INVESTMENT VALUATION OF UNDERGROUND FREIGHT TRANSPORTATION (UFT) SYSTEMS UNDER UNCERTAINTY

by

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DISSERTATION

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Abstract

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UNDER UNCERTAINTY

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A reliable, safe, and efficient freight transportation system is one of the most essential rudiments supporting the continuous economic growth of a nation. The United States (U.S.), as the world's largest economy relies heavily on its transportation and freight movement systems. Population growth and economic activity have created a critical need for freight transportation services. E-commerce and online retailing have effectively challenged conventional freight transportation services, increasing the demand for faster delivery. Underground freight transportation (UFT) systems are an innovative technology that can be a viable solution to satisfy the growing demand for freight transportation services. UFT systems are automated freight transportation systems that utilize space beneath congested roads and urban areas to transfer freight between intermodal terminals.

UFT systems can potentially reduce truck volume on congested roads and increase freight movement system capacity, thereby improving security and safety as well as mitigating adverse environmental impacts.

Successful implementation of large UFT systems require a detailed investment evaluation to explicitly show planners and decision-makers the economic feasibility of such systems. The main objectives of this study are (1) analysis of financial means and enabling legislations for implementing UFT systems; (2) deterministic investment analysis of implementing UFT systems; and (3) investment valuation of implementing UFT systems under uncertainty using a real options approach.

A comprehensive Life-cycle benefit-cost analysis of the UFT systems for five different scenarios of implementing UFT systems in Texas showed that these systems are economically feasible. Results of sensitivity analysis highlighted the most uncertain parameters affecting the economic feasibility of UFT systems. This analysis showed that the economic feasibility of the large and medium size UFTs is more sensitive to construction cost and revenue from shipments.

For the first time, a real options approach is used to capture the uncertainties and the available managerial flexibilities in investment valuation of UFT systems. The analysis of historical data showed that the freight rate follows a mean-reverting process. While the stochastic behavior of the construction cost is completely different (a GBM process). Yet, the extant real options methods adopted to transportation infrastructures have theoretical limitations to model UFT uncertainties with different attributes. Therefore, a novel bivariate real options model suitable for the investment valuation of UFT systems under uncertainty is developed. The proposed model estimates the market value of the project at each possible state of time and offers an optimal policy to invest in UFT systems.

While the data used and the quantitative results showed in this research may be particular to Texas, the methodology presented in this research can be followed for determining the economic feasibility of UFT systems elsewhere. The findings of this research provide decision-makers with information to objectively appraise UFT projects.

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Chapter 1

Introduction

Undoubtedly, freight transportation by truck is one of the significant contributors to roadway deterioration. Increase in freight movement demand puts more stress on already deteriorating and congested transportation systems. Just maintaining the U.S. highways and keeping them in their current condition would cost $101 billion in annual capital investment between 2008 and 2028 (ASCE 2013). Besides, Americans spend 6.9 billion hours in traffic (in 2014) that is equal to $160 billion in extra fuel and lost time (USDOT 2015a). This includes $28 billion of extra truck operating time and fuel (Schrank et al. 2015).

An efficient and sustainable freight transportation system plays a significant role in the economy of a region. The U.S. transportation system moved more than 20 billion tons of freight valued about $18,000 billion in the year 2013 (USDOT 2015b). This volume is expected to increase about 42 percent from 20 billion tons to 28.5 billion tons between years 2013 to 2040 due to population growth, economic expansion, increasing trade, and growing energy production. Building innovative freight transportation facilities, such as underground freight transportation (UFT) systems with potential high benefits and revenues can help increase the capacity of the current transportation systems with no additional land use and alleviate the congestion and deterioration problems caused by the growing need for freight transportation. The idea of the UFT system is to use underground space to transport different types of freight through a network of pipeline or tunnels. Most of cargos that normally move by trucks can be transported using this system. UFT systems not only will help to mitigate highway problems such as air and noise pollution, damage to road surfaces, excessive fuel consumption, traffic congestion and delays, etc., but also improve the security of freight transportation (O'Connell et al. 2008; Shahooei et al. 2018).

Nevertheless, the high initial cost of the proposed UFT systems has made the financing of such projects a national challenge. Thus, it is necessary to develop a robust funding and financing strategy. One of the most important requirements of developing a funding and financing approach is the identification of capital sources and appropriate project delivery systems (Zahed et al. 2018a). It is also critical to assess the eligibility and accessibility of those identified funding sources and delivery systems based on enabling legislation. Moreover, successful planning for implementation of such large and innovative infrastructure projects requires a rigorous investment valuation to explicitly show the advantages of the project for the public and private parties.

The body of knowledge on development and implementation of UFT systems is still growing. Prior research has mainly focused on (1) various applications, (2) development and technological advancements, and (3) financial aspects of UFT systems. However, after analyzing the literature on development and implementation of UFT systems, it was concluded that the existing literature does not encompass critical information on funding and financing of UFT systems. The current literature does not often address the identification and evaluation of available and eligible funding sources as well as project delivery systems for implementing UFT systems. Although the existing literature includes several financial and economic studies on implementation of UFT systems, there is still a significant gap in knowledge for a comprehensive investment analysis that considers both life-cycle benefit and cost components of UFT systems. These studies typically neglect the cost uncertainties and the value of decision-making flexibilities involved in investment valuation of UFT systems. Due to lack of experience in development of such large and innovative infrastructures, it is critical to consider uncertainties in financial evaluation of UFT projects.

The ultimate goal of this research is to (1) identify and evaluate viable financial means (funding sources and delivery systems) along with assessment of enabling legislations, (2) assess investment opportunities of implementing UFT systems, and (3) conduct an investment valuation of these systems under existing uncertainties and decision-making flexibilities.

1.1 Organization of Dissertation

In order to achieve the objectives of this research, the remainder of this dissertation is organized as follows. Chapter 2 provides a comprehensive review of the literature and a detailed list of research objectives. The results of the literature review on each research objective are presented, separately. Further, each objective is addressed in a chapter. Potential funding sources and project delivery mechanisms for implementation of UFT systems are identified in Chapter 3. This chapter also presents a review and eligibility assessment of the identified funding sources. Chapter 4 provides an extensive life-cycle benefit-cost analysis of the UFT systems. Deterministic investment valuation techniques such as discounted cash flow analysis, net present value analysis, breakeven analysis, and sensitivity analysis are used to evaluate the financial feasibility of different UFT system scenarios. Chapter 5 presents an investment valuation of UFT systems under uncertainties using a real options approach. A bivariate real options model is developed as a novel approach that overcomes the theoretical limitations of the existing real options techniques. The application of the model is demonstrated using an illustrative case example. Chapter 6 includes the conclusion of this dissertation and highlights its contributions.

Chapter 2

Background

2.1 Financial Means and Enabling Legislations of UFT Systems

Underground freight transportation is a class of automated transportation systems in which vehicles carry freight through tunnels or pipelines under roadways between intermodal terminals (Najafi et al. 2016). Most of the cargos that normally move by trucks can be transported using this system. UFT systems not only will help to mitigate highway problems such as air and noise pollution, damage to road surfaces, excessive fuel consumption, traffic congestion and delays, but also improve the security of freight transportation (O'Connell et al. 2008).

Nevertheless, the high initial cost of the proposed UFT infrastructure has made the financing of such projects a national challenge. One of the most important requirements of developing a financing approach is the identification of capital funding sources (Khmel and Zhao 2016). In fact, the financing method depends on available funding sources (Collier and Goodin 2002). Literature encompasses several studies on the financing of transportation projects. However, identification and critical assessment of available and eligible funding sources are not often addressed. This gap can be attributed to variations in states' regulations and policies.

The legal aspects of highway projects stemming from public and private partnerships have been widely studied in the literature. Fishman (2009) conducted a comprehensive study to identify significant public-private partnership (PPP) legal issues and suggested potential solutions to these problems. PPP is a long-term agreement between a government entity and private sector to provide a public service (World Bank Group 2014). Studying several cases, Fishman highlighted the complexity of financing and risk sharing arrangements as the major barrier to PPP projects and underscored the need for flexibility in every aspect of developing PPP agreements. Geddes and Wagner (2013) studied PPP enabling laws for each state of the U.S. to see how much each state's transportation-related laws are encouraging or discouraging private investment into transportation infrastructure projects. Papajohn and Bayraktar (2011) conducted a national survey to examine the state-of-practice of PPPs in several areas, such as PPP enabling laws in the United States' transportation industry. They found it is necessary for transportation agencies to have a flexible and certain legal framework in order to create PPPs and attract private sector experience and investment. Zhang (2005) studied a wide range of issues regarding PPPs, exploring case studies while conducting a literature review and interviews. Their study also declared that legal barriers are one of the impediments to public-private partnerships in infrastructure development.

Existing literature focuses on the legal issues that hinder involvements of the private sector in public projects and the recommendations made to overcome those problems. They typically do not assess the existing legislation that makes the partnerships of private sector with government transportation entities possible for different transportation infrastructure projects. Moreover, highway and road projects are the focus of existing legislation and explicit references to underground freight transportation are limited, which makes UFT eligibility analysis challenging.

2.2 Investment Valuation of UFT Systems

Economic assessment of cutting-edge transportation systems such as the UFT systems is imperative to their development. Liu et al. (1998) compared the cost of transporting coal from mines to power plants using coal log pipelines with other modes of transportation including truck, rail and coal slurry pipeline. The results showed coal log pipeline is more economical than truck, rail and slurry pipeline. This research identified the revenue from transporting coal as the only source of benefit for the system and ignored other significant UFT benefits such as air, water, and noise pollution reductions.

Howgego and Roe (1998) broke down the monetary cost of establishing a 20 cm pneumatic UFT system in three groups of construction, operation, and return on capital. Although the cost of tunneling and propulsion system was specified as the largest elements of capital cost, they admitted it is difficult to determine the exact cost of such systems. Howgego and Roe (1998) did not consider the monetary value of the benefits in their evaluation.

Roop et al. (2000) studied the application of freight pipelines in Texas. The results suggested that such systems are technically feasible while the capital investment is relatively substantial. To evaluate economic aspects, the authors limited the benefits of the system into only two categories of avoided marginal costs of truck traffic and avoided trucking industry expenses. Likewise, the cost of proposed system was roughly estimated based on average low bid price of items for different construction tasks and extrapolating available unit price of smaller size concrete culverts.

Liu (2004) investigated the feasibility of developing a new underground freight movement system for the city of New York. He justified the economic viability of five out of six proposed applications of UFT systems. Due to the lack of data, Liu evaluated the benefits of UFT systems only in terms of reductions in vehicle miles traveled (VMT) and air pollution. In addition, he did not consider monetary value of the benefits in evaluating the feasibility of the proposed systems.

Despite the attempts that have been made to evaluate the financial feasibility of UFT systems with different applications, a clear understanding about the life-cycle benefit and cost of such innovative systems is still obscure.

2.3 Investment Valuation of UFT Systems under Uncertainties

Decision making regarding investment in civil infrastructure system is often plagued by numerous epistemic and aleatory uncertainties (Ang and De Leon 2005; Ellingwood and Kinali 2009). Consideration of such uncertainties in an investment decision making framework is critical to effectively optimize the positive outcomes of the investment (Shahandashti and Pudasaini 2019; Pudasaini and Shahandashti 2018; Pudasaini et al. 2017). Investment decision regarding UFT system is no exception to that. However, current studies on the investment opportunities in the UFT systems typically neglect the cost uncertainties and the value of decision-making flexibilities involved in valuation of these systems. Most extant studies have used deterministic discounted cash flow (DCF) methods, such as net present value (NPV) analysis. While the implementation of UFT systems with high cost and limited historical data possess significant uncertainties, deterministic valuation techniques fail to incorporate uncertainties and managerial flexibility. It is therefore important to perform a more rigorous analysis of UFT systems under existing uncertainties. Real options analysis (ROA) is a promising approach that enables transportation financial planners to conduct investment analysis and integrate the value of flexibility in response to uncertain future outcomes (Pellegrino et al. 2013; Zhao et al. 2004; Rose 1998). Real options analysis uses financial options theory to estimate the value of different contingent claims or options on real assets by considering managerial decision flexibility (Cabero Colín et al. 2016; Merton 1973). Nevertheless, to the best of the author's knowledge, the current literature does not offer a real options model that can be utilized for investment valuation of UFT systems. The combination of uncertainties with differing attributes inherent in UFT projects makes valuation of these systems unique compared to other infrastructure and transportation development projects, such as highways and bridges. Existing real options models applied to transportation projects are theoretically deficient to properly assess the UFT investment options. A well-founded real options model should be designed and calibrated based on the unique characteristics and stochastic behavior of UFT uncertainties (Kashani et al. 2012).

2.4 Real Options Analysis in Transportation Infrastructure

Over the past three decades, real options techniques have been developed to evaluate investment opportunities in risky transportation infrastructure projects (Rose 1998; Huang and Chou 2006; Iyer and Sagheer 2011). For instance, researchers such as Ho and Liu (2002), Huang and Chou (2006), Cheah and Liu (2006), Brandao and Saraiva (2008), Ashuri et al. (2011), Liu et al. (2017) have used real options to value minimum revenue guarantees and risk sharing in public-private partnership projects, such as tollways with Build-Operate-Transfer (BOT) delivery systems. Ho and Liu (2002) created a real option model to evaluate the financial viability of BOT projects given a government debt guarantee. They presented a framework for evaluating the financial feasibility of privatizing infrastructures from both public and private point of view. Huang and Chou (2006) developed a compound option pricing model to value the minimum revenue guarantee and the option to abandon in the preconstruction phase of Build-Operate-Transfer (BOT) infrastructure projects. They applied their model to the Taiwan High-Speed Rail Project. Cheah and Liu (2006) proposed that the value of available options such as government guarantees, and subsidies should be incorporated in the negotiation framework of BOT projects. They used the Malaysia-Singapore Second Crossing project to show how a Monte Carlo real options approach can be used to value such options. Brandao and Saraiva (2008) presented a real options model for evaluating highway projects with minimum traffic guarantees, and they applied it to the 1000 mi BR-163 toll road project that links the Brazilian Midwest to the Amazon River.

Rose (1998), Zhao et al. (2004), Garvin and Cheah (2004), de Neufville et al. (2006) developed real options models to assess projects such as highway and high-speed rail systems. Rose (1998) illustrated the advantages of using real options to value a large-scale infrastructure project. He proposed a Monte Carlo simulation method to evaluate the interactions of two real options involved in the Transurban City Link project in Melbourne, Australia. This project included financing, construction, operation and maintenance of 22 kilometers of toll-roads. The results showed that option values could be highly significant (more than half of the market value of Transurban securities). Ignoring these options would seriously undervalue the project. Zhao et al. (2004) proposed a real options model for highway development, operation, expansion, and rehabilitation. Their model utilizes Monte Carlo and least-squares regression techniques to model traffic demand, land price, and highway deterioration uncertainties and their mutual interdependence. Garvin and Cheah (2004) used a binomial tree option pricing model to capture the strategic value of deferring the Dulles Greenway tollway project in Northern Virginia, US. They suggested that a deferral strategy would add value to the project due to the opportunity to obtain new information, thereby reducing project uncertainty. de Neufville et al. (2006) presented a simple spreadsheet real options model as a tool for engineers and designers to evaluate flexibility in engineering systems. They applied their model to a parking garage and showed how to minimize risks and maximize potential profits by adopting a flexible design.

A number of studies used real options analysis to evaluate intelligent transportation systems (ITS), such as Leviäkangas and Lähesmaa (2002), Hodota (2006), and de Neufville et al. (2008). Leviäkangas and Lähesmaa (2002) showed that conventional benefit-cost analysis methods are unable to show the full benefits and costs related to ITS. They developed two real options models to overcome the limitations of deterministic methods. They declared that using only one real options method may not fully manifest all the aspects of decision making. de Neufville et al. (2008) used a real options approach to assess the value of flexibility in using ITS technology. They evaluated options to continue developing ITS systems versus terminating the development based on future contingent benefits. Hodota (2006) used real options analysis to value the option to develop ITSs in the event of an unfavorable outcome at the research and development (R&D) stage. The author identified product attractiveness and user acceptance of ITS technology as the critical factors affecting the project value.

