Using Design Flexibility and Real Options to Reduce Risk in Private Finance Initiatives: The Case of Japan

by

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Abstract

Private Finance Initiative (PFI) is a delivery system for public works projects to design construct, manage and maintain public facilities by using private capital, management skills, and technical abilities. It was introduced in Japan about 10 years ago to encourage the stagnant Japanese economy and provide public services with higher quality and less cost to the country and the local authority. It has been applied to many public works projects, but not to large-scale infrastructure projects, such as toll road and airport projects. One of the main reasons for this is that specific methodologies of handling risks and uncertainties involved in long-term projects have not been introduced and demonstrated to either the public or the private sector.

This thesis aims to help those involved in large-scale infrastructure development projects apply PFI to those projects by proposing a flexible methodology that will allow them to handle risks. Specifically, this thesis 1) proposes a quantitative methodology so that project managers can handle uncertainty in large-scale engineering projects, and 2) demonstrates how project managers can apply the proposed methodology practically to real-world projects, including how to model and evaluate projects, and demonstrates how the proposed methodology is useful for reducing risks and enhancing the value of projects. As a quantitative methodology, this thesis proposes real options analysis as a tool for considering uncertainty and incorporating flexibility into design, based on the premise that it is crucial not how accurately project managers forecast uncertainty but how they can handle it. This thesis also explains barriers to the implementation of the proposed concepts and methodology, and recommends how to alleviate them.

The thesis uses two real-world case studies: the "Tokyo International Airport New Runway Extension Project" and the "Tokyo Bay Aqua-Line Project". Both show the process of modeling and analyzing projects and they demonstrate the benefits of the proposed concepts and methodologies, which can guide and encourage project managers to apply proposed concepts and methodology. The first case study applies a user-friendly methodology, which can alleviate the barriers to the implementation of the proposed concepts. The second case study illustrates that, by using their management skills, ingenuity, and originality, in PFI, project companies can not only reduce risks and enhance the value of projects but also contribute to the consumers' benefits and socioeconomics from the perspective of public policy, which realizes the idea of PFI.

Thesis supervisor: Richard de Neufville
Professor of Engineering Systems and Civil and Environmental Engineering

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Chapter 1 Introduction

1.1 Introduction of PFI in Japan

Investment in the Japanese construction industry has been decreasing since the end of the bubble economy in early 1990s. In addition, the conventional project delivery system used in Japan, where a government initiative provides public works phase by phase including design work, construction, operation, and maintenance separately, was not effective in utilizing the limited amount of public works investment. The privatization of public infrastructure became popular in several developed countries which introduced the idea of "Public-Private Partnership" to achieve better quality of services to the public at reduced costs. Drawing upon the U.K. proactive application of the private finance initiative (PFI), a form of Public-Private-Partnership, it was introduced in Japan in late 1999 as a means to encourage the stagnant Japanese economy.

PFI is a delivery system for public works projects to design construct, manage and maintain public facilities by using private capital, management skills, and technical abilities. PFI is used for public service projects that can benefit from the higher efficiency and effectiveness of private capital and skills in comparison to direct government management of infrastructure, and thereby to the robust development of Japan's economy. It aims to provide public services with higher quality while reducing the business costs to the country and the local authority.

One of the main characteristics of the PFI delivery system is that all the work is ordered as one project on a long-term comprehensive contract. This enables undertakers of a project to utilize the private sector's managerial skills and technical capabilities for the public facilities, to manage risks efficiently, and to combine all the design-build-operate-maintain steps and thereby achieve higher profitability, while the conventional project delivery system leads ineffectiveness and losses.

The number of PFI projects in Japan has been increasing. Recently, the number of ongoing projects has increased by 40 or 50 a year, and currently 130 projects have reached the operation stage. The field of PFI in Japan expands every year and has been applied to the fields of prisons, embassies, and hospitals. At the end of 2006, the largest number of projects was the education, including schools and libraries, and the second largest in health and environment, including hospitals and waste disposal.

1.2 Why Has Not PFI in Japan been Applied to Large-scale Infrastructure Development?

While the number of PFI projects has been increasing recently, they have not been applied to large-scale infrastructure systems, such as toll road and airport projects, but only to simple buildings, the so-called *box-types*. This is because there have not been specific methodologies of handling risks and uncertainties involved in such long-term projects, and neither public nor private sectors know how to respond to these factors. This discourages them from applying PFI to large-scale infrastructure development projects. In other words, PFI could be applied to large-scale infrastructure development if they knew how to handle it. Because private sector companies can consistently manage a project throughout its lifecycle in PFI, project managers can incorporate much more flexibility into design compared to a conventional project delivery system, based on the premise that it is crucial not how accurately project managers forecast uncertainty but how they can handle it. Flexible design enables them to handle and reduce risks and uncertainties. In reality, however, Japanese private sector companies have not conducted flexible design in PFI, although they have a lot of chances to consider flexibility. This is because there have not been specific and practical methodology to respond to and reduce risks, and to incorporate flexibility into design.

1.3 Purpose of This Thesis

This thesis aims to help those involved in large-scale infrastructure development projects apply PFI to those projects, by proposing a methodology that can reduce risks in them and demonstrating how they can apply it.

The first objective of the thesis is to propose a quantitative methodology so that project managers can handle uncertainty and reduce risks in large-scale infrastructure projects. Specifically, this thesis proposes real options analysis as a tool for considering uncertainties and incorporating flexibility into design. Using real options analysis, project managers can have a chance to reduce risks and enhance the value of projects.

The second objective of this thesis is to demonstrate how project managers can apply the proposed methodology practically to real-world projects and how the proposed methodology is useful for reducing risks and enhancing the value of projects by using two real-world projects as case studies. More specifically, this thesis illustrates the process of the analysis including how to model the analysis, calculate the value of projects, and evaluate them. Using two real-world case studies enables this thesis to demonstrate the effectiveness and advantage of different types of real options analysis. By demonstrating the effectiveness and usefulness of the proposed methodology, the author hopes the methodology may be included in official guidelines for project managers, since there has not been any specific methodology to manage risks in official guidelines, such as “The Guideline for Risk Allocation of PFI Projects” issued by the government of Japan.

However, there are significant barriers to the implementation of the proposed concepts and methodologies. Both public and private sectors prefer to maintain status quo, generally because they do not want the added burden of mastering skills or obtaining tools necessary for new concepts and new methodologies. Thus, the third objective of this thesis is to recommend how to alleviate the barriers to implementation of proposed methodology.

1.4 Thesis Structure

Chapter 1 outlines the introduction of PFI in Japan, and its restricted application to real-world projects. This chapter also identifies the purpose of the thesis.

Chapter 2 describes the current situation of the construction industry in Japan and the conventional delivery system. Next, it documents the idea and types of public-private-partnerships, using examples from the U.K. and the U.S. And then, it illustrates PFI in Japan by explaining its concept, characteristics, types, forms, and its current status in Japan.

Chapter 3 introduces the current trends of PFI projects in Japan so far, with current issues and risks involved in PFI. Next, focusing on the crucial demand risks, this chapter illustrates why forecasting is always wrong by detailing several experiences. Finally, this chapter documents how to react to risks and uncertainty, especially focusing on demand risks in this thesis, and introduces a project valuation and a risk management methodology.

Chapter 4 explains the basic concepts of project valuation along with time value of money, discount rate and the net present value (NPV), including the weighted average cost of capital (WACC), the capital asset pricing model (CAPM), and the arbitrage pricing theory (APT). It also explains the concept of the discounted cash flows method (DCF) as well as its limitation in real-world projects.

Chapter 5 introduces the basic concepts of financial options theory. Next, it explains the concepts and types of real options, and then explains several major real options as project evaluation methodologies and risk management, by detailing their characteristics.

Chapters 6 and 7 apply the proposed concepts and methodology to real-world projects as case studies. They aim to demonstrate how project managers can model analysis, especially model of uncertainty, and how it can be applied to real-world projects. Also, through the case studies, these chapters demonstrate how flexible design can contribute to reduction of risks and improvement of the value of projects.

Chapter 8 demonstrates the degree to which the proposed methodology has been applied as a valuation method in the real world thus far. It also describes barriers to the implementation of those proposed concepts and methodologies, and lastly makes recommendations to alleviate them.

Finally, Chapter 9 provides conclusions and suggests potential future work.

Chapter 2 Introduction of PFI in Japan

Investment in the construction industry in Japan has been decreasing since the end of the bubble economy in Japan in early 1990s [1]. Also, the conventional project delivery system used in Japan was not effective in utilizing the limited amount of public works investment. The privatization of public infrastructure became popular and the idea of "Public-Private Partnership" was introduced in several developed countries in order to achieve better quality of services to the public at reduced costs. Drawing upon the proactive application in the U.K., private finance initiative (PFI), a form of Public-Private-Partnership, was introduced in Japan in late 1999 as a means to encourage the stagnant Japanese economy. This chapter describes the current situation of the construction industry in Japan and the conventional delivery system in Section 2.1, and documents the idea and types of public-private-partnerships, as well as introduces examples of public-private-partnerships in the U.K. and the U.S. in Section 2.2. It illustrates PFI in Japan by explaining the concept, characteristics, and types of PFI in Japan in Section 2.3, and finally illustrates the current status of PFI in Japan in Section 2.4

2.1 Background of the Introduction of PFI in Japan

2.1.1 Overview of the Construction Industry in Japan

During the reconstruction period after World War II, the construction industry in Japan experienced a boom, including the development of large-scale infrastructure and various types of plants, and played a critical role in the country's accumulation of capital. The industry kept growing faster than most industries since the fiscal policy by the central government in 1970s provided for a lot of public works, and then it grew to a huge and exceptional industry due to the bubble economy in early 1990s. However, as Figure 2-1 shows, the industry fell into a recession in the middle of 1990s as the economic condition in Japan fell stagnant after the bubble economy [1]. Thus, the government's investment in the construction industry continued to decrease.

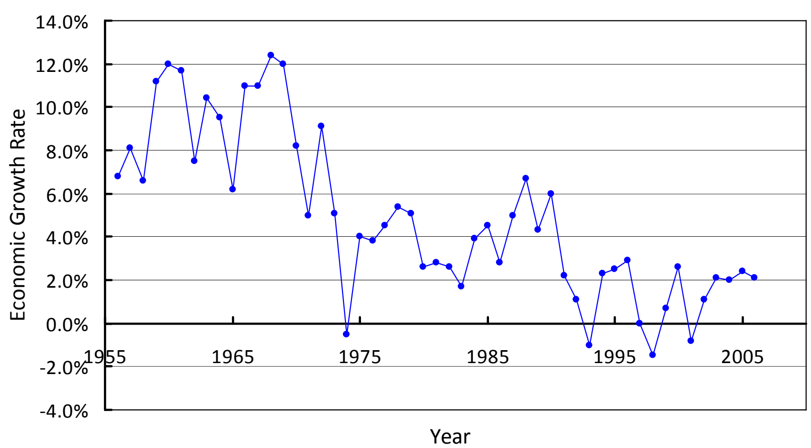


Figure 2-1: Transition of Economic Growth Rate in Japan

Source: Japan, Cabinet Office (2007) [1]

Although the economic condition in Japan has recovered gradually since 2004, because of the central government's policy to reduce its investment in public works due to the deficient budget of both the central and the local governments, the number of public works provided currently continues to decrease. Figure 2-2 shows this trends and the transition of the investment in public works in Japan [2]. The investment in public works was 18.1% in 1990 and was 10.2% in 2006 respectively.

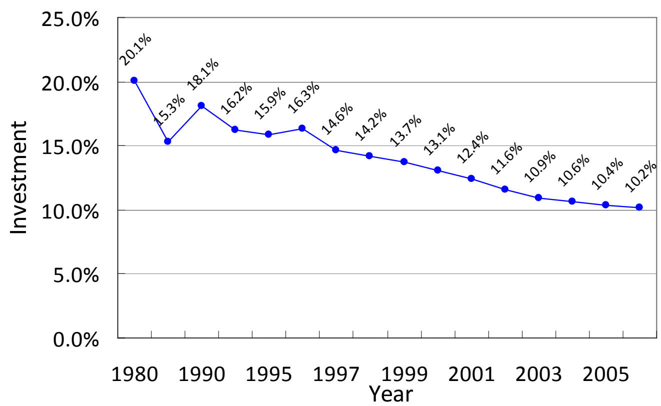


Figure 2-2: Transition of the Investment in Construction Industry in Japan (Government Construction)

Source: Japan Federation of Construction Contractors (2007) [2]

Construction industry has been one of the largest industries in Japan, involving 524,273 firms and 5,590,000 workers as of the end of 2006, which comprise approximately 8.8% of the total workforce [3]. The investment in the construction industry in Japan was ¥52.3 trillion in the fiscal year of 2006, and it has accounted for about 10.2% of the Gross Domestic Product (GDP) [2].

2.1.2 Conventional Project Delivery System in Japan

The conventional project delivery system of public works in Japan is the one where a government initiative provides public works phase by phase, including design work, construction, operation, and maintenance separately. For example, the design work and construction are ordered by the government to be performed by private companies, as selected through a bidding system; the operation of the project is performed by the government; and the maintenance is also issued to private companies, selected through a bidding system. However, this process is inefficient, because of the way work proceeds from phase to phase. For example, each company at each phase works individually, and thus inconsistency can emerge between phase and phase. A design company often misses important points for the construction conditions or operation of facilities, and it creates inappropriate design drawings and specifications, which then leads to the delay of construction and incremental cost for both design and construction. Thus, the conventional delivery system does not consider the entire project, and it does not optimize projects in terms of both cost and efficiency. Furthermore, government activities themselves are inefficient. The poor performance of the public sector can be seen in as follows [4]:

1. Inefficiency, overstaffing and low productivity
2. Poor quality of goods and services,
3. Unresponsiveness to the public,
4. Obsolete practices or products, and little marketing capability
5. Underutilized and under-performing assets

This may be because government activity is inherently monopolistic, so that there is little incentive to use resources in their most efficient manner, as there would be no penalty for poor quality or poor performance. Private sector companies, on the other hand, that perform poorly are replaced by their competitors, so they have a greater incentive to ensure efficiency. Thus the conventional project delivery system is inefficient and many people come to think that privatization is necessary to improve its efficiency.

2.2 Privatization of Public Infrastructure

2.2.1 Benefits of Public-Private Partnerships in Infrastructure

Under the circumstances described above, privatization in infrastructure development had been thought necessary to improve inefficiency. For instance, by inviting private participation in infrastructure development, it is expected that better quality of services at reduced costs could be provided to the public. In the field of infrastructure development, public-private partnerships, where government and private sectors share the risks and responsibilities of projects that would otherwise have to be accepted completely by government, are the most commonly employed form of privatization. The difference between the private sector and the public sector is that the private sector has a profit motive and is under a threat of bankruptcy while the public sector accepts a project if the non-monetary and monetary benefits are greater than the costs [5]. Public-private partnerships can be effective when both sectors desire to share common goals. Public-private partnerships intend to improve the efficiency of public infrastructure development by bringing into infrastructure projects these private sector attributes that governments in general do not hold. If structured appropriately, public-private partnerships enable a number of benefits. For example, the following are the possible contributions of the private sector to better infrastructure development programs [4].

1. It helps identify and develop new, innovatively designed, user-financed, profit making facilities or existing facilities in need of rehabilitation, renovation, or expansion.
2. By involving private sponsors and experienced commercial lenders, it assures in-depth review of the technical and financial feasibility of the project.
3. It accesses private capital market to supplement or substitute for hard-to-get government resources. New capital comes from a large and previously untapped pool of investors interested in higher-risk, higher-return investments than traditional municipal funds: this can leverage limited public funds and may improve the government's credit rating.
4. It builds more quickly and more cost effectively than governments usually can, and therefore satisfies public needs more quickly at lower cost. Construction is generally more rapid because private developers are more flexible and do not have to observe government procurement rules and bureaucratic constraints that delay planning and construction schedules.
5. It operates facilities more efficiently than government usually can, while complying with regulatory standards.
6. It accepts some risks that would otherwise have to be borne by public sector alone.

7. It transfers technology and trains government during the course of a project.
8. It establishes a private benchmark against which to measure the efficiency of similar projects and enhances public management of future projects.

Thus, public-private partnerships have become common as a new innovative delivery system for infrastructure development, where the public and the private sectors can combine their efforts to achieve efficient infrastructure development by making use of their own strengths and supplementing the others' weakness.

2.2.2 Types of Public-Private Partnership

Public-private partnerships for infrastructure development take many forms. Table 2-1 shows the possible arrangements [5]. Because the nature of infrastructure projects is very complicated and each has its own unique situations, it is necessary to apply an appropriate organization alternative, depending on the situation.

An increasing number of governments around the world have been considering and applying some sorts of private participation in their infrastructure provisions. As Sections 2.2.3 and 2.2.4 describe, the governments of the U.S. and the U.K. introduced public-private partnerships in infrastructure development.

Table 2-1: Types of Public-Private Participation

	Design	Construction	Operation	Financing	Ownership	Duration	
Government Department and Public Authority	X	X				-	More Public ↑
Service Contract			X X			Short (<5yrs)	
O&M Contract		X X	X X	X X		Short (<5yrs)	
Super-turnkey development	X X X	X X X	X X	X X		Medium	
Lease-Build-Operate (LBO)	X X X	X X X	X X X	X X X		Medium to Long	
Build-Transfer-Operate (BTO)	X X X	X X X	X X X	X X X		Long	
Wraparound Addition	X X X	X X X	X X X	X X X	X X X	Medium to Long	
Build-Operate-Transfer (BOT)	X X X	X X X	X X X	X X X	X X X	Long	
Buy-Build-Operate (BBO)	X X X	X X X	X X X	X X X	X X X	Infinite	
Build-Own-Operate (BOO)	X X X	X X X	X X X	X X X	X X X	Infinite	↓ More Private

X: Private sector merely provides services that are procured by the government.
XX: Private sector assumes some responsibility regarding the activity.
XXX: Private sector assumes full (or most) responsibility regarding the activity.

Source: Imamura arranged [5]

2.2.3 Public-Private Partnership in the U.K.

Private Finance Initiative (PFI) originated from the U.K. as a project delivery system for infrastructure development projects, following its trend of the financial reorganization by means of privatization, deregulation, and outsourcing [6]. The Thatcher government, which aimed to realize so-called *small government*, launched the preliminary approach toward PFI in late 1980s. The succeeding government introduced the idea of the value for money (VFM) in 1990, and promoted PFI in 1992 in order to maintain the standard of public works investments and to reduce the financial deficit. The idea of the VFM is explained in Section 2.3.2. After Tony Blair became Prime Minister, the government organized systems, including the simplification of the bidding process and creation of the guidelines. In the U.K., PFI has now become an established method of delivering many public services.

In the U.K., the investment in PFI projects had grown steadily from 1993 to 1998, when the public expenditure for PFI reached £3.0 billion. Figure 2-3 shows the number of projects and their total capital value for projects reaching financial close between 1995 and 2007. This figure illustrates that the number of projects peaked around the year 2000, but the total capital value has continued to increase. The number of projects to which PFI have been applied in total is 869 as of 2007. The average capital value of projects has reached £149million in 2006/07 [6].

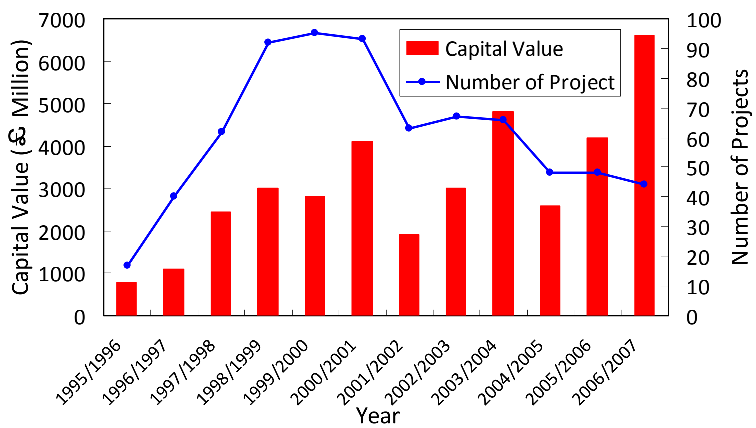


Figure 2-3: Size of Overall Market of PFI in the U.K. since 1995/1996
Source: PartnershipsUK (2007) [6]

Table 2-2 shows the number of PFI projects in each field and the total capital value invested in each field as of 2007 [7]. Health care has the largest number of PFI projects with 269 projects followed by the education field with 215, while there are 63 projects in transportation field. On the other hand, the capital value in the transportation field is £23,384 million as of 2007, while that of the health care and education are only £12,462 million and £9,322 million respectively. In addition, the capital value per project in the transportation field is £387 million per project, and thus the investment in the transportation field is the largest of all fields.

Table 2-2: Number of PFI Projects and Total Capital Value Invested in each Field

	Number of Projects	Capital Value (£Million)	Capital Value/Project (£Million)
Accomodation	111	6,592	59.4
Education	215	9,322	43.4
Environment	52	3,338	64.2
Equipment	35	1,480	42.3
Health	269	12,462	46.3
Housing	21	1,323	63.0
ICT	82	3,397	41.4
Leisure Service	13	225	17.3
Property	7	293	41.9
Transportation	63	24,384	387.0
Wider Market	1	10	10.0
Total	869	62,826	72.3

Source: PartnershipsUK (2007) [7]

Table 2-3 shows some of the examples of PFI projects in the U.K.

Table 2-3: Examples of PFI Projects in the U.K.

Projects	Sector	Contract Term (Years)	Capital Value (£ M)	Contract on	Operation from
Birmingham Northern Relief Road (M6 Toll)	Roads	53 year	485	2/1/1992	12/8/2003
A13 Thames Gateway	Roads	30 year	411	12/4/1996	9/1/2004
Second Severn Crossing	Roads	30 year	331	10/29/1990	6/5/1996
Sub Surface Lines (SSL) - District, Circle, Metropolitan, East London & Hammersmith & City	Underground Rail	30 year	6,687	6/21/1999	4/4/2003
Barts and the London NHS Trust - Redevelopment of the Royal Hospital of St Bartholomew and the Royal London Hospital	Hospitals	42 year	1,072	2/12/2002	4/20/2006
University Hospital Birmingham NHS Foundation Trust - Birmingham New Hospitals Project	Hospitals	35 year	627	6/14/2006	10/7/2011
South Lanarkshire Council - Secondary Schools Modernisation Programme (EDSL 21)	Secondary School	30 year	394	6/19/2006	8/1/2008
North Lanarkshire Council - Education 2010	Primary & Secondary School	31 year	280	6/8/2006	7/1/2008
Cambridge Waste Management PFI	Waste	28 year	730	2/21/2005	4/1/2007

Source: PartnershipsUK (2007) [7]

2.2.4 Public-Private Partnership in the U.S.

The delivery systems for the infrastructure development in the U.S. have been changing over the years. The Design-Bid-Build (DBB) method now used for infrastructure development is almost the same as the one used in Japan. However, unlike Japan, these contracts in the US are very elaborate, with the backing of a strong legal system, such that the engineers have a firm respected status as an independent profession. Even so, the increased conflicts and lawsuits, has created the search for new delivery systems have come to be considered [8]. There are several types of public-private partnerships delivery systems, such as Build-Operate-Transfer (BOT), Construction Management method (CM), Design-Build (DB) contracts, and Design-Build-Finance-Operate (DBFO), which are experiencing increased use throughout the country. Table 2-4 shows examples of the public-private partnership in the U.S and Canada [9].

Table 2-4: Examples of Public-Private Partnership Projects in the U.S. and Canada

Projects	Sector	Contract Term (Years)	Capital Value ($M)	Contract on	Operation from
E-470 TOLLWAY (Denver , Colorado)	Toll road	45 year	$1,200	1989	1991 (partly)
I-15 CORRIDOR RECONSTRUCTION PROJECT (Salt Lake City , Utah)	Toll road	25 Year	$1,600	1997	2001
ROUTE 3 NORTH (Northern Metropolitan Boston, Massachusetts)	Toll road	30 years	$385	1999	2004
HUDSON-BERGEN LIGHT RAIL Stage 1 (Hudson and Bergen Counties, New Jersey)	Light Rail Transit	15 year	$1,100	1996	2000
DULLES GREENWAY (Loudoun County, Northern Virginia)	Toll road	40 year	$350	1989	1995
SOUTH BAY EXPRESSWAY (SR 125) (San Diego County , California)	Toll road	35 year	$773	2000	2007
Highway 407 (Canada)	Toll road	99 year	C$1,000	1993	1997
Confederation Bridge (Canada)	Toll Bridge	35 year	C$840	1993	1997

Source: U.S. Department of Transportation, Federal Highway Administration (2007) [9]

2.3 PFI in Japan

Drawing upon the proactive application in the U.K., private finance initiative (PFI) was introduced in Japan in late 1999 as a means to stimulate the stagnant Japanese economy. Under the strain of a fiscal deficit, the national and local governments and the economic recession described in Section 2.1.1, PFI was expected to work as a novel scheme, by which public facilities would be developed and the government financial structure would be streamlined.

2.3.1 Outline of PFI in Japan

PFI is a delivery system to design construct, maintain and manage public facilities by using private capital, management skills, and technical abilities. PFI is used for public service projects that can benefit from the higher efficiency and effectiveness of private capital and skills in comparison to direct government management of infrastructure, and thereby to the robust development of Japan's economy. It aims to provide public services with higher quality while reducing the business costs to the country and the local authority.

The PFI Law was enacted in July 1999 and came into effect in September 1999 concerning the maintenance of communal and other public facilities with private capital [10]. The main objective of this law was originally to promote new business in order to recover from a serious economic recession. In addition to amending the PFI law twice, the government released the Policy Framework and five guidelines to promote implementation.

The Basic Policies, which were determined and announced by the Prime Minister on March 13, 2000 as a framework to implement any individual PFI project, stipulate in the preamble that potential effects of the implementation of PFI and the objectives of PFI Act are the following three points [10]:

1. PFI is expected to provide less expensive and quality public services. This includes restructuring the financial status for national and local governments, by utilizing managerial and technical skills that exists within the private sector. This will allow for more efficient management of risks.
2. The public sector's style of involvement in the implementation of the public services will be reformed, as private undertakers involve themselves in the public-private formation, forcing proper role sharing.
3. Creating business opportunities for the private sector boosts Japan's stagnant economy.

These new opportunities include PFI projects themselves, as well as other projects tied to PFI. Moreover, the financing market in general benefits from the emergence of PFI. The result is the emergence of many new businesses, and a generally positive reform of the economic structure.

2.3.2 Characteristics of PFI in Japan

The main characteristics of PFI are 1) long-term blanket order, 2) evaluation of the value for money (VFM), and 3) appropriate responsibility and risk allocation between public and private sector, all of which are stipulated in the guidelines published by the government [10].

(1) Long-term Blanket Order

As Section 2.1.2 describes, in the public works in Japan delivered by the conventional project delivery system, government issues orders for the private sector to perform design work, construction, operation, and maintenance separately. In addition, although the project lasts for a long time, orders are placed every year. On the other hand, in the delivery system of PFI, all the work is ordered as one project on a long-term contract, a more comprehensive manner. This enables undertakers of a project to utilize the private sector's managerial skills and technical capabilities for the public facilities, managing risks efficiently, and combining all of the design-build-maintain-operate steps and thereby achieving higher profitability. Figure 2-4 compares public works under the conventional delivery system with the ones under PFI.

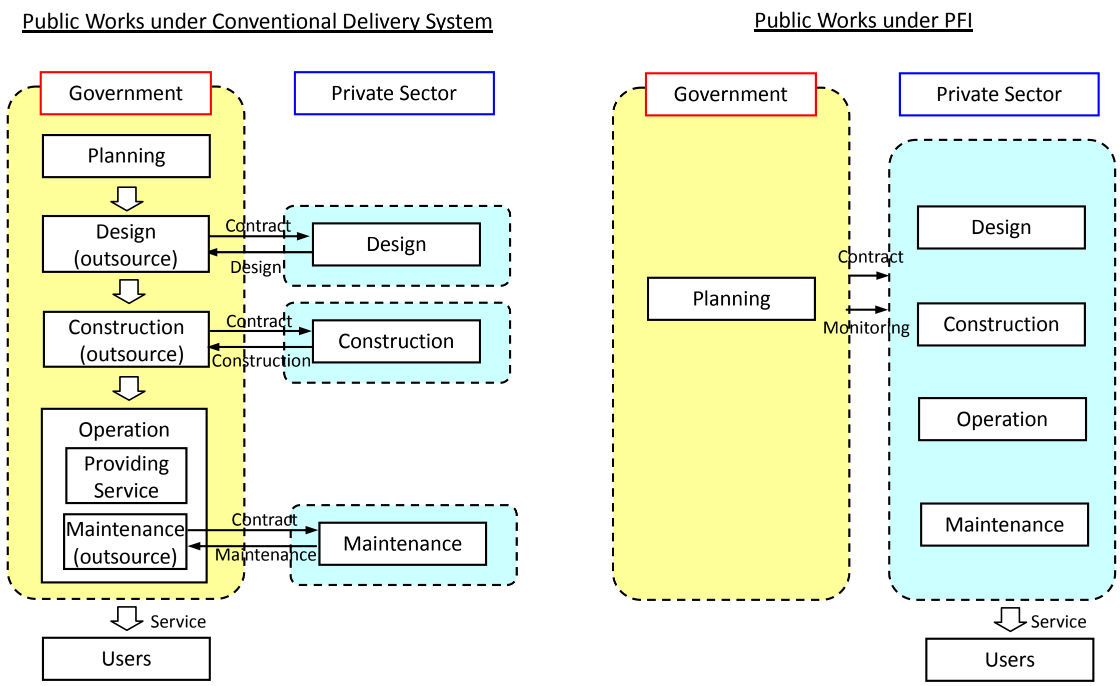


Figure 2-4: Comparison of Public Works under Conventional Delivery System and PFI

Source: Japan, Cabinet Office of Japan, PFI Promotion Office (2007) [10]

(2) Evaluation of the VFM

In PFI projects, the idea of the VFM is very significant. The idea of the VFM is to represent an efficient and economical use of government money. In principle, the VFM comes from two aspects of enhanced service quality and reduced costs. When the service quality remains unchanged, the lower cost leads to the VFM, on the other hand, even when the cost is the same or increased, significant improvement in service quality can result in the VFM. “The Guideline for the Evaluation of the VFM of PFI Projects” states that the selection of PFI projects should be based on whether the project can be achieved efficiently and effectively by the private sector. This decision is evaluated through the concept of the VFM of projects, which is a useful measurement of the selection decision process. If a privately managed project had higher value in terms of its cost than the other projects, the public sector intends to procure, then because of its higher VFM it is supposed to be implemented as a PFI project [11].

