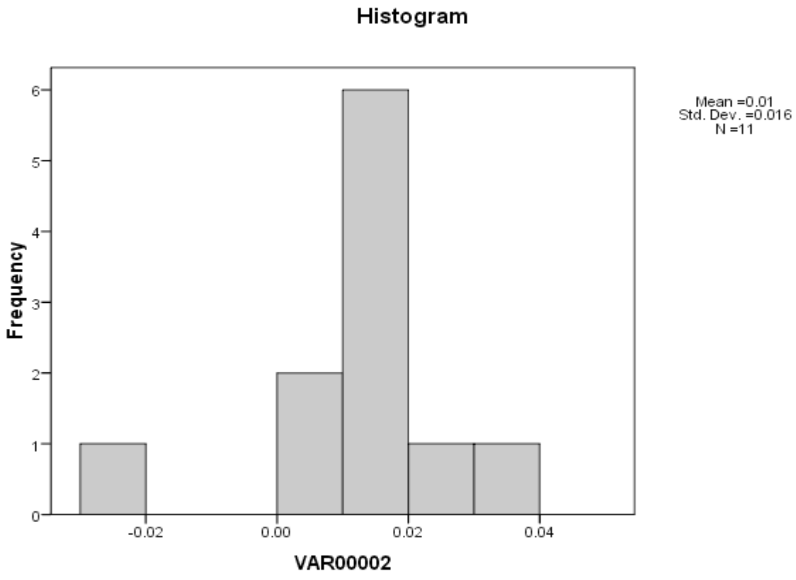
	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
VAR00002: the change of log (traffic)-Yearly	11	8.1%	124	91.9%	135	100.0%

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00002: the change of log (traffic)-Yearly	.205	11	.200*	.893	11	.153

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.



The calculated value of the test statistic is .893 which is less than the critical value at the 0.05 level. **The series (the change of log (traffic)-yearly) is normal**.

3) Test for autocorrelation: Using the change of log (traffic) on annual data

Since annual data is applied, it is reasonable to assume that if any autocorrelation is present, it is generated by a first autoregressive process. The null and alternative hypothesis can be expressed as:

H_0 : There is no serial correlation (there is no association between the variables), against

H_1 : Some correlation does exist

The output from the SPSS autocorrelation test is shown as follow.

Case Processing Summary

		VAR00002: the change of log (traffic)-Yearly
Series Length		135
Number of Missing Values	User-Missing	0
	System-Missing	124[a]
Number of Valid Values		11
Number of Computable First Lags		10

a. Some of the missing values are imbedded within the series.

Autocorrelations

Series:VAR00002: the change of log (traffic)-Yearly

Lag	Autocorrelation	Std. Error[a]	Box-Ljung Statistic		
			Value	df	Sig.[b]
1	.084	.264	.101	1	.750
2	-.170	.251	.562	2	.755
3	-.493	.237	4.905	3	.179
4	-.149	.221	5.356	4	.253
5	.123	.205	5.719	5	.335
6	.137	.187	6.257	6	.395
7	-.032	.167	6.293	7	.506
8	-.005	.145	6.294	8	.614
9	.004	.118	6.295	9	.710

a. The underlying process assumed is independence (white noise).

b. Based on the asymptotic chi-square approximation.

Box-Ljung test statistic is .101which is less than the 0.05 critical value and so the null hypothesis that there is no serial correlation is not rejected. **Then, it means that there is no serial correlation.**

In summary, based on the test for a random walk with drift, traffic volumes on monthly and yearly basis, follow a geometric Brownian motion process.

Appendix D Validating the Option-Values for the SES Project Using the Black-Scholes Model

The binomial model which is used to calculate a call and a put option in the SES project is checked against the equivalent values from a Black-Scholes (BS) model to check the accuracy of the binomial model approximation against a BS continuous time estimation. The results are provided in the table D1. The results show that the two models produce nearly the same values.

Option list	**Option type**	**Value of option using the binomial model (Million baht)**	**Value of option using the Black-Scholes model (Million baht)**
Deferral option-FI*	Call option	589	620
Abandon option-FI**	Put option	2,960	2,473
Debt guarantee option-Government**	Put option	814	764
Equity guarantee option – Government***	Put option	14	34

* values at beginning year, ** values at year 5th, *** values at year 7th

Table D1: A comparison of the binomial and Black-Scholes models.

Table D2 shows key inputs (the SES project) of the Black-Scholes option pricing model. There are 5 basic inputs (parameters) which are S= present value of the project operating asset, X= expenditure required to acquire the project asset, t= time duration, r_f = risk-free interest rate (6%), σ= standard deviation of traffic flow (20%).

Option List	**Inputs of the Black-Scholes option pricing model (the SES project)**
Deferral option-FI	S =25,147 million baht
	X =31,532.18 million baht
	T =1

Option List	**Inputs of the Black-Scholes option pricing model (the SES project)**
	r_f =6%
	σ =20%
Abandon option-FI	S =15,982.68 million baht
	X =18,942.84 million baht
	T =1
	r_f =6%
	σ =20%
Debt guarantee option-Government	S =2,574.68 million baht
	X =3,514.95 million baht
	T =1
	r_f =6%
	σ =20%
Equity guarantee option –Government	S =537.04 million baht
	X =551.04 million baht
	T =1
	r_f =6%
	σ =20%

Table D2: Inputs of the Black-Scholes option pricing model (the SES project)

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