To the author's knowledge, no real options models have been developed for the investment valuation of UFT systems under uncertainty and decision-making flexibility. Extant real options methods are not well-suited for modeling UFT uncertainties and decision-making flexibilities. This is because UFT systems typically differ significantly from conventional systems, such as highways and roads. Existing real options models are not designed to incorporate all of the uncertainties involved in UFT systems. Ideally, a real options model should be tailored to the specific context (Garvin and Ford 2012), and it should be able to correctly quantify the uncertainties specific to that setting (Kashani et al. 2014). Therefore, a new real options model must be developed and customized for UFT systems. Fundamental research is required to properly model and integrate the UFT underlying uncertainties into the investment analysis framework.

2.5 Gaps in Knowledge

Although the existing financial and economic studies have added valuable insight into implementing UFT systems with different technologies and applications, yet there is a significant gap in knowledge related to financial means and life-cycle investment analysis of these innovative transportation infrastructures:

- Existing studies on the financing of transportation projects often neglect to identify and critically assess the available funding sources for new and innovative transportation infrastructures, especially UFT systems;
- Existing literature on various delivery methods of transportation projects still has significant limitations on identifying viable delivery systems for implementing new and innovative transportation infrastructures, such as UFT systems;
- Existing literature on legal aspects of developing new transportation infrastructures focuses on the legal barriers of private sector partnership in delivery of such projects and typically do not recognize and assess the enabling legislations, especially for underground transportation infrastructures;
- Existing investment analysis efforts do not consider major benefits of the UFT systems, such as reduction in traffic congestion and shipment revenue;
- Existing investment studies are considering UFT systems that are not designed for moving standard size cargos for short and long distances. While, the design of standard size UFT systems is crucial for the widespread implementation and simple integration of these systems with other modes of transportation;

- Existing investment analysis efforts do not distinguish key factors affecting the economic feasibility of large size UFT systems and those affecting small or medium size systems;
- Existing investment analysis efforts do not determine the minimum shipping prices that make the UFT systems economically viable; and
- Existing investment analysis methods often neglect the uncertainties and decision-making flexibilities affecting the financial viability of UFT systems.

2.6 Research Objectives

The primary objectives of this research are organized in three main sets as follows:

1. Analysis of financial means and enabling legislations for implementing UFT systems to:
    a. Identify and critically assess the viable funding sources and delivery systems for implementing UFT systems;
    b. Identify and assess enabling legislation, which can facilitate financing of UFT projects through the identified funding sources.
2. Deterministic investment valuation of implementing UFT systems to:
    a. Identify the major cost and benefit components of the UFT systems;
    b. Assess the financial feasibility of UFT systems with different standard cargo sizes and for different route lengths;
    c. Identify key components affecting the economic feasibility of UFT systems; and

d. Determine minimum shipping prices that make the UFT systems economically viable.

3. Investment valuation of implementing UFT systems under uncertainty using a real options approach to:
   a. Determine the market value of the option to invest in UFT systems considering various underlying uncertainties;
   b. Incorporate the value of decision-making flexibilities as a significant factor in valuing the investment option
   c. Determine the optimal policy to invest in UFT systems; and
   d. Assess the effect of different operational levels on the value of the project.

These three sets of objectives are addressed in the next following chapters, respectively.

2.7 Case Study of Texas

Annually, more than 2 billion tons of freight moves in Texas. This volume is expected to increase by 88 percent from 2 billion to 3.8 billion tons between years 2014 and 2040 due to population growth, strong economy, increasing trade, and growing energy production (TxDOT 2016). According to the Texas Legislative Budget Board (2015), trucks carry sixty percent of goods shipped annually from Texas, and another nine percent is carried by services that use trucks for part of the delivery. Freight vehicle miles traveled are expected to increase 120 percent between 2011 and 2035 (Texas Legislative Budget Board 2015). Freight transportation is one of the most important factors contributing to deterioration of existing Texas transportation infrastructure. Thus, building efficient, sustainable, and safe intermodal transportation facilities, such as Underground Freight Transportation (UFT) systems with potentially high benefits can help mitigate this issue.

Implementing a LIM-based UFT system in Texas is used as a case to achieve the objectives of this research. A comprehensive investment valuation of this system is conducted for five different scenarios including three cargo sizes and three routes. The cargo sizes are considered based on the most common and standard cargo sizes used for moving freight by trucks, trains, and airplanes: pallet (small), crate (medium), and container (large) size. The routes are chosen with different lengths and from the most congested freight corridors in Texas: Interstate Highway 45 (I-45) freight corridor and Laredo border. Table 2-1 presents information about these five scenarios and Figure 2-1 shows the three different routes for the UFT system.

Table 2-1 Scenarios for implementing the UFT system in Texas (Data from Najafi et al. (2016))

Scenario	Route	Freight Type	Length (mile)
1	Port of Houston – Dallas	Shipping Container (Large)	250
2	Laredo Border	Shipping Container (Large)	5
3a	Port of Houston – Satellite Dist. Center	Shipping Container (Large)	15
3b	Port of Houston – Satellite Dist. Center	Crate (Medium)	15
3c	Port of Houston – Satellite Dist. Center	Pallet (Small)	15

Figure 2-1 Routes proposed for implementing UFT system in Texas (Najafi et al. 2016)

Chapter 3

Financial Means and Enabling Legislations

To address current and future challenges threatening sustainable freight movement, there is a need to identify funding sources and assess their accessibility based on enabling legislation to support innovative freight transportation systems, such as UFT. This research method includes two steps: (1) identification of potential funding sources through case study analysis, and (2) identification and assessment of enabling legislation, which can facilitate financing through the identified funding sources. Case studies were identified and evaluated to introduce several viable funding and financing sources that can be adopted for UFT projects in Texas. In consultation with several experts from industry and stakeholder committee members, the following criteria were developed to select study cases. Case studies must:

- Be located in Texas,
- Be recently funded,
- Have a variety of public and private funding contributions, and
- Have an introductory mechanism, such as toll collection to attract funding during the operation phase.

A stakeholder committee was formed as a part of a feasibility study conducted by the University of Texas at Arlington entitled "Integrating Underground Freight Transportation into Existing Intermodal Systems" for the Texas Department of Transportation. To appraise the eligibility of identified potential funding sources for constructing UFT systems in Texas, the following sections present a detailed review of literature, recent legislations, and statutes.

3.1 Identifying Funding Sources through Case Study Analyses

Based on the devised criteria for selecting case studies and the availability of data, four comparative projects were identified and studied as listed in Table 3-1.

Table 3-1 List of case studies

Project	Location
• North Tarrant Express (I-820 and SH 121/183)	Tarrant County, Texas
• North Tarrant Express 35W Project	Tarrant County, Texas
• Central Texas Turnpike System (CTTS)	Travis County, Texas
• SH 130 (Segments 5–6) Project	Caldwell/Guadalupe County, Texas

Conducting case study analyses on comparable transportation projects funded in Texas resulted in identifying major potential funding sources to finance UFT systems. The identified funding sources are: federal and state funds (public funds), TIFIA (Transportation Infrastructure Finance and Innovation Act) loans, senior bank loans, private activity bonds, and equity participation. Subsequently, the identified funding sources were reviewed by the stakeholder committee. The stakeholder committee recommended adding the Fixing America's Surface Transportation Act (FAST Act) as a new funding source to the list of potential funding sources for constructing UFT systems. Figure 3-1 shows the percentage of major funding sources used in case studies. These percentages can be assumed as the possible proportions that each type of funding source can contribute to when financing a UFT project in Texas.

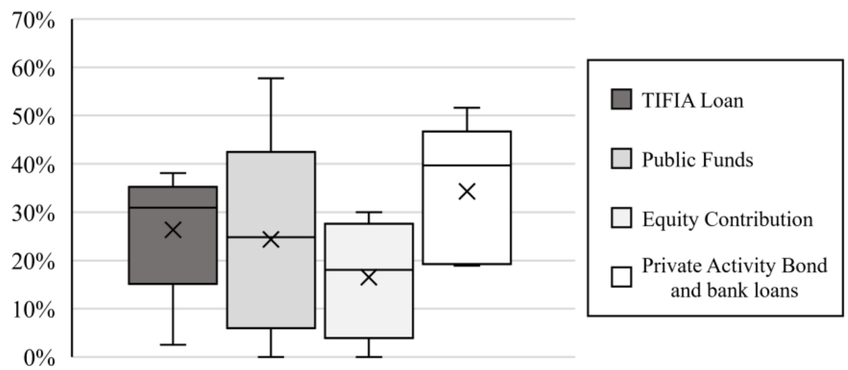


Figure 3-1 Potential contribution (proportion by percentage) of major funding sources for financing UFT systems based on case studies

Different possible mechanisms are available to finance UFT projects using identified funding sources. Risks associated with each funding source are highly dependent on the project delivery mechanism. Design-bid-build (DBB) and design, build, finance, operate, and maintain (DBFOM) are the two mechanisms used in the presented studied cases. DBB is the traditional project delivery for designing and constructing a facility through a two-step delivery process (AECOM 2007). Under a DBB contract, most of the risks -from financing to design, construction, operation, and maintenance are assumed by the project sponsor which is the transportation agency in this case (AECOM 2007). In this delivery system. A major portion of the capital is provided by public funding sources (federal, state, and local funds, TIFIA loan, and funding through the FAST Act). These funding sources are mostly subjected to risks, such as, design deficiencies, construction delay, poor quality, and cost overruns in construction, operation, and maintenance (Wang et al 2000; Pishdad-Bozorgi and de la Garza 2012; Gibson et. Al 2015). Comparatively, DBFOM is a long-term concession that transfers a large amount of the responsibility for developing and operating a transportation infrastructure to the private sector (FHWA 2016a). Private funding sources (private activity bonds, equity participation, and bank loans) are mostly subjected to risks such as inflation volatilities, political instabilities, change in policy and regulations, availability of finance, and revenue below expectation (Gibson et. Al 2015; Prieto 2012). Although public funding sources are less exposed to risk compared to DBB, they are still exposed to future financial risks, such as inflation volatility, revenue and expected payback period.

3.2 Review and Eligibility Assessment of the Identified Funding Sources

To assess the eligibility of identified funding sources and potential project delivery systems we reviewed federal and state level legislation. The following sections present the result of this study.

3.2.1 Public Funding Sources

According to the American Association of State Highway and Transportation Officials (AASHTO), most surface transportation projects in the U.S. are funded from public sources at the federal, state, and local levels. Each year, up to $200 billion is invested in surface transportation that is mostly provided by various taxes and fees (AASHTO 2015a). Federal funds, state revenues, and local funds contribute 21%, 43%, and 36% of total surface transportation funding in the United States, respectively (AASHTO 2016a).

Each fiscal year the House and Senate introduce “appropriations bills” to outline the amount of funds to be appropriated to each agency and state. The fiscal year (FY) 2016–17 general appropriations bills includes $23.1 billion in funding for TxDOT. Likewise, every five to six years, new “authorization bills” are passed by the Congress to reauthorize existing statute for funding different programs such as highway, transit, safety, and rail. These bills establish the terms and conditions under which a federal agency operates. They authorize the enactment of appropriations and specify how appropriated funds are to be used (U.S. Senate 2016). Two most recently passed bills are the FAST Act and TIFIA.

It is not surprising to find no appropriated fund specifically designated for a new and innovative underground freight transportation system in any of the recent authorization bills. However, construction of UFT can be funded using federal funds by getting it named as a specific project (such as a project with state and national significance) under one of these authorization bills with particular funding levels and time extent (Texas Transportation Institute 2002).

At the state level, the Texas Transportation Commission and TxDOT utilize the Unified Transportation Program (UTP) to lead in the development of needed transportation projects. The UTP is developed annually in accordance with the Texas Administrative Code section 16.105 (TAC §16.105) and approved by the Texas Transportation Commission each year before the end of August (TxDOT 2016). Due to the several advantages of UFT, such as mitigating traffic congestion and improving safety, this system could be considered as a project likely to be funded under TAC §16.105.

Likewise, revenue from local governments plays an important role in transportation finance. General fund appropriations are the largest source of local funding. The use of property taxes makes local transportation funding different from the federal and state governments' funding (AASHTO 2015b). Undoubtedly, local authorities can play a significant role in funding the construction of UFT with several programs and funding sources that are available at this level.

TIFIA Loan

In 1998, the Congress introduced the Transportation Infrastructure Finance and Innovation Act (TIFIA). Under this Act, qualified projects of regional and national importance are able to use credit support in different forms of direct loans, loan guarantees, and standby lines of credit. Since this act has been introduced, TIFIA has provided funding to 55 projects in the United States. Notably, Texas, with 10 projects, is the pioneer in using this loan for its transportation projects (USDOT 2016a).

Projects that are eligible for federal assistance through existing surface transportation programs and several other types of projects including intermodal freight transportation are eligible for the TIFIA credit program (USDOT 2016b). Under Title 23 of the U.S. Code, eligible projects are defined as within the scope of a TIFIA loan as follows:

> Public freight rail facilities, private facilities providing public benefit for highway users by way of direct freight interchange between highway and rail carriers, intermodal freight transfer facilities, projects that provide access to such facilities, and service improvements (including capital investments for intelligent transportation systems) at such facilities, are also eligible for TIFIA credit assistance (USHR 1998a).
>
> In addition, a logical series of such projects with the common objective of improving the flow of goods can be combined (USHR 1998b).

As shown explicitly in these two sections, a TIFIA loan can play a significant role in financing UFT as a new innovative, intermodal freight transportation facility.

FAST Act

The Fixing America's Surface Transportation (FAST) Act was signed into law on December 4, 2015. The five-year (through FY 2020) $305-billion bill replaces the Moving Ahead for Progress in the 21st Century (MAP-21) Act. Title VIII of the FAST Act— Multimodal Freight Transportation−focuses on multimodal freight transportation and its significance as an economical advantage for the United States globally (USDOT 2016c). The Act creates a multimodal freight policy along with a strategic plan for national multimodal freight transportation. It also assigns a National Multimodal Freight Network to support states in using resources and planning freight movement (USDOT 2016c).

The FAST Act provides grant programs to fund transportation projects with freight movement benefits. These programs will for the first time support freight transportation projects, by providing a dedicated source of funding. The FAST Act highlights the necessity of federal supervision to facilitate the local government's ability to cooperate and assist with freight transportation providers' needs (USDOT 2016c).

3.2.2 Private Funding Sources

Although private investment is not a substitute for government funds in providing the U.S. infrastructure, an effective use of both sources can lead to a better and higher quality infrastructure network. President Barack Obama announced the Build America Investment Initiative on July 14, 2014. The initiative calls for the Secretaries of the Treasury and Transportation to lead a working group to analyze how to increase the partnership of public and private sectors in developing infrastructure, increasing private sector financing contribution in infrastructure, and enhancing productivity, efficiency, and resilience (U.S. Department of the Treasury 2014).

Recent legislation and financing mechanisms have provided an opportunity to use private investments and redistribute project risks. The USDOT supports the construction of transportation projects by administrating several credit programs, such as direct loans and loan guarantees (USDOT 2016d). Credit programs have enhanced access to a wider range of capital and have expanded limited federal resources (AASHTO 2016b). The Federal Highway Association (FHWA) PPP website provides comprehensive coverage of PPP legislation for 23 U.S. States (FHWA 2016b).

The legislation most often associated with public private partnerships in Texas is HB 2475, introduced during the 84th Legislative Session (Texas State Legislature 2016a). HB 2475 supports private investment by establishing a Center for Alternative Finance and Procurement within the Texas Facilities Commission. This center assists governmental entities in the receipt of proposals, negotiation of agreements, and management of qualifying public-private partnerships under Chapter 2267.

Chapter 501 of the Texas Local Government Code supports private investment by expanding the authority of "economic development corporations" to carry out projects for transportation facilities such as airports, hangars, rail and marine ports, rail and freight facilities, as well as parking garages and lots located at airports or rail port facilities (Texas State Legislature 2016b). An economic development corporation will also be authorized to own and operate a facility as a "business" (Texas State Legislature 2016b). Chapter 2267 of the Texas Local Government Code supports private investment by (Texas State Legislature 2016c):

> (1) encouraging investment in this state by private entities and other persons, and (2) facilitating bond financing or other similar financing mechanisms, private capital, and other funding sources that support the development or operation of qualifying projects to expand and accelerate financing for qualifying projects that improve and add to the convenience of the public.

The above assessment of recent legislation clearly shows the eligibility of using private partnerships in funding UFT as a new innovative freight transportation project that brings more capacity, safety, and resilience to existing transportation systems.