Basically, the evaluation of the VFM can be conducted by comparing the *public sector comparator (PSC)* with the *life cycle cost (LCC)* of the prospective PFI projects, each of which should use the *net present value (NPV)* of the financial cost of the project, publicly managed or privately managed, respectively. Figure 2-5 shows the concepts of the VFM. The VFM should be primarily evaluated for the “Services sold to the public sector” project, for which the public sector pays all the cost in compensation for the public services provided.

VFM = PSC – LCC **Equation 2-1**

Where PSC: Public Sector Comparator
LCC: Life Cycle Cost

The PSC is the net present value of the estimated public finance cost. It is calculated based on the appropriate cash flow projection for the lifetime of the project, and a prospective formation, such as outsourcing, should be assumed. The calculation includes all the summation of all costs accrued over the various stages, including the design, construction, operation, and maintenance stages. Risks in these stages and indirect costs are also quantified and included in the PSC.

The LCC is the net present value of the financial cost the public sector would spend for the project privately managed under PFI. PFI projects are assumed to be a single project combining design, construction, maintenance, and operation of the public facilities. In comparison with the PSC, collateral facilities are excluded from PFI cash flow. The calculation should be made on a clear basis backed by the investigation of the market or the similar experiences.

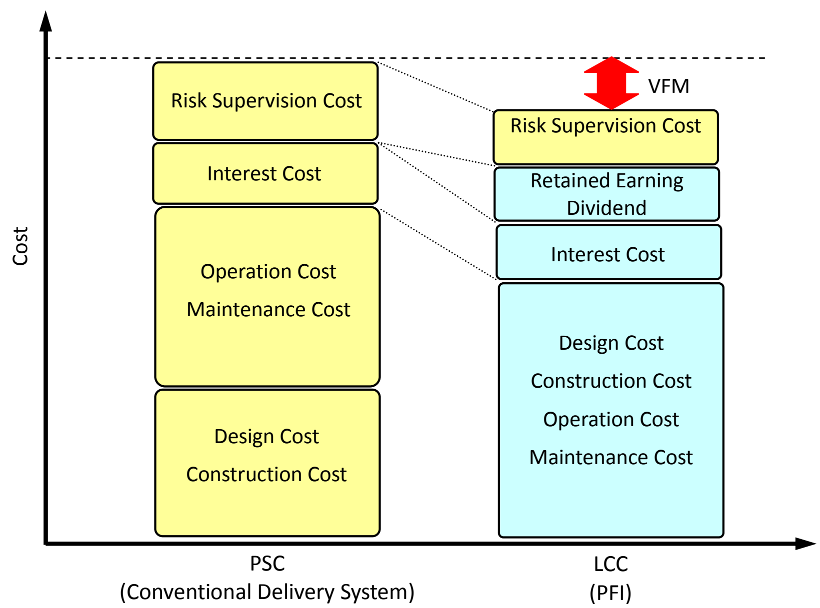


Figure 2-5: Concept of VFM
Source: The Cabinet Office of Japan, PFI Promotion Office (2007) [10]

(3) Risk Allocation of PFI

In PFI projects, risks should be identified and characterized as much as possible, and should be allocated based on the idea of "Who could manage the risk best shall bear it." According to "The Guideline for Risk Allocation of PFI Projects", which outlines basic concepts and policies that help in better managing risks that may occur over the course of PFI projects, the risk management should proceed by first recognizing the potentials and the sources of the risks, then valuating the influence of the risk, by identifying the risk taker for each risk, and lastly allocating the risk [12]. There are a variety of risks in long-term projects such as PFI, and these risks can occur in each stage of the project: investigation and design, acquisition, construction, operation and maintenance, termination, and common risks that may occur in a combination of those stages. The guideline also states that characterizing, allocating, and quantifying risks should be arranged on a case-by-case basis, because each project has many different aspects within its risk profile, making it necessary for risk allocation arrangements should be structured based on the attributes of each project [12].

2.3.3 Project Scheme of PFI

In PFI projects, governments do not make a contract with those companies which actually conduct the business, including any design company, construction company, operation company and maintenance company; they only make arrangements with a project company, the so-called *special purpose company* (SPC) that the mentioned companies capitalize and establish. Figure 2-6 illustrates the general project scheme of PFI. By establishing an SPC, it is possible to eliminate some of the influence that the financial condition of those companies which comprise an SPC, may wield. Also, it enables an SPC to apply project finance to PFI. Project finance is the financial method for the long-term infrastructure development projects, in which project debt and equity are used to finance the project and debt is repaid from the operational cash flow in the project rather than the general assets or creditworthiness of the project sponsors.

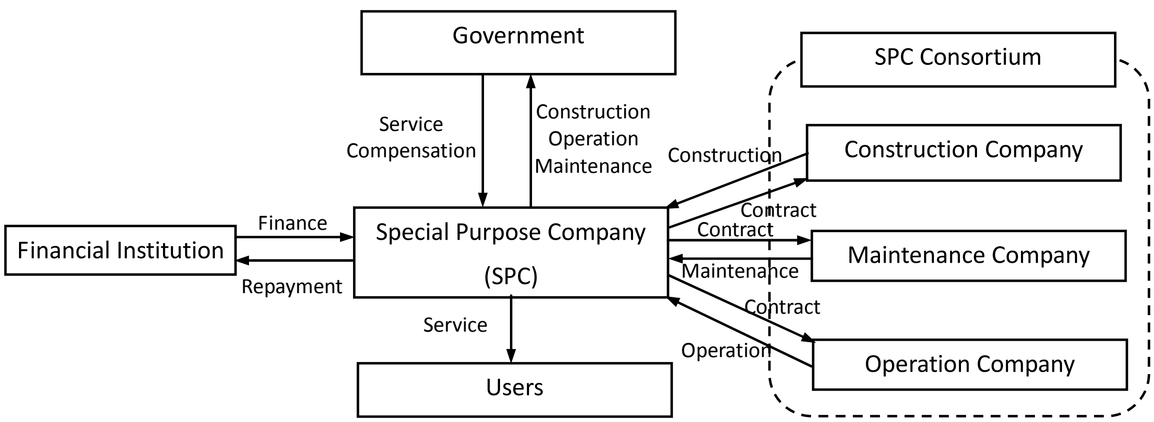


Figure 2-6: General Project Scheme of PFI

Source: The Cabinet Office of Japan, PFI Promotion Office (2007) [10]

2.3.4 Types of Facility Ownership of PFI

The facility ownership of PFI can exist in three forms: BTO (Build-Transfer-Operate), BOT (Build-Operation-Transfer) and BOO (Build-Own-Operation), as Section 2.2.2 explains.

(1) BTO (Build-Transfer-Operate)

A private developer finances and builds a facility and upon completion, transfers legal ownership to the sponsoring government. The government then leases the facility back to the developer under a long-term lease. During the lease, the developer operates the facility and has the opportunity to recover its investment and earn a reasonable return from user charges and other commercial activities.

(2) BOT (Build-Operation-Transfer)

A private developer is awarded a franchise (concession) to finance, build, own, and operate a facility, as well as collect user fees for a specified period, after which ownership of the facility is transferred to the public sector. This is perhaps the most common form of public private partnership for building new infrastructure. In contrast to a sale or permanent concession, the government retains strategic control over the project.

(3) BOO (Build-Own-Operation)

A private developer finances, builds, owns, and operates a facility in perpetuity under a franchise. While this mechanism is subject to several regulatory constraints on pricing and operations, the long-term property rights provide a significant financial incentive for capital investment in the facility.

2.4 Current Status of PFI in Japan

The number of PFI projects in Japan has been increasing every year and rose to 265 at the end of fiscal year 2006. As Figure 2-7 shows, in recent years, the number of ongoing projects has increased by 40 or 50 a year. Currently 130 projects have reached the operation stage. In FY 2006, the total capital value of projects reached 2.0 trillion yen, as Figure 2-8 shows.

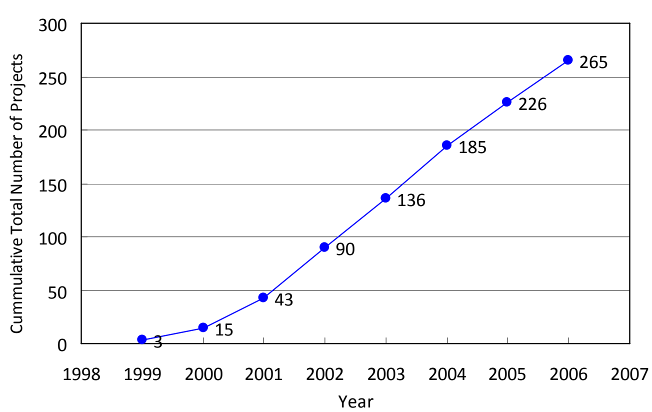


Figure 2-7: Growth in the Number of Projects

Source: Japan, Cabinet Office, PFI Promotion Office (2007) [10]

The field of PFI in Japan expands every year and recently has been applied to the fields of prisons, embassies, hospitals, and airport facilities. As of the end of 2006, the largest number of projects is the education field, including schools and libraries, and the second largest is the health and environment field, including hospitals and waste disposal.

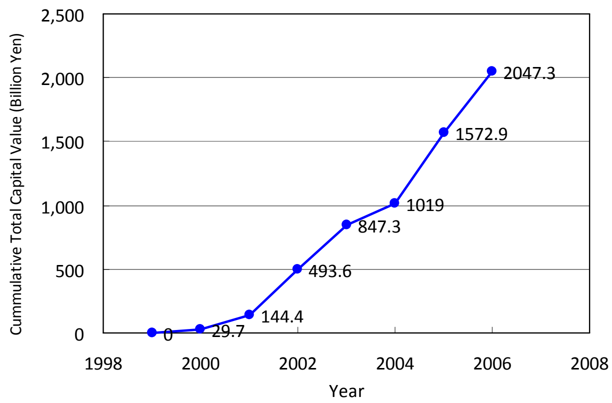


Figure 2-8: Market Growth on Project Cost Basis

Source: Japan, Cabinet Office, PFI Promotion Office (2007) [10]

Table 2-5: Number of Projects in Each Field as of 2006

Fields	Administrator			Total
	Central Government	Local Government	Other	
Education (school, library, etc.)	1	57	27	85
Life and Welfare (facility for social welfare for aged, etc.)	0	12	0	12
Health and Environment (hospital, waste disposal, etc.)	0	49	0	49
Industry (sightseeing facility, etc.)	0	15	0	15
Housing and Urban Regeneration	6	28	0	34
Emergency Services (police office, prison, etc.)	6	11	0	17
Governmental building and accommodation	20	4	1	25
Others (complex facility, etc.)	0	26	0	26
Total	33	202	30	265

Source: Japan, Cabinet Office, PFI Promotion Office (2007) [10]

However, as Table 2-5 shows, PFI has not been applied to large-scale infrastructure projects, such as toll roads, toll bridges, and airport projects, while there have been a lot of experiences in those fields with PFI in the U.K.

Chapter 3 Risks and Uncertainty in PFI

The number of PFI projects has certainly been increasing recently. However, it has not been applied to large-scale infrastructure development projects, such as toll road, toll bridges, and airport projects, but only to simple buildings, the so called *box-types*. This is because there have not been specific methodologies of handling risks and uncertainties involved in such long-term projects, and neither public nor private sectors know how to respond to those factors. In other words, PFI could be applied to large-scale infrastructure development if they knew how to do it. Because private sector companies can consistently manage projects throughout its lifecycle in PFI, project managers can incorporate much more flexibility into design compared to the conventional delivery system. Flexible design enables them to handle and reduce risks and uncertainties. In reality, however, Japanese private sector companies have not conducted flexible design, although they have a lot of chances to consider flexibility. This chapter introduces the current trends of PFI projects that have been applied in Japan so far, with current issues and risks involved in PFI covered in Section 3.1. Next, focusing on the demand risks, which is one of the crucial risks, Section 3.2 illustrates why forecasting is always wrong by detailing several experiences. Finally, this chapter documents how to handle risks and uncertainty, especially focusing on demand risks in this thesis, and demonstrates a risk management methodology from Section 3.3.

3.1 Why Has PFI Not been applied in Japan to Large-scale Infrastructure Development?

3.1.1 Trends in the Application of PFI Projects

A variety of types of PFI have been applied to the actual project so far, as Table 2-4 shows. However, PFI in Japan has not been applied to large scale public works such as toll road and airport projects, but only to simple buildings, the so-called *box-types*, such as hospitals, schools, waste disposals, government buildings, social welfare facilities, and public institutions. Large-scale public infrastructure is rarely investigated as PFI projects for several reasons even though privatized projects in other countries such as the U.S. and the U.K. substantially include those types of projects.

3.1.2 Issues involved in PFI so far

It has been about eight years since PFI was introduced in Japan in 1999. According to the investigation by the central government in Japan, both the private and public sectors have had several concerns and complaints about the implementation of PFI so far. Private sector companies complain that the public and the private sectors have not stood on an equal footing. The public sector insists that since the implementation process of PFI requires a huge amount of time, it is very hard for those in governments used to the conventional delivery system to use this delivery system. Also, some people in management positions in government tend to hesitate to apply PFI because they think that it is unclear how effective PFI is. The government investigation breaks down these issues into several categories as follows [13]:

1) Clarification of the required level of performance

The private sector has pointed out that it is very unclear exactly what the public sector requires the private sector to do in PFI. For this reason, the documents for required performance should be distributed to the private sector before bidding, so that it does not end up well organized with a lot of unclear points, which leads to the ambiguity of the risk allocation.

2) Propulsion of standardization of contract process

The contract process is so complicated that it is time-consuming work for both the public and private sectors. One of the main reasons for this is the fact that contract documents are not standardized.

3) Necessity of organization about analysis of risks and risk management

"The Guideline for Risk Allocation of PFI Projects" does not include the specific methodologies of handling and evaluating risks and the countermeasures against risks. Therefore, specific direction about evaluation of risks and methodologies of handling them should be demonstrated in the guideline.

4) Propulsion of more transparent bidding process and of bidding process so that the private sector can utilize its originality and ingenuity.

After the bidding, the reason why those who lost the bidding were not selected has not been explained to them, leading them to feel the selection process is not transparent. In addition, the idea of PFI is to implement private sector's originality and ingenuity, including managerial skills and technical capabilities. However, because the private sector has not gotten any feedback from the public, the private sector has no idea what to do for the next projects.

5) Appropriate response to the issues during operation phase

As a project continues, there can be a change in the institutions as well as technological innovation. It is necessary to adjust to these changes appropriately.

6) Evaluation method of the VFM

The evaluation process of the VFM is not unified, so the method of calculating the VFM has differed from one project to another, leading to a time-consuming process.

7) Financing method

In PFI in Japan, a loan is a main financing method, rather than bonds financing, since the cost of a loan is lower than that of bonds. This is because the level of interest is very low and it takes time and cost more to procure bond financing. Also, the secondary market of debt financing is not well developed. However, in the current dynamic world, it is possible that the situation changes.

8) Necessity of equal footing of government support, such as subsidy and taxation

It is necessary to keep realizing the appropriate equal footing of subsidy and taxation by governments.

Every issue needs to be solved as immediately as possible for PFI to be implemented appropriately. Above all, risk analysis and risk management are the most important factors for the implementation of PFI. It is very complicated and difficult to identify and quantify the influences of the risks involved in PFI projects, such as demand, time or cost overruns. Time or cost overruns are common in the real-world construction projects and the influences are relatively large. From the perspective of benefit and cost in PFI, those risks directly influence the costs and benefits for both the public and private sectors. In PFI, the private sector has to take a variety of risks that public sector used to take in a conventional project delivery system in the long-term project life cycle, such as design, construction, operation and maintenance. The larger the scale of the project is, the more risk and more uncertainties the project involves. This discourages both public and private sectors from applying PFI to large-scale infrastructure development projects. Therefore, PFI has not been applied to large-scale infrastructure projects, such as toll road, toll bridge and airport projects.

3.1.3 Risks Involved in PFI

There are a variety of risks involved in PFI projects as well as the public-private partnership projects. General risks involved in long-term infrastructure projects include those associated with pre-construction, completion, demand, force majeure, tort liability, political, and financial [8].

Pre-construction Risk
Right-of-way acquisition, environmental compliance, regulatory permissions, and other project requirements before the construction period may cause delays and cost overruns during the project development. The public sector often performs the right-of-way acquisition, while the private sector tends to be responsible for the other aspects in many privatized projects. Pre-construction risk may involve objection from the residential sector.

Completion (Construction) Risk
During the construction period, design changes, unforeseen geological and weather conditions, the difficulty of adapting an innovative technology, and the unavailability of materials and labor can cause delays and cost overruns. The private sector typically takes primary responsibility for these cost overruns and delays during the construction period, but allocates the risk to the contractor through a fixed price contract. The exception to this case is that of force majeure. The public sector takes on some responsibility for the these risks associated with public control, such as the development of the connecting road network or those that cannot be completely attributed to the private sector, such as unforeseen geological conditions. Construction risks may be lower for extensions, expansions, or rehabilitations than for new projects.

Demand Risk
Demand risks may encompass the *greatest risk* for large-scale infrastructure projects although completion risks may also be great as well for those projects. These risks are associated with insufficient traffic levels and toll rates too low to generate expected revenues. The private sector assumes the risk to the full extent in some projects, while the government provides a minimum traffic or revenue guarantee in others. To mitigate the risk, some relatively new projects adopt the congestion pricing system. In some cases, the government gives incentives for the quality of services, measured by criteria such as a high occupancy rate and safety improvements.

Force Majeure Risk
Force majeure involves risks beyond the control of a project's public and private partners, including natural disasters such as earthquakes, floods, storms, and other disasters such as war. These impair the facility's ability to generate earnings. Since neither the public sector nor the private sector can control the risk, they often jointly assume it. For example, the public sector may extend the concession to allow the private sector to recover from the event. When private insurance is available, as is usually the case for earthquakes, the private sector may purchase (or be required to purchase) insurance to transfer the risk.

Tort Liability Risk
Tort liability includes the risks of having to pay substantial legal awards as a result of accidents on the toll road/bridge/tunnel. This risk does not seem to be large in Japan.

Political Risk
Political risk concerns government actions or policy changes that could impair a facility's ability to generate earnings. Governments may change laws effecting the concession, such as tax laws or regulations that may severely damage the project's value. With suspended government support, the private sector can become limited in its ability to charge and collect tolls as specified under the agreement, or to settle contract disputes fairly under a neutral resolution system. To assuage private sector fears, governments generally agree to compensate the private company for termination of the concession and violation of the concession agreement, including agreed toll rates. However, private concessionaires generally assume the risk associated with dispute resolution, and the ability to obtain compensation in the event of a government violation of the concession agreement.

Financial Risk
Financial risk is defined as the risk that project cash flows may provide insufficient returns on the private debt and equity invested in the project. Financial risks arise from inadequate structuring of the project; however, it may involve economic risk, such as a change in the consumer price or a business partner's default. It may also include an operational risk, or inefficient operations. The private sector is generally responsible for financial risk, although in some cases governments may provide debt guarantees. Governments also may provide cash grants, equity, and return on the private capital that gets invested.

From the risks listed above, *demand risks must be the most important for large-scale infrastructure projects*, because demand risks directly influence the revenue of the project. The main factor in revenue for projects is the level of future demand, since private sector companies would suffer if they cannot anticipate conditions of the future market reasonably accurately. In addition, PFI projects are inherently subject to greater demand risks compared to the ones under the conventional project delivery system. Therefore, demand risks must be managed well into PFI project lifecycle.

3.2 Demand Risks and Forecasting

3.2.1 Forecast is Always Wrong

It is obvious that forecasting the future demand is always very unreliable and wrong, and this is based upon numerous experiences. Longer periods, such as those over 10 to 20 years, show how unreliable a prediction is. This is because in forecasting it is nearly impossible to obtain correct estimates [14]. Basically, forecasting is an estimation of the future, based upon past trends. Even so, the future is highly uncertain. Project managers are not able to predict the future demand accurately. Past trends are continually changing because of technical change, economic / financial change, regulatory change, industrial change, and political change, all of which make a big impact on the initial forecasting and make the actual outcomes differ widely from even the best initial forecast. Thus, there remains great uncertainty and risks in the future, and they make forecasting of the future demand unreliable and often wrong.

3.2.2 Examples of the Discrepancy between Forecast and Actual Results

It can be well explained how forecasting is unreliable and wrong by demonstrating and analyzing several examples [14]. For example, Table 3-1 shows measure of the accuracy of the U.S. Federal Aviation Administration (FAA) projections of aviation demand for forecasts published one and ten years prior to the year being forecast [15]. For short-term trends, the errors of forecast generally tend to be modest. Between 1995 and 2005, the average error for forecasts published one year earlier was 0.1 percent.

Table 3-1: Forecast Evaluation for Domestic Commercial Carrier Enplanements Percent Variance: Actual vs Forecast, Forecast Published One Year Earlier and Ten Years Earlier

Year being Forecast	Forecast Published One Year Earlier	Forecast Published Ten Years Earlier
1995	(2.2)	(11.4)
1996	1.8	(12.2)
1997	(1.4)	(17.4)
1998	(1.7)	(14.9)
1999	1.3	(9.9)
2000	1.4	(5.5)
2001	(4.6)	(4.7)
2002	4.4	(14.5)
2003	(0.9)	(12.5)
2004	0.2	(20.0)
2005	3.2	(13.9)
Mean Error	0.1	(12.5)

Source: FAA Aerospace Forecast Fiscal Years 2006-2017 (2006) [15]

On the other hand, the forecast error for forecast published ten years earlier tends to be larger than that for forecast published one year earlier. The average error for forecasts published ten years earlier was -12.5 percent. This may be because of unanticipated external events that have long-term impacts on the aviation system. In addition, the comparison between actual values and forecasts ten years prior shows the actual values were less than the forecast values.

Table 3-2 shows the actual and forecast of the annual number of passengers Boston Logan International Airport for 2004 and 2007 by the U.S. Federal Aviation Administration (FAA), New England Regional Aviation System Plan, and Massachusetts Port Authority [16] [17] [18].

Table 3-2: Actual and Forecast Annual Number of Passengers Boston-Logan International Airport for 2004 and 2007

Forecast		Passengers (millions)		Percent error
For	Done in	Actual	Forecast	Over actual
2004	1999	13.1	14.5	11
2007	2002	14.0	12.8	(8.6)

Source: FAA Terminal Area Forecast Summary (2004) [16], New England Regional Aviation System Plan (2002) [17], Massport (2007) [18]

The actual number of the passengers in 2004 turned out to be less than the forecast by 11%, and the actual number of the passengers in 2007 was more than the forecast by 8.6%. There were some potential causes for this forecasting error, as follows:

Technical Change (Increase factor)
New technology such as e-commerce, satellite-based navigation, and electronic ticket systems has been developed, which has reduced employment cost and passenger boarding time. Cheaper fare may encourage people to use airplanes. The cheaper the fare is, the more the passengers are.

Economic / Financial (Decrease factor)
The Southeast Asian financial crisis in 1997-1998 discouraged people from traveling to the United States. The rapid rise of oil prices in 2004 to 2005 made a significant impact on the airline industry. In addition, the decrease was caused by the recession in 2001.

Regulatory (Decrease factor)
Because of the terrorist attacks of September 11th, the regulation of security at the airport was very stringent, and made air travel much less attractive than before.

Industrial (Decrease factor)
The bankruptcies and disappearance of the major airlines, such as TWA, when it merged with American Airlines and went out of existence in 2001, United Airlines bankrupted in 2002, U.S. Airways bankrupted in 2002, and Air Canada bankrupted in 2003, decreased the number of passengers and flights.

Unexpected Events (Decrease factor)
The 1991 Gulf War and the concomitant rise in fuel prices, the outbreaks of terrorism in 1986, 1991, and 2001, the War in Iraq along with the outbreak of SARS in 2003. Airline Market in Asia shrunk, such as Hong Kong, Beijing, and Singapore.

Taking into consideration all of the above factors, there were significant uncertainties regarding the cause of the decrease or increase in passengers and flights in Boston-Logan International Airport. Amongst these, the terrorist attacks of September 11th in 2001 and the bankruptcy of the major airline companies were major factors of this decrease and increase.

Flyvbjerg et al (2005) performed an investigation on the accuracy of forecasting the demand of transportation [19]. This research illustrates that 84% of the rail projects have actual traffic over 20% below forecasted traffic, and 50% of the road projects have a difference between actual and forecasted traffic of more than plus or minus 20%. In other words, their result showed the tendency to overestimate or underestimate in both railway and road projects. Thus, it also shows that it is very difficult to forecast the future demand of transportation projects. This is explained in detail in Section 7.3.5.

Table 3-3 compares the traffic demand in the Tokyo Bay Aqua-Line as forecasted during the design phase and the actual traffic volume [20]. The forecasted traffic demand estimated during the planning phase for the first several years was 33,000 vehicles per day. However, because the actual traffic volume (10,000 vehicles per day in 1998) when the service was first available was much lower than the forecast, Japan Highway Corporation modified their forecast from 33,000 to 25,000 vehicles per day in 2000 as well as reduced the toll fee. Nevertheless, the actual traffic has been still below the forecast since the reduction of the toll fee. From this reality, it is also shown that forecasting future demand of traffic is very hard. There are numerous uncertainties in the future, and forecasting based on past data always provides incorrect results in any method.

Table 3-3: Transition of the Traffic Volume in the Aqua-Line (vehicles / day)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Average Traffic (% of Projected Initial Traffic)	10,000 (40%)	9,600 (39%)	11,900 (48%)	13,300 (53%)	13,700 (55%)	14,100 (56%)	14,900 (60%)	16,300 (65%)	17,600 (70%)	19,800 (79%)

Source: East Nippon Expressway Co., Ltd. (NEXCO East Japan) (2008) [20]
Note: This table was not officially disclosed. Author investigating by phone to East Nippon Expressway Limited.

Table 3-4 shows the forecast and the actual GDP in Japan as compiled by the Ministry of Land, Infrastructure and Transport in Japan [21]. This is not the forecasting of demand, but it also illustrates that there were very high errors in the forecast.

Table 3-4: Forecast and Actual Results of GDP in Japan

Forecast Year	1985			1990			2000		
	Actual	Forecast	Error Rate	Actual	Forecast	Error Rate	Actual	Forecast	Error Rate
1968	368	498	***35%***	-	-	-	-	-	-
1975	368	443	***20%***	470	562	***20%***	-	-	-
1980	-	-	-	470	494	***5%***	536	707	***32%***
1985	-	-	-	-	-	-	536	712	***33%***
1990	-	-	-	-	-	-	536	663	***24%***
1995	-	-	-	-	-	-	536	580	***8%***

Source: Japan, Ministry of Land, Infrastructure and Transport (2003) [21]

3.3 Reaction to Risks and Uncertainty

The fact that forecasting is unreliable and wrong makes project managers concerned about many future risks in large-scale infrastructure development projects, and discourages them from bidding for such projects. Certainly, if they do not recognize that forecasting is always wrong and there are always a lot of uncertainties, it would be very hard for them to challenge those projects. However, if they take for granted that there are always risks and uncertainties in large-scale infrastructure development projects, and take to anticipation of how their designs will have to serve different loads than the ones they now think are most probable, they can manage risks in projects [14]. Project managers need to make sure that any design they propose will function well under these different conditions, they need to check the performance of their design under different loads, and when they find deficiencies they need to alter these designs as part of avoiding future problems. The fact that forecasts are wrong means that project managers need to create flexible designs that can adapt to a range of future conditions.

3.4 Flexible Design – Real Options Analysis

Incorporating flexibility into design enables project managers not only to respond to risks described in Section 3.2, especially demand risks, but also to manage risks proactively. Flexible design can improve their capability of reacting to circumstances that change incessantly, and allow them to manage uncertainties and risks actively, and thereby enhance the expected value of the project. Furthermore, flexible design can improve the VFM in PFI projects, and thereby it enables PFI itself to be successful in terms of its idea as Section 2.3.2 explains.

de Neufville, et al (2006) demonstrated that project managers can discover flexibility in the engineering systems by changing and adapting operations of the system [22]. Flexible design enables them to handle downside risks and minimize their losses, avoiding unpleasant outcomes. It also can allow them to take advantage of upside opportunities, which could bring about unexpected benefits and profit to projects. Flexible design enables them to take advantage of unfolding uncertainties in engineering systems. Real options analysis is a strong method, which allows project managers to handle those risks proactively. de Neufville also demonstrated the applicability of flexible design to PFI projects by introducing the examples in the U.K. [22].

de Neufville and Neely (1999) developed hybrid real options which is a composite method combining the decision analysis and the real options valuation [23]. Taking advantages of these two analytical methods enables it effectively to evaluate projects with uncertainties.