Equity Participation

Equity participation is a favorable funding instrument specifically in the case of new and innovative infrastructure projects, such as UFT systems with high benefits during its life cycle. Although financial mechanisms may not directly generate revenue, they promote construction of new infrastructure systems that can generate substantial revenues. For instance, constructing an underground freight transportation facility needs a large investment. The required funding should be provided through one or a combination of funding mechanisms, such as, equity participation. Future revenues from transporting freight using this facility will return the investment and produce profit for investors. As the life expectancy of such facilities increases, the risks for return on the investment and potential revenues are going to increase. Therefore, a thorough and extensive financial and sensitivity analysis is required prior to investing in such projects to explicitly show the impact of life expectancy on investment risks.

Subcontractors that perform specific services, such as the construction, operation, and maintenance of a project may contribute as equity participants (FHWA 2016c). Other potential equity participants include financial institutions, such as investment banks and insurance companies. These institutions may also function as a lender, along with commercial banks and public agencies. As stated by Chapter 370 Texas Government Code (subchapter G) (Texas State Legislature 2016d):

> An authority may authorize the investment of public and private money, including debt and equity participation, to finance a function described by this section.

Further, Section 370.311 emphasizes that:

> An authority may only enter into a comprehensive development agreement under Section 370.305 with a private equity investor if the project is identified in the department's Unified Transportation Program or is located on a transportation corridor identified in the statewide transportation plan.

Since UFT can be defined as a project under the Unified Transportation Program (UTP), equity participation can be used to attract funding.

Private Activity Bonds

Revenue bonds provide funding for projects that make revenue (e.g., a toll road or bridge). Bond holders will be paid back using the revenue from such projects (AASHTO 2016c). Financing UFT using revenue bonds can be similar to toll roads. Most toll roads are funded by borrowing debt supported by revenues from future tolls. This toll revenue is like a fee that UFT can charge each freight car to transfer freight using the facility. In this method, the public authority (i.e., TxDOT) can issue a bond against anticipated toll revenues to fund the construction of a UFT. When UFT starts to operate, the revenues collected from freight cars will be used as a pay back and interest to bond holders. The revenue bonds can be very attractive for investors since the interest is exempt from federal and state income taxes.

Similarly, a private partner can finance such projects by issuing private activity bonds and repaying the debt from facility revenues. Private activity bonds for these kinds of arrangements can be issued on a tax-exempt basis (AASHTO 2016c). This financing opportunity encourages the private sector to invest in infrastructure projects such as UFT and shifts the risk of long-term debt from government to the private party (AGC 2016). In this case, the federal government provides a form of credit assistance by exempting tax from these kinds of bonds leading to lower debt-service payments for private partners (Kile 2014).

Under Section 142 of the Internal Revenue Code (amended by SAFETEA-LU), highway and freight transportation facilities are eligible to use private activity bonds (PAB) (AASHTO 2016d). The PAB legislation indicates the interest of federal government in attracting private sector contribution in the transportation infrastructure projects (AASHTO 2016d). Access to tax-exempt interest rates reduces the capital cost considerably and facilitates future investments (AASHTO 2016d; AGC 2016). SAFETEA-LU section 11143 offers a new tax-free class of private activity bonds with a volume cap of $15 billion (FHWA 2016d). The provision plans to promote the private participation in the delivery, operation and ownership of transportation infrastructure projects including freight transportation projects. The tax exemption could be significant and provide about 15–20% of the present value on long-term borrowing (Mercator Advisors LLC 2007).

Chapter 4

Deterministic Investment Valuation of UFT Systems

The feasibility of potential transportation projects such as UFT systems should be rigorously evaluated using proper methods to assure that benefits of the project (e.g., improved safety and decreased travel times) outweighs the costs (e.g., capital costs). The objectives of this chapter is conduct a deterministic investment analysis of implementing UFT systems in Texas and ultimately:

- Identify the major cost and benefit components of the UFT systems;
- Assess the financial feasibility of UFT systems with different standard cargo sizes and for different route lengths;
- Identify key components affecting the economic feasibility of UFT systems; and
- Determine minimum shipping prices that make the UFT systems economically viable.

4.1 Methodology

Life-cycle benefit-cost analysis has historically been considered the most objective and credible product of feasibility studies for transportation projects (FHWA, 1998). In this research, a life-cycle benefit-cost analysis method is used to conduct deterministic investment valuation of an LIM-based UFT system for five different scenarios developed in collaboration with a stakeholder committee and several experts from industry. Here, the term investment valuation refers to the analytical process of estimating the value of an asset or a project.

This analysis includes life-cycle cash flow determination and calculation of three common economic measures including (1) net present value (NPV) of the system, (2) benefit-cost ratio, and (3) internal rate of return (IRR). This analysis is followed by sensitivity analysis to test the vulnerability of the results to variations in key input parameters. Breakeven analysis method is used to answer two fundamental questions to (1) find a practical range for pricing freight shipment so that the system remains economical, and (2) the time which the UFT system would return all the expenditures and generate profit.

To conduct a life-cycle benefit-cost analysis, the cash inflows and outflows of all the five alternatives are initially created. The UFT system life-cycle cost and benefit components are listed in Table 4-1. The raw direct and indirect costs and benefits are obtained from Najafi et al. (2016).

Table 4-1 List of cost and benefit components of the UFT system

List of Cost Components	List of Benefit Components
• Fuel Tax Revenue Loss	• Air Pollution Reduction
• Tire Tax Revenue Loss	• Noise Pollution Reduction
• Maintenance of Tunnel	• Water Pollution Reduction
• LIM Power Consumption	• Traffic Congestion Reduction
• LIM Maintenance	• Infrastructure Damage Reduction
• Tunnel Construction	• Accident Reduction
• Handlers	• Electricity Tax Revenue
• Administration	• Shipment Revenue
• Freight Vehicles	
• LIM	
• Terminal Land	
• Terminal Development	

The initial costs, such as cost of tunneling or pipelines, cost of terminal land and development, and cost of the LIM system are considered as one-time costs. Other costs and benefits are assumed as annually recurring in the life cycle of the UFT system. Then present values of the life-cycle benefits and costs of all the suggested alternatives are calculated. The net present value of each UFT alternative is calculated using Equation (4-1), by taking difference between the present values of life-cycle benefits (cash inflows) and its actual costs (cash outflows).

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \qquad (4\text{-}1)$$

Where B_t is the UFT benefits at time t, and C_t is the UFT costs at time t; i is the discount rate, and n is the length of time for the project's benefit and cost streams. For a chosen period, if NPV is positive, the proposed UFT system is considered economically viable. In the case of alternative projects, the project with the highest net present value can be selected as the most beneficial. Net present value is the most widely used method as a decision rule for project selection (Kocabas et al., 2010).

Further, benefit-cost ratio (B/C) of the UFT system for each scenario is computed by dividing present value of benefits by the sum of the discounted costs. Equation (4-2) presents this ratio. If the ratio is greater than or equal to 1.0, the proposed system is economically desirable.

$$\frac{B}{C} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \qquad (4\text{-}2)$$

The internal rate of return (IRR) is also calculated and compared to the market interest rates. The IRR represents the discount rate which equates NPV to zero. If the rate of return exceeds the adopted discount rate, then the UFT system is economically viable. In case of alternative projects, a project with the higher IRR is most beneficial.

In this analysis, the life expectancy of a freight vehicle is assumed 20 years and the salvage value for depreciated vehicles is assumed to be 40% of their original cost (Zahed et al. 2017). Discounting factors are used to identify the present values of costs and benefits that occur in the coming years. The overall life expectancy for UFT is assumed to be 100 years. The 2016 discount rate of 1.5 percent recommended by the U.S. Office of Management and Budget (USOMB) (U.S. Office of Management and Budget, 2016) is used for the benefit-cost calculations.

Benefit-cost analysis is followed by a sensitivity analysis. In this analysis, the value of each key variable is changed one at a time while other inputs are remained constant. The amount of change in the B/C ratio is recognized as the sensitivity of the

B/C ratio to that variable. In this regard, two items with the highest values from each list of costs and benefits are used as the key variables to test for sensitivity. Accordingly, the sensitivity analysis is performed for up to 30 percent variations in key input variables. A 30% variation in the key input variables compares well with the variations considered in the similar sensitivity analyses in the literature (Flyvbjerg et al. 2002).

Since the UFT system is evaluated for a long period of 100-years, a sensitivity analysis is also performed on the selected discount rate. Considering the historical discount rates suggested by U.S. Office of Management and Budget (2016), discount rates from 0.5 percent (optimistic case) to 5.0 percent (pessimistic case) are assessed. Finally, a breakeven analysis is performed to determine a point in time (breakeven point) when total benefits are equal to total expenses. Likewise, a breakeven analysis is conducted to find the minimum amount of shipment price that makes the costs and benefits of the UFT system equal.

4.2 Results

4.2.1 Life-Cycle Benefit-Cost Analysis

Cash inflows and outflows of the five UFT scenarios are created for the life cycle of 100 years. The present value of benefits and costs are calculated for each scenario, and presented in Tables 4-2 to 4-6, respectively.

Table 4-2 The present value of costs and benefits for scenario 1

Cost Components	**PV of Costs ($million)**	**Benefit Components**	**PV of Benefits ($million)**
Fuel Tax Revenue Loss	$1,520.26	Air Pollution Reduction	$19,499.00
Tire Tax Revenue Loss	$99.15	Noise Pollution Reduction	$308.46
Maintenance of Tunnel	$6,105.35	Water Pollution Reduction	$51.78
LIM Power Consumption	$881.70	Traffic Congestion Reduction	$2,423.60
LIM Maintenance	$32.75	Infrastructure Damage Reduction	$566.24
Tunnel Construction	$11,651.64	Accident Reduction	$3,194.75
Handlers	$8.80	Electricity Tax Revenue	$77.11
Administration	$181.08	Shipment Revenue	$55,081.91
Freight Vehicles	$1,014.13		
LIM	$12.50		
Terminal Land	$1.43		
Terminal Development	$10.05		
Total	$21,518.84		$81,202.85

Note: All the present values of costs and benefits are presented in year 2016 dollars. Non-discounted values of costs and benefits are reported in Najafi et al. (2016).

Table 4-3 The present value of costs and benefits for scenario 2

Cost Components	**PV of Costs ($million)**	**Benefit Components**	**PV of Benefits ($million)**
Fuel Tax Revenue Loss	$24.32	Air Pollution Reduction	$311.98
Tire Tax Revenue Loss	$1.58	Noise Pollution Reduction	$4.94
Maintenance of Tunnel	$97.69	Water Pollution Reduction	$0.83
LIM Power Consumption	$14.54	Traffic Congestion Reduction	$89.36
LIM Maintenance	$0.52	Infrastructure Damage Reduction	$9.06
Tunnel Construction	$186.43	Accident Reduction	$51.12
Handlers	$8.80	Electricity Tax Revenue	$1.23
Administration	$181.08	Shipment Revenue	$881.31
Freight Vehicles	$16.72		
LIM	$0.20		
Terminal Land	$1.59		
Terminal Development	$10.05		
Total	$543.53		$1,349.83

Note: All the present values of costs and benefits are presented in year 2016 dollars. Non-discounted values of costs and benefits are reported in Najafi et al. (2016).

Table 4-4 The present value of costs and benefits for scenario 3a

Cost Components	PV of Costs ($million)	Benefit Components	PV of Benefits ($million)
Fuel Tax Revenue Loss	$91.22	Air Pollution Reduction	$1,169.94
Tire Tax Revenue Loss	$5.95	Noise Pollution Reduction	$18.51
Maintenance of Tunnel	$366.32	Water Pollution Reduction	$3.11
LIM Power Consumption	$52.88	Traffic Congestion Reduction	$145.42
LIM Maintenance	$1.96	Infrastructure Damage Reduction	$33.97
Tunnel Construction	$699.10	Accident Reduction	$191.69
Handlers	$8.80	Electricity Tax Revenue	$4.63
Administration	$181.08	Shipment Revenue	$3,304.91
Freight Vehicles	$60.82		
LIM	$0.75		
Terminal Land	$2.22		
Terminal Development	$10.05		
Total	$1,481.14		$4,872.17

Note: All the present values of costs and benefits are presented in year 2016 dollars. Non-discounted values of costs and benefits are reported in Najafi et al. (2016).

Table 4-5 The present value of costs and benefits for scenario 3b

Cost Components	PV of Costs ($million)	Benefit Components	PV of Benefits ($million)
Fuel Tax Revenue Loss	$31.81	Air Pollution Reduction	$408.02
Tire Tax Revenue Loss	$2.07	Noise Pollution Reduction	$6.45
Maintenance of Tunnel	$235.93	Water Pollution Reduction	$1.08
LIM Power Consumption	$29.86	Traffic Congestion Reduction	$50.71
LIM Maintenance	$1.96	Infrastructure Damage Reduction	$11.85
Tunnel Construction	$450.25	Accident Reduction	$66.85
Handlers	$4.48	Electricity Tax Revenue	$1.61
Administration	$318.74	Shipment Revenue	$1,660.72
Freight Vehicles	$43.28		
LIM	$0.75		
Terminal Land	$2.20		
Terminal Development	$6.55		
Total	$1,127.89		$2,207.30

Note: All the present values of costs and benefits are presented in year 2016 dollars. Non-discounted values of costs and benefits are reported in Najafi et al. (2016).

Table 4-6 The present value of costs and benefits for scenario 3c

Cost Components	**PV of Costs ($million)**	**Benefit Components**	**PV of Benefits ($million)**
Fuel Tax Revenue Loss	$19.16	Air Pollution Reduction	$245.69
Tire Tax Revenue Loss	$1.25	Noise Pollution Reduction	$3.89
Maintenance of Tunnel	$165.00	Water Pollution Reduction	$0.65
LIM Power Consumption	$16.43	Traffic Congestion Reduction	$30.54
LIM Maintenance	$1.96	Infrastructure Damage Reduction	$7.13
Tunnel Construction	$314.90	Accident Reduction	$40.25
Handlers	$4.48	Electricity Tax Revenue	$0.97
Administration	$318.74	Shipment Revenue	$743.61
Freight Vehicles	$18.55		
LIM	$0.75		
Terminal Land	$0.90		
Terminal Development	$4.64		
Total	$866.75		$1,072.73

Note: All the present values of costs and benefits are presented in year 2016 dollars. Non-discounted values of costs and benefits are reported in Najafi et al. (2016).

Figure 4-1 illustrates the percentage of each cost and benefit component for all the scenarios. Shipment revenue and air pollution reduction are the major benefits of the UFT system in all five scenarios. On the other hand, the main cost of the system is attributed to tunnel construction that happens at the beginning of the project. Maintenance of tunnel and administration cost are the other two highest cost components of the UFT system, which occur during the life cycle of UFT. Since the capital cost of constructing UFT tunnel or pipeline are high, the maintenance cost is respectively substantial.

Comparing all the scenarios, it is noticed that the percentage of administration cost is relatively higher for UFT systems transporting crate and pallet size cargos (medium and small size). Since the pallet size UFT has a higher number of shipments per day (Najafi et al. 2016; Zahed et al. 2019), it demands more equipment and personnel that makes the administration cost greater than the container size UFT.

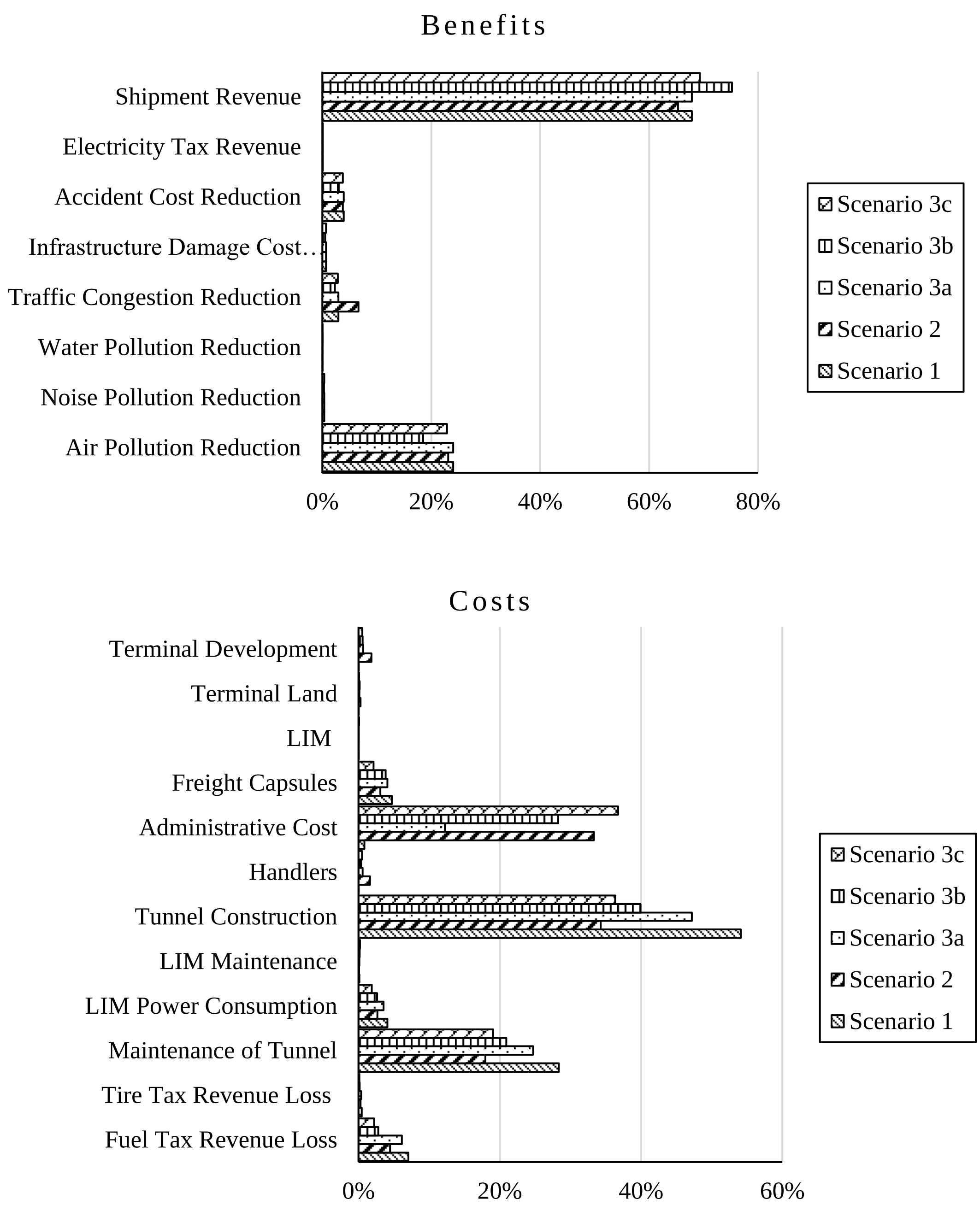


Figure 4-1 Contribution of each cost and benefit component (percent)

The net present value of the system for each scenario is determined by calculating the difference between sum of benefits and sum of costs. The NPVs of the UFT scenarios are summarized in Table 4-7.

Table 4-7 The results of life-cycle benefit-cost analysis

Life-Cycle Benefit-Cost Analysis Metrics	Scenarios				
	1	2	3a	3b	3c
NPV[a]	$59.7	$0.8	$3.4	$1.1	$0.2
IRR	12.44%	9.92%	11.6%	6.44%	3%
B/C	3.77	2.48	3.3	1.96	1.24

[a]The values are in U.S. billion dollars.

The positive NPVs for all the five scenarios indicate that the LIM-based UFT systems are economically promising. Scenario 1 has the highest NPV that presents a UFT system for longer (402.32 Km) and larger cargo size (Container). The benefit-cost ratio and IRR are also calculated for each scenario and presented in Table 4-7. All the benefit-cost ratios are greater than one that shows all the UFT scenarios are economically favorable. The most promising alternatives are Scenarios 1 and 3a with benefit-cost ratios of 3.77 and 3.4, respectively.

Benefit-cost ratio of 1.24 draws attention to scenario 3c for more investigation. Using sensitivity analysis, this scenario is examined further to check whether it is safe to be considered. The result of sensitivity analysis is presented in the next section. All the calculated IRRs are higher than the discount rate (1.5%) used in this study (Table 4-7). In essence, Table 4-7 describes that implementing an LIM-based UFT system can be highly beneficial for the existing freight transportation system by adding more capacity and reducing costs (costs associated with traffic congestion, accidents, pavement damages, etc.).

4.2.2 Sensitivity Analysis

The life-cycle benefit-cost analysis is followed by a sensitivity analysis to assess the vulnerability of the results to different key inputs. Using the results of cash flow analysis, key variables are determined for each scenario. While shipment revenue and air pollution reduction have the highest values in the list of benefits for all cases, the key cost components are not the same for all scenarios. Tunnel construction and maintenance of the tunnel are the two key cost variables for Scenarios 1 and 3a. However, the two key cost components of Scenarios 2, 3b, and 3c are tunnel construction and administration cost. These key variables are changed while all the other components are kept unchanged. Figure 4-2 shows the result of sensitivity analysis for all the five scenarios.

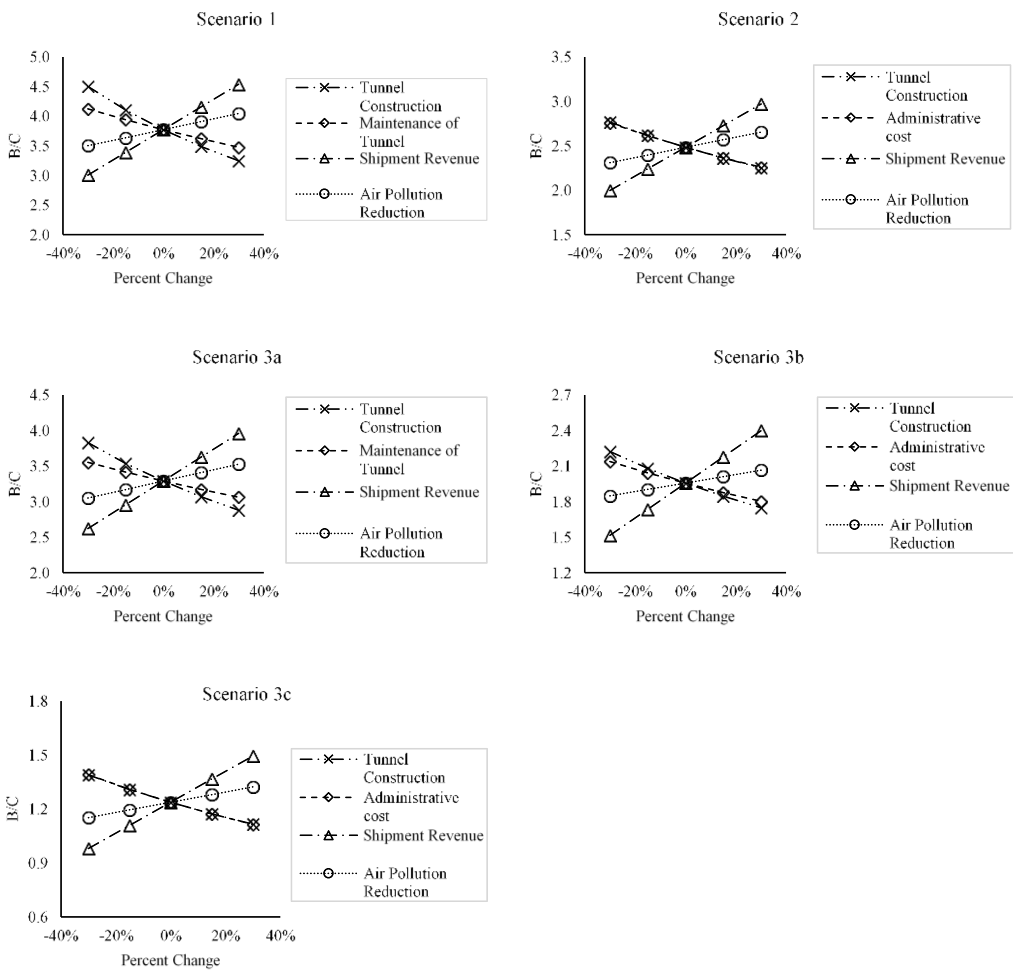


Figure 4-2 Sensitivity of benefit-cost ratio to key variables

In Figure 4-2, the vertical and horizontal axes represent the benefit-cost ratios and percent changes in the key variables, respectively. Slope of each line indicates the degree of benefit-cost ratio sensitivity to the corresponding key variable. In essence, a line with higher slope implies higher sensitivity. For example, the benefit-cost ratio is highly sensitive to variation in shipment revenue for all scenarios. According to sensitivity diagrams for scenarios 2 and 3c, it can be observed that benefit-cost ratio changes with a same rate varying administration and tunnel construction cost. Furthermore, sensitivity diagrams show if the shipment revenue reduced by 30 percent, the benefit-cost ratio would become less than one for scenario 3c. Therefore, freight pricing is very sensitive in the process of planning the small size UFT scenarios.

Figure 4-3 illustrates the sensitivity of B/C ratios of the UFT scenarios to changes in discount rates. Almost all the scenarios will have a B/C ratio more than one while changing the discount rate. This analysis shows that the Scenario 3c is highly vulnerable to discount rate. The B/C ratio for this scenario would become less than one if the discount rate exceeds 3 percent.

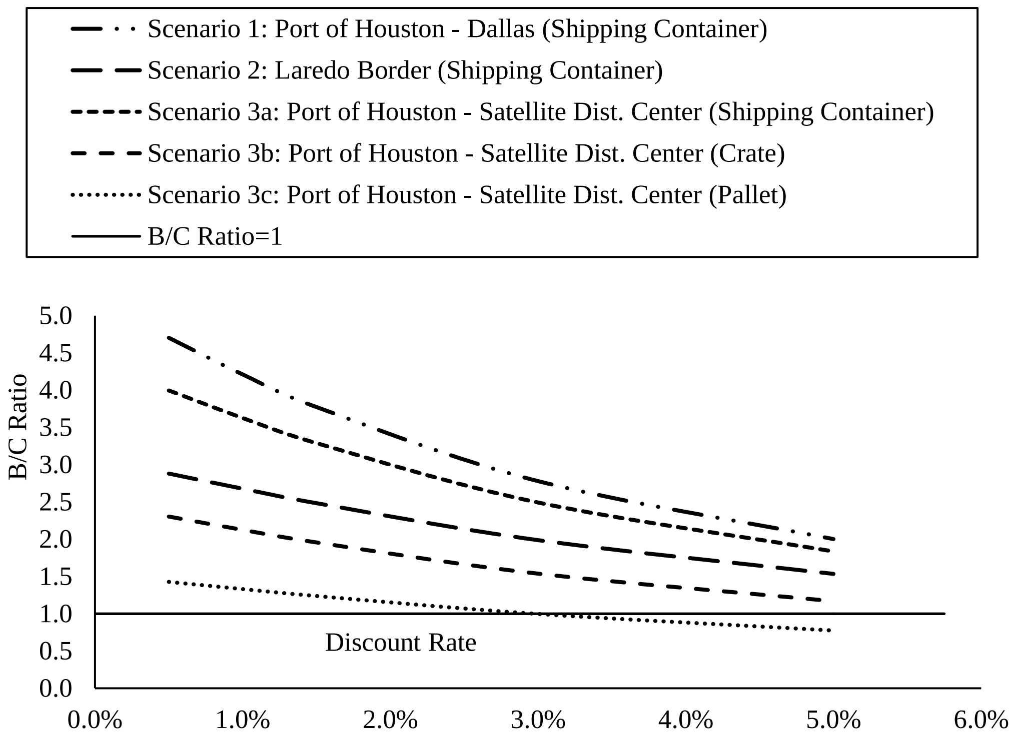


Figure 4-3 Sensitivity of benefit-cost ratio to discount rate

4.2.3 Breakeven Analysis

Breakeven analysis method is used to answer two critical questions about: (1) a practical range for pricing freight shipment so that the system remains economical, and (2) the payback period (breakeven time) of UFT systems.

The results of breakeven analysis on the UFT service life are presented in Figure 4-4. These diagrams show the present value of the life-cycle benefits and costs for different life spans of UFT scenarios. The intersection of benefit and cost diagrams specifies the payback period of a UFT scenario where NPV is zero. Figure 4-4 shows that the payback periods for Scenarios 1 and 3a are within 10 years. Payback period of 10 years is considerably short for projects in this scale and is a point that may attract public and private parties to consider investment in such systems (Cole 2005). On the other hand, the payback period of Scenario 3c (42 years) is too long to attract private funding.

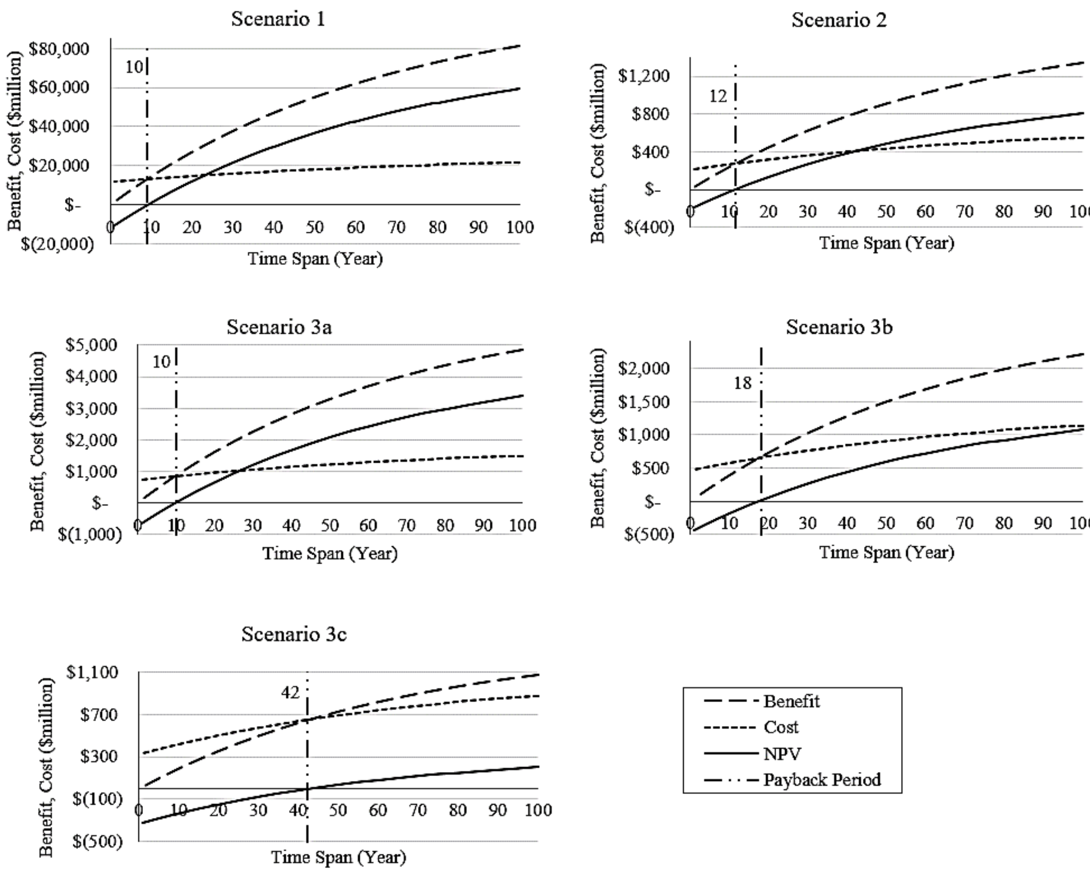
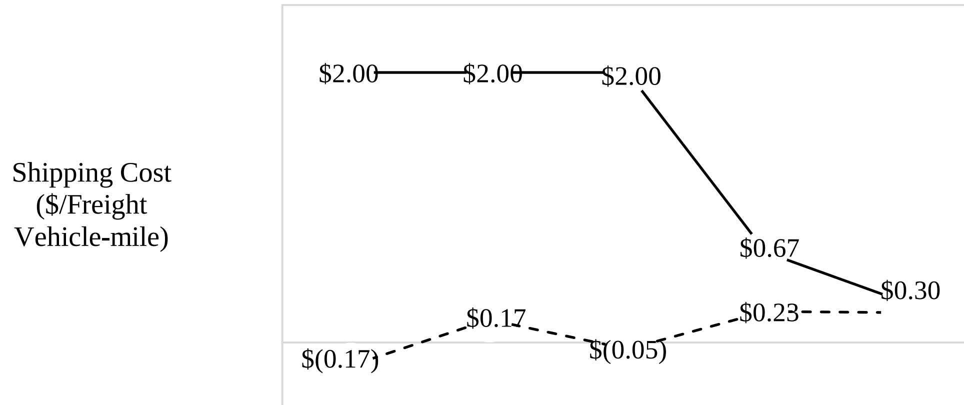


Figure 4-4 Breakeven analysis of time

Figure 4-5 shows the results of the breakeven analysis on shipping prices. This analysis offers decision makers a plausible range to consider for shipment pricing. The solid line represents the shipping price of each cargo moved by the UFT for each scenario. These prices are determined based on the market price of shipping a standard size cargo for a mile with truck, in Texas (DAT Solutions LLC 2016). The dashed line indicates the minimum shipping price that could be perceived for each scenario to be economically feasible. This minimum price is defined as breakeven price. As it is shown in Figure 4-

55, the breakeven price becomes negative for Scenarios 1 and 3a. This delineates that, if these UFT scenarios transport the cargos without any charges, the social benefits are still recovering the capital investment after the anticipated life of the UFT system of 100 years.