Cardin (2007) developed a practical real option analysis using simulations that de Neufville proposed by demonstrating the simulation method, which is one of the real options approaches [24].

Lee (2007) illustrated the process to systematically and structurally consider and apply flexibility in the case of the National Health Service in the U.K. under the PFI delivery system using real options approach [25].

Minato (2007) described the application of real options approach as a realistic managerial device to react to uncertainty in concession / BOT projects [26]. Real options can change the risk profile of projects, and be more valuable to the private sector, as well as allowing the public to cooperate with each other in order to obtain their mutual interests.

Smit (2003) focused on the optional and strategic characteristics of investment in infrastructure projects analyzing an airport expansion in Europe [27]. Airports with infrastructures that are less constrained by growth regulations capture more value, because they are in a better position to exercise growth options available in the airport industry.

Marukawa (2003) demonstrated the difference in the value of the projects between under PFI and under a conventional project delivery system using real options analysis and a real-world project as a case study [28].

3.5 Focus of This Thesis

As this chapter explains, demand risks are one of the crucial risks in large-scale infrastructure development projects. Accurately estimating demand is almost impossible, leading to forecast that are always unreliable and often wrong. Thus, it should be emphasized not how accurately project managers forecast demand in large-scale infrastructure development projects, *but how they can handle risks and uncertainties in large-scale infrastructure development projects.* Key to handling demand risks should be the incorporation of flexibility into design. PFI projects can explicitly provide project managers with the opportunity to use flexibility, unlike the conventional delivery system, because they can utilize the private sector's managerial skills and technical capabilities over the entire long-term contractual period as Chapter 2 describes. Therefore, by managing risks and uncertainty appropriately, PFI can be applied to large-scale infrastructure projects such as toll roads, toll bridges, and airport projects.

The rest of this thesis focuses on demand risks in large-scale infrastructure development projects and it demonstrates how flexible design enables project managers to handle demand risks and to enhance the value of the project compared to the conventional delivery system, by using real options approach.

Chapter 4 Basic Valuation Concepts

The value of a project is determined by the net present value (NPV) of net cash flows over the lifetime of a project. Although there are several different evaluation criteria for capital budgeting, such as discounted cash flow method (DCF), internal rate of return (IRR), cost-benefit ratio, and real options analysis method, the basic valuation concept stems from the net present value (NPV) analysis. This chapter explains the basic concepts of the NPV analysis along with time value of money and discount rate, which includes the weighted average cost of capital (WACC), the capital asset pricing model (CAPM), and the arbitrage pricing theory (APT). It also explains the concept of the DCF method and its limitation in real-world projects.

4.1 Time Value of Money

A lot of projects, especially large-scale engineering systems, evolve over a long time span [29]. It is necessary to compare benefits and costs that occur at different times in order to evaluate whether the project should be worthwhile investing or not, since costs incurred in a certain period generate benefits for many years.

The project value is one of the most important components in decision-making whether or not investing. When evaluating the value of projects over time, the problem comes from the fact that money has a time value [29]. In general, a dollar today is not the same as a dollar tomorrow, and a dollar today is more valuable than a dollar tomorrow, since a dollar today can be invested to earn interest immediately [30]. The problem is one of comparability [29]. Since in order to evaluate validly, it is necessary to convert all costs and benefits into comparable amounts, which is the present value (PV). The PV is quite sensitive to two factors, the duration of "life" of the project, N, and most particularly, the discount rate, r. Present Value can be calculated as follows:

$$\text{PV (Present Value)} = \frac{CashFlow}{(1+r)^N} \qquad \textbf{Equation 4-1}$$

These factors, especially the discount rate, cannot be known precisely [29]. Therefore, it is mandatory to select an appropriate method of setting the discount rate. The following section introduces several commonly used methods of estimating the discount rate.

4.2 Discount Rate

Finance theory suggests several techniques of setting the discount rate based on the risk profile of the project. These include the weighted average cost of capital (WACC), the capital asset pricing model (CAPM), and the arbitrage pricing theory (APT). This section explains these methods of estimating the discount rate.

4.2.1 Weighted Average Cost of Capital

One of the commonly used methods of setting the discount rate is to adopt the averaged opportunity cost of capital for a publicly-traded firm. This cost of capital is called the weighted average cost of capital (WACC), and can be calculated from the weighted average return on debt and equity in the firm. Equation 4-2 shows the simplified formula of the WACC only looking at debt and equity sources [31].

$$WACC = \left(\frac{D}{D+E} \cdot r_d + \frac{E}{D+E} \cdot r_e \right) \quad \textbf{Equation 4-2}$$

Where *WACC*: Weighted Average Cost of Capital,
r_d: Expected rate of return on debt (Cost of debt)
r_e: Expected rate of return on equity (Cost of equity)
D: Amount of debt
E: Amount of equity

This WACC formula consists of variables which refer to the firm as a whole. This results in the weakness of this method in that the WACC formula is only applicable to those projects of which risk profile is close to that of the firm's average, that is, it is not appropriate to apply this method to calculating discount rate for those projects which are riskier than firm's average risk characteristics [31]. This limitation of the WACC method leads to the capital asset pricing model (CAPM), which is able to adjust the discount rate in accordance with the level of the risk.

4.2.2 Capital Asset Pricing Model

The capital asset pricing model (CAPM) is the most well-known and widely used model to set an appropriate discount rate in order to evaluate projects, and it has been used by large companies as a method to estimate cost of equity capital for a long time [31]. The CAPM assumes the existence of a perfect market where stock prices are not affected by their trade and all the information is perfectly shared among investors [32]. In the CAPM, risks associated with projects are categorized into two factors: the systematic (market) risks and the idiosyncratic (unique) risk [31]. Since the idiosyncratic risks are specific to a company or projects, their risk can be eliminated by broadly diversifying investments. On the other hand, the systematic risks are based on the market, and thus it cannot be diversified. The CAPM proposes that the risk-adjusted rate of return that an equilibrium market requires from an investment is a function of its systematic risk component [32]. Equation 4-3 shows the formula of the CAPM.

$$E(r_i) = r_f + \beta_{im}\left[E(r_m) - r_f\right] \quad \textbf{Equation 4-3}$$

Where $E(r_i)$: Expected rate of return of the capital investment (asset)
r_f: Risk-free rate of return
$E(r_m)$: Expected rate of return of the market
β_{im} : Sensitivity of the asset returns to the market returns

The relationship in Equation 4-3 illustrates a straight line called the security market line (SML). This indicates that the expected risk-adjusted rate of return for an investment linearly correlates with the market risk components, β_{im}, which implies the sensitivity of the asset returns to the market returns. Equation 4-4 shows the β_{im} [31].

$$\beta_{im} = \frac{Cov(r_i, r_m)}{Var(r_m)}$$ **Equation 4-4**

Where $Cov(r_i,r_m)$: Covariance between the expected rate of return of the investment (r_i) and the expected rate of return of the market (r_m)
$Var(r_m)$: Variance of the expected rate of return of the market.

The beta can be computed as the ratio of the covariance of the returns on the individual capital investment and the market portfolio to the market variance.

A capital investment has β equal to 1.0, if its return moves up and down exactly according to the market portfolio (a broad set of investments). On the other hand, if the return of a project is influenced with greater magnitude in the same direction as the market (i.e. β>1.0), this project must be considered riskier and investors require a larger return on it than the market portfolio, and thus discount rate becomes larger. In the securities industry, β is periodically updated, which is measured by regressing changes in the price of the stock over the changes in the market index. The slope of that regression line is labeled as β and is a widely used measure of a stock's risk. Using the data of β and the expected rate of return on market and on bonds, the CAPM provides a practical method of calculating the discount rate.

The cost of capital for projects should be based not on the risk profile of the firm but on the projects themselves. Each project should apply a different risk-adjusted discount rate to represent its unique level of risk. Therefore, the discount rate for valuing should be based on the CAPM, instead of just applying the WACC.

4.2.3 Arbitrage Pricing Theory

The arbitrage pricing theory (APT) is another method of setting the expected risk adjusted rate of return of an asset. Like the CAPM, the APT assumes that the risk-adjusted rate of return is influenced by correlation with the market risk components, β_{im}. However, contrary to the CAPM, the APT does not require an efficiently diversified market portfolio. The APT minimizes idiosyncratic (unique) risk by buying and selling simultaneously different assets that have highly correlated returns [32]. Equation 4-5 shows the formula of the APT.

$$E(r_i) = r_f + \beta_{i,1}\lambda_1 + \beta_{i,2}\lambda_2 + \cdots + \beta_{i,n}\lambda_n$$ **Equation 4-5**

Where r_f : Risk-free rate

$\beta_{i,j}$: Security *i*'s "beta" for risk factor *j* (*j* = 1, 2, …, n)

λ_j : Premium for risk factor *j*.

Equation 4-5 implies that if $\lambda_1 = [E(r_m) - r_f]$ and all the other λ s = 0, the expected return calculate by the APT is equivalent to that by the CAPM. The APT is applicable to any subset of assets and does not require an efficiently diversified market portfolio. Therefore, the APT is considered more applicable than the CAPM.

However, the APT does not specify the set of exogenous factors to determine the risk-adjusted rate of return [31]. That is, the expected return of the market consists of no more than one of the factors. Prices of traded assets, the GDP growth rates, and interest rate spreads are the examples of commonly used factors. In addition, the CAPM seems to be more frequently used than the APT in order to estimate expected rates of return for individual assets such as shares of an individual company or capital projects [33]. Also, the APT has not been developed and generally accepted as a method to estimate expected return rates. Thus, in the meantime, the CAPM appears to keep providing a simple and useful way to estimate expected returns [33].

4.3 Net Present Value (NPV), Discounted Cash Flow (DCF) Method

The Net present value (NPV) is a standard and basic financial evaluation model that is commonly used to evaluate investments. The NPV of a project is the present value of its expected future incremental cash inflows and outflows over the project lifetime. This method requires the future cash flows to be discounted by discount rate to adjust them as comparatives. For the calculation of the NPV, it is necessary to determine the expected cash inflows generated by the project, the expected cash outflows necessary for implementing the project, and the discount rate [34]. The NPV is the sum of the discounted inflows and outflows as shown in Equation 4-6.

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{E(FCF_t)}{(1+r_i)^t}$$ **Equation 4-6**

Where I_0: Investment at time zero

E(FCFt): Expected value of free cash flow at time *t*

r_i: The rate of expected return on the investment, adjusted for risk

n: the number of periods into the future when payoffs occur, provided that

r_i: remains constant in each period

The discounted cash flow (DCF) method is a standard financial valuation methodology based on the NPV calculation method. It is recommended for capital budgeting that explores investment opportunities. The NPV intuitively tells us whether or not the project is worthwhile investing more than it costs. If a project has a positive NPV, the project is worthwhile investing. Thus, the result of the DCF analysis indicates the project value and influences the process of making a decision during planning a project. Also, the NPV estimates how much value a project would add for shareholders.

However, the DCF method also has a critical limitation. It is not able to incorporate any flexibility into decision-making. The DCF method assumes that the cash flows are not changeable and predetermined over the lifetime of a project, although in real world project, the value of the project always fluctuates depending on updated information and forthcoming decisions. Therefore, it is necessary to consider the other methodologies that can incorporate flexibility into decision-making process, such as real options analysis.

Chapter 5 Real Options for Project Valuation

Real options analysis is a method that evaluates projects in which there are opportunities to make a decision. Real options analysis applies financial options theory to actual projects such as infrastructure developments, real asset investments, and manufacturing projects. Project managers can find options in these projects, such as those to abandon, those to expand, those to defer and so on. This chapter introduces basic concepts of financial options theory. Next, it explains the concepts and types of real options, and then explains several major real options analyses as a project evaluation methodology and risk management, by detailing their characteristics.

5.1 Financial Options

5.1.1 Basic Concepts

There are many criticisms that the standard discounted cash flow (DCF) method is appropriate only for short-term and low risk projects. Myers investigated the application of the DCF method to securities and real corporate projects, and summarized that this method has a limitation for the project with significant growth or high risks and that the option-pricing model should be appropriate for valuing those investments [35] [36].

Financial options are categorized into two basic types: one is “call option” and the other is “put option”. A *call option* provides the stockholders with the “right to buy underlying assets for a specified price within or at a certain date,” while a *put option* provides the stockholders with the “right to sell underlying assets for a specified price within or at a certain date” [37]. *Underlying assets* are such assets as market-traded stocks, stock indices, foreign currencies, debt instruments, or commodities. *European Option* means an option contract that may be exercised only during a specified period of time just prior to the expiration date, while *American Option* indicates an option contract that may be exercised at any time between the date of purchase and the expiration date. *Strike price* is the stated price per share for which the underlying asset may be purchased, which is the case of a call option, or sold, which is the case of a put option, by the option holder upon exercise of the option contract. *Option price* is the price of an option contract determined in the competitive marketplace where the buyer of the option pays to the option seller for the rights conveyed by the option contract. If you decide not to use the option to buy the stock, and you are not obliged to, your only cost is the option. *Volatility* is the degree of the fluctuation of prices, which is the standard deviation of the prices.

The important point of an option is that an option holder has the “right” to exercise the option, but “no obligation” to exercise it. Option holders would exercise only if conditions are favorable [31]. They can enjoy the upside risks and potential gain is unlimited [38]. If conditions are not favorable, they do not have to exercise it, and they can avoid downside risks, limiting the loss to the price of getting the option, which is option cost.

Figure 5-1 shows a payoff diagram for a European call option. At any price of underlying assets greater than the strike price, it is favorable to exercise the option. This payoff is the maximum difference between the two prices as shown in Equation 5-1.

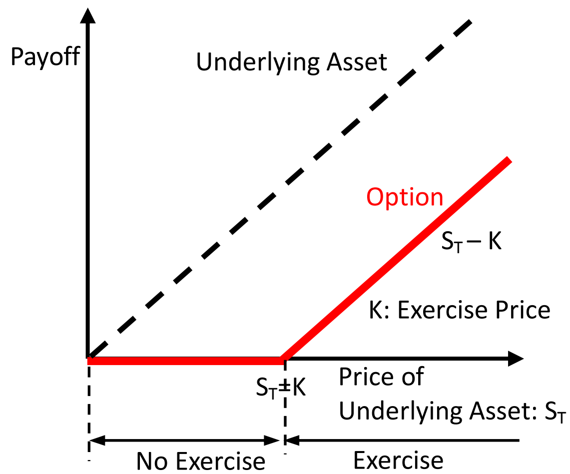


Figure 5-1: Payoff Diagram of a European Call Option
Source: R. A. Brealey, S.C. Myers, and F. Allen (2004) [31]

Payoff (European call) = $Max(S\text{-}K, 0)$ **Equation 5-1**

Where S: Price of the underlying asset at the expiration date
K: Strike price

Likewise, Figure 5-2 illustrates the payoff diagram for a European put option. Equation 5-2 shows the payoff for the European put option. As Figure 5-2 shows, the option has a non-zero value when it exceeds the exercise price at its expiration.

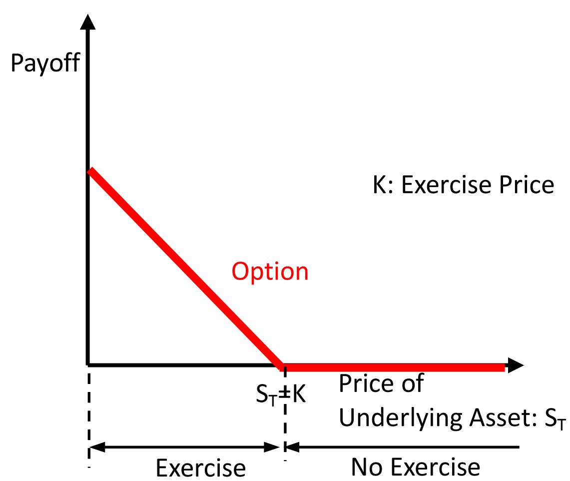


Figure 5-2: Payoff Diagram of a European Put Option
Source: R. A. Brealey, S.C. Myers, and F. Allen (2004) [31]

Payoff (European put) = $Max(K\text{-}S, 0)$ **Equation 5-2**

Where S: Price of the underlying asset at the expiration date
K: Strike price

American options have the same payoff schemes as the European options do, except that they can be exercised anytime prior to the maturity date.

There are six main factors which influence the value of each financial option, such as 1) price of the underlying asset: S_T, 2) strike price: K, 3) time to maturity: T, 4) volatility of the underlying asset: σ, 5) risk-free rate of interest: r_f, and 6) cash dividends: D.

If the current price of the underlying asset increases, the value of a call option increases, while the value of a put option decreases. On the other hand, if the strike price increases, the value of a call option decreases, while the value of a put option increases. As the time to maturity extends, both an American call option and put option increases in their value, while the time to maturity does not affect the value of either a European call or put option. Volatility indicates the degree of uncertainty, which can be represented by standard deviation, and it is the most crucial factor to influence the value of options. The more the volatility of the underlying asset is, the more the value of every option is, because higher volatility stimulates the opportunity of large payoffs, while the downside payoffs remain zero gains. Figure 5-3 illustrates how high volatility increases the payoff of the underlying asses using a European call option example [39]. Table 5-1 shows the summary of the main influences of each factor on the value of options [37].

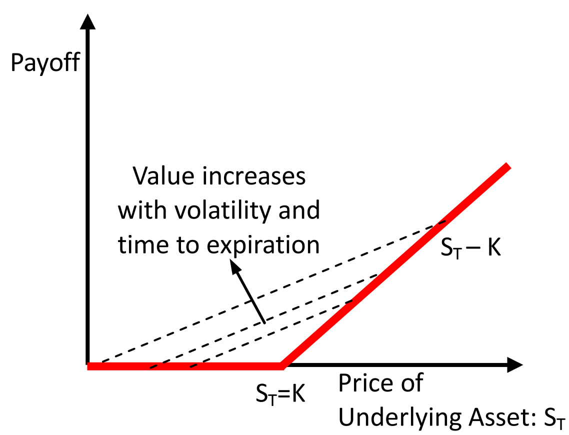


Figure 5-3: The Value of a European Call Option Increases with High Volatility (σ)
Source: de Neufville [39]

Table 5-1: Main Influences on Option Value of Financial Options

Factors	European Call	European Put	American Call	American Put
(1) Underlying Asset Price: S_T	↑	↓	↑	↓
(2) Strike Price: K	↓	↑	↓	↑
(3) Time to Maturity: T	N/A	N/A	↑	↑
(4) Volatility: σ	↑	↑	↑	↑
(5) Interest Rate: r_f	↑	↓	↑	↓
(6) Cash Dividends: D	↓	↑	↓	↑

Source: Hull [37]

5.1.2 Basic Assumptions

Two crucial assumptions underlie the pricing of the option value. One is no-arbitrage opportunity and the other is that stock prices randomly fluctuate in a perfect, efficient market [40].

(1) No-Arbitrage Opportunity
Arbitrage involves obtaining profit from differences in two or more markets through simultaneous transactions. As an asset is brought in one market and sold immediately at a higher price in another market, arbitrage enables investors to gain a risk-less profit without investing anything. In a competitive and well-developed market, if there are arbitrage opportunities, the law of supply and demand will immediately make the two asset prices the same. There are no risks in that portfolio and the return on the portfolio is the risk-free rate. Therefore, no arbitrage opportunity exists in the market.

(2) Stock Prices Fluctuate Randomly in a Complete Efficient Market
Financial assets are assumed to be traded in perfect markets when the option prices theoretically determined. Their characteristics are as follows: (1) they operate in "equilibrium," (2) they are "perfectly competitive," (3) they include risk-free assets, (4) each individual has "the same right to access to the capital market," (5) "infinitely divisible securities exist in the market," and (6) there are "no transaction fees and costs" [40].

5.1.3 Financial Option Valuation Methodologies

There are three major methodologies of calculating the value of financial options: (1) the Black-Scholes Option Pricing Model, (2) the binomial lattice model, and (3) simulations.

(1) The Black-Scholes Option Pricing Model (OPM)

The Black-Scholes Option Pricing Model (OPM) is the simplest and most well-known solution to the option pricing as it applies to those European call and put options which do not pay dividends [41]. It derives the theoretical value of the option using five factors: 1) the price of the underlying asset (S), 2) the strike price (K), 3) the time until expiration (T), 4) the risk-free rate of interest (rf), and 5) the volatility or standard deviation of returns on the stock (σ) [42]. Equation 5-3 provides the theoretical value of a European call option [31]:

$$C = S \cdot N(d_1) - K \cdot e^{-r_f T} \cdot N(d_2)$$ **Equation 5-3**

Where C: Theoretical value of a European call option with no dividends

$$d_1 = \frac{\ln(S/K) + (r_f + \sigma^2/2) \cdot T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$N(x)$: Cumulative probability function for a standardized normal distribution

Similarly, the theoretical value of European put options with no dividends can be calculated by the Black-Scholes OPM. Equation 5-4 provides the mathematical formulation of this value [31]:

$$P = K \cdot e^{-r_f T} \cdot N(-d_2) - S \cdot N(-d_1)$$ **Equation 5-4**

Where P: Theoretical value of a European put option with no dividends

(2) Binomial Lattice Model

Another widely used method for determining price of options is the binomial lattice model, which is developed by a discrete-time approach that considers the volatility of the price through the replicating portfolio that reflects the historical return distribution, and is more simplified compared to the Black-Scholes OPM [42] [43]. This method is called the binomial lattice model since it assumes that the price of the underlying asset would go to one of only two possible values during the next periods of time. The binomial lattice method creates the payoff of the underlying asset, illustrating how the price of the underlying asset would evolve in a risk-neutral environment [38]. In a risk-neutral situation where investors require take no risk compensation, the value of financial options and the expected return on the assets is evaluated by the risk-free rate, that is, the risk-free rate can be applied for the potential cash flow adjustment. This risk-neutral approach can solve the problem associated with the discount rate in uncertainty [37].

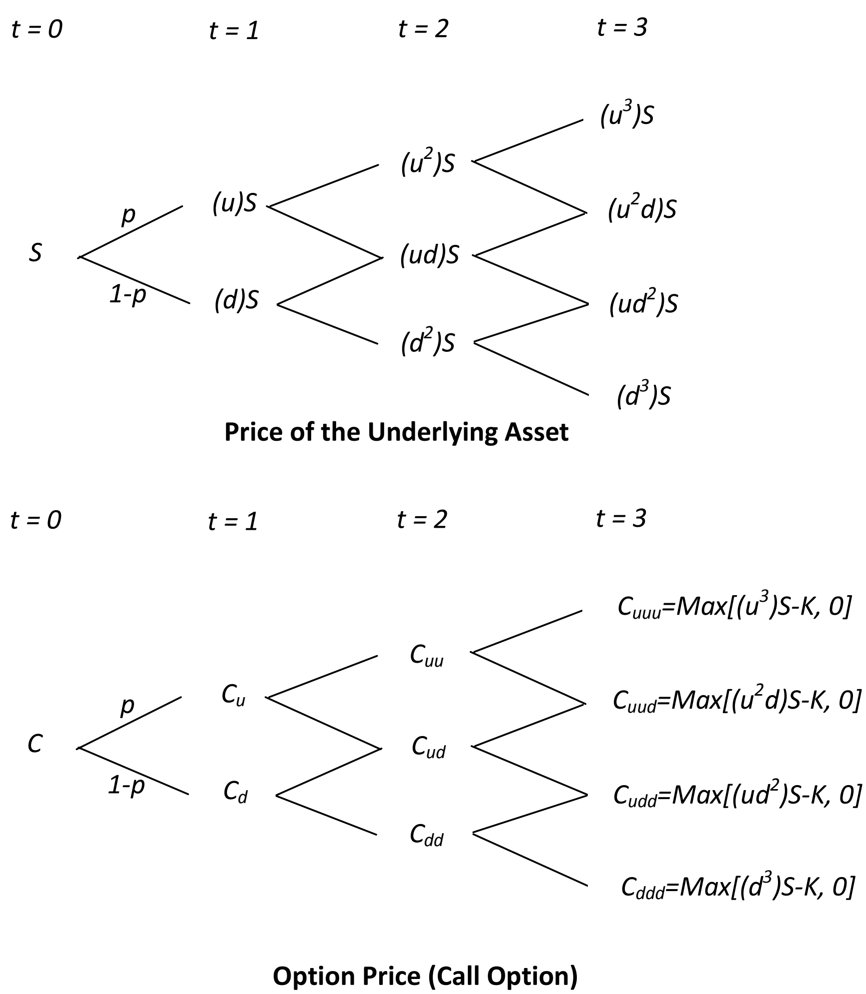


Figure 5-4: Three Steps Binomial Lattice Model

Figure 5-4 shows an example of a three-stage binomial lattice model. In the binomial lattice model, the price of an underlying asset at a certain time can move either upward with multiplier *u* at the probability of *q*, or downward with multiplier *d* at the probability of *1-q*. The values of *u* and *d* can be calculated by Equation 5-5 [42]. Using these values, with the initial value of the asset (*S*), the number of time period (*n*), and the strike price (*K*), the expiration date payoffs to the option (i.e., C_{uuu}, C_{uud}, C_{udd}, and C_{ddd}) can be determined.

$$u = e^{\sigma\sqrt{T/n}}$$
$$d = e^{-\sigma\sqrt{T/n}} = 1/u \qquad \textbf{Equation 5-5}$$

Where σ: Volatility or standard deviation of underlying assets in percent
T: Time to maturity date of the option
n: Number of time period until the expiration of the option

The value of the call option at any point of time can be obtained by calculating backward from the subsequent time period. The probability of shifting the preferable situation, which is called the risk-neutral probability, can be determined so that the expected sum of each outcome divided by the risk-free rate equals to the initial price of underlying asset. The theoretical price of a European call is the expected sum of the payoffs of both the upside and downside situation. Equations 5-6 and 5-7 show the value of the call option at *j*th state and risk-neutral probability respectively [42].

$$C_j = \frac{p \cdot C_{ju} + (1-p) \cdot C_{jd}}{r}$$ **Equation 5-6**

$$p = \frac{r-d}{u-d}$$ **Equation 5-7**

Where C_j: Value of the call option in the *j*th state

C_{ju}: Value of the call option in the $(j+1)$th state which corresponds to the upward movement from the *j*th state

C_{jd}: Value of the call option in the $(j+1)$th state which corresponds to the downward movement from the *j*th state

r: one plus the risk-free rate, r_f, provided that r_f remains constant in each period

In case the price of the underlying assets changes annually with the rate of ν, the probability of upward movement, *p*, can be modified, by adopting a sufficiently large *n*. Equation 5-8 shows the probability of upward movement with annual certain changes [39] [44].

$$p = \frac{1}{2}\left(1 + \frac{\nu}{\sigma}\sqrt{T/n}\right)$$ **Equation 5-8**

Where ν: Annual growth rate of the underlying asset

By repeating the calculation of Equation 5-6 from the final period to the initial period, the value of the call option can be determined as shown in Equation 5-9.

$$C = \frac{\sum_{j=0}^{n} \frac{n!}{j!(n-j)!} p^j (1-p)^{n-j} Max\left[u^j d^{n-j} S - K, 0\right]}{(1+r_f)^n}$$ **Equation 5-9**

(3) Simulations

Applying methods such as Monte-Carlo simulations, project managers can estimate the value of options for situations that the Black-Scholes OPM and the binomial lattice model cannot do. The development of computer technology has enabled this method. Monte-Carlo simulations create the stochastic distribution of possible outcome of outputs (Y) that correspond to probability-distributed sampled inputs (X). It can simulate as many uncertain variables as computational power allows [24]. Monte-Carlo simulations can be performed with spreadsheet software such as Excel® and Crystal Ball ©. The result simulated by this method helps project managers figure out characteristics of outputs.

5.2 Real Options

The options for engineering systems or engineering projects are "real" in that they deal with "real projects", unlike financial options [38]. There are many opportunities to incorporate flexibilities into design of systems and into the development of projects. Project managers are able to find "option-like" flexibilities in projects that can improve or enhance the value of the systems or projects through design or through management process [32]. Flexibility enables them to take advantage of upside opportunities and to avoid downside losses, and therefore it is called "real" options. Real options approach can be applied to business strategy, such as project valuation and risk management, and this approach is applicable in various types of fields, such as infrastructure development, manufacturing system, real estate development, and government policy [32].

5.2.1 Difference between Real Options and Financial Options

In case of financial options, options are the "right" to purchase or sell the underlying asset at a predetermined cost but not the "obligation" to do so [37]. In the same way, real options are also the right to exercise but not the obligation. Real options are different from financial options in terms of the definition of the underlying and the time span [45]. Firstly, the "underlying" for financial options is the underlying asset, and they require a uniquely defined underlying asset in order to evaluate their value [45]. For instance, the stock price is the "underlying asset" of the stock. On the other hand, the "underlying" of real options is the agent that influences the value of the project [45]. Depending on the characteristics of the projects, it sometimes can be financial assets, but sometimes can be other agents such as market size [45]. Secondly, real options can be applied in projects with long-term lifetime such as several decades, while financial options are used in relatively in short-span such as the maturity of two years or less. The value of real options cannot be obtained from the past trend but have to be evaluated with special analysis to evaluate the future value of projects [39].