	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 3c
Shipping Price	$2.00	$2.00	$2.00	$0.67	$0.30
Breackeven Price	$(0.17)	$0.17	$(0.05)	$0.23	$0.22

Figure 4-5 Breakeven analysis of shipping price

Chapter 5

Investment Valuation of UFT Systems Under Uncertainty

A comprehensive life-cycle benefit-cost analysis (deterministic investment analysis) of UFT system for five different scenarios was presented in Chapter 4. The analysis showed the economic feasibility of investing in UFT projects. It also identified some key input variables that significantly affect the robustness of the results. Any uncertainties regarding these variables would make the results of this analysis inaccurate. The sensitivity analysis on key input variables showed the benefit to cost ratio of UFT project is highly sensitive to shipment price (freight rate) and tunnel construction cost.

Real options analysis is an investment valuation technique designed to incorporate uncertainties regarding input variables and estimate the value of managerial decisions contingent upon future information (Balasubramanian et al. 2000; Trigeorgis 1995; Dixit and Pindyck 1994). Contingent cash flows of a UFT system can be incorporated by modeling future changes (stochastic and deterministic) in underlying parameters as real options. This approach values managerial flexibility, such as investing in a UFT project immediately versus delaying the investment, abandoning the project, managing time to build, and so forth. Optimal decisions can be derived from the results of such investment valuation models.

The construction industry and the cost of construction has changed drastically in light of advancements in technology and construction practices (Shahandashti 2014). Improvements in tunneling techniques such as modern tunnel boring machines (TBM) have increased the productivity of the tunneling process. Variations in demand, construction material prices, labor cost, and land prices are among other factors causing variations in construction cost (Shahandashti and Ashuri 2015). Potential changes in UFT construction costs (particularly tunneling) are especially important in any UFT valuation model. It is also essential to model future changes in freight rates and integrate them into the real options model. These sources of uncertainty do not follow similar patterns, and they behave quite differently. For instance, construction cost is often considered to follow a Geometric Brownian Motion (GBM) process (Mirzadeh and Birgisson 2016; Yiu and Tam 2006), while the historical freight rates follow a mean-reverting process (Sødal et al. 2008; Adland and Cullinane 2006; Koekebakker et al. 2006; Brennan and Schwartz, 1979).

So far, no real options models have been developed for the investment valuation of UFT systems under uncertainty and decision-making flexibility. Also, existing real options models applied to transportation projects are theoretically deficient to properly incorporate UFT uncertainties and assess the UFT investment options.

The objectives of this chapter is to develop a novel real options model suitable to perform an investment valuation of implementing UFT systems under uncertainty to:

- Determine the market value of the option to invest in UFT systems considering various underlying uncertainties;
- Incorporate the value of decision-making flexibilities as a significant factor in valuing the investment option
- Determine the optimal policy to invest in UFT systems; and

- Assess the effect of different operational levels on the value of the project.

5.1 Methodology

To achieve the objectives of this chapter a real options valuation model is developed to integrate uncertainties with dissimilar features as well as decision-making flexibilities in the valuation of UFT systems. The proposed model estimates the value of a UFT system considering project volatilities and contingent outcomes. It provides the optimal timeline for implementation of a UFT system based on future market conditions. A summary of the modeling steps is presented in Figure 5-1. These steps are discussed more in detail in the following sections.

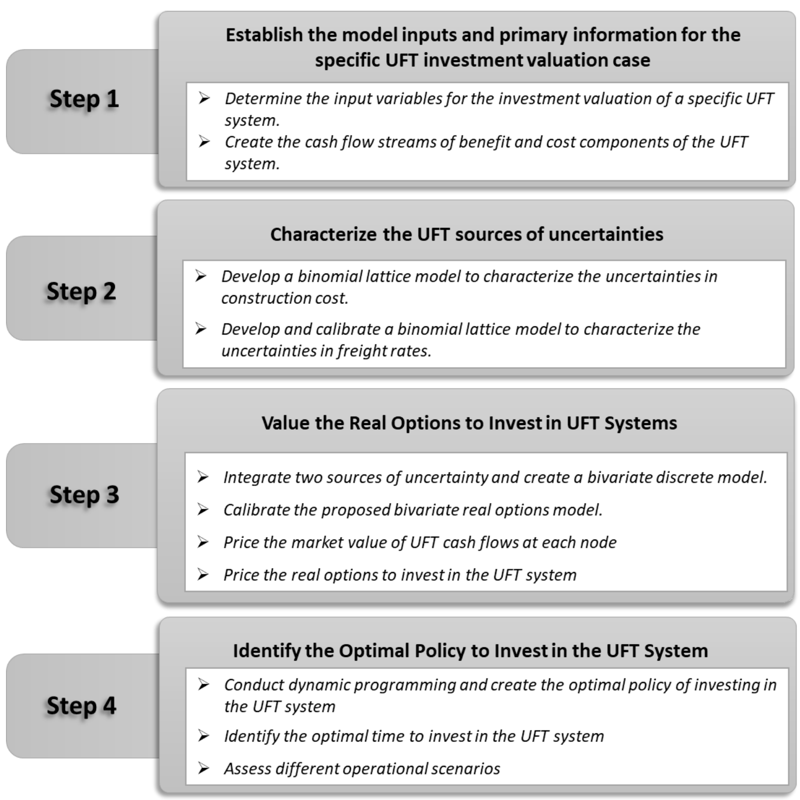


Figure 5-1 The modeling steps for valuating UFT system real options

5.1.1 Step 1: Establish the Model Inputs and Primary Information for the Specific UFT Investment Valuation Case

The first step in the model is to create the UFT investment case and establish the input variables. This involves making assumptions and determining critical information, such as the service life of the system, decision window, construction project duration, interest rates and discount rates. This step establishes the boundary conditions and the overall structure of the model. It is critical for accurate valuation for any project using real options. Most infrastructure real options models neglect the time to build. This is problematic because construction times can be quite long. Ignoring time to build may change the outcomes, leading to erroneous results. Step 1 also includes identifying the cost and benefit components, collecting data and estimating the dollar amounts of these variables, and creating life-cycle cash flow streams of costs and benefits.

5.1.2 Step 2: Characterize the UFT Sources of Uncertainties

After establishing the UFT investment valuation case and collecting the required data, major sources of uncertainty should be characterized. As highlighted in Chapter 4, the major underlying uncertainties for UTFs are construction costs and freight rates. This step presents simple modeling techniques to characterize future variation in each underlying uncertain source, based on their behavior.

Develop a binomial lattice model to characterize the uncertainties of construction cost:

To model the construction cost (X), the proposed binomial pricing approach assumes that UFT project life, T, can be partitioned into n equal discrete time periods, $\Delta t = T/n$, and the underlying asset value X follows a binomial process. During each period, X can either increase by a factor of U (U > 1) with probability θ_u or decrease by a factor of D (D < 1) with probability θ_d (which $\theta_d = 1 - \theta_u$). Considering the GBM behavior of X, the "up-state" and "down-state" factors are an exponential function of volatility (σ) and time period (Δt), $U = exp\,(\sigma\sqrt{\Delta t})$ and $D = 1/U = exp\,(-\sigma\sqrt{\Delta t})$ (Hull 2017; Cox et al. 1979). If the current value of X is assumed to be the first value (initial node) of the binomial lattice ($X(0,0) = X_0$), the value of X after one period would be either $X(0,1) = U.X_0$ or $X(1,1) = D.X_0$ for the up-state and down-state conditions, respectively. The binomial lattice of the future costs, $X(i,n)$, can be created by continuing the upward and downward movements with constant increasing and decreasing factors (Figure 5-2). If any node at time n, $n = 1, 2, \dots, T$, can be reached with i number of down moves, $0 \le i \le n$, and $n - i$ number of up moves, $0 \le n - i \le n$, the value of X at that node would calculated as $X(i,n) = X_0 U^{n-i} D^i$. Based on the probability mass function of the binomial distribution, the probability of $X(i,n)$ to occur is $P[X(i,n)] = \binom{n}{i} {\theta_u}^{n-i}(1-\theta_u)^i$.

Having a feasible value for X at each node of the binomial lattice, the cash flow of the UFT cost and benefit components related to construction cost, such as maintenance cost can be calculated. This step yields a binomial lattice of construction cost dependent cash flows, $C(i,n)$. In this new binomial lattice, sum of the cash flow of all the UFT components that are dependent to the construction cost is calculated at each possible state (i) in time (n).

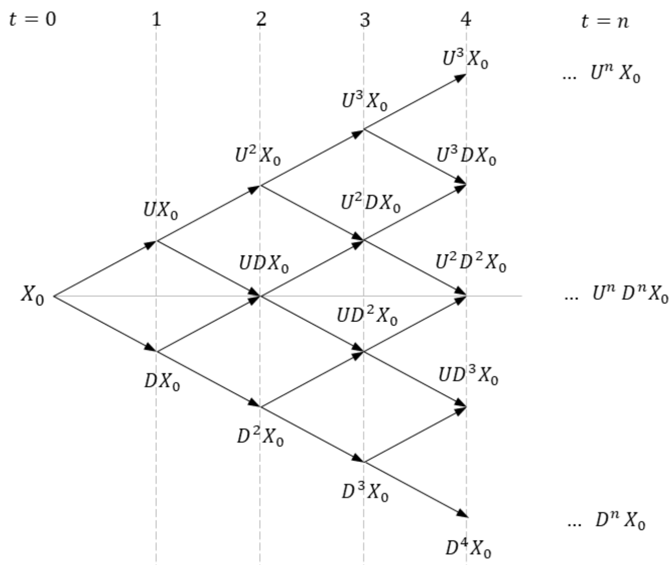


Figure 5-2 A representation of binomial lattice

Develop and calibrate a binomial lattice model to characterize the uncertainties of future freight rates:

The revenue from freight movement is one of the largest benefits of implementing UFT systems, which significantly impacts the economic viability of these innovative systems (Zahed et al, 2018b). A reliable valuation of UFT systems requires a careful analysis of revenues under existing freight rate uncertainties. Freight rate fluctuations often coincide with commodity prices, which tend to be mean reverting (Sødal et al. 2009). A sudden change in the spot price of a commodity is frequently followed by a corresponding change in supply and subsequent price adjustment. As a result, the price tends to revert toward the commodity's long-run marginal cost of production (Wei and Zhu 2006). Likewise, a sudden drift in a freight rate will typically met with different spillover effects between the market that pulls the rates back to an equilibrium state (Sødal et al. 2009; Beenstock and Vergottis 1993). Analyzing the historical north America freight rate indices provided by CASS Information Systems (2017) clearly shows that the freight rate indices follow a mean-reverting process. Modeling freight rate uncertainties using the typical GBM process may lead to unrealistic results. A careful calibration of the binomial lattice is necessary to properly assess the freight rate uncertainties.

A binomial lattice of freight rate indices is developed using the same method explained in the previous section for modeling construction cost. Assuming the current value of the freight rate to be R_0, this value after one period would be $R(0,1) = U'.R_0$ with probability of θ'_u in the up-state, and be $R(1,1) = D'.R_0$ with probability of $\theta'_d = 1 - \theta'_u$ in the down-state. Where the values of growth factors can be calculated using the freight rate volatility (σ') and time period (Δt), $U' = exp\,(\sigma'\sqrt{\Delta t})$ and $D' = 1/U' = exp\,(-\sigma'\sqrt{\Delta t})$. The freight rate lattice, $R(j,n)$, can be completed by continuing this process similar to the construction cost lattice.

To capture the mean-reverting behavior of freight rates, the binomial lattice model is calibrated using an Ornstein-Uhlenbeck process (Uhlenbeck and Ornstein 1930). Using this process, researchers such as Hahn and Dyer (2011, 2008), Bastian-Pinto et al. (2009), Guthrie (2009), Smith and McCardle (1999), Hull and White (1994), Dixit and Pindyck (1994), and Nelson and Ramaswamy (1990) have employed different methods to capture the mean-reverting behavior of variables. For instance, Guthrie (2009) adjusted the probability of up and down jumps in the binomial lattice by normalizing the autoregressive parameters used in the Ornstein-Uhlenbeck process. If the log freight rate is assumed to follow a first-order autoregressive process, and R_j denotes the jth observation of the log freight rate, then

$$R_{j+1} - R_j = \alpha_0 + \alpha_1 R_j + u_{j+1}, \qquad u_{j+1} \sim N(0, \phi^2), \tag{5-1}$$

Where α_0, α_1, and ϕ are constants, and α_1 is negative. The negative α_1 causes the freight rate to revert to its long-run level after a sudden shock. This first-order autoregressive process can be normalized to an arbitrary frequency by using Ornstein-Uhlenbeck process with rate of mean reversion a, long-run level b, and volatility σ. According to the Ornstein-Uhlenbeck process, when viewed from date t, the change in the log price over the next Δt units of time is normally distributed with a mean of $(1 - e^{-a\Delta t})(b - R_t)$and a variance of $\sigma^2(1 - e^{-2a\Delta t})/2a$, where a, b, and σ are constants. That is,

$$R_{j+1} - R_j \sim N\left((1 - e^{-a\Delta t})(b - R_t), \frac{\sigma^2}{2a}(1 - e^{-2a\Delta t})\right). \tag{5-2}$$

On the other hand, the autoregressive process of freight rate represented in the Eq. (5-1) implies that changes in R are normally distributed with mean $\alpha_0 + \alpha_1 R_j$ and variance ϕ^2. Therefore, it is arguable that the parameters α_0, α_1, and ϕ in Eq. (5-2) are related to the Ornstein-Uhlenbeck parameters by the following equations

$$\alpha_0 = (1 - e^{-a\Delta t})b, \quad \alpha_1 = -(1 - e^{-a\Delta t}), \ \phi^2 = \frac{\sigma^2}{2a}(1 - e^{-2a\Delta t}). \tag{5-3}$$

Solving these equations for a, b, and σ yields (Guthrie, 2009)

$$a = \frac{-\log(1+\alpha_1)}{\Delta t}, \quad b = \frac{-\alpha_0}{\alpha_1}, \quad \sigma = \phi\left(\frac{2\log(1+\alpha_1)}{\alpha_1(2+\alpha_1)\Delta t}\right)^2. \qquad (5\text{-}4)$$

In many cases the time steps in the real options model (Δt_m) may differ from the time steps in the data (Δt_d) used to estimate model parameters. For instance, we may use monthly freight rate indices while the model is developed based on annual time steps. Moreover, the accuracy of the results of discrete-time real option models increases with smaller time steps. The proposed model should be adjusted simultaneously for the time periods. The parameters presented in Eq. (5-2) and Eq. (5-3) should be calculated using the real data time steps (Δt_d) and denoted by $\hat{\alpha}_0$, $\hat{\alpha}_1$, $\hat{\phi}$, $\hat{a}$, $\hat{b}$, and $\hat{\sigma}$. Using these normalized parameters, the binomial lattice of the freight rate with specific size of time step (Δt_m) can be created, following the steps discussed in the previous section. Since the time steps are not equal, the corresponding freight rates should also be determined. Assuming the binomial lattice of freight rate starts with the current log price of the freight rate R_0 and the log price increase and decrease by $\pm\hat{\sigma}\sqrt{\Delta t_m}$, the log price of the freight rate at node $R(j,n)$ can be calculated using the following formula

$$R(j,n) = e^{x(j,n)} = R_0 e^{(n-2j)\hat{\sigma}\sqrt{\Delta t_m}}. \qquad (5\text{-}5)$$

Moreover, the probability of up move at node (j, n) equals to

$$\theta_u(j,n) = \begin{cases} 0 & if\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} \leq 0, \\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} & if\ 0 < \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} < 1, \\ 1 & if\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} \geq 1 \end{cases} \qquad (5\text{-}6)$$

This equation indicates that if the freight rate becomes too large or too small, the next move in the binomial lattice is likely to be in the opposite direction. A binomial lattice of probabilities should be created at this stage to be used in future steps. It is straightforward to obtain the upper and lower limits by solving the boundary conditions for $log\,R(j,n)$, as

$$\begin{cases} \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} \leq 0 & \rightarrow & \log R(j,n) \geq \hat{b} + \frac{\hat{\sigma}\sqrt{\Delta t_m}}{1-e^{-\hat{a}\Delta t_m}} & Upper\ limit \\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b}-\log R(j,n))}{2\hat{\sigma}\sqrt{\Delta t_m}} \geq 1 & \rightarrow & \log R(j,n) \leq \hat{b} - \frac{\hat{\sigma}\sqrt{\Delta t_m}}{1-e^{-\hat{a}\Delta t_m}} & Lower\ limit \end{cases}.$$

Thus, the binomial lattice that is calibrated for a mean-reverting process is truncated with upper and lower limit prices. Figure 5-3 illustrates the calibrated binomial lattice for freight rate fluctuations.

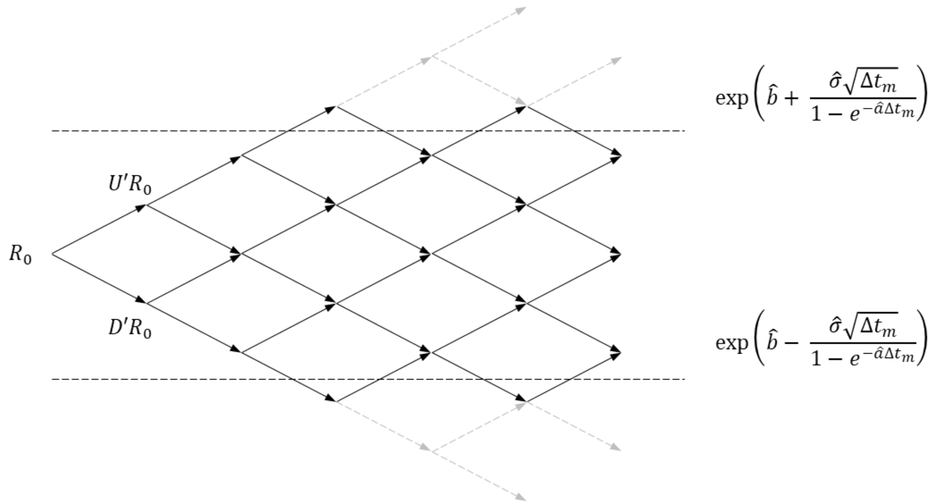


Figure 5-3 Calibrated binomial lattice of freight rate with a mean-reverting process

5.1.3 Step 3: Value the Real Options to Invest in UFT Systems

The goal of this step is to value the real option to invest in a UFT system using proper decision analysis techniques. The binomial lattice model developed in the previous step will be used to determine the value of the future cash flows and eventually the project's real options at each possible state. Finally, the optimal policy to invest in a UFT system is derived by dynamic optimization.

Arbitrage-free asset pricing is often used as a practical method to estimate the market value of future cash flows and eventually price the value of the available real options. The notion is to estimate the market value of a portfolio of traded assets (consisting of a risk-free bond and risky asset), that generates a cash flow stream similar to the one being valued (Guthrie, 2009). The dynamics of the underlying asset (uncertain input parameter) is spanned by this portfolio, commonly known as a replicating, or tracking, portfolio, in a complete market. Arbitrage-free asset pricing assumes that capital markets are complete, i.e., that any contingent claim may be replicated by portfolio of assets. This characteristic purges the pricing model of individual risk preferences, and it enables the use of risk-neutral probabilities in estimating the market value of the project cash flow (Garvin and Cheah 2004). Suppose the construction cost X is the only state variable with value $X_0 U^{n-i} D^i$ at state i and time period n. Let portfolio $h(B,S)$ be a portfolio consisting of a riskless bond and a risky asset, replicating (tracking) the state variable cash flows. Consider the value of the replicating portfolio $h(B,S)$ consisting x units of risk-free bond (B) and y units of the spanning asset (S) is defined by $V_t^h = xB_t + yS_t$. In a binomial setting, after one period this portfolio would have possible values of $V_1^{h+} = x(1+r_f) + yS_u$ and $V_1^{h-} = x(1+r_f) + yS_d$, with probabilities of π_u and $\pi_d = 1 - \pi_u$, respectively. Considering the arbitrage-free condition $D \leq (1+r_f) \leq U$, the expected value of the portfolio after one period is $\mathbb{E}^{\Pi}[V^h] = [\pi_u V_1^{h+} + \pi_d V_1^{h-} / (1+r_f)]$, where Π represents the risk-neutral probabilities of π_u and π_d as martingale measures. By extending this concept to the existing investment case, the market value of the cash flows corresponding to the underlying state variable can be evaluated. Generally, if risky cash flow C is considered to have the values of C_u and C_d in up-state and down-state after one period, the risk-neutral probabilities and the market value of the cash flow estimate, V_C can be calculated using the following formulations:

$$V_C = \frac{\pi_u C_u + \pi_d C_d}{R_f}, \quad \pi_u = \frac{K-D}{U-D} \quad and \quad \pi_d = \frac{U-K}{U-D}. \qquad (5\text{-}7)$$

Where $R_f = 1 + r_f$ is the return on a one-period risk-free bond and r_f denotes the one-period risk-free interest rate. Depending on the underlying assumptions, different estimates for K has been presented in the literature. Studies, such as Cox et al (1979), Copeland and Antikarov (2001), Björk (2009), and Hull (2017) assumed that in a risk-neutral world with the absence of arbitrage, the tracking portfolio has risk-free future payoffs that can be discounted using a risk-free interest rate. They assumed that the present value of the project itself (without flexibility) is the best unbiased estimate of the market. They considered K as a growth factor that is comparable enough to the one-period risk-free rate of return and can be valued as $K = (1 + r_f \Delta t)$ or $K = e^{r_f(\Delta t)}$. Although this assumption seems extreme, as Copeland and Antikarov (2001) note "this assumption is no stronger than those used to estimate the project NPV in the first place." Other studies, such as Hull (2017) and Guthrie (2009) assumed that the volatility of a project is almost the same as the volatility of its underlying risky asset. They determined K as a risk-adjusted growth factor that contains the market price of the risk. Then, they performed risk-neutral pricing to determine the martingale measures and the market value of the option. Hull (2017) showed that the market price of the risk is $\lambda = (\mu - r)/\sigma$. Works like Rendleman (1999), Guthrie (2009) used the capital asset pricing model (CAPM) to adjust the model for the market price of the risk. This approach is used in this study as well. Accordingly, K is a risk-adjusted growth factor that can be calculated by subtracting the CAPM risk premium $(E[\tilde{R}_m] - R_x)\beta_x$, from the expected growth factor of the state variable $E[\tilde{R}_x]$ (Guthrie, 2009), as

$$K = E[\tilde{R}_x] - (E[\tilde{R}_m] - R_x)\beta_x. \tag{5-8}$$

Given the historical national highway construction cost index (NHCCI), proportional changes in the NHCCI ($\tilde{R}_x$) should be regressed onto the total return on the market portfolio ($\tilde{R}_m$). The slope coefficient would be β_x, and K can be calculated using Eq. (5-8) (Merton 1987; Rendleman 1999; Guthrie, 2009).

The presented valuation approach can be extended to estimate the market value of the future revenue cash flows, if the UFT system is implemented. Suppose that the UFT system is planned to be implemented at terminal node (j,n) in the binomial tree. The market value of the UFT revenues at node (j,n) would be the UFT systems cash flow generated at that node ($CF(j,n)$), plus the market value estimates of the UFT system after one period

$$V_{CF}(j,n) = [CF(j,n) + \frac{\pi'_u(j,n)V_{CF}(j,n+1) + \pi'_d(j,n)V_{CF}(j+1,n+1)}{R_f}]. \qquad (5\text{-}9)$$

where π'_u and π'_d are calibrated risk-neutral probabilities of the UFT revenues.

While this approach is a simple and promising method for estimating the market value of a project cash flows, it is deficient when two or more underlying sources of uncertainty (state variables) exist. It is necessary to extend this approach to be able to estimate the market value of the UFT investment option considering both construction cost and freight rate uncertainties.

Bivariate discrete model

Previous research introduced option pricing models that incorporate two or more uncertain parameters with GBM process, such as Stapleton and Subrahmanyam (1984), Boyle (1988), Boyle et al. (1989), Kamrad, and Ritchken (1991), Copeland and Antikarov (2001), and Mirzadeh and Birgisson (2016). Moreover, works such as Bastian-Pinto et al. (2009) and Hahn and Dyer (2011) presented real options models incorporating two mean-reverting parameters. This paper contributes to the body of literature by presenting a modeling approach that estimates the market value of the option to invest in projects such as UFT systems including two major sources of uncertainty with different stochastic behaviors. The presented bivariate real options model is designed to incorporate the combination of GBM and mean-reverting processes.

The bivariate real options model derives from previous work, especially Boyle et al. (1989). The goal of the current step is to first estimate the value of the project cash flow at each node considering two uncertain parameters. Future cash flows regarding these two state variables are presented by two separate lattices in Step 2. The UFT project total cash flow at each node is the summation of the cash flows generated from each state variable and other independent cash flows. At any state (i, j) and time n, the market value of the project cash flow, $V(i, j, n)$, is equal to the cash flow which the UFT may generate at that time combined with the value of the expected future cash flows if the UFT is implemented. Since the value of cash flows generated from each parameter is estimated from their two possible values (up-state and down-state) after one period $(n + 1)$, the value of the project cash flow would be estimated from four possible future cash flows, consequently. Table 5-1 illustrates the possible combination of moves that each state variable could make.

Table 5-1 Movement combinations of two binomial moves

Movements	Cash Flow Values	Probabilities
Up, Up	$V(i, j, n+1)$	θ_u, θ'_u
Up, Down	$V(i, j+1, n+1)$	θ_u, θ'_d
Down, Up	$V(i+1, j, n+1)$	θ_d, θ'_u
Down, Down	$V(i+1, j+1, n+1)$	θ_d, θ'_d

To better understand the process, suppose the lattices of each of the cash flows are located on two different hyperplanes in a three-dimensional space. These hyperplanes should position in a way that coincide at the starting node and to be congruous at one side. As illustrated by Ho and Liu (2002) and Mirzadeh and Birgisson (2016), positioning the binomial lattices as a pyramid is a straightforward way to demonstrate the four possible outcomes. Figure 5-3 shows a three-step binomial pyramid and the position of nodes in a space. This binomial pyramid consists of many individual small pyramids that are created at each node. These individual pyramids are illustrated in Figure 5-4.

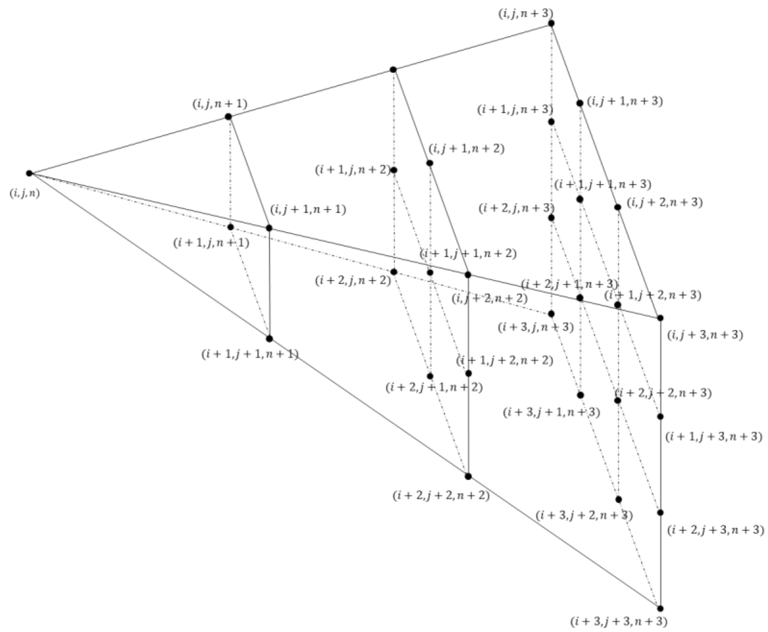


Figure 5-4 Binomial pyramid for modeling two state variables

The binomial pyramid created in this paper is shaped from positioning the binomial lattice of construction cost as the first risky variable, vertically, and placing the binomial lattice of freight rate as the second parameter, horizontally.

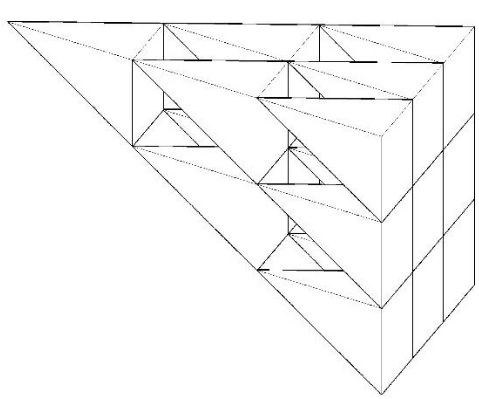


Figure 5-5 Binomial pyramid consisting of many individual smaller ones

Having the cash flow values obtained from the binomial lattices in the previous step (Step 2), the value of the total cash flows at each node of the binomial pyramid can be calculated using

$$V(i,j,n) = [CF(i,j,n) + \frac{\pi_{uu}(i,j,n)V(i,j,n+1)+\pi_{ud}(i,j,n)V(i,j+1,n+1)}{R_f} + \frac{\pi_{du}(i,j,n)V(i+1,j,n+1)+\pi_{dd}(i,j,n)V(i+1,j+1,n+1)}{R_f}] \quad (5\text{-}10)$$

where π_{uu}, π_{ud}, π_{du}, and π_{dd} are the risk-neutral probabilities of four possible movements at the end of each time period, and $CF(i,j,n)$ is the cashflow received at that node. The first and second subscripts indicate the movement direction of the first (construction cost) and second (freight rate) state variables, respectively. Since the probability of movement in each possible direction is conditional, the correlation between state variables should be incorporated in the risk-neutral probabilities. Boyle et al. (1989) developed a method to approximate the multivariate lognormal distribution with a discrete distribution using a multiplicative binomial lattice. Their model considers a bivariate case which they extend to the n-dimensional case. The risk-neutral probabilities used in this study are adopted from this seminal work. In the bivariate case, for $U_i D_i = 1$, and $U_i = \exp(\sigma_i \sqrt{\Delta t})$, where $i = 1, 2$, the characteristic function of four outcomes with up move probabilities of π_{uu}, π_{ud}, π_{du}, and π_{dd} is calibrated to the characteristic function for the bivariate normal distribution with time interval Δt. The aforementioned probabilities can be represented as

$$\pi_{uu} = \frac{1}{4}\left(1 + \rho + \sqrt{\Delta t}\left(\frac{\mu_1}{\sigma_1} + \frac{\mu_2}{\sigma_2}\right)\right) \quad (5\text{-}11)$$

$$\pi_{ud} = \frac{1}{4}\left(1 - \rho + \sqrt{\Delta t}\left(\frac{\mu_1}{\sigma_1} - \frac{\mu_2}{\sigma_2}\right)\right) \quad (5\text{-}12)$$

$$\pi_{du} = \frac{1}{4}\left(1 - \rho + \sqrt{\Delta t}\left(-\frac{\mu_1}{\sigma_1} + \frac{\mu_2}{\sigma_2}\right)\right) \quad (5\text{-}13)$$

$$\pi_{dd} = \frac{1}{4}\left(1 + \rho + \sqrt{\Delta t}\left(-\frac{\mu_1}{\sigma_1} - \frac{\mu_2}{\sigma_2}\right)\right). \quad (5\text{-}14)$$

Where ρ is the correlation coefficient between the state variables, $\mu_i = r - 1/2\,\sigma_i^2$ is the drift of the continuous lognormal distribution, r is continuously compounded annual interest rate, and σ_i^2 is the annualized variance of the rate of return of a state variable.

Calibration for one mean-reverting parameter

The market value of the project cash flow at each node of the binomial pyramid can now be estimated. However, since one of the state variables (freight rate) follows a mean-reverting process, the binomial pyramid should be calibrated using a criterion similar to the one explained in Step 2. Based on the mean-reverting characteristic of freight rates, the probability of reaching at a number of nodes in the binomial pyramid is, for all practical purposes, zero. Similar to the binomial lattice of the freight rate that is truncated with two boundary lines (upper and lower limits), the binomial pyramid will also be truncated with two boundary planes (vertical) in a three-dimensional perspective. Figure 5-6 illustrates how the binomial pyramid is sliced by two boundary planes.