5.2.2 Types of Real Options

Project managers can find real options everywhere in projects and systems. For example, firms can defer their investment in new projects to collect more useful information or to wait for the better entry time into the market [46]. Another example is that firms can minimize the initial investment in projects and expand the project depending on the demand. Table 5-2 shows types of real options [39]. It is necessary to understand which type of real options can be applied to projects in order to manage risks and uncertainties in them [26].

Table 5-2: Types of Real Options

Type	Description	Implementing Criteria
Options to Wait	Investing now might be profitable, but it might be also profitable tomorrow. Leaving investment opportunity open and waiting for more profitable opportunity indicates holding a Call-Like options	Max[immediate investment, Waiting, 0]
Options to Expand	Expanding the level of projects allows greater participation in upside. Cost of expansion is like strike price.	Max[current status, expanded project]
Options to Restart Temporarily Closed Operation	Similar to options to wait to invest or expand.	Max[remain closed, re-open operation]
Options to Abandon	Abandoning investment can eliminates further losses in projects, which includes shut down costs and salvage prices	Max[continuing, abandoning]
Options to Contract	Options to contract can reduce the participation level and exposure to losses, although it basically incurs short-term scale down costs.	Max[current status, contracted project]
Options to Shut Down Operations Temporarily	This is the special case of options to contract, and it can eliminate losses, but incur shut-down costs.	Max[current status, temporarily shut down]
Combinations of Options	Combinations of options above.	-

Source: de Neufville [39]

5.2.3 Real Options "on" Projects and "in" Projects

de Neufville summarizes that real options can be categorized into two types in terms of where the primary flexibility exists around the project and systems design: real options "on" projects and "in" projects [39].

(1) Real Options on Projects
The flexibility associated with the uncertainty is called real options "on" projects [38]. If uncertainty comes from the market factors that firms cannot control such as future demand and lies "on" the project, the real option that project managers can apply is real options on projects. This option is similar to financial options and can be applied using the option pricing theory, such as the Black-Scholes OPM and the binomial lattice model.

(2) Real Options in Projects
On the other hand, options that can be created within the design of the system or projects are called real options "in" projects [39]. Real options "in" projects can be created in the design of systems and projects, and they require further technical understanding or managerial strategy to obtain the options and to analyze feasible flexibilities within the system. In other words, if project managers have technical understanding about the system and projects and are prepared strategically for the projects, they can manage risks and uncertainties by using real options in projects.

5.3 Real Options Valuation Methods

As Section 5.1.3 describes, there are three major methods for real options valuation, such as the Black-Scholes OPM, the binomial lattice model, and the simulation method. In addition, there is another real options method, which is decision analysis. This section reviews each real options method that is already discussed in Section 5.1.3, and explains more characteristics of each method. It also explains decision analysis.

5.3.1 Black-Scholes Option Pricing Model

The Black-Scholes approach is the most popular and fundamental European call option valuation model, which is one of many applications of the partial differential approach. The Black-Scholes approach can provide a ballpark estimation and it is easy to calculate not only in the field of financial options but also in the field of real options [37]. However, this relatively simple method is not always able to provide project managers with the answer of option values. For example, the Black-Scholes approach requires one fixed decision date (European options), and it is impossible to obtain solutions to more complicated real options such as the one that allows exercise of option at any time before the maturity, which is American options. Also, it is difficult to model what would happen in the real situation. Furthermore, underlying assumption such as volatility, price, and duration limits the use of approach. Thus, it is very difficult to apply this approach to large-scale complex engineering projects targeted in this thesis.

5.3.2 Binomial Lattice Model

Another widely used method for options pricing is the binomial lattice model, which is a more simplified discrete-time approach to valuation of options compared to the Black-Scholes approach as discussed in Section 5.1.3. One of the characteristics of this approach is that this is based on risk-neutral argument, and thus the model does not require risk-adjusted discount rates. This approach gives project managers the approximate evolution of the value of the underlying assets in a simple but flexible way, and estimates the precise value of many complicated option features including the early exercise of American options [42]. In addition, this approach can illustrate the intermediate decision-making processes between now and the exercise of option, which guides decision-maker to understand how they should decide at each point in time [37]. However, like the Black-Scholes approach, this method requires advanced financial knowledge and not easy to use. Project managers who are not familiar with advanced finance theory have difficulty in understanding and in explaining this approach. Furthermore, it is very difficult to conduct if there are several uncertainties at the same time, while it is very effective if there is only one uncertainty.

5.3.3 Simulations

Monte-Carlo simulations are an analytical method that generates the statistical distribution of possible outcomes corresponding to probability-distributed sampled inputs. It enables the calculation of the options value with random thousands of possible simulations for future scenarios for uncertain variables [47]. Because of the development of computer technology, computer simulation such as Excel® can be constructed easily. Thus, the best advantage of this approach is that project managers can conduct this analysis without advanced financial knowledge, although the value of the project calculated by this approach is not precise in terms of financial theory. Also, users can explain the analysis result by using various types of graphs and charts [47]. Furthermore, they can model several uncertain factors at the same time.

5.3.4 Decision Analysis

Decision analysis is also one of the real options approaches for evaluation of projects. It enables decision-makers to develop insights on real options and to estimate the approximate value of flexibility, especially those projects with sequential decision opportunity and variable outcomes over time [29]. This method is very useful in practice because it enables project managers to figure out complicated problem from the perspective of smaller or simpler problems, and to analyze objectively and make a decision including considering risks and effect of future project adjustments [48]. Project managers can utilize decision tree in order to model decision alternatives and choose the most preferable alternatives by comparing the expected value of each alternative.

Figure 5-5 shows an example (2-stage) of decision tree model. Project managers can find the most preferable scenario by calculating the expected values of each alternative at each stage and choosing the best alternatives at the stage, and repeating the same calculation from the final stage to the initial stage [29].

In this decision tree model, there are two decision stages, D_1, D_{11}, D_{12}, D_{21} and D_{22}. At D_1, there are two alternatives, C_1 and C_2. These alternatives have several outcomes such as D_{11}, D_{12} for C_1 with probabilities of p_{11} to p_{12}, and D_{21} and D_{22} for C_2 with probabilities of p_{21} to p_{22}. All of these outcomes also have several alternatives. For example, D_{11} have alternatives of C_{11} and C_{12}. Likewise, D_{22} have alternatives of C_{23} and C_{24}. All of these alternatives also have several outcomes. For instance, alternative, C_{11} have outcomes of O_{111} to O_{11n} with the probability of p_{111} to p_{11n}. The expected value of each alternative at the first stage is calculated by Equation 5-10, and the one at the second stage is calculated by Equation 5-11.

$$E(C_j) = \sum_{i=1}^{n_j} p_{ji} \cdot O_{ji} \qquad \textbf{Equation 5-10}$$

Where $E(C_j)$: Expected value of alternative C_j (j=1 or 2)
p_{ji}: Probability of outcome O_{ji}
O_{ji}: ith outcome of alternative C_j
n_i: Number of outcomes associated with alternative C_j

$$E(C_{kj}) = \sum_{i=1}^{n_j} p_{kji} \cdot O_{kji}$$ **Equation 5-11**

Where $E(C_{kj})$: Expected value of alternative C_{kj} (k=1 or 2, j=1, 2, 3 or 4)
p_{kji}: Probability of outcome O_{kji}
O_{kji}: ith outcome of alternative C_{kj}
n_i: Number of outcomes associated with alternative C_{kj}

By comparing $E(C_{11})$ with $E(C_{12})$, project managers are able to select the alternative with the better yield. In the same way, they can compare $E(C_{13})$ with $E(C_{14})$, $E(C_{21})$ with $E(C_{22})$, and $E(C_{23})$ with $E(C_{24})$. Considering the probabilities of p_{11}, p_{12}, p_{21}, or p_{22}, they can find out the expected value of C_1 and C_2. Comparing $E(C_1)$ with $E(C_2)$, they can find out the best scenario. This analysis can be easily expanded with more stages or more decision alternatives.

Decision analysis is different from the DCF analysis since it can consider the project specific uncertainties and the evolution of the project, while the DCF calculates the project value based only on the fixed scenario of the project, which does not consider any uncertainty. By incorporating possible outcomes and their probabilities into the analysis, decision analysis enables project managers to evaluate the value of projects considering risks and uncertainties in projects, although it does not provide precise values of options in terms of financial theory. This method is particularly useful when you have a decision that involves drastic change, such as a regulation change [39].

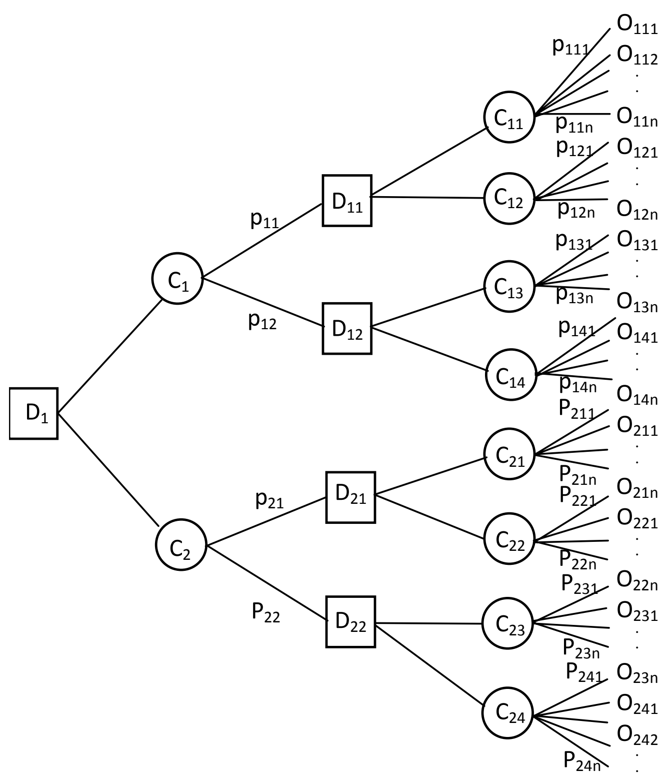


Figure 5-5: Two-Stage Decision Tree

5.4 Choice of Methodologies

When project managers evaluate the value of the project, it is necessary to select which real options valuation method should be applied to projects. Every method has both advantages and disadvantages. The Black-Scholes OPM is very easy to calculate the value of the project, and it can provide ballpark estimation. However, it is applicable only one fixed decision date such as European options. In addition, it is difficult to model what would happen in the real situations. The underlying assumptions limit the use of approach, such as price volatility, duration, etc. Furthermore, it is necessary for users to be familiar with advanced financial background.

The binomial lattice model gives project managers the approximate evolution of the value of the underlying assets in a simple but flexible way, and estimates the precise value of many complicated option features including the early exercise of American options. In addition, this approach can illustrate the intermediate decision-making processes between now and the exercise of option, which guides decision-maker to understand how they should decide at each point in time. This approach can provide the true value of real options in terms of financial theory. On the other hand, when project managers use this method, it is necessary for them to understand advanced financial theory. Moreover, it is difficult to set several uncertain factors in the analysis at the same time.

Compared to the methods explained above, simulations do not require project managers to understand advanced financial theory. Although it does not produce the true value of projects in terms of finance theory, simulations can demonstrate the analysis results with various types of graphs and charts. Furthermore, project managers can model several uncertain factors at the same time unlike the binomial lattice model.

Decision analysis can illustrate and facilitate the evaluation of projects especially those that involve sequential decisions and variable outcomes over time. It is also particularly useful when there would be a drastic change in systems, such as a regulation change. The drawback of this method is that it does not provide the true value of projects in terms of financial theory. Also, when developing a lot of branches, it would be too complicated.

When project managers select a methodology of real options, it is necessary to consider the advantages and disadvantages of each methodology to be applied so that the methodology could be appropriate for the characteristics of projects. Table 5-3 summarizes the characteristics of each methodology.

Table 5-3: Characteristics of Each Methodology of Real Options Approaches

	Advantages	Drawbacks	Targeted Audience
Black-Scholes Option Pricing Model	• Provide ballpark estimation. • Easy to calculate the value.	• Applicable to only one fixed decision date. • Difficult to model what would happen in the real situation. • Underlying assumption limit the use of approach. (price, volatility, duration, etc)	• Project managers and designers with advanced financial knowledge • Both public and private sectors
Binomial Option Pricing Method	• Provide approximate evolution of the value of the underlying assets in a simple but flexible way. • Illustrate the intermediate decision-making processes between now and the exercise of option, which guides decision-maker to understand how they should decide at each point in time. • Provide the true value of projects based on financial theory.	• It is necessary to understand real options approach in terms of financial theory. • Difficult to set several uncertain factors in the analysis at the same time.	• Managers and decision makers with advanced financial knowledge • Both public and private sectors
Simulation Method	• NOT necessary to understand financial theory. • User-friendly tools are available • Demonstrate the analysis result visually • Model several uncertain factors at the same time.	• Not produce the true value of projects.	• Any managers and decision makers without advanced financial knowledge • Both public and private sectors
Decision Analysis	• Depict and facilitate the evaluation of projects especially those involve sequential decisions and variable outcome over time. • Considers the project specific uncertainties and the evolution of the project. • Particularly useful when there is a drastic change in systems.	• Not provide the true value of projects. • Too complicated, when developing a lot of branches.	• Any managers and decision makers without advanced financial knowledge • Both public and private sectors

Chapter 6 Case Study 1: Tokyo International Airport New Runway Extension Project

This chapter uses the "Tokyo International Airport New Runway Extension Project" as a case study of this thesis and demonstrates how the proposed methodologies and concepts can be applied in real-world projects. The purpose of this case study is to demonstrate how those project managers who do not have financial background can model the analysis, calculate the value of projects, and evaluate it by applying the proposed methodologies, and 2) to demonstrate the proposed methodology is useful for reducing risks and enhancing the value of the project, provided that this project had been conducted under PFI instead of a conventional project delivery system.

6.1 Project Overview

6.1.1 Tokyo International Airport (Haneda Airport)

The Tokyo International Airport or Haneda Airport (HND) is located in the bay area, near the center of Tokyo. This airport is the busiest and most important hub airport in Japan for domestic air travel [49]. Haneda Airport is consistently ranked among the world's busiest passenger airports in terms of the number of passengers, and its ranking was fourth in 2006. Currently it has three runways (Runway A: 3,500m, Runway B: 2,500m, Runway C: 3,000m), serving nearly 60 million passengers every year. The total capacity of Haneda Airport is 296,000 aircraft (a/c) per year.

6.1.2 New Runway Extension Project

However, its capacity has already reached a limit in meeting the increasing demand, and it has become necessary to respond to this demand as soon as possible. In order to solve this problem, the *Tokyo International Airport New Runway Extension Project* was launched in 2002 to build a 4th runway, which is called the *Runway D*, to increase the total capacity of the airport [49]. This extension enables the airport to expand its capacity from 296,000 a/c per year to 407,000 a/c per year.

1Figure 6-4 shows the structure of the Runway D. The new runway will be constructed on an artificial island approximately 3,000 meters long and 500 meters wide, on the south side of the airport. As the new runway island is planned in the estuarine waters of the Tama River, the course of the river shall not be affected by the reclaimed island. Therefore, a pile elevated platform is applied for the part in the river mouth, and reclamation is applied for the part outside the alignments of the river mouth. Two approaching taxiway bridges for aircraft connecting the existing airport to the new runway island, 600 meters long and 60 meters wide, are planned as well. The pile elevated platform of the new runway island is 1,100 meters long and 500 meters wide in total. It is a jacket structure composed of approximately 200 steel jacket units measuring 60 meters long and 45 meters wide. The water depth at the construction site is 15 to 19 meters, below which is 30 to 40 meters of thick sedimentary layers made of soft clayey soil.

Long steel pipe piles are used as bearing piles for the pile elevated platform. By the end of the fiscal year of 2006, the design had been completed, and the construction phase started in March 2007, and it is currently scheduled to be completed and start operation in December 2010.

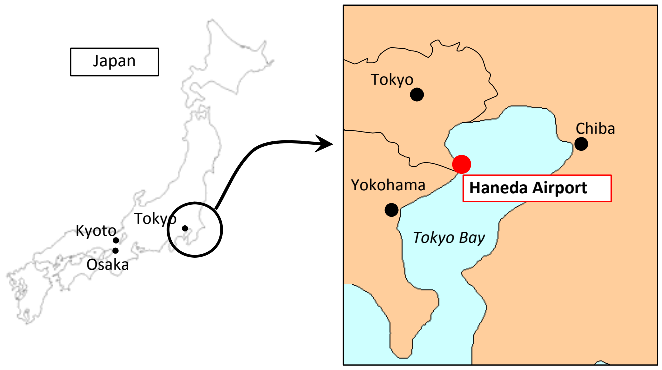


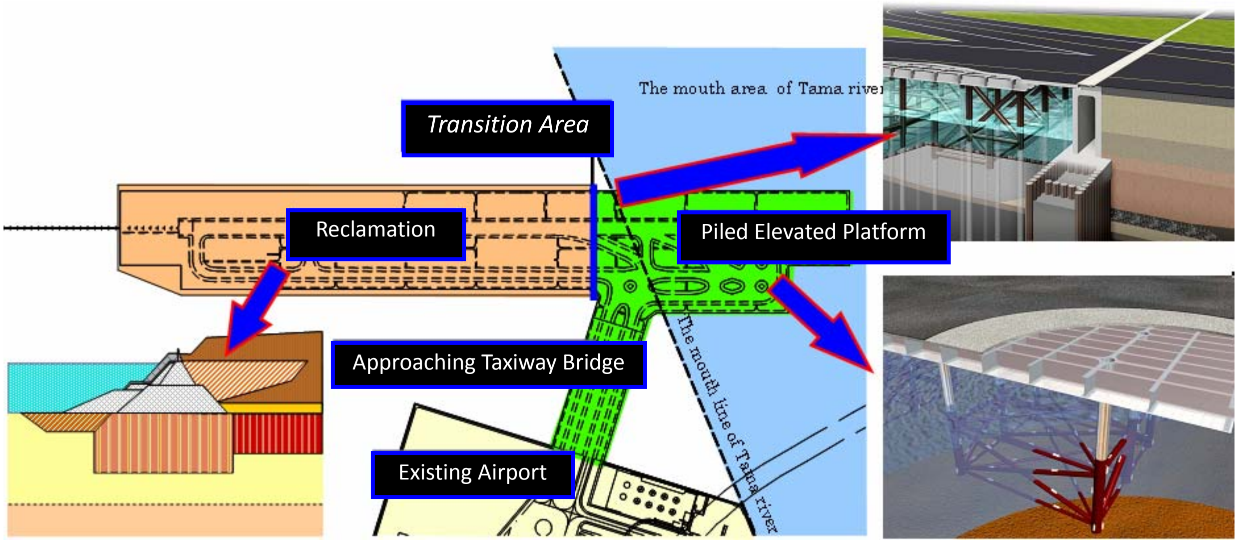
Figure 6-1: Location of the Tokyo Int'l Airport

Figure 6-2: Tokyo Int'l Airport

Source: Japan, Ministry of Land, Infrastructure and Transport, Kanto Regional Development Bureau (2007) [49]

Figure 6-3: Plan of New Runway Island in Tokyo Int'l Airport

Source: Japan, Ministry of Land, Infrastructure and Transport, Kanto Regional Development Bureau (2007) [49]



1Figure 6-4: Structure of Runway D

Source: Japan, Ministry of Land, Infrastructure and Transport, Kanto Regional Development Bureau (2007) [49]

6.1.3 Is Current Design Optimal?

As Section 6.1.2 describes, the new runway is expected not only to improve airport capacity but also to bring about a major impact on the overall economy. Yet two key questions are if this project is really optimal, and the design of this project can respond to the future uncertainty.

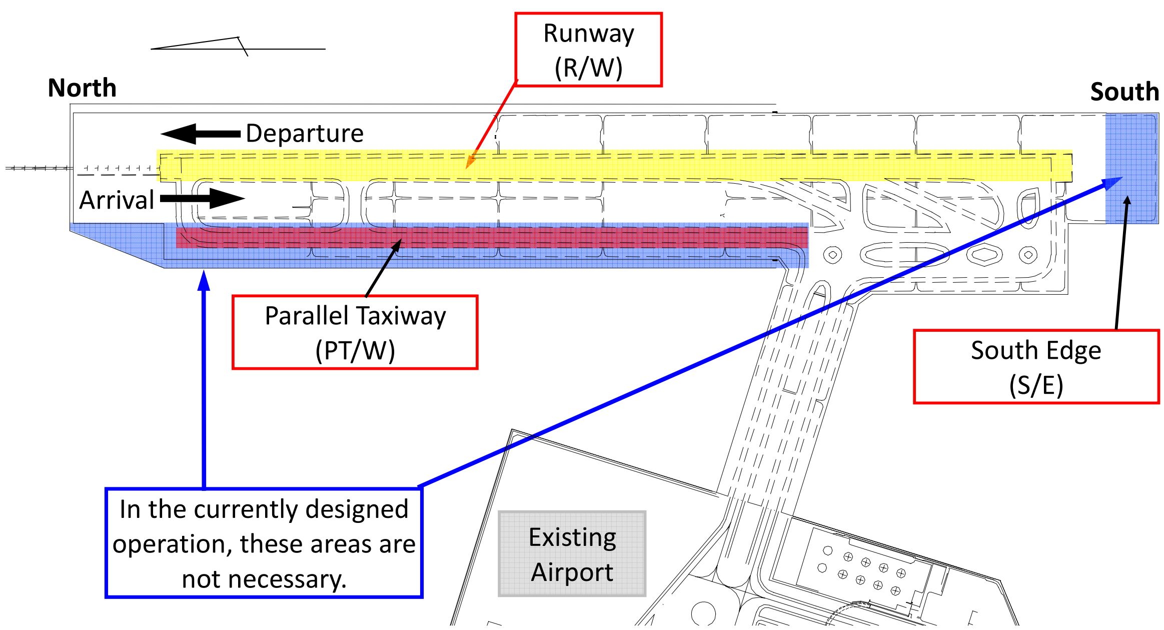


Figure 6-5: Areas Necessary or Unnecessary for Currently Planned Operation

Figure 6-5 shows the areas necessary or unnecessary for the currently planned operation at the Runway D. The current design of the Runway D consists of the Runway (R/W) and the Parallel Taxiway (PT/W). At the Runway D, airplanes depart from south to north and land from north to south, and the projected capacity is based on this operation. Usually, a parallel taxiway is necessary for a runway since airplanes have to move to a runway in the both directions in order to take off and to go to terminal after landing. But for the Runway D, a parallel taxiway will be used only when those airplanes which are running for takeoff must return to the terminal. This possibility is very low. Because there is a turning pad at the end of the runway, it is possible for these to return to the terminal by using this area. Therefore, the operation use of the PT/W is extremely low.

Additionally, the area at the south edge of the runway (S/E), is also not used since airplanes do not depart and land this way. Therefore, neither the PT/W nor the S/E is necessary for the currently planned operation, and it can conclude that this runway island is not optimally designed. This project was supported by taxpayers' money (¥570 billion), yet the investments have been excessive, demonstrating a clear need to revaluate if the PT/W and the S/E is worthwhile investing in or not. The areas, the PT/W and the S/E, would be used only if airplanes depart from north to south and land from south to north. If there is a significant need for these areas in the future, it should be constructed then, otherwise these areas should not be constructed.

6.1.4 Projected Capacity of the Airport

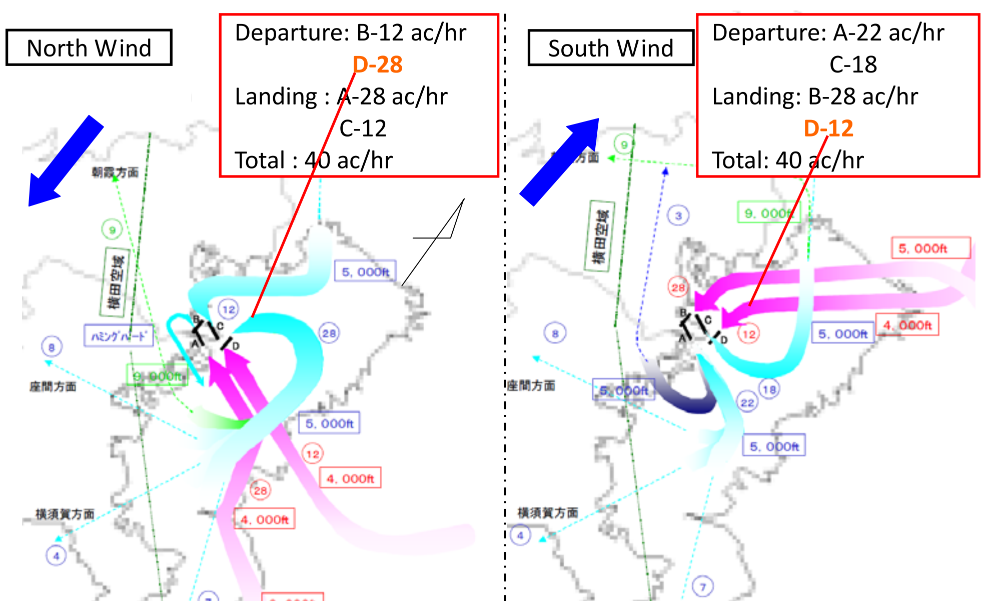


Figure 6-6: Currently Designed Capacity

Source: Japan, Ministry of Land, Infrastructure and Transport, Kanto Regional Development Bureau (2007) [49]

Another key question is when such departures and landings are necessary. In the current plan, when the north wind blows, the Runways B and D are used for departure and the Runway A and C are used for landing. When the south wind blows, the Runway A and C are used for departure and the Runway B and D are used for landing. With regard to this planning, during blowing of south wind, only 12 a/c land at the Runway D per hour, while during blowing north wind, 28 a/c depart from the Runway D per hour. This is because runway usages are determined so that the entire capacity of the airport can be maximized. However, at the Runway D, if airplanes depart from north to south and land from south to north, which means that airplanes depart and land in the both directions, it is possible for the entire capacity of the airport to be increased.

6.1.5 Flexible Design

However, estimating this capacity is very complicated because all of the four runways' capacities are related complexly to one another. For this reason, estimating the overall capacity is outside the scope of this project. This case study assumes that the opposite departure (from north to south) and landing (from south to north) could increase the total capacity of the airport. In other words, the PT/W and the S/E could increase the capacity. If the demand exceeds the capacity at a certain point in the future, the PT/W and the S/E should be constructed, considering the cost and benefit of the option. If the demand is below the capacity, it would not be best to construct them. In other words, the PT/W and the S/E do not have to be constructed until the demand of passengers exceeds the projected capacity and its expansion benefits exceed its costs. If such flexibility is incorporated into the design process, project managers are able to respond to future risks and uncertainties, such as demand of passengers. These responses can help to minimize the initial investment, reduce risks, respond to uncertainties, and maximize the value of the project.

6.2 Goal of the Case Study

As the actual Tokyo International Airport New Runway Extension Project showed, projects which are conducted under a conventional delivery system may not respond well to future uncertainties and risks, and as a result, lead the excessive expenditures losses of the taxpayer's money. However, if this project had been conducted under PFI, project managers could have incorporated flexibility into the design and those losses might have been avoided. Therefore, the goal of this case study is 1) to demonstrate how those project managers who do not have financial background can model the analysis, calculate the value of projects, and evaluate it by applying the proposed user-friendly methodologies, and 2) to demonstrate the proposed methodology is useful for reducing risks and enhancing the value of the project, provided that this project had been conducted under PFI instead of a conventional project delivery system.

6.3 Evaluation of the Project

This section explains the risks involved in the project, how those risks can be reduced by incorporating flexibility into design. It also explains what real options approach can be applied to the case study and illustrates the scenarios that should be analyzed in the case study. Furthermore, it demonstrates how project managers can perform demand modeling.

6.3.1 Risks Involved in the Project

There are usually a lot of uncertainties in large-scale engineering systems which include technical change, economic change, regulatory change, industrial change, and political change [39]. This case study also includes uncertainties such as the number of passengers, landing charge, capital investment in the future, the operating and maintenance costs, and unexpected events in the future. Since the main purpose of the project is to respond to the increasing demand of passengers, the most significant uncertainty in this project is the demand of passengers. Therefore, this case study set the demand of passengers as the only uncertainty for the simplicity, assuming that the effect of the other uncertainty would be very little.

6.3.2 Countermeasure to the Risk in the System

The countermeasure to the risk of traffic exceeding capacity is to hold strategic options, where the minimum size of the runway island is initially constructed, allowing for an expansion of the PT/W and the S/E only when the demand of passengers exceeds the capacity and its expansion benefits exceed its costs. This enables the project managers to avoid the downside risk if the traffic demand was much below the capacity, because the project cost can be reduced by constructing the smaller initial facility compared to the one with larger initial capacity. Also, it enables the project managers to take advantage of upside opportunity by expanding the capacity if the demand of passengers exceeds the initial capacity and its expansion benefits exceed its costs. Thus, holding the option to have a minimum initial facility and to expand the capacity, when the demand exceeds the capacity and its expansion benefits exceed its costs, may reduce risks and enhance the value of the project. This case study develops several scenarios with flexibility and without flexibility.

6.3.3 Methodology for the Analysis

As Section 6.2 describes, one of the goals of this case study is to demonstrate the process of flexible design to those project managers who do not have advanced finance background. Therefore, this case study uses Monte-Carlo simulations, which is a user-friendly method and enables them to apply it without learning advanced finance theory as real options analysis.

6.3.4 Analysis Process

The simulation method as a real options analysis requires project managers to set up three scenarios: 1) a *static scenario*, 2) a *scenario recognizing uncertainty*, and 3) a *scenario recognizing uncertainty and considering flexibility* [47].