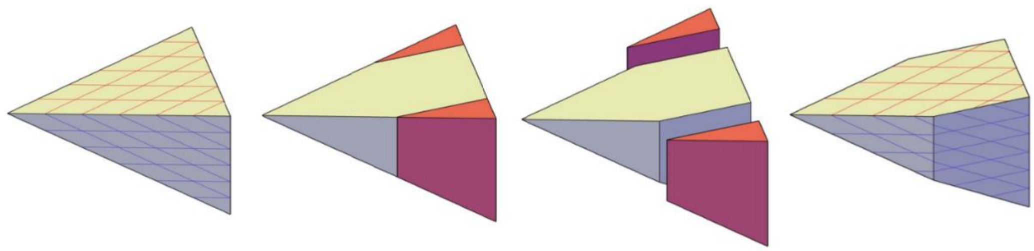


Figure 5-6 Calibration of a binomial pyramid for one GBM and another mean-reverting parameter

At the nodes corresponding to the lower boundary condition, when the probability of an up move in freight rate is zero $\theta_u(i,n) = 1$, the current market value of the UFT cash flow is equal to the value taken from freight rate cash flows at the up-state combined with other possible cash flows discounted back to the present using the risk-free interest rate. Thus, the only possible movements in the binomial pyramid are up-up and down-up. Fig. 5-7 demonstrates a detailed section of the binomial pyramid, which is sliced with a lower boundary hyperplane. This figure shows that the probability of a down move in the horizontal lattice (representing the variable with the mean-reverting process) is zero. Therefore, the value of the UFT cash flows at node (i,j,n) can result only from two values at nodes $(i,j,n+1)$ and $(i+1,j,n+1)$.

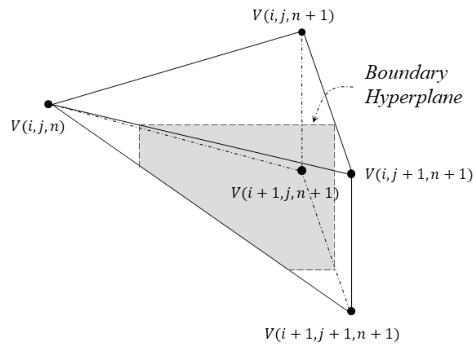


Figure 5-7 A section of the binomial pyramid sliced by a lower boundary hyperplane

This illustration provides a visualization of the extension of a univariate binomial pricing model to develop a bivariate model that considers two state variables with different stochastic behaviors. However, this visualization would be impractical when considering projects with long life spans or a large number of time periods. By transposing the binomial pyramid on a two-dimensional plane, a quadranomial tree of outcomes is achieved that simplifies the generalized model. Figure 5-8 shows a quadranomial combinations of two state variables.

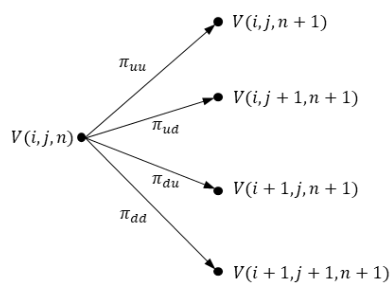


Figure 5-8 Quadranomial tree for modeling two state variables

It is now necessary to determine the risk-neutral probabilities at each node of the new quadranomial tree. The calibrated binomial lattice of up move probabilities $\theta_u(j,n)$ constructed in Step 2 is used to achieve this goal. Nevertheless, to build the quadranomial tree of the risk-neutral probabilities, the tree showed in Figure 5-8 should be expanded. This expansion would create a quadranomial tree with a large number of nodes. Figure 5-9 illustrates a three-step quadranomial tree. Although this expansion appears complicated, it can be easily constructed if the number of nodes at each time is determined. If there are n time intervals (Δt), since there are two state variables with two possible outcomes, it noticeable that the number of possibilities (nodes) at each time $n = 0, 1, 2, \dots, T$ is $(n+1)^2$. For example, if the option to invest in a UFT system expires after 10 years (with $\Delta t = 1$ year), the number of nodes at year 10 would be $(10+1)^2 = 121$. Having determined the number of nodes at each time step of the quadranomial tree, the calibrated trees for risk-neutral probability as well as the value of the UFT cash flows can be constructed.

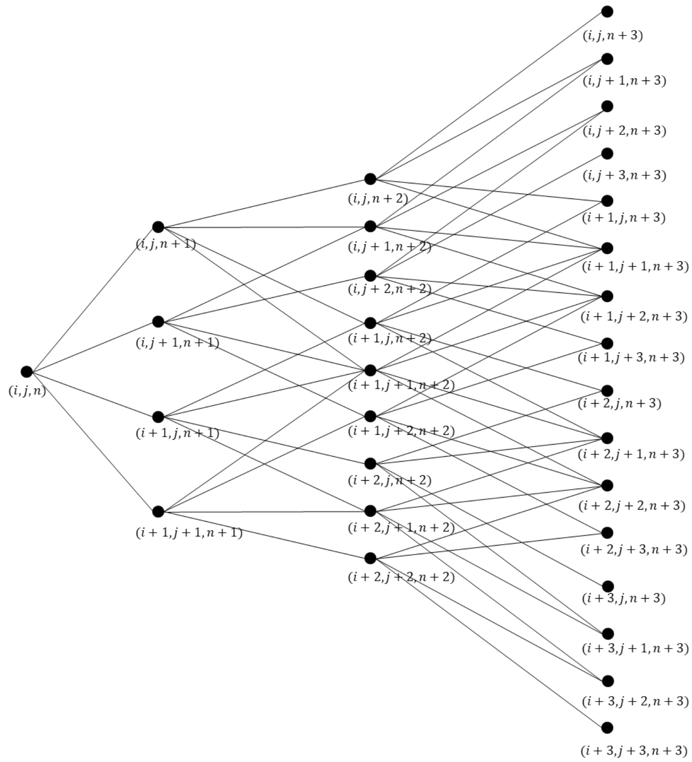


Figure 5-9 A three-step quadranomial tree

The last step is to calculate the market value of the real options to invest in a UFT system, at each node. Backward induction is applied to the lattice to determine the value at the present time. First, the market value of the option at the expiration date should be determined. For instance, if the decision to invest in a UFT system can only be made in a 10-year window, the value of this option at the end of the 10th year would be zero. Because the project has not been implemented and no revenues are generated. Hence, the option value to invest in the above UFT system is zero at year eleven. The value of the option to invest in the UFT system can be calculated using Eq. (5-10). However, at each node the manager has the opportunity to decide whether to exercise the option and implement the

UFT or wait for future information to be revealed. Therefore, it is necessary to compare the value of the option for two possible actions at each node.

5.1.4 Step 4: Identify the Optimal Policy to Invest in the UFT System

A dynamic programming approach is employed to maximize the outcomes of this investment valuation case and achieve an optimal decision. By adopting the notion of the Bellman's "principle of optimality" (Bellman and Dreyfus 1962), a complicated multi-period optimization problem is broken down into a sequence of simpler problems. At each date, the manager only has to decide what action to take on that date. All relevant information about the past is summarized by the state that the project is currently in, and all relevant information about the future is summarized by the market values of the firm appearing in the lattice.

Suppose we are currently at a node in the last column of the quadranomial tree. If the manager decides to wait to exercise the implementation option, the value of the real option would be obtained from the four possible values of the project in the next year. Since no time remains and the option expires in the next year, the value of waiting would be zero. On the other hand, if the manager decides to exercise the option and implement the project, the value of the option to invest can be calculated by deducting the implementation cost from the Eq. (5-10). By comparing these two values, the optimal policy can be achieved. In general, the market value of the UFT project can be obtained by

$$V'(i,j,n) = \tag{5-15}$$

$$Max\left\{\underbrace{\frac{\pi_{uu}(i,j,n)V'(i,j,n+1)+\pi_{ud}(i,j,n)V'(i,j+1,n+1)+\pi_{du}(i,j,n)V'(i+1,j,n+1)+\pi_{dd}(i,j,n)V'(i+1,j+1,n+1)}{R_f}}_{Wait}, \underbrace{V(i,j,n)}_{Invest}\right\}$$

The manager can now decide the best time to invest. In addition, a separate tree can be built to illustrate the manager's optimal decision.

5.2 Model Implementation

This section presents an illustrative example of implementing the proposed bivariate real options model for investment valuation of a UFT system under various uncertainties. Several assumptions have been made to avoid unnecessary complexities for an illustrative case example. Historical freight index provided by Cass Information Systems Inc. (2017) is used as a proxy to model the freight rate uncertainties. The historical NHCCI data (FHWA 2019) is used as a proxy to model construction cost uncertainties.

Suppose transportation authorities and stakeholders are planning to increase the freight movement capacity and mitigate the traffic congestion near port of Houston, Texas, by implementing a container sized LIM-based UFT system that moves freights from port of Houston, 15 miles (24 km) away to a satellite distribution center (Scenario 3a). It is assumed that this system would move 3,000 shipping containers every day. The goal is to evaluate the investment option and the optimal time to invest in this system in the next five years. It is assumed that the investors have a 5-year time window to invest in the project and they can operate the system for 15 years. This means for instance if the investors implement the system at year one, they can operate and collect revenue from the facility till year 15, or if they decide to build the facility at year 4, they can operate the system till year 19. Also, the option to invest will be expired after the 5th year. This investment valuation case is quite challenging, since the uncertainties about the future freight rates and fluctuations in the construction cost could significantly affect the investment decision. The proposed real options model is adopted to incorporate these major sources of uncertainty and value the real options to invest in the UFT system. The suggested model is implemented following the steps presented in Figure 5-1.

Step 1. The cost data for the UFT case is acquired from Chapter 4. The cost of construction such as tunneling and terminal development are considered as one-time costs occurring at the beginning of the project, while other costs and benefits are considered as annual or recurring that happen every year. All the costs and benefits except construction cost and revenue from freight shipment are considered constant, throughout the service life of the project. Table 5-2 lists all the one-time and recurring cost components. A discount rate of 2.5% and a service life of 15 years are used to perform a DCF analysis of the project. Not considering the managerial flexibilities and the underlying uncertainties, the NPV of the project is calculated to be approximately -$5.7 million. This negative NPV shows the project is not viable at all.

Table 5-2 Cost components of the UFT example

Capital Cost Components	Costs ($)
Tunnel Construction	$699,098,400
Terminal Land	$2,215,748
Terminal Development	$10,052,784
Freight Vehicles	$7,200,000
LIM System	$750,000
Handlers	$8,800,000
Total Capital Cost (volatile)	**$728,116,932**
Annual Cost Components	**Present Value ($/year)**
Tunnel Operation and Maintenance	$6,990,984
LIM Maintenance	$37,500
LIM Power Consumption	$1,009,097
Administrative Cost	$3,455,860
Fuel Tax Revenue Loss	$1,740,787
Tire Tax Revenue Loss	$113,530
Air Pollution Reduction	$22,327,488
Noise Pollution Reduction	$353,203
Water Pollution Reduction	$59,288
Traffic Congestion Reduction	$2,775,168
Infrastructure Damage Cost Reduction	$648,380
Accident Cost Reduction	$3,658,176
Electricity Tax Revenue	$88,301
Total Annual Costs (fixed)	**$16,562,246**
Shipment Revenue (volatile)	**$37,422,000**

Step 2. The historical NHCCI data is analyzed to calculate the binomial lattice parameters (σ, U, D) for modeling the construction cost uncertainties. Considering the modeling time interval of $\Delta t_m = 1$ year, the binomial lattice increasing and decreasing factors are $U = 1.07$ and $D = 0.93$, respectively. If $C_0 = \$728{,}116{,}932$ is considered to be the current construction cost of implementing the UFT system, the prospected construction cost at each node can be calculated using $C(i,n) = C_0(1.06)^{n-i}(0.93)^i$. Risk-neutral probabilities of the up-state and down-state can be calculated using Eq. (5-

7). But first, the risk-adjusted growth rate K is calculated to be 0.99, assuming the market risk premium and the CAPM β_x equal to 3.6% and 0.13, respectively. Further the market value of the construction cost at each node can be calculated using Eq. (5-9).

Cass freight index studied to create the binomial lattice of future projected freight rates. Since the freight rate follows a mean-reverting process, the binomial lattice is calibrated using the methodology presented in the previous section. By regressing the changes in the log freight rates on a constant and the lagged loge freight rates, fitted to a first-order autoregressive process, the normalization parameters ($\hat{a}$, $\hat{b}$, and $\hat{\sigma}$) presented in Eq. (5-1) to (5-4) can be determined. These parameters are calculated to be $\hat{a} = 1.19$, $\hat{b} = 0.82$, $\hat{\sigma} = 0.15$. Having the normalize parameters, the calibrated freight rate increasing factor (U'), and the boundary values (R_{high} and R_{low}) would be $U' = 1.16$, $R_{high} = \$2.815$, and $R_{low} = \$1.825$, respectively. Further, by adopting Eq. (5-5) the binomial lattice of freight rate is created. Likewise, the probability of up move at each node ($\theta_u(j,n)$) is calculated using Eq. (5-6). To calculate the value of the UFT annual cash flows, the fixed annual cash flows should be treated differently than the annual shipment revenue, which has uncertainties. Using Eq. (5-9) the value of the compound future cash flows from the UFT revenue is calculated at each node. The fixed annual cash flows are discounted back using regular NPV formulations.

Step 3. Next, the quadranomial of the UFT real options model is created by transforming all the binomial lattices to quadranomial, separately. The quadranomial of the revenue cash flows shall be calibrated according to the corresponding calibrated binomial lattice. In the case of UFT implementation, the value of the project at each state of the quadranomial $V(i, j, n)$ would be the value of the future cash flows generated from the system minus the implementation cost at each node. To evaluate the market value of the option to invest in the UFT system, a quadranomial for the five-year decision time window is created. The value of the investment option at each node $V'(i, j, n)$ can be calculated using Eq. (5-15) and the four risk-neutral probabilities (Eq. (5-11 to 5-14)). Since the contracted operation time of the project is 15 years, the values of the project at each node $V(i, j, n)$ should be calculated only from that time period. For instance, for valuing V at year two, the value of the project is calculated from the cash flows that the UFT would generate until year 17. Table 5-3 shows the maximum project values or the values of the UFT investment option at each possible state. The tree is not completely filled, since it is adjusted according to the mean-reverting behavior of the freight rate. Nodes denoted by a dash (-) show that the project value is negative, and it is best not to exercise the option. Therefore, the option value is zero at such nodes. These nodes are mostly located in conditions where the construction cost would increase, or the shipment revenues become minimal.

Fig 5-10. Demonstrates a three-dimensional (3D) plot of the UFT investment option values at each node of the quadranomial. This plot clearly depicts the effects of model calibration and the extent of the UFT option values at nodes of the quadranomial tree.