First, in a *static scenario*, project managers can calculate the value of the project based on the NPV method. This scenario assumes the most likely cash flows based on the deterministic projection of demand of passengers, which is a single demand scenario.

Next, in a *scenario recognizing uncertainty*, project managers recognize uncertainty by simulating possible demand scenarios outcomes. Since each scenario results in different NPVs, the collection of demand scenarios outcomes results in an expected net present value (ENPV), and the distribution of possible outcomes for a project [47].

Finally, in a *scenario recognizing uncertainty and incorporating flexibility*, project managers can obtain the best ENPV by incorporating flexibility into design, and realize the value of the flexibility, which is the difference between the ENPV and the NPV obtained in a *scenario recognizing uncertainty* [47].

The advantage of the simulations is to illustrate the result of analysis graphically. Project managers can create the Value At Risk and Gain (VARG), which is cumulative distribution functions, from the result of each scenario in both a *scenario recognizing uncertainty* and a *scenario recognizing uncertainty and incorporating flexibility*, which implies that the worse case could occur. Even if the worst case could occur, project managers can avoid the losses from the worse case by using flexibility. Furthermore, project managers can find out how they can avoid downside losses and take advantage of upside opportunities from the VARG [47].

6.3.5 Scenarios to Analyze

This case study considers three scenarios.

Base Scenario

Base Scenario is a *static scenario*. The initial investment in this scenario is to build the entire runway island, including the runway (R/W), the parallel taxiway (PT/W) and the south edge (S/E), which is the design that the government actually planned and conducted. This scenario recognizes neither uncertainty nor flexibility.

Scenario 1

This is a *scenario recognizing uncertainty*. The initial investment in this scenario is the same as that in Base Scenario. However, this scenario recognizes the future uncertainty, which is demand of passengers, while Base Scenario considers a deterministic projection for demand of passengers.

Scenario 2

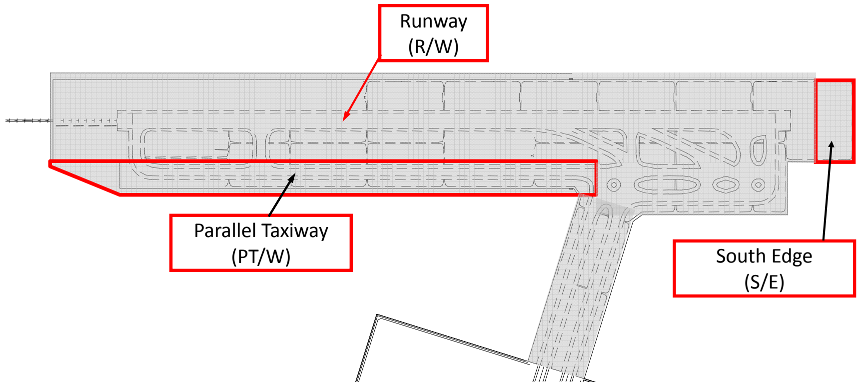
This is a *scenario recognizing uncertainty and incorporating flexibility*. The initial investment in this scenario is only the runway (R/W). But this scenario considers not only uncertainty, which is demand of passengers, but also incorporate flexibility, which is to hold the option to expand the capacity, such as the PT/W and the S/E, when the demand exceeds the capacity for two consecutive years after 10 years of operation.

Table 6-1 shows the summary of scenarios to analyze and Figure 6-7 shows the conceptual diagram of each scenario.

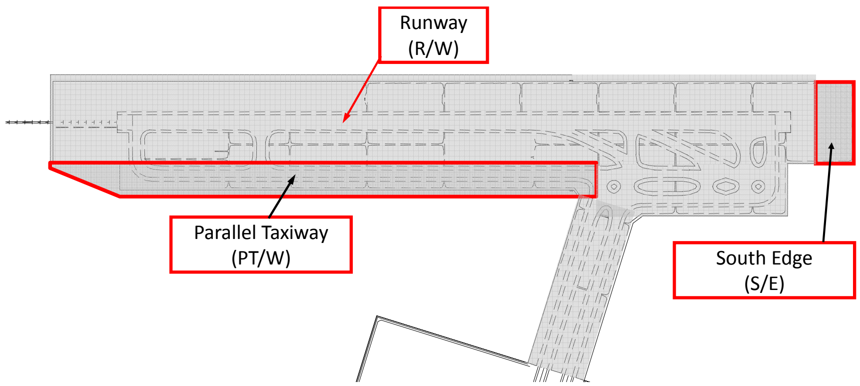
Table 6-1: scenarios to Analyze

	Base Case	Scenario 1	Scenario 2
Initial Investment	R/W, PT/W&S/E	N/A	N/A
Future Uncertainty	R/W, PT/W&S/E	Recognizing	N/A
Flexibility	R/W	Recognizing	Future Expansion (PT/W & S/E)

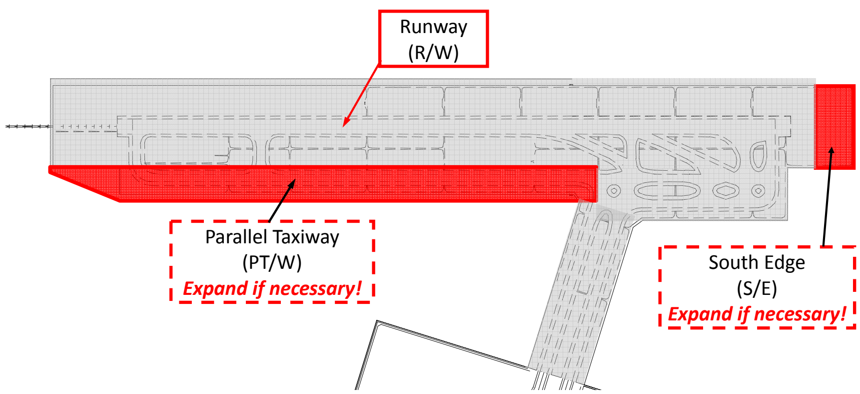
Source: Applied R de Neufville,et al [47]



Base Scenario



Scenario 1



Scenario 2

Figure 6-7: Conceptual Diagram of Each Scenario

6.3.6 Demand Modeling

As Section 6.3.1 explains, the major uncertainty in this project was the demand of passengers, and it is necessary for project managers to know how to evaluate that uncertainty. There are a lot of methods used to forecast the future demand. For example, the National Institute of Population and Social Security in Japan applies the cohort method and regression analysis when they forecast and analyze the traffic volume in Japan, applying the forecasted data of the future population and the future GDP in Japan [50]. However, as Section 3.2.1 describes, forecasts are always wrong. Therefore, project managers have to recognize that any results of forecast by any means may always be wrong.

Figure 6-8 shows the demand forecasting for Tokyo International Airport. According to the Japanese government's estimation, it is forecasted that the number of passengers will be 73.2 million in 2012, 80.3 million in 2017, and 85.5 million in 2022 [49].

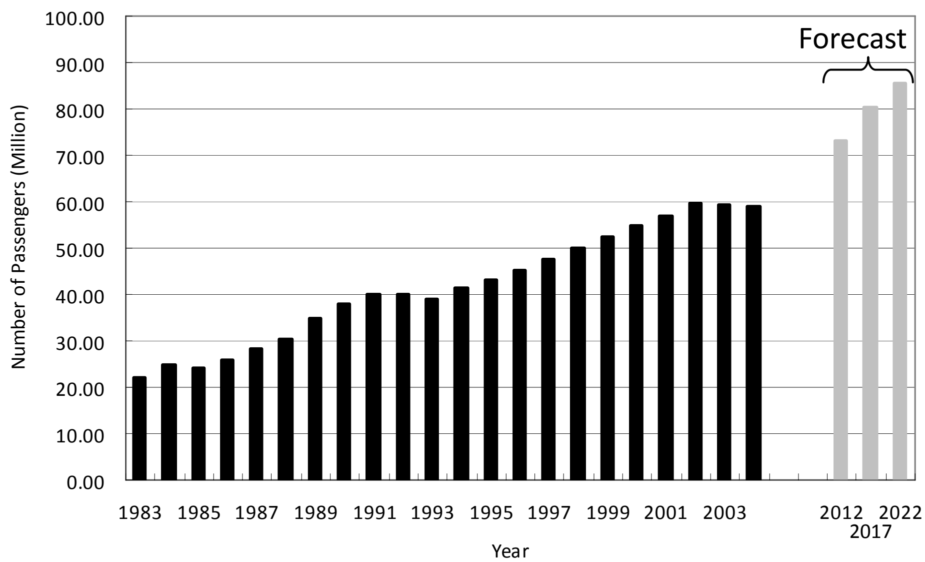


Figure 6-8: Demand Forecasting for Tokyo Int'l Airport
Source: Japan, Ministry of Land, Infrastructure and Transport (2007) [49]

This forecast was based on the forecast of the total population, the forecast of the GDP and other several factors in Japan [51]. Again, forecasting is always wrong. Table 6-2 is a comparison of 10-year of forecasting international passenger travel to Japan with the actual results for the same period [14]. These results clearly show that every forecast was wrong. In addition, the forecast of the total population in Japan and the GDP are also very difficult to assess. Thus, the forecasted demand above could be wrong.

However, when project managers analyze projects, it is necessary for them to utilize some forecasts, although they are nothing but estimates. Thus, this case study considers the demand curve that is calculated by the forecast of the total population and the forecast of the GDP in Japan. The important thing is to recognize that this forecast is just preferable projection and to incorporate uncertainty factors into this demand, using various demand scenarios with the growth rate and its volatility.

Table 6-2: Comparison of 10-year forecasts of international Passengers to Japan with actual results

Forecast		Passengers (millions)		Percent error
For	Done in	Actual	Forecast	Over actual
1980	1970	12.1	20.0	65
1985	1975	17.6	27.0	53
1990	1980	31.0	39.5	27
1995	1985	43.6	37.9	(13)

Source: R. de Neufville, A. Odoni, Airport Systems: Planning, Design, and Management [14]

(1) Forecasting Demand of Passengers by Regression Model

Although there are several methods that are available for forecasting demand for the project, this case study uses a *regression model* for estimating the future demand based on the forecasts of the population and the GDP in Japan [52] [53] [54]. Equation 6-1 provides the formula of the regression model:

$$PAX(t) = 2 \times Pop(t) \times \left(A + B \times GDP(t)\right) \qquad \textbf{Equation 6-1}$$

Where $PAX(t)$: Demand of Passenger in Tokyo Int'l Airport at time= t
$Pop(t)$: Population in Japan at time=t
$GDP(t)$: Real GDP at time= t
A, B: Regression parameters

The values of the parameters, A and B, can be calculated based on the data of the demand of passengers in the past, and forecast and the past data of both the population and the GDP in Japan. Figure 6-9 and Table 6-3 show the result of the regression model illustrating the demand of passengers from 2006 to 2030 in Tokyo International Airport.

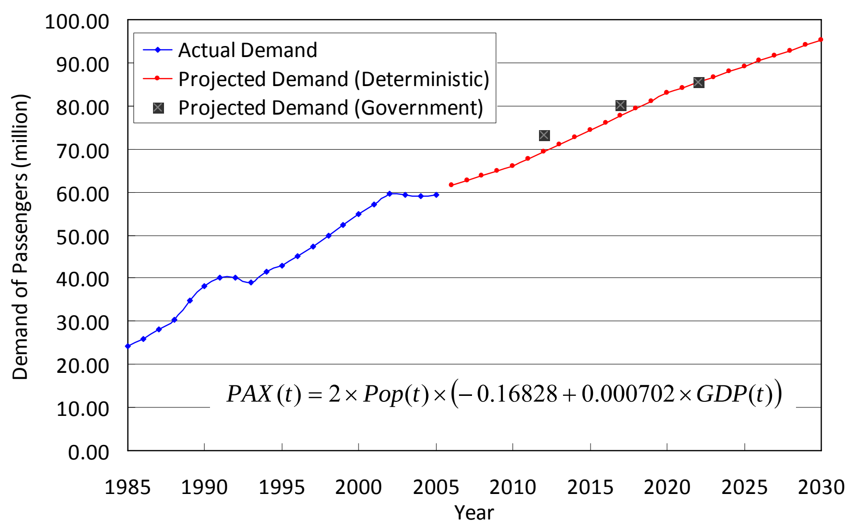


Figure 6-9: Result of Regression Model of Number of Passengers in Tokyo Int'l Airport

Table 6-3: Forecast of Demand of Passengers in Tokyo Int'l Airport

Year	Population (in million)		Real GDP (in trillion)		Passengers (million)	
1985	121.05	Actual Number of Population [55]	¥367.7	Actual GDP [56]	24.27	Actual Number of Passengers [51]
1986	121.66		¥378.1		25.88	
1987	122.24		¥397.0		28.19	
1988	122.75		¥423.4		30.28	
1989	123.21		¥441.6		34.96	
1990	123.61		¥467.9		38.09	
1991	124.10		¥478.0		40.06	
1992	124.57		¥483.2		39.98	
1993	124.94		¥478.3		39.12	
1994	125.27		¥489.3		41.44	
1995	125.57		¥501.0		43.02	
1996	125.86		¥519.3		45.08	
1997	126.16		¥522.4		47.43	
1998	126.47		¥517.3		49.91	
1999	126.67		¥521.8		52.27	
2000	126.93		¥537.9		54.77	
2001	127.29		¥531.4		57.01	
2002	127.49		¥536.7		59.49	
2003	127.69		¥554.7		59.41	
2004	127.79		¥569.8		59.05	
2005	127.77		¥576.0		59.47	
2006	127.76	Forecasted Number of Population [52]	¥582.4	Forecasted GDP [53]	***61.54***	***Number of Passengers calculated by Regression Analysis***
2007	127.69		¥588.8		***62.65***	
2008	127.57		¥595.3		***63.75***	
2009	127.40		¥601.8		***64.84***	
2010	127.18		¥608.4		***65.91***	
2011	126.91		¥618.8		***67.62***	
2012	126.60		¥629.3		***69.32***	
2013	126.25		¥640.0		***71.03***	
2014	125.86		¥650.9		***72.73***	
2015	125.43		¥661.9		***74.43***	
2016	124.96		¥673.2		***76.13***	
2017	124.46		¥684.6		***77.82***	
2018	123.92		¥696.3		***79.51***	
2019	123.34		¥708.1		***81.20***	
2020	122.73		¥720.1		***82.87***	
2021	122.10		¥730.2		***84.17***	
2022	121.43		¥740.5		***85.45***	
2023	120.74		¥750.8		***86.72***	
2024	120.01		¥761.3		***87.98***	
2025	119.27		¥772.0		***89.22***	
2026	118.50		¥782.8		***90.44***	
2027	117.71		¥793.8		***91.65***	
2028	116.90		¥804.9		***92.85***	
2029	116.07		¥816.1		***94.03***	
2030	115.22		¥827.6		***95.19***	

(2) Creating Possible Outcomes by Randomized Simulations

The demand curve shown in Figure 6-9 is still a deterministic projection and this is usually used for a static analysis (Base Scenario in this case study). However, it is essential to recognize and consider uncertainty in this demand forecasting. Uncertainty is recognized in the model by simulating possible scenarios outcomes. It indicates how fluctuations can be incorporated around deterministic projections based on the relevant probability distribution [24]. In this case study, 2,000 Monte-Carlo simulations are generated where all of those simulations create demand scenarios over a 20-year span. The uncertainty of the demand of passenger is randomized as Equation 6-2.

$$PAX_{RAN}(t) = [(1 - RAND()) + 2 \times RAND() \times \sigma] \times PAX(t)$$ **Equation 6-2**

Where $PAX_{RAN}(t)$: Deterministic Demand of Passenger at time= t
$PAX(t)$: Demand of Passenger at time=t
σ : Volatility (= 50%)

When designing airport project, especially for forecasting the demand of passenger, it is necessary for project managers to consider the wide range of inaccuracy of the deterministic projection. de Neufville strongly suggests that they apply plus or minus 50% volatility over 20 years, based on a lot of past experiences of inaccuracy of forecasts in airport planning and design [14]. Therefore, this case study uses plus or minus 50% volatility for the demand of passengers.

6.4 Design Conditions

6.4.1 Capacity of the System

According to the Ministry of Land, Infrastructure and Transport in Japan, the improved maximum capacity of the airport by the runway extension in Tokyo Int'l Airport is 40 aircrafts per hour, and it estimated this capacity can accommodate 87 million passengers per year [49]. Therefore, this thesis assumes that the capacity in terms of the number of passenger in this airport with the Runway D is 87 million. Also, this thesis assumes that the capacity of the airport would be increased by 40%, which is the capacity of 121.8 million, if airplanes depart and land in the both direction at the Runway D after the expansion of the capacity.

6.4.2 Cash Flow Pro-forma

The cash flow pro-forma must be established when project managers evaluate the value of the project using real options approach. In order to estimate the cash flows of the project, it requires the service revenues, operational costs, and capital investments. Cash flows can be calculated as follows:

Cash Flows (CF) = Operational Revenue (OR) **Equation 6-3**
– Operational Costs (OC)
– Capital Investments (CI)

For simplicity, this case study does not consider depreciation and taxes. This section develops and explains the models derived from this data in the project.

(1) Operational Revenue (OR)
Project managers need to estimate the revenues from the service. The operational revenue can be calculated as follows:

Operational Revenue(OR)=Landing Charge(LC)*Passenger Demand(PAX) **Equation 6-4**

Landing Charge (LC)

There are several types of revenues and costs in the airport management, such as that from aeronautical charges, non-aeronautical charges, and off-airport or non-operation charges [54]. In the current operation of Tokyo Int'l Airport, these charges apply, but in terms of a runway, aeronautical charges, which are the charges for services or facilities directly related to the processing of aircraft and their passengers, is the main charge [54]. The aeronautical charges have several categories such as landing charge, terminal-area air navigation charge, passenger service charge in terminals, security charge, and charges for airport noise [54]. In terms of a runway, landing charge is the main source of the revenue. Thus, I assume that the revenue is only from the landing charge. The landing charge in Tokyo Int'l Airport as of 2006 is ¥490,000 for B747-400D, ¥350,000 for B777-200, ¥230,000 for B777-724, and so on [57]. This case study sets the average landing charge of this airport as ¥332,000 / aircraft by assuming the probabilities for each type of aircraft of 23% for B747-400D, 35% for B777-200D, and 41% for B767-300 [57]. This case study also assumes that this landing charge is fixed until 2030. For the simplicity, this case study also sets the revenue for each year is landing charge multiplied by the minimum of the number of passenger or the capacity of the airport. Note: $1 = ¥104 as of May 9, 2008.

Passenger Demand (PAX)

As Section 6.3.6 explains, the demand of passengers is the uncertain factor of the system and it is developed by 2,000 Monte-Carlo simulations, which should be plugged into Equation 6-4.

(2) Operational Cost (OC)

Costs for operation and maintenance are categorized into the ones above. From the past disclosed information by the government, operating and maintenance cost in all airports in Japan in 2005 was ¥147.4 billion [58]. This case study assumes that these costs depend on the scale of air traffic. The whole air traffic in Japan in 2005 was 1,431,000 aircrafts and 300,000 aircrafts in Tokyo International Airport, which is about 20% of the whole traffic. Thus, the operation and maintenance costs for Tokyo International Airport in each year are assumed ¥29.48 billion, which is also assumed equally for the current three runways. The operating cost and maintenance costs for the one runway are assumed to be one-third of ¥29.48 billion, which is equal to ¥9.84 billion. Additionally, the current construction plan indicates that the specific maintenance cost for the Runway D is ¥100 billion for the next 30 years. Thus, the maintenance cost of ¥3.33 billion should also be included in the operating and maintenance cost for the new runway. Therefore, the operating and maintenance costs for the Runway D are set as ¥13.17 billion.

(3) Project Time Period

As Section 6.3.6 explains, this case study sets the time period of the project estimation of this airport as 20 years.

(4) Capital Investment (CI)

Capital investment is the initial construction cost and the expansion cost of the parallel taxiway and the south edge. In the actual project, the construction cost is ¥570 billion [49]. Therefore, the initial investment in Base Scenario and Scenario 1 is ¥570 billion. In Scenario 2, this case study assumes that the initial investment can be set by prorating the area where it needs. In the area of the taxiway (827,625m^2), the structure of the runway island is reclamation (¥64,700/m^2), and thus the construction cost of this area is ¥53.55 billion [49]. In the area of the south edge (45,120m^2), the structure of the runway island is piled elevated platform (¥786,500/m^2), and thus the construction cost is ¥35.48 billion [49]. Therefore, considering the bank revetment area (assumed 5% extra) and the joint area for the both areas so that the expansion could be possible, the initial construction cost of Scenario 2 is ¥505 billion. ([570-(53.55+35.48)]*1.05) The expansion cost of Scenario 2 (the parallel taxiway and the south edge) is the same as the difference between the initial cost of Base Scenario or Scenario 1, and that of Scenario 2. Considering the extra cost of the joint area (assumed 10% extra), the expansion cost is ¥97.9 billion. ((53.55+35.48)*1.1) The initial investment is assumed to be paid equally every year through the construction for 4 years, while the expansion investment is supposed to be paid equally every year for 2 years.

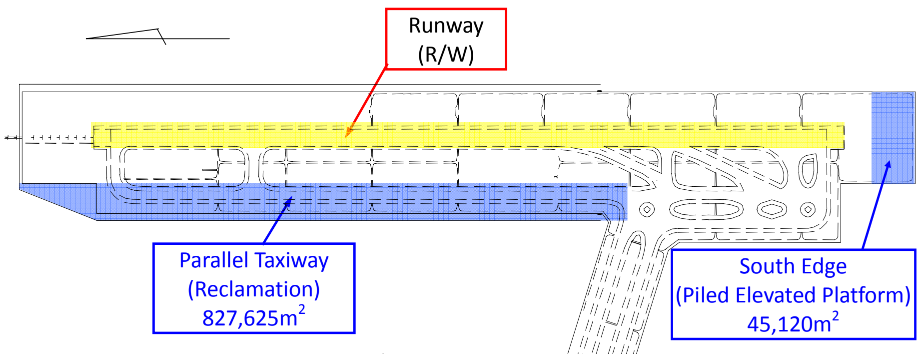


Figure 6-10: Expansion Area of Runway D

(5) Construction Period

Construction periods of the initial construction and the expansion are 4 years and 2 years respectively, which are based on the actual construction [49].

6.4.3 Discount Rate

As Chapter 4 explains, the WACC or the CAPM should be appropriate as a project specific discount rate when evaluating the value of projects. But the actual project was discounted by the interest rate of long-term government bonds of 4%, in accordance with the practice of the Japanese government for large-scale public works. Therefore, this case study also uses the discount rate of 4% [59].

6.5 Results of Project Evaluation

6.5.1 Demand Development

Figure 6-11 shows some examples of simulations of the uncertain demand based on 2,000 Monte-Carlo simulations. All of these scenarios can be considered and incorporated into the calculation of the expected value of the plans statistically for Scenarios 1 and 2.

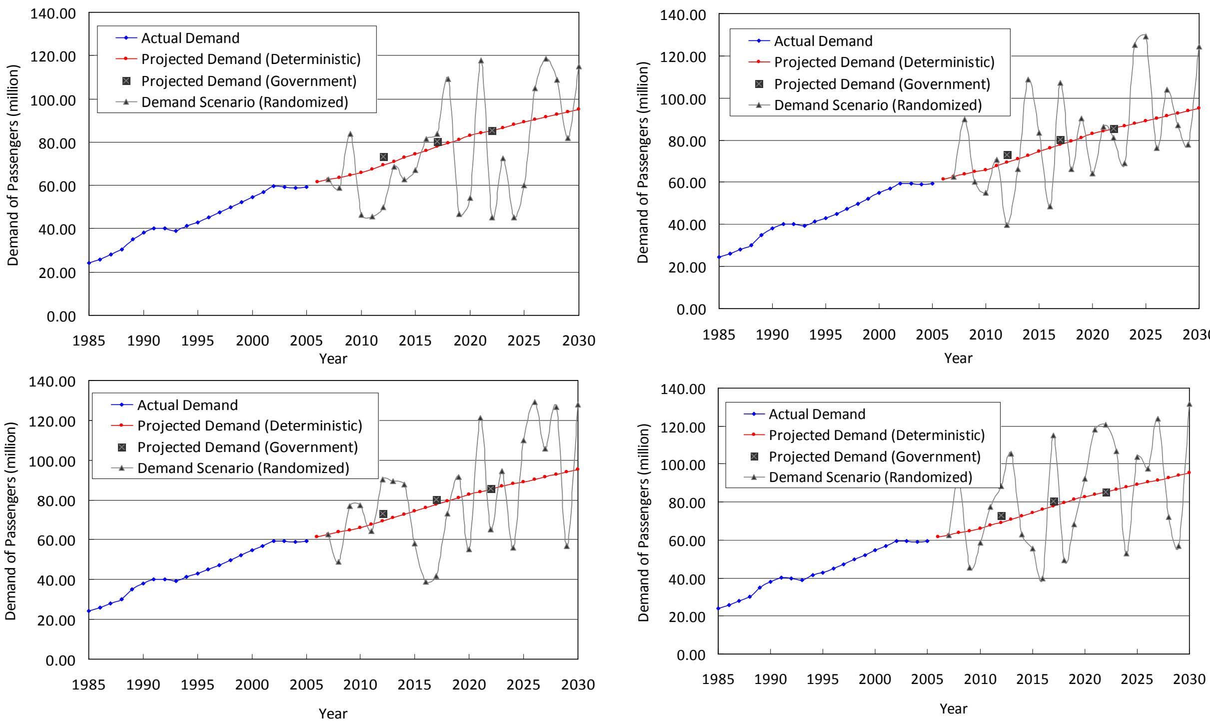


Figure 6-11: Examples of Simulations of the Uncertain Demand

6.5.2 Static Analysis – Base Scenario

Base Scenario conducted the basic DCF analysis, which does not consider uncertainty. Table 6-4 shows the cash flow pro forma, and calculating the NPV of the project assumes the passenger demand growth as projected. In this case, the NPV of the project is ¥837.8 billion. However, this value is not realistic since the actual passenger demand can change from this optimistic deterministic value.

Table 6-4: Result of Static Analysis (Base Scenario)

Year	Construction Phase				Operation Phase									
	2007	2008	2009	2010	2011	2012	2018	2019	2020	2021	2022	2028	2029	2030
Annual Passengers Demand (PAX)	62,653,434	63,752,510	64,838,112	65,909,687	67,617,325	69,324,327	79,512,479	81,195,352	82,871,885	84,170,783	85,454,975	92,849,624	94,027,977	95,189,062
Capacity of Airport (Constant)	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000
Revenue (Yen Million)					108,118	110,848	127,138	129,829	132,510	134,587	136,640	139,111	139,111	139,111
Operational & Maintenance Cost (Yen Million)					13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170
Initial Capital Investment (Yen Million)	142,500	142,500	142,500	142,500	0	0	0	0	0	0	0	1	2	3
Annual Cash Flow (Yen Million)	-142,500	-142,500	-142,500	-142,500	94,948	97,678	113,968	116,659	119,340	121,417	123,470	125,940	125,939	125,938
Present Value of Cash Flow (Yen Million)	-142,500	-137,019	-131,749	-126,682	81,162	80,284	74,032	72,865	71,672	70,115	68,559	55,267	53,140	51,096
Net Present Value (Yen Million)	837,828													

Note: Year 2013-2017 and 2023-2027 are abbreviated due to the limited space.

6.5.3 Analysis Recognizing Uncertainty – Scenario 1

Scenario 1 considers the uncertainty in the static model but does not consider flexibility. As Section 6.3.6 explains, 2,000 Monte-Carlo simulations are conducted. By plugging them into the cash flow pro forma, the net present value of the project was calculated. Table 6-5 shows one of the possible results of the cash flow pro forma and calculating the NPV of the project recognizing uncertainty, of which NPV is ¥695.1 billion. But this NPV is just one of the 2,000 scenarios. This simulation can generate 2,000 NPVs for each scenario, and can also generate a distribution for each scenario. As Chapter 5 describes, one of the advantages of using simulations is to demonstrate the result of the analysis graphically. Figure 6-12 shows the histogram distribution of simulated 2,000 net present value of the project. The ENPV of this scenario is ¥713.6 billion. Although this design assumes that there are equal chances that the demand will change either higher or lower, this design limits the higher value of the project since the capacity is fixed, while there are still lower chances to generate losses [47].

Table 6-5: Example of the Result of Analysis Recognizing Uncertainty (Scenario 1)

Year	Construction Phase				Operation Phase											
	2007	2008	2009	2010	2011	2012	2018	2019	2020	2021	2022	2023	2024	2028	2029	2030
Passengers Demand (PAX) (Determinastic)	62,653,434	63,752,510	64,838,112	65,909,687	67,617,325	69,324,327	79,512,479	81,195,352	82,871,885	84,170,783	85,454,975	86,724,411	87,979,133	92,849,624	94,027,977	95,189,062
Randomized Passengers Demand (PAX_{RAN})	62,653,434	92,883,424	35,877,894	97,629,057	69,655,467	47,440,376	77,885,603	65,791,590	56,568,367	112,590,865	100,976,297	115,498,210	76,220,791	136,272,499	57,445,043	132,541,589
Capacity (Constant)	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000
Revenue (Yen Million)					111,377	75,856	124,537	105,199	90,451	139,111	139,111	139,111	121,875	139,111	91,853	139,111
Operational & Maintenance Cost (Yen Million)					13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170	13,170
Initial Capital Investment (Yen Million)	142,500	142,500	142,500	142,500	0	0	0	0	0	0	0	0	0	0	0	0
Annual Cash Flow (Yen Million)	-142,500	-142,500	-142,500	-142,500	98,207	62,686	111,367	92,029	77,281	125,941	125,941	125,941	108,705	125,941	78,683	125,941
Present Value of Cash Flow (Yen Million)	-142,500	-137,019	-131,749	-126,682	83,948	51,523	72,342	57,481	46,413	72,728	69,930	67,241	55,806	55,267	33,201	51,097
Net Present Value (Yen Million)	695,066															

Note: Year 2013-2017 and 2025-2027 are abbreviated due to the limited space.

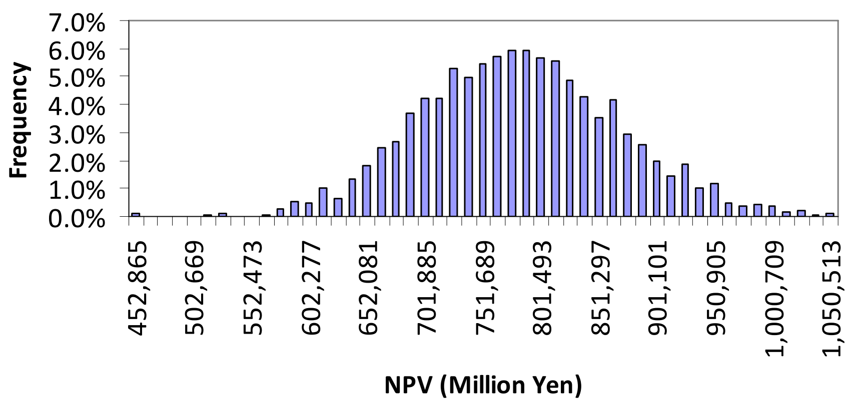


Figure 6-12: Histogram Distribution of the NPV of the Project (Scenario 1)

6.5.4 Analysis Recognizing Uncertainty and Incorporating Flexibility – Scenario 2

Scenario 2 incorporates not only uncertainty but also flexibility into design. Depending on the demand of passengers, this scenario exercises options to expand the capacity. Table 6-6 shows one of the possible results of the cash flow pro forma and calculating the NPV of the project recognizing uncertainty and holding the option to expand. The NPV shown in Table 6-6 is

$741.0 billion, although this value is just one of the possible results. Figure 6-13 shows the histogram distribution of simulated 2,000 net present values of the project. In this design, the ENPV is ¥785.1 billion, which is higher than that of Scenario 1. Because the option to expand is exercised when the demand is higher than the current capacity and its expansion benefits exceed its costs, the ENPV is improved. The estimated value of the option exercised in order to incorporate flexibility into the design can be calculated by the difference between the ENPV of Scenario 1 and Scenario 2, which is ¥71.5 billion.

Table 6-6: Example of the Result of Analysis Recognizing Uncertainty and Incorporating Flexibility (Scenario 2)

Year	Construction Phase				Operation Phase (No Expansion)				Operation Phase with Expansion Optiton							
	2007	2008	2009	2010	2011	2012	2018	2019	2020	2021	2022	2023	2024	2028	2029	2030
Passengers Demand (PAX) (Determinastic)	62,653,434	63,752,510	64,838,112	65,909,687	67,617,325	69,324,327	79,512,479	81,195,352	82,871,885	84,170,783	85,454,975	86,724,411	87,979,133	92,849,624	94,027,977	95,189,062
Randomized Passengers Demand (PAX_{RAN})	62,653,434	38,272,689	72,492,715	70,997,971	56,280,100	72,202,706	55,607,122	47,762,797	77,922,890	##########	##########	63,768,735	52,205,901	##########	66,435,890	61,281,107
Capacity (Flexible)	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	87,000,000	##########	##########	##########	##########	##########
Exercise of Flexibiity (Expansion Option)											Expand					
Expanded Capacity	0	0	0	0	0	0	0	0	0	0	34,800,000	0	0	0	0	0
Revenue (Yen Million)					89,990	115,450	88,914	76,371	124,597	139,111	139,111	101,964	83,476	194,755	106,229	97,987
Operational & Maintenance Cost (Yen Million)					12,580	12,580	12,580	12,580	12,580	12,580	12,580	13,170	13,170	13,170	13,170	13,170
Initial Capital Investment (Yen Million)	126,255	126,255	126,255	126,255	0	0	0	0	0	0	0	0	0	0	0	0
Expansion Construction Cost (Yen Million)	0	0	0	0	0	0	0	0	48,967	48,967	0	0	0	0	0	0
Annual Cash Flow (Yen Million)	-126,255	-126,255	-126,255	-126,255	77,410	102,870	76,334	63,791	63,050	77,564	126,531	88,794	70,306	181,585	93,059	84,817
Present Value of Cash Flow (Yen Million)	-126,255	-121,399	-116,729	-112,240	66,171	84,552	49,585	39,844	37,866	44,791	70,258	47,408	36,093	79,686	39,267	34,412
Present Value Expansion Cost (Yen in Million	0	0	0	0	0	0	0	0	29,408	28,277	0	0	0	0	0	0
Net Present Value (Yen Million)	741,014															

Note: Year 2013-2017 and 2023-2027 are abbreviated due to the limited space.

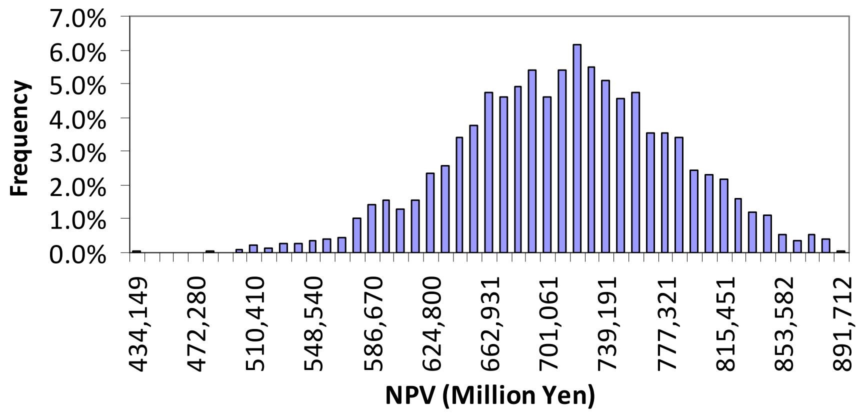


Figure 6-13: Histogram Distribution of the NPV of the Project (Scenario 2)

Figure 6-14 shows the value at risk and gain distribution (VARG) for Scenarios 1 and 2. The distribution in Scenario 2 is skewed to the right hand side, which is the upper side of the net present value, compared to the one in Scenario 1. This demonstrates that flexible design reduces risks and enhances the value of the project, and enables project managers to take advantage of upside benefits and to avoid downside risk.

Table 6-7 shows the performance improvements achieved with flexible design. Overall, Scenario 2, which holds flexibility in design, has advantages over Scenario 1 in each criterion. The initial investment in Scenario 2 is less than that of Scenario 1, which indicates that the flexibility can reduce the costs of the initial investment. The ENPV, the maximum and minimum NPV in Scenario 2 is higher than that of Scenario 1, and thus the flexibility can enhance the overall value of the project.

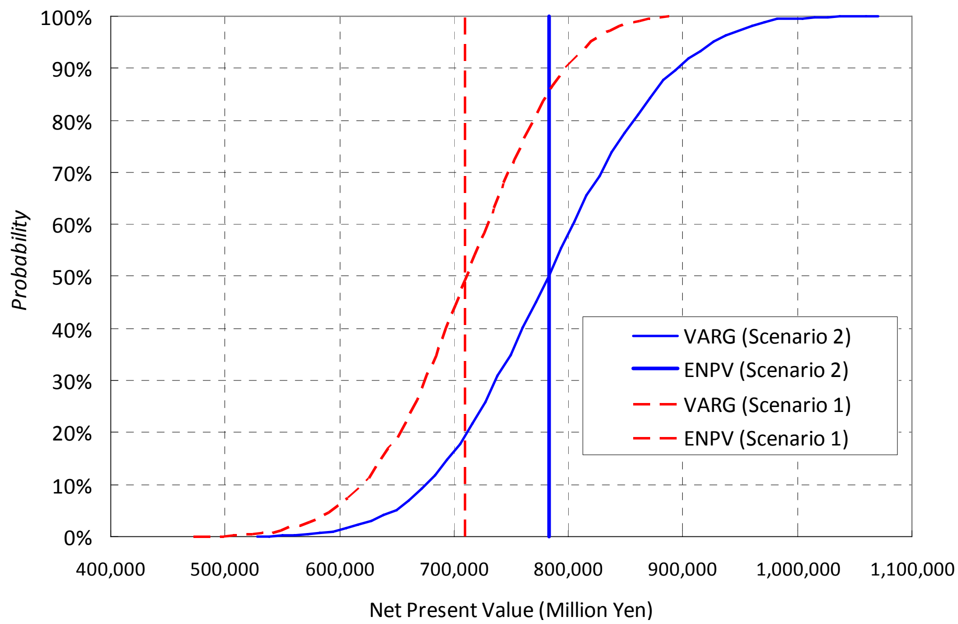


Figure 6-14: Value-At-Risk and Gain Distribution for Two Scenarios

Table 6-7: Summary of the Analysis

Criteria	Design		Comparison
	Scenario 1 (No Flexibility)	Scenario 2 (Flexible)	
Expected Net Present Value (Million)	¥713,642	¥785,120	Flexibility Better
Initial Cost (Million)	¥570,000	¥505,019	Flexibility Better
Maximum Value (NPV) (Million)	¥919,795	¥1,077,365	Flexibility Better
Minimum Value (NPV) (Million)	¥452,671	¥532,827	Flexibility Better
Flexibility Value (Million)	-	¥71,478	-

6.6 Conclusion of the Case Study of the Tokyo International Airport New Runway Extension Project

This chapter demonstrates how the proposed concepts and methodologies can be applied in real-world projects using a case study of the Tokyo International Airport New Runway Extension Project.

This case study demonstrates how project managers can model the analysis of the project, calculate the value of the project and evaluate it, including setting up scenarios with or without options to expand, modeling the demand of passengers, building cash flows pro forma, and developing the calculation and evaluation process.

Next, the case study selects Monte-Carlo simulations as a project valuation methodology and demonstrates this methodology is practically useful when designing large-scale engineering infrastructure development projects. Monte-Carlo simulations generate the statistical distribution of possible outcomes for demand of passengers and it enables the calculation of the options value with 2,000 of possible simulations for uncertain variables. Because of the development of computer technology, project managers can conduct this methodology easily and without advanced finance theory. Therefore, as this chapter shows, they are able to use this practical methodology in real-world projects without acquiring new advanced skills.

Finally, the case study demonstrates that incorporating flexibility into design can reduce risks and enhance the value of the project. As Section 6.5 shows, Scenario 2 with smaller initial size and with the option to expand the capacity, can avoid the downside risk of demand of passengers, and can take advantage of the upside opportunity. The analysis shows the flexible design is better than the design without flexibility in any criteria, such as the ENPV and the initial investment cost. The VARG graphically illustrates the usefulness of flexibility clearly. Thus, project managers are able to optimize the project. Because under PFI, project managers can apply their management skills and their ingenuity, they can apply flexible design to large scale infrastructure development, and thereby they can manage risks in PFI as this chapter demonstrates.

Chapter 7 Case Study 2: Tokyo Bay Aqua-Line Project

This chapter also demonstrates how the proposed methodologies and concepts can be applied in real-world projects, using another relevant case study, the "*Tokyo Bay Aqua-Line Project*". This large expressway project consists of bridges and tunnels across Tokyo Bay in Japan. The purpose of this case study is to demonstrate how project managers can model the analysis, calculate the value of projects, and evaluate it by applying the proposed methodologies, 2) to demonstrate the proposed methodology is useful for reducing risks and enhancing the value of the project, and 3) to demonstrate alternatives of enhancing the value of the project other than the real options approach, provided that this project had been conducted under PFI instead of a conventional project delivery system.

7.1 Project Overview

7.1.1 Project Description

The "Tokyo Bay Aqua-Line" project consists of bridges and tunnels across Tokyo Bay in Japan, which connect the cities of Kawasaki (Kanagawa Prefecture) and Kisarazu (Chiba Prefecture). The total length of these bridges and tunnels is 15.1 km, which includes two 9.6km tunnels underneath the Tokyo Bay (the longest underwater tunnel for vehicles in the world) and two 4.4 km bridges [60]. There is an artificial island, "*Umi-Hotaru*" which has parking garages, a rest area with restaurants, a gift shop, and amusement facilities, at the cross-over point between the bridges and tunnels. There is also a very distinctive tower-like facility in the middle of the tunnel, which is called "*Kaze-no-To*". The purpose of this facility is to supply air to the tunnels and this utilizes the mostly constant winds in the Tokyo Bay as a source of power [61].

This road began service on December 18, 1997 with anticipation and some trepidation after 10 years of construction, which cost ¥1.44 trillion. It was designed to improve the drive time between Chiba and Kanagawa (15 minutes), which are two important industrial regions, and to reduce the traffic through the center of Tokyo. Before this road was in service, one had to drive a roundabout 100 km along the shores of Tokyo Bay and pass through the center of Tokyo.

7.1.2 Issue in the Project

Many researchers, economists and mass media thought that the demand of the traffic estimated by the Japan Highway Public Corporation (a government corporation) and the economic ripple effect was overestimated. For example, Yasuda criticized not only the planning and design but also the government policy [62]. Concerns about overestimates of the future traffic volume were well warranted, as the actual average daily traffic volume for the first 10 years was below the estimated volume (25,000 vehicles /day).

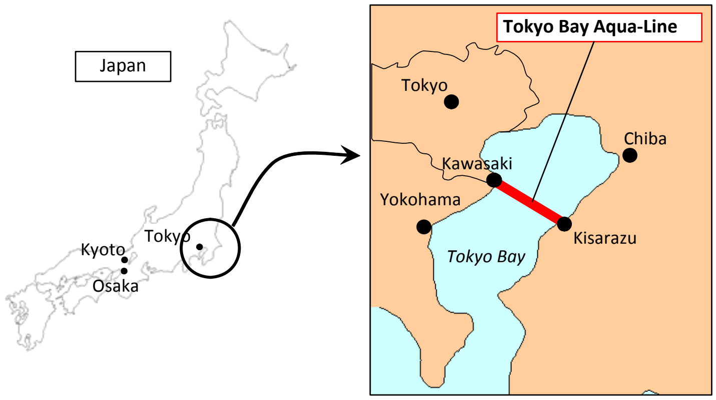


Figure 7-1: Location of the Tokyo Bay Aqua-Line

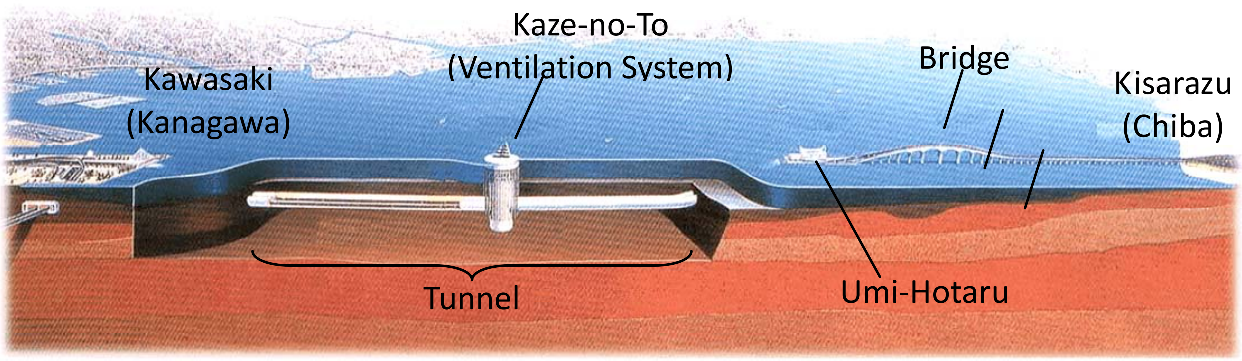


Figure 7-2: Outline Drawing of the Tokyo Bay Aqua-Line
Source: Japan, Chiba Prefecture [60]

Figure 7-3: Kaze-no-To
Source: Japan, Chiba Prefecture [60]

Figure 7-4: Umi-Hotaru
Source: Japan, Chiba Prefecture [60]

Table 7-1 shows the transition of the average traffic volume in the Aqua-Line from 1998 to 2007 [20]. For the first two years (1998-1999), the average traffic volume was less than half of the estimated volume. Taking into consideration this serious situation, the toll fee was reduced 25% from the initial price. (i.e. standard-sized car: from ¥4,000 to ¥3,000) after two years operation to encourage more driving. The traffic volume increased slightly after the reduction of the toll fee. But it was still below the 80% of the initial estimated volume in 2007.

Table 7-1: The Transition of the Traffic in the Aqua-Line (vehicles / day)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Average Traffic (% of Projected Initial Traffic)	10,000 (40%)	9,600 (39%)	11,900 (48%)	13,300 (53%)	13,700 (55%)	14,100 (56%)	14,900 (60%)	16,300 (65%)	17,600 (70%)	19,800 (79%)

Source: East Nippon Expressway Co., Ltd. (NEXCO East Japan)[20]
Note: This table was not officially disclosed. Author investigating by phone to East Nippon Expressway Limited.

Although the Japan Highway Public Corporation did not announce officially the income and expenditure report for this road specifically, there were a lot of minus balance, according to the annual financial report [63]. Thus, the overestimates in planning and the excessive design brought about many losses in this project. Furthermore, the financial self-sufficiency for the project was in jeopardy.

7.2 Goal of the Case Study

As the actual Tokyo Bay Aqua-Line Project demonstrated, projects which are conducted under a conventional delivery system may not respond well to future uncertainties and risks, and as a result, lead the excessive expenditures losses of the taxpayer's money. However, if this project had been conducted under a PFI type delivery system, project managers could have incorporated flexibility into the design and those losses might have been avoided. Therefore, the goal of this case study is 1) to demonstrate how project managers can model the analysis, calculate the value of projects, and evaluate it by applying the proposed methodologies, 2) to demonstrate the proposed methodology is useful for reducing risks and enhancing the value of the project, and 3) to demonstrate alternatives of enhancing the value of the project other than the real options approach, provided that this project had been conducted under PFI instead of a conventional project delivery system.

7.3 Evaluation of the Project

This section describes the risks involved in the project, how those risks can be reduced by incorporating flexibility into design. It also explains what real options approach can be applied to the case study and illustrates the scenarios that should be analyzed in the case study. Furthermore, it demonstrates how project managers can perform demand modeling.

7.3.1 Risks Involved in the Project

There are various types of risks and uncertainties in any large-scale engineering system, as exemplified in this project. As was obvious after the Aqua-Line began service, the traffic demand that project managers in this project were not able to adequately predict was a main uncertainty in the project. Therefore, this case study sets the demand of traffic as the only risk driver, due to the very significant impact it has on the project valuation. Other risks and uncertainties are assumed to have little effect on the project valuation compared to the level of traffic.

7.3.2 Countermeasure to the Risk in the System

The countermeasure to the risk of traffic demand is to hold strategic options, where only a minimum amount of lanes are developed at the initial construction, allowing for an expansion of lanes only when the traffic demand exceeds the capacity of the road and its expansion benefits exceed its costs. For example, the design with the initial construction of 2 lanes and the possible expansion of 2 lanes enables project managers to avoid the downside risk if the traffic demand was much below the capacity of the expressway with the initial lanes of 4, because the project cost can be reduced by constructing the smaller initial facility compared to the one with larger initial capacity. Also, it enables project managers to take advantage of upside opportunity by expanding the capacity if the traffic demand exceeds the initial capacity and its expansion benefits exceed its costs. Thus, holding the option to have a minimum initial facility and to expand the capacity, when the demand exceeds the capacity and its benefits exceeds its costs, may reduce risks and enhance the value of the project. This case study develops several scenarios with flexibility and without flexibility.

7.3.3 Methodology for the Analysis

This case study selects the combination of binomial lattice model and decision analysis as a project valuation methodology. Binomial lattice model is useful for developing traffic demand, which is the only uncertainty in this case study. But because the traffic demand does not exist until the open of this expressway, it is necessary not only to find out the past trend from comparable and similar projects in the past to set up the growth rate and the volatility, but also consider the inaccuracy of the forecast of initial demand based on the past research result. Decision analysis can not only deal with various scenarios but also consider as many possible outcomes for each scenario as possible, which can treat the various inaccuracy rates for the initial demand forecast. Thus, this case study deals with the development of new traffic demand by applying binomial lattice model and the inaccuracy of the forecast of the initial demand by applying decision analysis.

7.3.4 Scenarios to Analyze

This case study considers *five* scenarios as follows:

Base Scenario
The initial size of the road is 4 lanes (2 tunnels) and no lanes will be added for the overall project life, which is the same as the actual project. In the actual project, the initial design consisted of 6 lanes (3 tunnels) but the actual number of lanes is 4 (2 tunnels) and this will not be expanded in the future, even if it was designed for the expansion from 4 lanes to 6 lanes. This reason is explained later in this section.

Scenario 1
The initial size of the road is 2 lanes (1 tunnel) and no lanes will be added in the overall project life. In other words, this scenario considers uncertainty but does not consider and incorporate flexibility into design.

Scenario 2
The initial size of the road is 6 lanes (3 tunnels) and no lanes will be added in the overall project life. Like Scenario 1, this scenario considers uncertainty but does not consider and incorporate flexibility into design.

Scenario 3
The initial size of the road is 2 lanes (1 tunnel). In addition, this scenario considers uncertainty and incorporates flexibility into design. In other words, project managers hold an option to expand the capacity from 2 lanes to 4 lanes (2 tunnels) if the demand of the traffic exceeds it and its expansion benefits exceed its costs.

Scenario 4
The initial size of the road is 4 lanes (2 tunnels). In the same way as Scenario 3, this scenario also considers uncertainty and incorporates flexibility into design. In other words, project managers hold an option to expand the capacity from 4 lanes to 6 lanes (3 tunnels) if the demand of the traffic exceeds it and its expansion benefits exceed its costs.

Table 7-2 shows scenarios to analyze and Figure 7-5 illustrates the conceptual diagram of each scenario.

Table 7-2: Scenarios to Analyze

	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Uncertainty Consideration	Yes	Yes	Yes	Yes	Yes
Flexibility	No	No	No	Yes	Yes
Initial Scale	4 Lanes	2 Lanes	6 Lanes	6 Lanes	4 Lanes
Expansion Scale	-	-	-	2 to 4 Lanes	4 to 6 Lanes

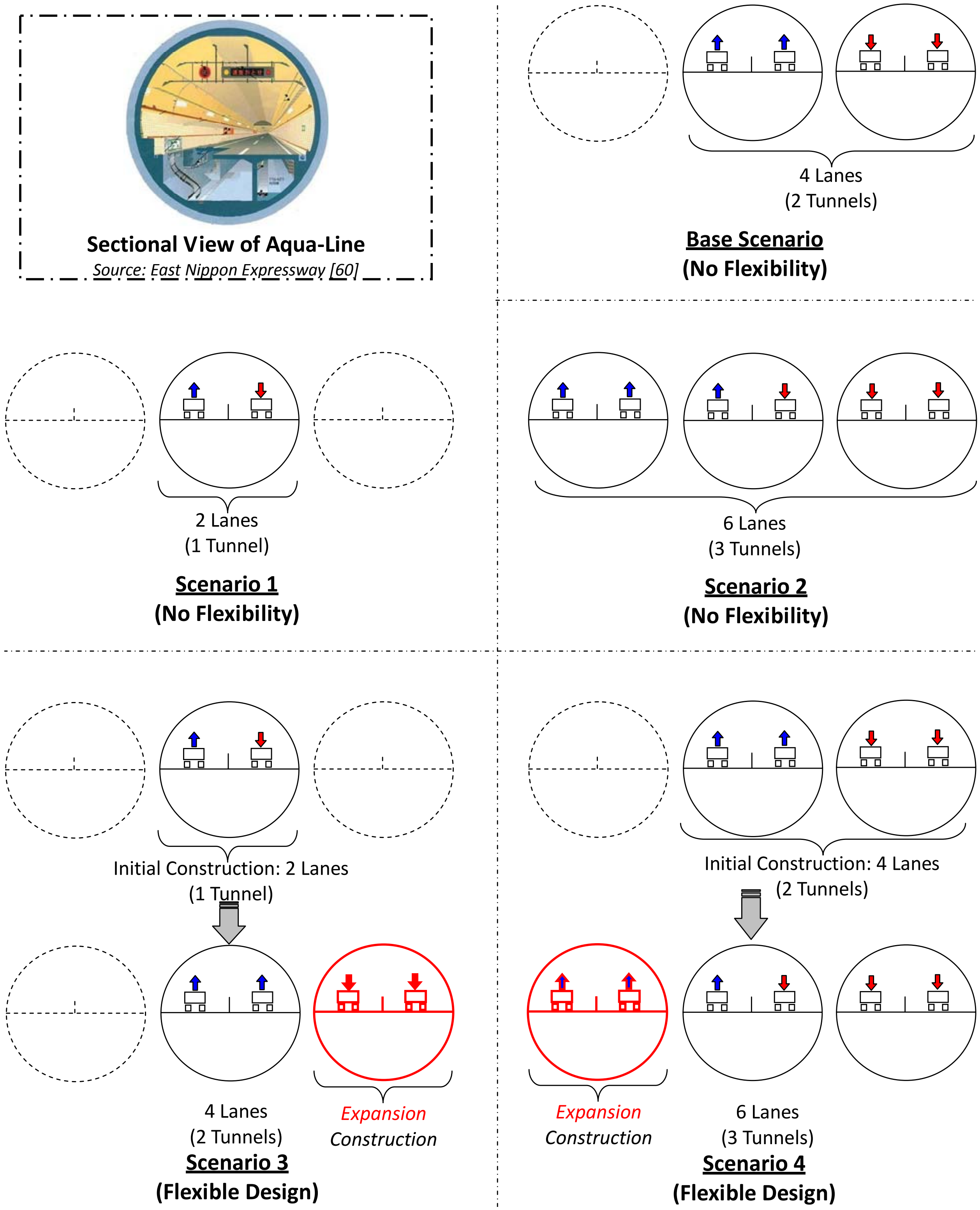


Figure 7-5: Conceptual Diagram of Each Scenario

There are 4 lanes in the actual project. During the planning phase, the structure of this expressway was designed to increase 2 more lanes (1 tunnel) so that it could accommodate demand if the traffic would exceed the current capacity sometime in the future. However, the actual project was conducted under the conventional delivery system, which did not include any flexibility to accommodate for the risks and uncertainties in the project. The reason for this is that the government, which ordered the project, could not manage the overall project with unified recognition due to the problem of a single annual budget, supervision costs, and the immobility of the government servants. Thus they could not demonstrate flexible management. For example, regarding the single annual budget, under the conventional delivery system, whether the expansion can be conducted or not depends on single annual financial condition or single annual budget restrictions. Therefore, even if the original design included the expansion possibility, if the financial budget at that year does not reflect funds for such an expansion, the expansion cannot be realized. Thus, the conventional delivery method cannot hold the desired flexibility. On the other hand, PFI projects, because it uses the project finance system, can therefore manage the project throughout its lifetime, and thereby project companies can incorporate flexibility into design.

7.3.5 Demand Modeling

As Section 7.3.1 explains, the major uncertainty in this project was the demand of daily traffic, and it is necessary for project managers to know how to evaluate that uncertainty. Again, as Section 3.2.1 and Section 6.3.6 describe, forecasts are always wrong. Therefore, project managers have to recognize that any results of forecast by any means may always be wrong.

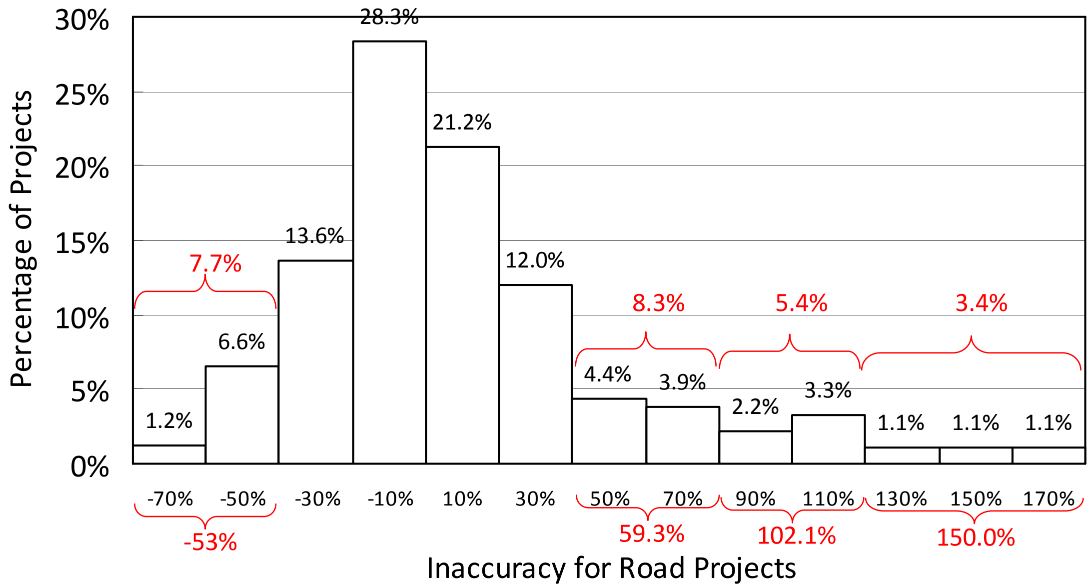


Figure 7-6: Inaccuracy of Traffic Forecasts for Road Projects

Source: Flyvbjerg, et al [19]

It is useful that project managers consider the research results by Flyvbjerg in order to recognize how inaccurate forecasts are [19]. Figure 7-6 demonstrated the distribution of inaccuracy of traffic forecasts for 183 road projects. A negative percentage in horizontal axis means that actual traffic is lower than forecasted traffic by that percentage; correspondingly, a positive percentage means that actual traffic is higher. For example, 28.3% of investigated road projects had forecasted traffic is lower than actual traffic by 0% to 20%, and 12.0% had traffic is higher than actual traffic by 20% to 40%. This case study applies this distribution as the modified factor which considers inaccuracy of forecasts. In concrete terms, this case study set the initial traffic of 25,000 vehicles per day, which was actually forecasted, with consideration of inaccuracy rate shown in Figure 7-6 [60]. Table 7-3 illustrates the original figure and the designed figure that should be used in this case study for the inaccuracy rate for road projects and percentage of projects from Figure 7-6. This case study categorizes designed figure for both inaccuracy for road projects and percentage of projects into *eight* ranges, such as (a) to (h). Thus, this case study deals with the demand uncertainty by considering inaccuracy of forecast of the initial traffic, and considers the eight percentages of projects (a) to (h).