Table 5-3 The quadranomial of the UFT investment option values

$V'(i,j,n)$		n					
i	j	0	1	2	3	4	5
0	0	$55,199,705	$11,914,869	$69,532			
0	1		$7,826,496	$1,416,573	-	-	
0	2			$518,469	-	-	-
0	3					-	-
0	4						
0	5						
1	0		$99,638,140	$57,368,643			
1	1		$82,953,377	$34,732,103	$7,127,080	-	
1	2			$18,117,115	$2,657,155	-	-
1	3					-	-
1	4						
1	5						
2	0			$146,193,773			
2	1			$123,557,233	$78,658,849	$35,864,869	
2	2			$106,942,245	$61,974,085	$13,228,330	-
2	3					$7,791,750	-
2	4						
2	5						
3	0						
3	1				$161,729,929	$124,689,999	
3	2				$145,045,166	$102,053,459	$56,617,481
3	3					$85,438,471	$39,932,717
3	4						
3	5						
4	0						
4	1					$202,379,775	
4	2					$179,743,235	$139,688,561
4	3					$163,128,246	$123,003,798
4	4						
4	5						
5	0						
5	1						
5	2						$212,345,630
5	3						$195,660,867
5	4						
5	5						

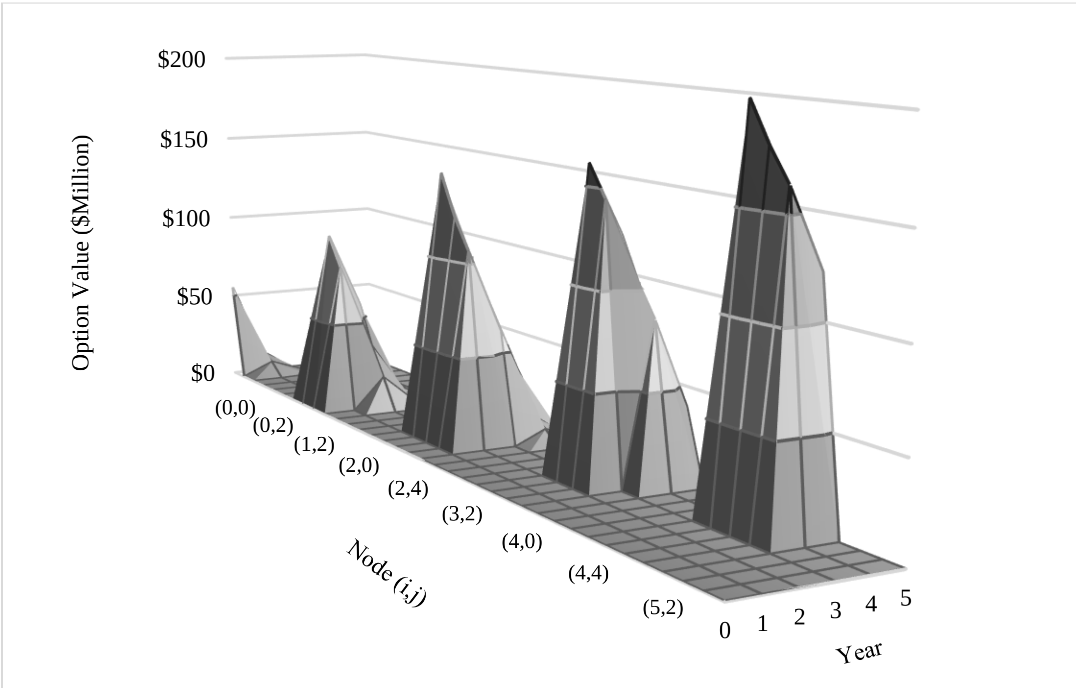


Figure 5-10 The 3D plot of the UFT option values over the quadranomial tree

Step 4. The optimal time to invest in the UFT system can be found by comparing the value of the project payoffs and waiting for upcoming possible states. Table 5-4 shows the optimal policy to invest in the UFT system. The shaded cells highlight the threshold for investing in the UFT system. This table helps decision-makers to decide whether to invest in the project or wait for another year. Suppose a manager had not invested in year zero, and now is in year one where the construction cost has increased and the freight rate has decreased (node (0,1,1)). The optimal policy is to wait for the next year's information to reveal. According to the optimal policy table, the manager can invest in the UFT system only if the construction cost drops (nodes (1,0,2) and (1,1,2)), no matter what happens to the freight rate.

Table 5-4 The optimal policy to implement the UFT system

Optimal policy		n					
i	j	0	1	2	3	4	5
0	0	*Invest*	*Wait*	*Wait*			
0	1		*Wait*	*Wait*	*Wait*	*Wait*	
0	2			*Wait*	*Wait*	*Wait*	*Wait*
0	3					*Wait*	*Wait*
0	4						
0	5						
1	0		*Invest*	*Invest*			
1	1		*Invest*	*Invest*	*Wait*	*Wait*	
1	2			*Invest*	*Wait*	*Wait*	*Wait*
1	3					*Wait*	*Wait*
1	4						
1	5						
2	0			*Invest*			
2	1			*Invest*	*Invest*	*Invest*	
2	2			*Invest*	*Invest*	*Invest*	*Wait*
2	3					*Wait*	*Wait*
2	4						
2	5						
3	0						
3	1				*Invest*	*Invest*	
3	2				*Invest*	*Invest*	*Invest*
3	3					*Invest*	*Invest*
3	4						
3	5						
4	0						
4	1					*Invest*	
4	2					*Invest*	*Invest*
4	3					*Invest*	*Invest*
4	4						
4	5						
5	0						
5	1						
5	2						*Invest*
5	3						*Invest*
5	4						
5	5						

This figure shows although the average value of the investment option would increase by waiting to the last project involvement year (year 5), the wide range of the option value indicates the riskiness of the decision.

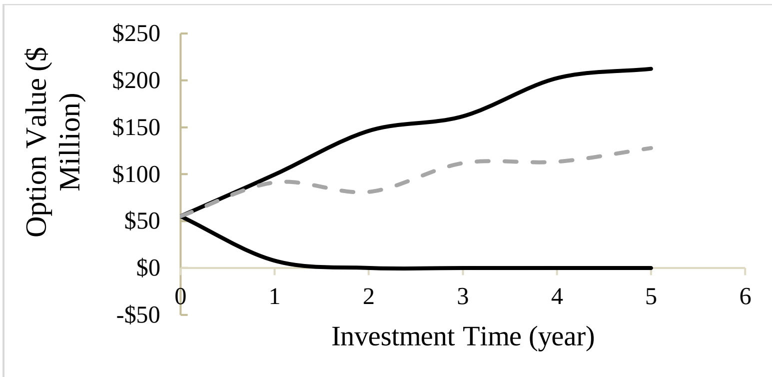


Figure 5-11 The range of the UFT investment option value

The real options analysis presented above is conducted for a UFT system that is assumed to move 3000 containers per day. However, the maximum operational capacity of the studied UFT system is designed to be 5760 shipments per day (Najafi et al. 2016). To assess the effect of UFT capacity on the dynamics of the investment options and the optimal policy that can be adopted, different operational scenarios including 1000, 2000, and 5760 shipments per day are also analyzed. Results show that the project is not worth it if the UFT system was about to move only 1000 containers per day. On the contrary, if the UFT system operates at capacity (5760 shipments per day) the project is beneficial at any anticipated condition of the construction cost and freight rate for the next five years. Table 5-5 and 5-6 illustrate the option prices and the optimal policy for implementation of the UFT system in case of 2000 shipments per day. Fig 5-12. Also demonstrates the 3D plot of the UFT investment option values at each node of the quadranomial. Results show that the proposed UFT system with this operational characteristic is most unfavorable. The project would be sound only if the market condition corresponds to nodes (4,1) and (4,2) in year four and (5,2) and (5,3) in year five.

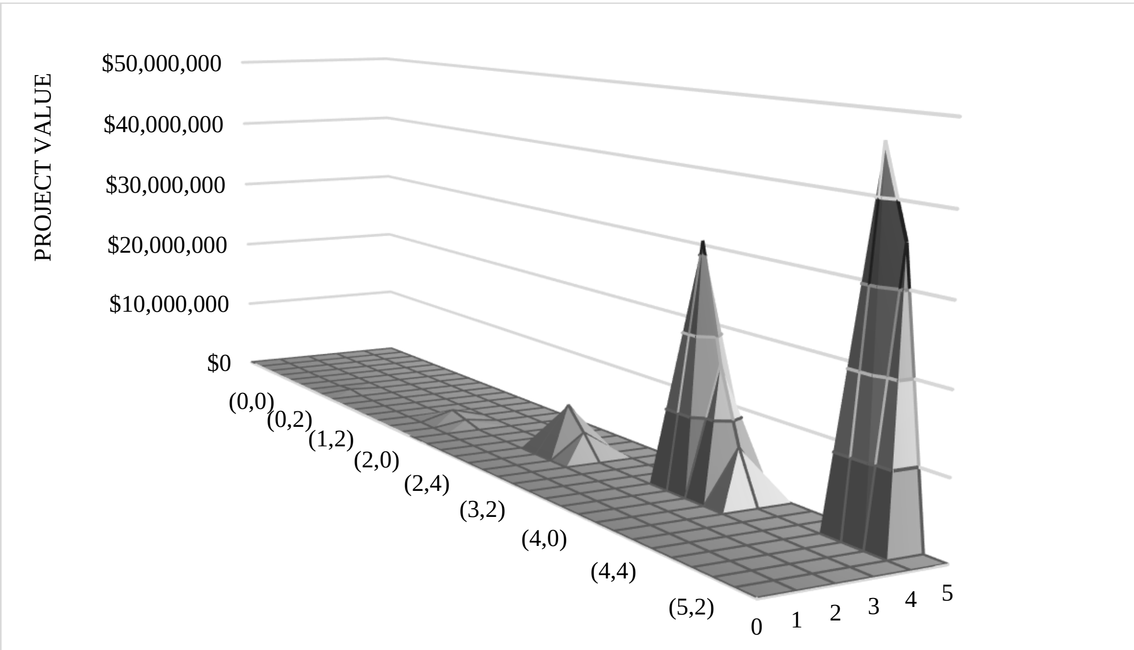


Figure 5-12 The 3D plot of the UFT option values for 2,000 shipments per day

Table 5-5 The investment option values for the UFT system moving 2000 containers per day

$V'(i,j,n)$		n					
i	j	0	1	2	3	4	5
0	0	$7,291	-	-			
0	1		-	-	-	-	
0	2			-	-	-	-
0	3					-	-
0	4						
0	5						
1	0		$24,591	-			
1	1		$255,428	-	-	-	
1	2			-	-	-	-
1	3					-	-
1	4						
1	5						
2	0			$62,200			
2	1			$1,276,536	-	-	
2	2			$650,696	-	-	-
2	3					-	-
2	4						
2	5						
3	0						
3	1				$6,375,506	-	
3	2				$3,334,819	-	-
3	3					-	-
3	4						
3	5						
4	0						
4	1					$31,837,162	
4	2					$16,746,135	-
4	3					$6,896,221	-
4	4						
4	5						
5	0						
5	1						
5	2						$46,466,310
5	3						$35,343,134
5	4						
5	5						

Table 5-6 The optimal policy to implement the UFT system with 2000 shipment per day

Optimal policy		n					
i	j	0	1	2	3	4	5
0	0	*Wait*	*Wait*	*Wait*			
0	1		*Wait*	*Wait*	*Wait*	*Wait*	
0	2			*Wait*	*Wait*	*Wait*	*Wait*
0	3					*Wait*	*Wait*
0	4						
0	5						
1	0		*Wait*	*Wait*			
1	1		*Wait*	*Wait*	*Wait*	*Wait*	
1	2			*Wait*	*Wait*	*Wait*	*Wait*
1	3					*Wait*	*Wait*
1	4						
1	5						
2	0			*Wait*			
2	1			*Wait*	*Wait*	*Wait*	
2	2			*Wait*	*Wait*	*Wait*	*Wait*
2	3					*Wait*	*Wait*
2	4						
2	5						
3	0						
3	1				*Wait*	*Wait*	
3	2				*Wait*	*Wait*	*Wait*
3	3					*Wait*	*Wait*
3	4						
3	5						
4	0						
4	1					*Invest*	
4	2					*Invest*	*Wait*
4	3					*Wait*	*Wait*
4	4						
4	5						
5	0						
5	1						
5	2						*Invest*
5	3						*Invest*
5	4						
5	5						

Chapter 6

Conclusion

Although national and state governments have critical roles in providing capital to fund new transportation infrastructure projects, adopting private sector investment is inevitable. First, feasible funding sources for constructing UFT systems in Texas were recognized as: federal and state funds, TIFIA loans, funds provided under the FAST Act, senior bank loans, revenue bonds, private activity bonds, and equity participation.

Also, the eligibility of those funding sources was explicitly studied. Although thorough scrutiny of legislation and policies showed no laws that specifically address the eligibility of UFT projects using public or private funding mechanisms, there is an opportunity to define UFT projects as projects eligible to use these mechanisms due to certain legislation. This study not only provides a proper understanding of funding and financing mechanisms for constructing UFT systems in Texas but also could be instructive to other local governments.

A comprehensive Life-cycle benefit-cost analysis of the UFT systems for five different scenarios showed that these systems are economically feasible. Results of the sensitivity analysis show that the economic feasibility of the large and medium-size UFTs is more sensitive to tunnel construction cost and revenue from shipments. They also indicate that the economic feasibility of the UFT system with the short route and small size is more sensitive to higher discount rates and the policies concerning the shipment pricing. These results suggest planners and policymakers be more meticulous in estimating the aforementioned parameters. Results of the breakeven analysis highlight a shorter payback period for the large and medium-size UFTs compared to small size scenarios. A breakeven analysis is also used to give decision-makers a degree of freedom to regulate proper shipment prices. The results show that the price of shipment for all the UFT scenarios is highly competitive compared with the current price of shipment by trucks. It also indicates that the large size UFT system provides the opportunity to substantially lower the shipment prices.

The results provide in Chapter 4 contributes to the body of knowledge by (1) recognizing the major costs (administration, tunnel construction and maintenance) and benefits (shipment revenue, reduction in air pollution and traffic congestion) of different UFT projects with different cargo sizes and lengths; (2) designing UFT scenarios for moving standard size cargos in short and long distances (The design of standard size UFT systems are crucial for the widespread implementation and simple integration of these systems with other modes of transportation.); (3) distinguishing the key factors affecting the economic feasibility of large size UFT systems and those affecting small or medium size systems; and (4) determining the minimum shipping prices (or a flexible range) that make the UFT systems economically viable.

While the results of the presented deterministic investment analysis indicate the economic feasibility of the UFT systems, there are still several risks that may affect the success of these projects. Chapter 4 highlights the risky variables for every different UFT scenarios which require further evaluations under uncertainty considerations.

A real options analysis approach was adopted to capture the available managerial flexibilities and uncertainties embedded in construction costs and shipping rates. The analysis of historical data showed that the freight rate follows a mean-reverting process. While the stochastic behavior of the construction cost is completely different (a GBM process).

To the author's knowledge, no real options models have been developed for the investment valuation of UFT systems under uncertainty and decision-making flexibility. Yet, the extant real options methods adopted to transportation infrastructures have theoretical limitations to model UFT uncertainties with different attributes. Therefore, a novel bivariate real options model suitable for the investment valuation of UFT systems under uncertainty is developed and presented in Chapter 5. The proposed model overcomes the inherent theoretical deficiencies of existing transportation infrastructure real options models by (1) presenting appropriate techniques to model the various UFT underlying uncertainties with different attributes, (2) developing a novel approach to model the volatility of the UFT project by integrating multiple uncertainties, and (3) establishing a method to estimate the real value of the investment in a UFT project.

One of the UFT scenarios presented in Chapter 4 was used as an illustrative case to demonstrate the implementation of the developed real options model. The results highlighted the market value of the project at each possible state of time. An optimal policy to invest in UFT systems was achieved through this analysis. Results show how the value of the project would change with different operational scenarios. In essence, our analysis showed that even though the economic feasibility of UFT systems is highly sensitive to the change in the shipping price and construction cost, the project would be beneficial, and the investment can be carried out if the UFT system operates at its capacity. This analysis provides decision makers a dynamic timeline for implementing a UFT system even if they rather wait for new market information that will reveal in the future.

While the data used and the quantitative results showed in this research may be particular to Texas, the methodology presented in this research can be followed for determining the economic feasibility of UFT systems elsewhere. The findings of this research provide decision-makers with information to objectively appraise UFT projects. To achieve more accurate results, future development upon the presented real options model that could incorporate more uncertain parameters is recommended.

The benefits of this study go beyond just an investment analysis, it equips transportation policy makers with a tool that can better decide to implement UFT systems leading to improvement in many areas, such as safety, environmental sustainability, infrastructure condition, traffic and congestion reduction, freight movement and economic vitality (Shhandashti et al. 2017; Ashuri et al. 2014).

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Biographical Information

Having been born in an academic family, Ehsan has always aspired to education, research, and teaching. He received his bachelor's and master's degree from two outstanding universities in Iran, Shiraz University and the University of Tehran. Ehsan joined the University of Texas at Arlington (UTA) in 2015 to pursue his doctoral degree in Civil Engineering- Construction Engineering and Management. During his Ph.D. studies, he has worked as a graduate teaching and research assistant at the Department of Civil and Engineering. As a young researcher, he was involved in several research projects funded by various public and private entities, such as Texas Department of Transportation (TxDOT), Federal Highway Association (FHWA), and North Texas Council of Governments (NCTCOG). Ehsan's research interest was mainly focused on asset management, investment valuation under uncertainty, finance, and economics of civil infrastructure projects. His research outcome is included several technical reports, manuals, scientific papers, and educational material such as brochures, info-sheets, and video clips. Along the way, Ehsan has been involved in several project activities and organizations which have brought much recognition to the university as a whole. He successfully completed his doctoral research under the supervision of Dr. Mohsen Shahandashti and received his Ph.D. degree in August 2019.