Table 7-3: Original Figure and Designed Figure of Inaccuracy for Road Projects and Percentage of Projects

	Inaccuracy for Road Projects			Percentage of Projects	
	Original Figure	***Designed Figure for this Case Study***	Number of Vehicles per day	Original Figure	***Designed Figure for this Case Study***
(a)	170% (160 to 180%)	***150.0%***	62,500	1.1%	***3.4%***
	150% (140 to 160%)			1.1%	
	130% (120 to 140%)			1.1%	
(b)	110% (100 to 120%)	***102.1%***	50,525	3.3%	***5.4%***
	90% (80 to 100%)			2.2%	
(c)	70% (60 to 80%)	***59.3%***	39,825	3.9%	***8.3%***
	50% (40 to 60%)			4.4%	
(d)	30% (20 to 40%)	***30.0%***	32,500	12.0%	***12.0%***
(e)	10% (0 to 20%)	***10.0%***	27,500	21.2%	***21.2%***
(f)	-10% (-20 to 0%)	***-10.0%***	22,500	28.3%	***28.3%***
(g)	-30% (-20 to 40%)	***-30.0%***	17,500	13.6%	***13.6%***
(h)	-50% (-40 to 60%)	***-53.0%***	11,750	6.6%	***7.7%***
	-70% (-60 to 80%)			1.2%	

Next, this case study deals with the traffic demand developed from the initial traffic by using the binomial lattice model. The binomial lattice model requires the growth rate and the volatility of the uncertainty. Because this project was conducted by a new construction, there was no continuous past trends of traffic demand unlike the previous case study of the Tokyo International Airport New Runway Extension Project. This case study uses the demand data from a comparable and similar project in terms of the characteristics and scale of a project. Seto-Ohashi Bridge project can be a comparable project for this case study. It is a series of bridges connecting Okayama prefecture in Honshu and Kagawa prefecture in Shikoku in Japan across a series of five small islands in the Seto Inland Sea. It was constructed from 1978 to 1988, and its construction cost ¥1.13 trillion [64]. The length of the road is 13.1 km with 4 lanes, which ranks as the longest two-tiered bridge system in the world.

Figure 7-7: Seto-Ohashi Bridge

Source: Honsyu-Shikoku Expressway Company Ltd. [64]

Table 7-4: Comparison of the Tokyo Bay Aqua-Line Project with the Seto-Ohashi Bridge Project

	Tokyo Bay Aqua-Line	Seto-Ohashi Bridge
Construction Period	July, 1987 – December 1997 (10.5 years)	October, 1978 – April, 1988 (9.5 years)
Construction Cost	¥1.44 trillion	¥ 1.13 trillion
Number of Lanes	4 Lanes	4 Lanes

Source: Honsyu-Shikoku Expressway Company Ltd. [64]

As Table 7-4 shows, the characteristics of the Seto-Ohashi Bridge project can be comparable to the Tokyo Bay Aqua-Line project in terms of project scale such as construction period, cost, and the number of lane as well as the fact that this was also a newly constructed road [64]. Therefore, this case study uses the traffic transition data of the Seto-Ohashi Bridge shown in Table 7-5.

Table 7-5: Traffic Transition of Seto-Ohashi Bridge

Year	Number of Vehicles per day
1989	9,100
1990	9,800
1991	11,300
1992	12,000
1993	12,600
1994	13,700
1995	14,400
1996	15,200
1997	16,100
1998	15,700
1999	15,500
2000	14,800
2001	14,500
2002	14,100
2003	14,000
2004	14,000
2005	14,100
2006	14,300
2007	14,500

Source: Honsyu-Shikoku Expressway Company Ltd. [64]

Project managers can estimate the average growth rate and volatility by using the following equations, based on the past trends [65].

$$\nu = \frac{1}{\Delta t} \cdot \sum_{t=1}^{N-1} \ln \frac{u(t+\Delta t)}{u(t)} \bigg/ (N-1)$$ **Equation 7-1**

$$\sigma = \sqrt{\frac{1}{\Delta t} \cdot \sum_{t=1}^{N=1} \left\{ \ln \frac{u(t+\Delta t)}{u(t)} - \nu \right\}^2 \bigg/ (N-2)}$$ **Equation 7-2**

Where u: Traffic demand
ν : Average annual growth rate of traffic demand
σ : Volatility (standard deviation) of the growth rate of traffic
N : Number of traffic data
ΔT : Length of incremental time period

From these equations, the growth rate, ν and the volatility, σ in Seto-Ohashi Bridge Project can be calculated as 2.74% and 5.00% respectively. This case study applies these growth rate and volatility to the traffic demand.

The binomial lattice model develops a distribution of the traffic demand in the future, requiring the growth rate and the volatility of the traffic volume. The values calculated above are plugged into the Equation 5-5 and 5-8 to obtain an upward movement with multiplier, u and its probability, p as follows:

$$u = e^{\sigma\sqrt{\Delta T}} = 1.05$$

$$d = 1/u = 0.95$$

$$p = \frac{1}{2}\left(1 + \frac{\nu}{\sigma}\sqrt{\Delta T}\right) = 0.77$$

Where σ : Standard Deviation of demand
ν : Growth rate of demand
ΔT : Time length of one period

7.3.6 Development of Real Options Analysis (Binomial Lattice Model) for the Project

Once project managers can get the initial demand, the growth rate and the volatility of traffic demand, they can develop binomial lattice model so that they can incorporate flexibility into design. Developing the binomial lattice model, they have to build a cash flow pro forma, considering capacity constraints. While there are virtually no limitations in the growth of traffic volume applied to the project, there are ceilings on the actual capacity of the system. Due to the flexibility, which is the option to expand capacity, the calculation of the cash flow is made complex because the operational revenues would increase if the option is exercised. Therefore, project managers must develop a model that can handle capacity constraints and changes in capacity. Ishii clearly developed this framework, which this thesis applies [66].

(1) Project Value Calculation Model for the Scenarios without Option to Expand Capacity

Figure 7-8 shows the structure of the traffic flow by the general binomial lattice model. The traffic demand moves in one of only two directions, up or down, and the intermediate branches all recombine.

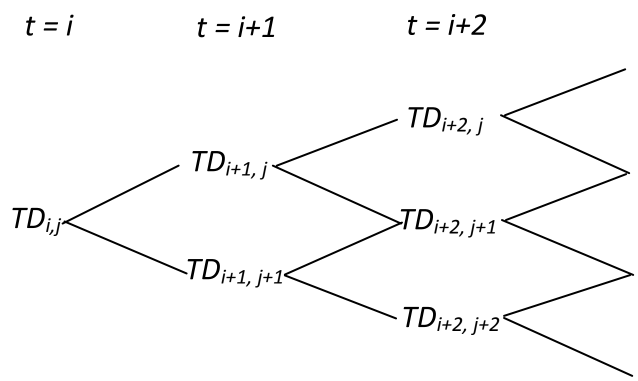


Figure 7-8: Binomial Lattice Structure of Traffic Demand Movement

By using the binomial lattice evaluation, project managers can develop the relationship among the demands, $TD_{i,j}$, $TD_{i+1,j}$, and $TD_{i+1,j+1}$, by the following figure and equations as Section 5.1.3 shows.

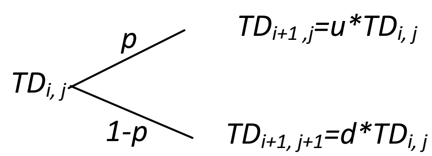


Figure 7-9: Binomial Lattice Evolution of Traffic Demand

With this distribution of demand, project managers can calculate the cash flow at each node. This calculation compares the demand and the capacity, and the smaller figure should be chosen to represent the constraint of operational capacity.

$$CF_{i,j} = [\min[TV_{i,j}, CP] \times T \times 365 - OC - D] \times (1-t) - CI + D \qquad \textbf{Equation 7-3}$$

Where $CF_{i,j}$: Annual cash flow at node (i, j) (where traffic demand = $TD_{i,j}$) (yen)
$TD_{i,j}$: Annual traffic demand at node (i, j) (vehicles / day)
CP: Capacity of the system (vehicles / day)
T: Toll (yen / vehicle)
OC: Annual Operational Cost (yen)
D: Depreciation (yen)
t: Tax rate (%)
CI: Capital Investments (yen)

Note that in this calculation, it is assumed that roads are filled with vehicles if traffic volume is larger than or equal to the capacity, and that the exceeded traffic volume is ignored. The binomial lattice of cash flows can be constructed as Figure 7-10 shows.

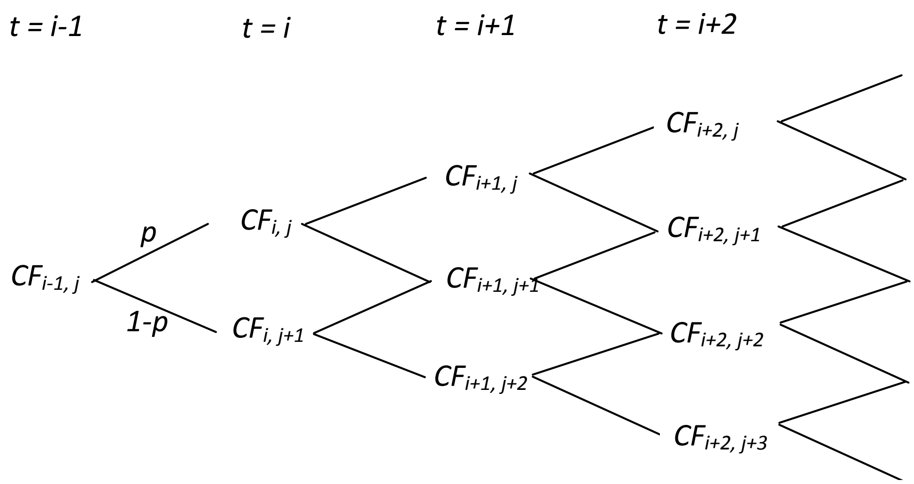


Figure 7-10: Binomial Lattice of Cash Flows of the Project

Finally, project managers can calculate the expected value of the project by a backward induction process. The following steps describe the process to calculate the value of the cash flow stream of the project, illustrating a case example of a three-stage binomial lattice:

<u>Step 1:</u>
Compute the expected value at the final period of the cash flow of the two adjoining nodes that both descend from the same node in the preceding period. In other words, the process starts with the calculation of the expected values of cash flows at the final period: EV3,1 and EV3,2. Then make the same computation for all the other adjoining pairs as Figure 7-11 shows.

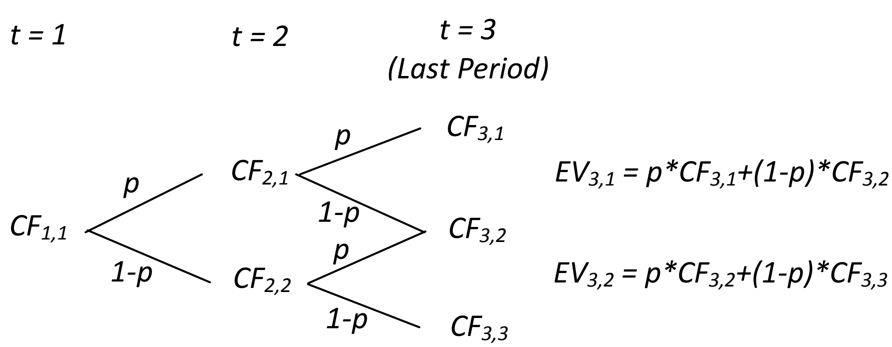


Figure 7-11: First Step in the Backward Induction Process

Step 2:
Discount the expected value of cash flow by a project specific discount rate, r, so that the resulting value represents the value at time = *N-1* (where *N* is the final period). In other words, the expected values calculated in Step 1 are discounted so that they represent the value at t = 2.

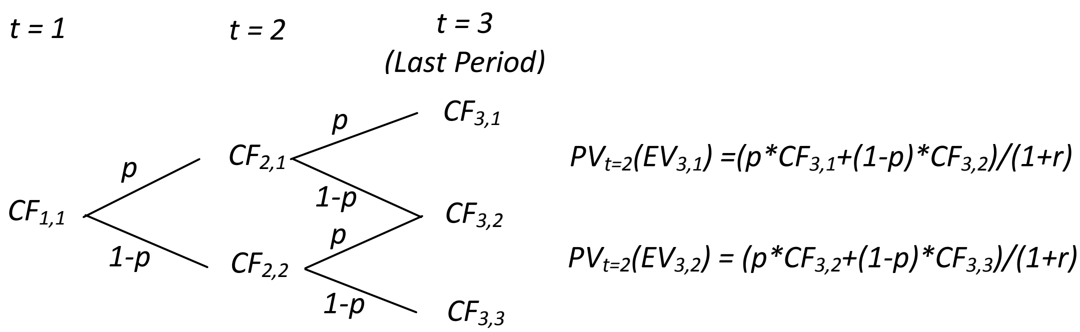


Figure 7-12: Second Step in the Backward Induction Process

Step 3:
Add the discounted value of the expected cash flow obtained in Step 2 to the cash flow at the preceding node from which the two adjoining nodes both descend. The obtained value represents the expected net present value, at time = *N*-1, of the project provided that the project reached the node (*N*-1, *j*) (*j* = 1, 2…*N*). Then replace the cash flow at time = *N*-1 by the calculated expected net present value of the project. In other words, the cash flow at *t* = 2 needs to be replaced by the sum of the value obtained in Step 3 and the cash flow at *t* =2.

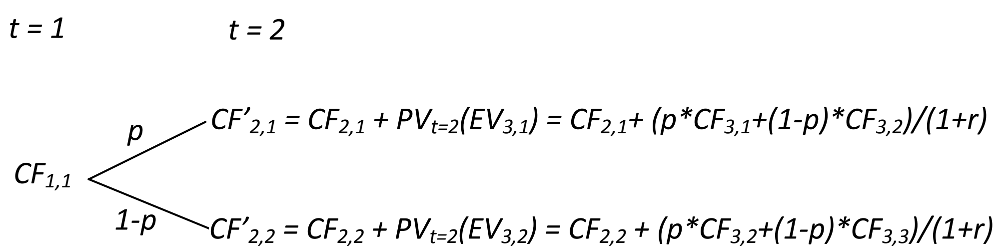


Figure 7-13: Third Step in the Backward Induction Process

Step 4:
Repeating Step 1 through 3, make the same calculation with each of the preceding time periods.

The above process of backward induction can be mathematically summarized by a recurring formula. Equation 7-4 provides the formula for the calculation of the net present value (at time = *i*) of the cash flow stream descending from the node (*i, j*). Repeatedly using this equation from the final period to the first period, project managers can calculate the total present value of the project.

$$NPV_i(CFS_{i,j}) = CF_{i,j} + \frac{p \cdot NPV_{i+1}(CFS_{i+1,j}) + (1-p) \cdot NPV_{i+1}(CFS_{i+1,j+1})}{1+r} \quad \textbf{Equation 7-4}$$

Where $CF_{i,j}$: Cash flow at the node (i, j)
$CFS_{i,j}$: Cash flow stream that descend from the node (i, j)
$NPV_i(CFS_{i,j})$: Net present value of the cash flow stream, $CFS_{i,j}$, at time = i
r: Discount rate

Finally, combining Equations 7-3 and 7-4, project managers can calculate the net present value of the project with consideration of the capacity constraint.

(2) Project Value Calculation Model for the Scenarios with Option to Expand Capacity

The option to expand the capacity of the system affects the binomial lattice structure of the cash flow because the cash flow is a function of the capacity. Once the option is exercised, the cash flow stream will be completely different from the one without an option. Therefore, project managers need to prepare two different binomial lattice models of cash flow, and they must switch these models at the time of the implementation of the option.

If the system is designed with the expansion option of increasing the number of lanes from l_1 to $l_2(=l_1+2)$, project managers need to construct two binomial lattice models using both lanes, and they also need to calculate the project value using the cash flow stream corresponding to the actual configuration of the system. For instance, assuming that the system capacity has been expanded from the lanes of l_1 to l_2 at a certain time that is represented by the node (i, j) (i.e., the node where the traffic demand = $TD_{i,j}$) in Figure 7-14. Once the expansion option has been exercised, the cash flow lattice that descends from this node must be calculated using l_2, instead of l_1, while the rest of the lattice structure should remain unchanged as Figure 7-15 shows. Therefore, project managers need to switch the cash flow lattice that they use in the calculation of the project value depending on whether or not the option to expand the capacity has been exercised.

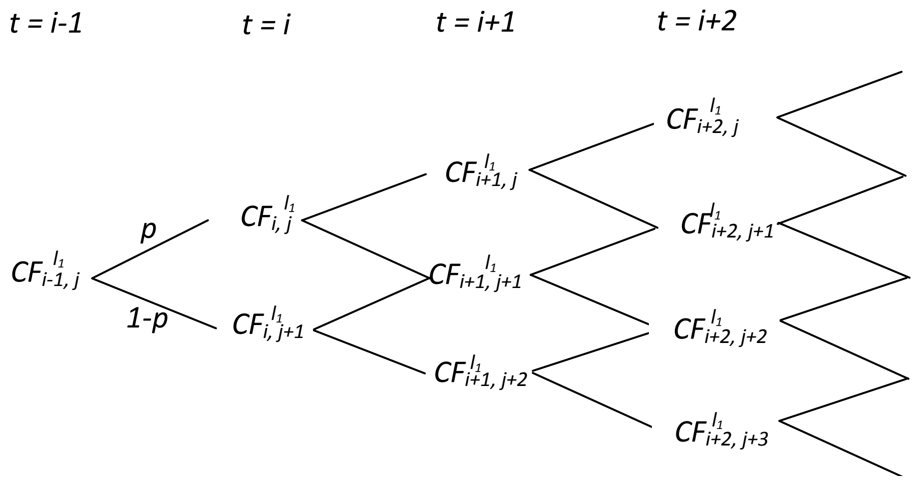


Figure 7-14: Cash Flow Lattice for the Scenarios without the Option to Expand Capacity

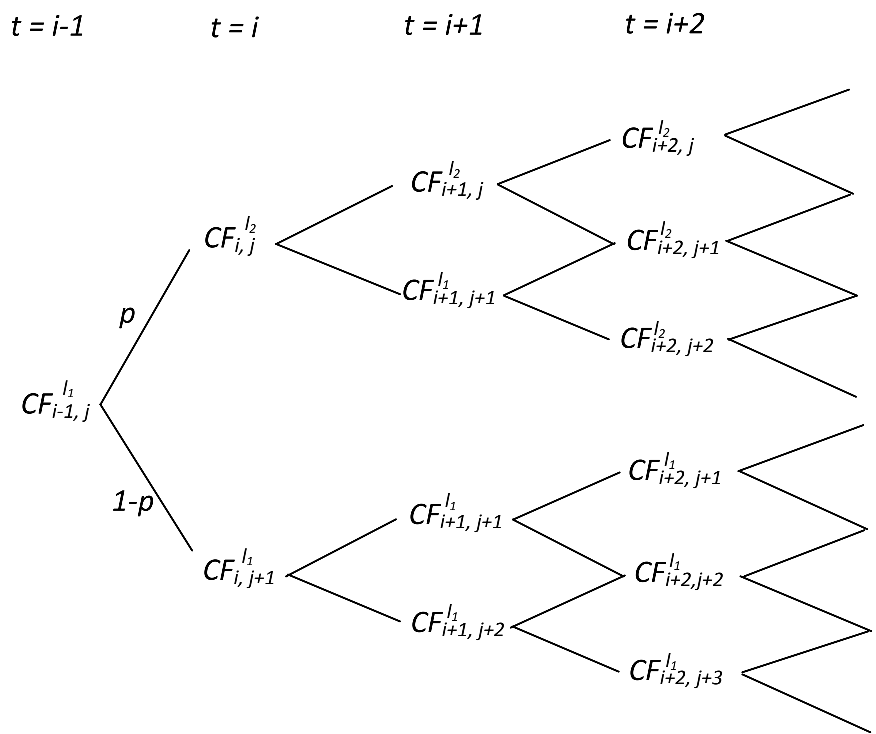


Figure 7-15: Cash Flow Lattice for the Scenarios with the Option to Expand Capacity

Except for the switching of the cash flow lattice, the process of calculating the value of the project with the option is essentially the same as that of the one with no expansion option. Therefore, Equation 7-5, which can be derived from Equation 7-4 for projects with no options, provides the formula that will calculate the total net present value of the project in which the expansion option is exercised at the node (i, j).

$$NPV_{project} = NPV_1\left(CFS_{1,1}^{l_1}\right) + \frac{-NPV_i\left(CFS_{i,j}^{l_1}\right) + NPV_i\left(CFS_{i,j}^{l_2}\right) - CI}{\left(1+r\right)^{i-1}} \qquad \textbf{Equation 7-5}$$

Where $NPV_{project}$: Net present value of the project

$NPV_i\left(CFS_{i,j}^{l_m}\right)$: Value of the cash flow stream, $CFS_{i,j}^{l_m}$, discounted so that it represents the value at time = *i*

$CFS_{i,j}^{l_m}$: Cash flow stream of the system with the number of lanes l_m descending from the node (*i, j*)

CI: Implementation cost of the expansion option (=Capital Investment)

r: Discount rate

Using Equation 7-5, project managers can make a rule for deciding whether or not they should exercise the option at the node (*i, j*). The last term of Equation 7-5 represents the difference between the project values that the project managers will earn by exercising the option compared with not exercising it. Therefore, if this value is greater than zero, they should exercise the option; otherwise, it will be advantageous not to implement the option. As a result, project managers can set up the following decision criterion:

Exercise the expansion option at the node (*i, j*) if:

$$VOP_{i,j} = \frac{-NPV_i\left(CFS_{i,j}^{l_1}\right) + NPV_i\left(CFS_{i,j}^{l_2}\right) - CI}{\left(1+r\right)^{i-1}} > 0 \qquad \textbf{Equation 7-6}$$

Where $VOP_{i,j}$: Value of exercising the expansion option at the node (*i, j*)

7.3.7 Analysis Process

This case study first considers scenarios with "no flexible design" such as Base Scenario, and Scenarios 0 and 1, and with "flexible design" such as Scenarios 3 and 4, including consideration of the size of the system. Then, this case study considers *eight* patterns of the initial demand from (a) to (h), considering inaccuracy of forecasts. Based on the initial demand, and the growth rate and volatility of traffic from the comparable project in the past, each scenario develops the binomial lattice model in order to develop the traffic demand and cash flows, and incorporate flexibility into design. Figure 7-16 shows the decision tree of project evaluation. This model includes both the decision analysis and binomial lattice model.

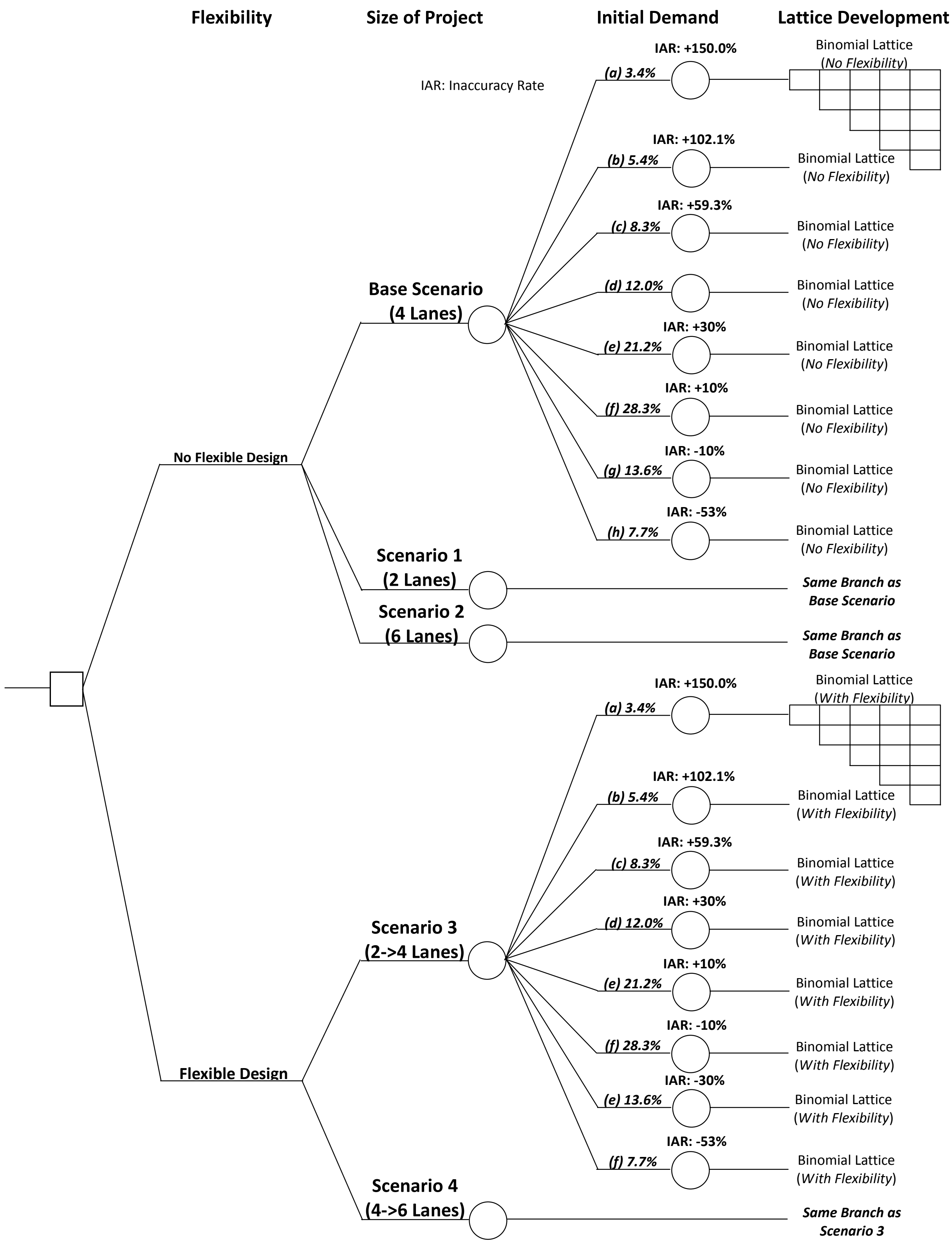


Figure 7-16: Decision Tree of Project Evaluation

7.4 Design Conditions

7.4.1 Capacity of the System

As Section 7.3.4 shows, this case study considers three cases regarding the possible number of lanes, 1) 2 lanes (1 tunnel), 2) 4 lanes (2 tunnels), and 3) 6 lanes (3 tunnels). According to the Road Construction Ordinance in Japan, the daily standard design traffic volume is 18,000 vehicles per lane [67]. Therefore, this case study applies this figure, and the capacity in each scenario is 36,000 vehicles per day for 2 lanes (1 tunnel), 72,000 vehicles per day for 4 lanes (2 tunnels), and 108,000 vehicles per day for 6 lanes (3 tunnels) respectively.

7.4.2 Cash Flow Pro-forma

The cash flow pro-forma must be established when project managers and designers evaluate the value of the project using real options approach. In order to estimate the cash flows of the project, it requires the operational revenue, operational costs, and capital investments as inputs, as well as other inputs. Cash flows can be calculated as follows:

Cash Flows (CF) = [Operational Revenue (OR) **Equation 7-7**
– Operational Costs (OC)
– Depreciation (D)] * (1–Tax rate (t))
– Capital Investments (CI)
+ Depreciation (D)

This section develops and explains the calculating models used on data in this project.

(1) Operational Revenue (OR)

Project managers need to estimate the revenues from the operation. The operational revenue can be calculated as follows:

Operational Revenue (OR) = Toll (T) * Traffic Demand (TD) **Equation 7-8**

Toll (T)

Table 7-6 shows the toll for various types of cars [63]. This case study uses the actual projected service charge for the analysis, and the weighted average toll of ¥5,160 is used.

Table 7-6: Toll Used in the Analysis

Type of Car	Toll	Traffic Proportion
Light Car	¥3,900	4%
Standard-sized Car	¥4,900	87%
Medium-sized Car	¥5,900	3%
Full-sized Car	¥8,100	2%
Truck	¥13,500	3%
Weighted Average Toll		5,163 ≒5,160

Source: Tokyo Bay Crossing Road Company [63]

<u>Traffic Demand (TD)</u>

This case study uses the traffic demand as Section 7.3.5 describes. This initial demand should be considered for 8 patterns as Table 7-3 shows, and the traffic demand is based on the binomial lattice development with the growth rate of 2.74% and the volatility of 5.00%.

(2) Operational Cost (OC)

Operational Cost includes the maintenance costs, repairing cost, and safety costs. Based on the annual financial statements (Periods 12 to 15) of the Tokyo Bay Crossing Road Company, supervision costs of the Aqua-Line from 1998 to 2000 were as shown in Table 7-7 [63]. This case study assumes that the operational costs for the project are the average supervision costs from 1998 to 2000, and that the operational costs will be the same throughout the project life. The average of the supervision costs each year is calculated as ¥5.48 billion.

Table 7-7: Balance of Tokyo Bay Crossing Company and Average Operational Costs (Billion Yen)

	Revenues (a)	Costs (b)			Difference of Balance (a) – (b)
		Supervision Costs	Interest	Total	
1998	14.81	5.64	41.21	46.84	32.02
1999	14.42	5.44	40.42	45.87	31.45
2000	14.33	5.36	40.20	45.56	31.23
Average Supervision Cost		**5.48**			

Source: Tokyo Bay Crossing Road Company [63]

(3) Project Time Period

Based on the fact that the Tokyo Bay Aqua-Line set the redemption period of 40 years, this case study also sets the time period of 40 years [63].

(4) Capital Investment (CI)
Capital investments are divided into three costs for 1) land, 2) initial construction, and 3) expansion construction which is the cost when the option is exercised. The total project cost of the Aqua-Line was ¥1,440 billion which included the interest accrued during construction phase of ¥280 billion. Therefore, the net project cost (land + construction cost) was ¥1,160 billion. Marukawa assumed that land acquisition cost was about 5% of the net project cost (¥58 billion) and this case study does likewise [29].

This case study assumes that the construction cost of one tunnel (2 lanes) is ¥300 billion. In this respect, the initial construction costs are assumed to be ¥802 billion in Scenario 1 (2 lanes, 1 tunnel), ¥1,402 billion in Scenario 2 (6 lanes, 3 tunnels), ¥802 billion in Scenario 3 (initially, 2 lanes, 1 tunnel), and ¥1,102 billion in Scenario 4 (initially, 4 lanes, 2 tunnels). The expansion construction cost in Base Scenario, Scenarios 1 and 2 is zero since these scenarios do not expand, and the one in Scenarios 3 and 4 is ¥300 billion. This case study also assumes that land cost and the initial construction cost occur and should be paid in the year 0 and that all of the expansion costs occur at the time of the expansion and should be paid at that time. Table 7-8 shows the summary of capital investments.

Table 7-8: Capital Investments (Billion Yen)

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Land Acquisition Cost	58	58	58	58	58
Initial Construction Cost	1,102	802	1,402	802	1,102
Expansion Construction Cost	-	-	-	300 (2 to 4 lanes)	300 (4 to 6 lanes)

(5) Construction Period
It took about 10 years to build the Aqua-Line. This case study uses the construction period of 10 years.

(6) Depreciation and Tax
Depreciation can be computed as capital investments divided by the rest of the project time period. The case study assumes that the 40% tax rate applies to each scenario.

7.4.3 Discount Rate

As Chapter 4 explains, the WACC or the CAPM should be appropriate as a project specific discount rate when evaluating the value of projects. But the actual project was discounted by the interest rate of long-term government bonds of 4%, in accordance with the practice of the Japanese government for large-scale public works. Therefore, this case study also uses the discount rate of 4% [59].

7.5 Results of Project Evaluation

7.5.1 Binomial Lattice Distribution of Traffic Demand

Based on the binomial lattice model, project managers can calculate the distribution of the traffic for the Aqua-Line. Table 7-9 shows the distribution of traffic demand and Table 7-10 shows the distribution of probabilities in case the initial demand is (f) 22,500 with the inaccuracy rate of -10%.

Table 7-9: Binomial Lattice Distribution of Traffic Demand (f) (vehicles / day)

Year 0	1	2	3	9	10	11	12	19	20	21	22	29	30	31	32	38	39	40
22,500	23,654	24,866	26,141	35,287	37,096	38,998	40,998	58,178	61,161	64,297	67,594	95,920	100,838	106,008	111,443	150,433	158,145	166,254
	21,403	22,500	23,654	31,929	33,566	35,287	37,096	52,642	55,341	58,178	61,161	86,792	91,242	95,920	100,838	136,117	143,096	150,433
		20,359	21,403	28,891	30,372	31,929	33,566	47,633	50,075	52,642	55,341	78,533	82,559	86,792	91,242	123,164	129,479	136,117
			19,366	26,141	27,482	28,891	30,372	43,100	45,309	47,633	50,075	71,059	74,703	78,533	82,559	111,443	117,157	123,164
				23,654	24,866	26,141	27,482	38,998	40,998	43,100	45,309	64,297	67,594	71,059	74,703	100,838	106,008	111,443
				21,403	22,500	23,654	24,866	35,287	37,096	38,998	40,998	58,178	61,161	64,297	67,594	91,242	95,920	100,838
				19,366	20,359	21,403	22,500	31,929	33,566	35,287	37,096	52,642	55,341	58,178	61,161	82,559	86,792	91,242
				17,523	18,421	19,366	20,359	28,891	30,372	31,929	33,566	47,633	50,075	52,642	55,341	74,703	78,533	82,559
				15,855	16,668	17,523	18,421	26,141	27,482	28,891	30,372	43,100	45,309	47,633	50,075	67,594	71,059	74,703
				14,347	15,082	15,855	16,668	23,654	24,866	26,141	27,482	38,998	40,998	43,100	45,309	61,161	64,297	67,594
					13,647	14,347	15,082	21,403	22,500	23,654	24,866	35,287	37,096	38,998	40,998	55,341	58,178	61,161
						12,981	13,647	19,366	20,359	21,403	22,500	31,929	33,566	35,287	37,096	50,075	52,642	55,341
							12,348	17,523	18,421	19,366	20,359	28,891	30,372	31,929	33,566	45,309	47,633	50,075
								15,855	16,668	17,523	18,421	26,141	27,482	28,891	30,372	40,998	43,100	45,309
								14,347	15,082	15,855	16,668	23,654	24,866	26,141	27,482	37,096	38,998	40,998
								12,981	13,647	14,347	15,082	21,403	22,500	23,654	24,866	33,566	35,287	37,096
								11,746	12,348	12,981	13,647	19,366	20,359	21,403	22,500	30,372	31,929	33,566
								10,628	11,173	11,746	12,348	17,523	18,421	19,366	20,359	27,482	28,891	30,372
								9,617	10,110	10,628	11,173	15,855	16,668	17,523	18,421	24,866	26,141	27,482
								8,702	9,148	9,617	10,110	14,347	15,082	15,855	16,668	22,500	23,654	24,866
									8,277	8,702	9,148	12,981	13,647	14,347	15,082	20,359	21,403	22,500
										7,874	8,277	11,746	12,348	12,981	13,647	18,421	19,366	20,359
											7,490	10,628	11,173	11,746	12,348	16,668	17,523	18,421
												9,617	10,110	10,628	11,173	15,082	15,855	16,668
												8,702	9,148	9,617	10,110	13,647	14,347	15,082
												7,874	8,277	8,702	9,148	12,348	12,981	13,647
												7,124	7,490	7,874	8,277	11,173	11,746	12,348
												6,446	6,777	7,124	7,490	10,110	10,628	11,173
												5,833	6,132	6,446	6,777	9,148	9,617	10,110
												5,278	5,548	5,833	6,132	8,277	8,702	9,148
													5,020	5,278	5,548	7,490	7,874	8,277
														4,776	5,020	6,777	7,124	7,490
															4,543	6,132	6,446	6,777
																5,548	5,833	6,132
																5,020	5,278	5,548
																4,543	4,776	5,020
																4,110	4,321	4,543
																3,719	3,910	4,110
																3,365	3,538	3,719
																	3,201	3,365
																		3,045

Note: Years 4-8, 13-18, 23-28, and 33-37 are abbreviated due to the limited space.

Table 7-10: Binomial Lattice Distribution of Probabilities (f)

Year 0	1	2	3	9	10	11	12	19	20	21	22	29	30	31	32	38	39	40
1.000	0.774	0.599	0.464	0.100	0.077	0.060	0.046	0.008	0.006	0.005	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	0.226	0.350	0.406	0.262	0.225	0.192	0.162	0.043	0.035	0.028	0.023	0.005	0.004	0.003	0.003	0.001	0.001	0.000
		0.051	0.119	0.306	0.296	0.280	0.260	0.112	0.096	0.083	0.070	0.021	0.017	0.014	0.012	0.004	0.003	0.002
			0.012	0.208	0.231	0.245	0.253	0.186	0.169	0.153	0.137	0.054	0.046	0.040	0.034	0.012	0.010	0.009
				0.091	0.118	0.143	0.166	0.217	0.210	0.200	0.190	0.102	0.092	0.081	0.072	0.032	0.027	0.024
				0.027	0.041	0.059	0.078	0.190	0.196	0.199	0.199	0.150	0.139	0.128	0.118	0.063	0.056	0.050
				0.005	0.010	0.017	0.026	0.129	0.143	0.155	0.165	0.175	0.169	0.162	0.155	0.101	0.093	0.084
				0.001	0.002	0.004	0.007	0.070	0.084	0.097	0.110	0.168	0.169	0.169	0.168	0.135	0.127	0.120
				0.000	0.000	0.001	0.001	0.031	0.040	0.050	0.060	0.135	0.142	0.148	0.153	0.153	0.149	0.144
				0.000	0.000	0.000	0.000	0.011	0.015	0.021	0.027	0.092	0.101	0.111	0.119	0.149	0.150	0.150
					0.000	0.000	0.000	0.003	0.005	0.007	0.010	0.054	0.062	0.071	0.080	0.126	0.131	0.135
						0.000	0.000	0.001	0.001	0.002	0.003	0.027	0.033	0.040	0.047	0.094	0.101	0.108
							0.000	0.000	0.000	0.001	0.001	0.012	0.015	0.019	0.024	0.062	0.069	0.076
								0.000	0.000	0.000	0.000	0.005	0.006	0.008	0.011	0.036	0.042	0.048
								0.000	0.000	0.000	0.000	0.002	0.002	0.003	0.004	0.019	0.023	0.027
								0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.009	0.011	0.014
								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.005	0.006
								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.003
								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
									0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
										0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
											0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000	0.000	0.000
													0.000	0.000	0.000	0.000	0.000	0.000
														0.000	0.000	0.000	0.000	0.000
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																0.000	0.000	0.000
																0.000	0.000	0.000
																0.000	0.000	0.000
																0.000	0.000	0.000
																	0.000	0.000
																		0.000

Note: Years 4-8, 13-18, 23-28, and 33-37 are abbreviated due to the limited space.

7.5.2 Net Present Value of the Project without Expansion Option

As Section 7.3.6 shows, project managers can develop the net present value of the cash flow stream without option to expand capacity. Table 7-11, Table 7-12, Table 7-13, Table 7-14 and Table 7-15 show the net present value of the cash flow stream in Base Scenario and Scenarios 1, 2, 3, and 4 respectively in case the initial demand is (f) 22,500 with the inaccuracy rate of -10%.

Table 7-11: Net Present Value of the Project (Base Scenario) (f) (million)

Year 0	1	2	3	9	10	11	12	19	20	21	22	29	30	31	32	38	39	40
¥-184,322	¥1,032,292	¥1,055,098	¥1,077,737	¥1,202,765	¥1,220,226	¥1,236,148	¥1,250,261	¥1,269,086	¥1,255,027	¥1,235,115	¥1,208,662	¥875,269	¥817,018	¥756,437	¥693,433	¥258,810	¥175,901	¥89,675
	¥954,477	¥975,639	¥996,748	¥1,116,534	¥1,134,095	¥1,150,508	¥1,165,551	¥1,208,325	¥1,201,061	¥1,189,051	¥1,171,710	¥875,248	¥817,014	¥756,437	¥693,433	¥258,810	¥175,901	¥89,675
		¥901,390	¥920,771	¥1,032,768	¥1,049,719	¥1,065,812	¥1,080,868	¥1,137,576	¥1,135,068	¥1,128,739	¥1,118,100	¥874,905	¥816,935	¥756,421	¥693,430	¥258,810	¥175,901	¥89,675
			¥850,431	¥953,166	¥969,018	¥984,210	¥998,600	¥1,061,066	¥1,061,560	¥1,058,992	¥1,052,955	¥869,806	¥815,630	¥756,109	¥693,365	¥258,810	¥175,901	¥89,675
				¥878,912	¥893,392	¥907,338	¥920,635	¥982,738	¥984,795	¥984,376	¥981,152	¥844,056	¥801,522	¥751,174	¥692,154	¥258,810	¥175,901	¥89,675
				¥810,613	¥823,631	¥836,192	¥848,198	¥906,028	¥908,583	¥909,084	¥907,265	¥800,546	¥766,511	¥726,064	¥678,482	¥258,810	¥175,901	¥89,675
				¥748,358	¥759,951	¥771,134	¥781,820	¥833,487	¥835,890	¥836,522	¥835,163	¥746,334	¥718,008	¥684,398	¥644,923	¥258,810	¥175,901	¥89,675
				¥691,883	¥702,150	¥712,039	¥721,473	¥766,532	¥768,492	¥768,872	¥767,482	¥688,249	¥663,444	¥634,160	¥599,936	¥258,344	¥175,901	¥89,675
				¥640,750	¥649,807	¥658,513	¥666,798	¥705,553	¥707,004	¥707,019	¥705,429	¥631,661	¥609,068	¥582,513	¥551,611	¥248,959	¥173,756	¥89,675
				¥594,478	¥602,439	¥610,073	¥617,316	¥650,305	¥651,272	¥650,927	¥649,116	¥579,378	¥558,458	¥533,945	¥505,495	¥229,081	¥160,829	¥84,696
					¥559,578	¥566,241	¥572,542	¥600,308	¥600,836	¥600,163	¥598,149	¥531,963	¥512,520	¥489,806	¥463,508	¥209,564	¥147,076	¥77,427
						¥526,581	¥532,029	¥555,069	¥555,200	¥554,230	¥552,032	¥489,061	¥470,954	¥449,867	¥425,515	¥191,904	¥134,631	¥70,850
							¥495,371	¥514,135	¥513,906	¥512,668	¥510,304	¥450,241	¥433,344	¥413,729	¥391,139	¥175,925	¥123,371	¥64,898
								¥477,097	¥476,543	¥475,061	¥472,546	¥415,115	¥399,312	¥381,029	¥360,034	¥161,466	¥113,182	¥59,513
								¥443,583	¥442,734	¥441,033	¥438,382	¥383,332	¥368,519	¥351,442	¥331,888	¥148,384	¥103,963	¥54,641
								¥413,258	¥412,143	¥410,243	¥407,469	¥354,574	¥340,657	¥324,670	¥306,422	¥136,546	¥95,621	¥50,232
								¥385,819	¥384,464	¥382,383	¥379,497	¥328,552	¥315,446	¥300,446	¥283,378	¥125,835	¥88,073	¥46,243
								¥360,992	¥359,418	¥357,174	¥354,188	¥305,007	¥292,634	¥278,527	¥262,528	¥116,143	¥81,243	¥42,633
								¥338,527	¥336,756	¥334,364	¥331,287	¥283,702	¥271,992	¥258,694	¥243,661	¥107,373	¥75,064	¥39,367
								¥318,200	¥316,250	¥313,725	¥310,565	¥264,425	¥253,316	¥240,748	¥226,591	¥99,438	¥69,472	¥36,412
									¥297,696	¥295,050	¥291,815	¥246,982	¥236,416	¥224,510	¥211,144	¥92,258	¥64,412	¥33,738
										¥278,152	¥274,850	¥231,199	¥221,125	¥209,818	¥197,168	¥85,762	¥59,834	¥31,318
											¥259,499	¥216,918	¥207,289	¥196,523	¥184,521	¥79,883	¥55,692	¥29,129
												¥203,996	¥194,769	¥184,494	¥173,078	¥74,564	¥51,944	¥27,148
												¥192,303	¥183,441	¥173,609	¥162,724	¥69,751	¥48,552	¥25,355
												¥181,724	¥173,191	¥163,760	¥153,355	¥65,397	¥45,483	¥23,734
												¥172,151	¥163,916	¥154,849	¥144,878	¥61,456	¥42,707	¥22,266
												¥163,489	¥155,524	¥146,785	¥137,208	¥57,891	¥40,194	¥20,938
												¥155,651	¥147,931	¥139,489	¥130,267	¥54,665	¥37,921	¥19,737
												¥148,560	¥141,060	¥132,887	¥123,987	¥51,745	¥35,864	¥18,649
													¥134,843	¥126,914	¥118,305	¥49,104	¥34,002	¥17,666
														¥121,508	¥113,163	¥46,714	¥32,318	¥16,776
															¥108,511	¥44,552	¥30,794	¥15,970
																¥42,595	¥29,415	¥15,241
																¥40,824	¥28,168	¥14,582
																¥39,222	¥27,039	¥13,985
																¥37,773	¥26,017	¥13,445
																¥36,461	¥25,093	¥12,957
																¥35,274	¥24,257	¥12,515
																	¥23,500	¥12,115
																		¥11,753

Note: Years 4-8, 13-18, 23-28, and 33-37 are abbreviated due to the limited space.

Table 7-12: Net Present Value of the Project (Scenario 1) (f) (million)

Year 0	1	2	3	9	10	11	12	19	20	21	22	29	30	31	32	38	39	40
¥-63,541	¥837,453	¥846,373	¥853,753	¥851,430	¥840,355	¥826,872	¥812,314	¥691,243	¥671,059	¥650,068	¥628,238	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
	¥797,028	¥807,676	¥817,146	¥837,310	¥832,113	¥823,616	¥811,427	¥691,243	¥671,059	¥650,068	¥628,238	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
		¥765,884	¥776,748	¥813,488	¥812,822	¥809,498	¥803,187	¥691,241	¥671,059	¥650,068	¥628,238	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
			¥733,919	¥782,325	¥785,067	¥785,685	¥783,902	¥691,224	¥671,054	¥650,067	¥628,238	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥745,804	¥751,016	¥754,548	¥756,167	¥690,985	¥670,990	¥650,050	¥628,233	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥705,607	¥712,506	¥718,091	¥722,167	¥687,740	¥670,111	¥649,813	¥628,170	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥663,195	¥671,122	¥678,037	¥683,777	¥673,664	¥661,899	¥646,577	¥627,296	¥448,918	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥619,874	¥628,277	¥635,910	¥642,642	¥649,982	¥642,710	¥632,531	¥619,105	¥448,917	¥419,041	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥576,819	¥585,244	¥593,092	¥600,254	¥619,200	¥615,250	¥608,941	¥599,983	¥448,905	¥419,039	¥387,970	¥355,656	¥132,741	¥90,218	¥45,993
				¥535,060	¥543,160	¥550,825	¥557,967	¥583,572	¥581,936	¥578,398	¥572,714	¥448,694	¥418,990	¥387,959	¥355,654	¥132,741	¥90,218	¥45,993
					¥502,969	¥510,169	¥516,961	¥545,205	¥545,016	¥543,298	¥539,849	¥445,583	¥418,190	¥387,767	¥355,613	¥132,741	¥90,218	¥45,993
						¥471,922	¥478,157	¥506,056	¥506,606	¥505,915	¥503,819	¥432,004	¥410,319	¥384,749	¥354,868	¥132,741	¥90,218	¥45,993
							¥442,144	¥467,817	¥468,589	¥468,324	¥466,892	¥409,787	¥392,250	¥371,520	¥347,238	¥132,741	¥90,218	¥45,993
								¥431,727	¥432,408	¥432,191	¥430,967	¥382,463	¥367,695	¥350,288	¥329,953	¥132,741	¥90,218	¥45,993
								¥398,455	¥398,910	¥398,560	¥397,311	¥353,414	¥340,350	¥325,037	¥307,247	¥132,436	¥90,218	¥45,993
								¥368,168	¥368,369	¥367,836	¥366,485	¥325,244	¥313,259	¥299,277	¥283,107	¥127,202	¥88,815	¥45,993
								¥340,732	¥340,693	¥339,981	¥338,519	¥299,271	¥288,113	¥275,140	¥260,180	¥117,177	¥82,188	¥43,243
								¥315,904	¥315,647	¥314,772	¥313,210	¥275,725	¥265,301	¥253,221	¥239,330	¥107,485	¥75,359	¥39,633
								¥293,439	¥292,985	¥291,962	¥290,309	¥254,420	¥244,660	¥233,388	¥220,463	¥98,715	¥69,179	¥36,367
								¥273,112	¥272,479	¥271,323	¥269,587	¥235,143	¥225,983	¥215,442	¥203,392	¥90,780	¥63,587	¥33,412
									¥253,925	¥252,648	¥250,837	¥217,700	¥209,083	¥199,204	¥187,946	¥83,600	¥58,528	¥30,738
										¥235,750	¥233,872	¥201,917	¥193,792	¥184,512	¥173,969	¥77,103	¥53,950	¥28,318
											¥218,521	¥187,636	¥179,956	¥171,217	¥161,323	¥71,225	¥49,807	¥26,129
												¥174,714	¥167,436	¥159,188	¥149,880	¥65,906	¥46,059	¥24,148
												¥163,022	¥156,108	¥148,303	¥139,526	¥61,093	¥42,667	¥22,355
												¥152,442	¥145,858	¥138,454	¥130,157	¥56,738	¥39,599	¥20,734
												¥142,869	¥136,584	¥129,543	¥121,680	¥52,798	¥36,822	¥19,266
												¥134,208	¥128,192	¥121,479	¥114,010	¥49,232	¥34,309	¥17,938
												¥126,370	¥120,598	¥114,183	¥107,069	¥46,006	¥32,036	¥16,737
												¥119,278	¥113,727	¥107,581	¥100,789	¥43,087	¥29,979	¥15,649
													¥107,510	¥101,608	¥95,107	¥40,446	¥28,118	¥14,666
														¥96,202	¥89,965	¥38,056	¥26,433	¥13,776
															¥85,313	¥35,893	¥24,910	¥12,970
																¥33,936	¥23,531	¥12,241
																¥32,166	¥22,283	¥11,582
																¥30,564	¥21,154	¥10,985
																¥29,114	¥20,133	¥10,445
																¥27,803	¥19,208	¥9,957
																¥26,616	¥18,372	¥9,515
																	¥17,615	¥9,115
																		¥8,753

Note: Years 4-8, 13-18, 23-28, and 33-37 are abbreviated due to the limited space.

Table 7-13: Net Present Value of the Project (Scenario 2) (f) (million)

Year 0	1	2	3	9	10	11	12	19	20	21	22	29	30	31	32	38	39	40
¥-476,796	¥1,041,211	¥1,065,650	¥1,090,199	¥1,235,274	¥1,258,105	¥1,280,193	¥1,301,369	¥1,405,213	¥1,410,192	¥1,411,569	¥1,408,862	¥1,222,390	¥1,162,085	¥1,090,292	¥1,005,738	¥376,221	¥255,699	¥130,356
	¥958,562	¥980,543	¥1,002,627	¥1,133,327	¥1,153,967	¥1,173,974	¥1,193,206	¥1,290,427	¥1,296,086	¥1,298,764	¥1,298,071	¥1,156,019	¥1,108,220	¥1,051,014	¥983,330	¥376,221	¥255,699	¥130,356
		¥903,390	¥923,207	¥1,040,434	¥1,058,943	¥1,076,888	¥1,094,144	¥1,182,047	¥1,187,443	¥1,190,275	¥1,190,218	¥1,074,180	¥1,034,740	¥987,560	¥931,782	¥376,221	¥255,699	¥130,356
			¥851,295	¥956,179	¥972,707	¥988,720	¥1,004,105	¥1,082,106	¥1,086,828	¥1,089,265	¥1,089,139	¥987,036	¥952,741	¥911,887	¥863,793	¥375,349	¥255,699	¥130,356
				¥879,897	¥894,620	¥908,868	¥922,539	¥991,123	¥995,082	¥996,971	¥996,539	¥902,451	¥871,411	¥834,569	¥791,358	¥359,974	¥251,689	¥130,356
				¥810,867	¥823,955	¥836,603	¥848,720	¥908,700	¥911,938	¥913,289	¥912,528	¥824,429	¥795,876	¥762,069	¥722,498	¥329,951	¥231,910	¥122,263
				¥748,406	¥760,014	¥771,215	¥781,925	¥834,114	¥836,696	¥837,558	¥836,493	¥753,694	¥727,345	¥696,220	¥659,860	¥300,834	¥211,392	¥111,419
				¥691,889	¥702,158	¥712,049	¥721,486	¥766,626	¥768,615	¥769,034	¥767,695	¥689,691	¥665,335	¥636,639	¥603,183	¥274,489	¥192,827	¥101,607
				¥640,751	¥649,807	¥658,513	¥666,799	¥705,559	¥707,012	¥707,030	¥705,444	¥631,779	¥609,227	¥582,727	¥551,899	¥250,651	¥176,029	¥92,729
				¥594,478	¥602,439	¥610,073	¥617,316	¥650,305	¥651,272	¥650,927	¥649,116	¥579,378	¥558,458	¥533,945	¥505,495	¥229,081	¥160,829	¥84,696
					¥559,578	¥566,241	¥572,542	¥600,308	¥600,836	¥600,163	¥598,149	¥531,963	¥512,520	¥489,806	¥463,508	¥209,564	¥147,076	¥77,427
						¥526,581	¥532,029	¥555,069	¥555,200	¥554,230	¥552,032	¥489,061	¥470,954	¥449,867	¥425,515	¥191,904	¥134,631	¥70,850
							¥495,371	¥514,135	¥513,906	¥512,668	¥510,304	¥450,241	¥433,344	¥413,729	¥391,139	¥175,925	¥123,371	¥64,898
								¥477,097	¥476,543	¥475,061	¥472,546	¥415,115	¥399,312	¥381,029	¥360,034	¥161,466	¥113,182	¥59,513
								¥443,583	¥442,734	¥441,033	¥438,382	¥383,332	¥368,519	¥351,442	¥331,888	¥148,384	¥103,963	¥54,641
								¥413,258	¥412,143	¥410,243	¥407,469	¥354,574	¥340,657	¥324,670	¥306,422	¥136,546	¥95,621	¥50,232
								¥385,819	¥384,464	¥382,383	¥379,497	¥328,552	¥315,446	¥300,446	¥283,378	¥125,835	¥88,073	¥46,243
								¥360,992	¥359,418	¥357,174	¥354,188	¥305,007	¥292,634	¥278,527	¥262,528	¥116,143	¥81,243	¥42,633
								¥338,527	¥336,756	¥334,364	¥331,287	¥283,702	¥271,992	¥258,694	¥243,661	¥107,373	¥75,064	¥39,367
								¥318,200	¥316,250	¥313,725	¥310,565	¥264,425	¥253,316	¥240,748	¥226,591	¥99,438	¥69,472	¥36,412
									¥297,696	¥295,050	¥291,815	¥246,982	¥236,416	¥224,510	¥211,144	¥92,258	¥64,412	¥33,738
										¥278,152	¥274,850	¥231,199	¥221,125	¥209,818	¥197,168	¥85,762	¥59,834	¥31,318
											¥259,499	¥216,918	¥207,289	¥196,523	¥184,521	¥79,883	¥55,692	¥29,129
												¥203,996	¥194,769	¥184,494	¥173,078	¥74,564	¥51,944	¥27,148
												¥192,303	¥183,441	¥173,609	¥162,724	¥69,751	¥48,552	¥25,355
												¥181,724	¥173,191	¥163,760	¥153,355	¥65,397	¥45,483	¥23,734
												¥172,151	¥163,916	¥154,849	¥144,878	¥61,456	¥42,707	¥22,266
												¥163,489	¥155,524	¥146,785	¥137,208	¥57,891	¥40,194	¥20,938
												¥155,651	¥147,931	¥139,489	¥130,267	¥54,665	¥37,921	¥19,737
												¥148,560	¥141,060	¥132,887	¥123,987	¥51,745	¥35,864	¥18,649
													¥134,843	¥126,914	¥118,305	¥49,104	¥34,002	¥17,666
														¥121,508	¥113,163	¥46,714	¥32,318	¥16,776
															¥108,511	¥44,552	¥30,794	¥15,970
																¥42,595	¥29,415	¥15,241
																¥40,824	¥28,168	¥14,582
																¥39,222	¥27,039	¥13,985
																¥37,773	¥26,017	¥13,445
																¥36,461	¥25,093	¥12,957
																¥35,274	¥24,257	¥12,515
																	¥23,500	¥12,115
																		¥11,753

Note: Years 4-8, 13-18, 23-28, and 33-37 are abbreviated due to the limited space.

Table 7-14: Net Present Value of the Project without Option (Scenario 3) (f) (million)

Year 0	1	2	3	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	32	33	34	39	40
¥-63,541	¥837,453	¥846,373	¥853,753	¥797,028	¥781,091	¥764,505	¥747,253	¥729,311	¥710,650	¥691,243	¥671,059	¥650,068	¥628,238	¥605,534	¥581,923	¥557,366	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
	¥797,028	¥807,676	¥817,146	¥796,787	¥781,025	¥764,488	¥747,249	¥729,309	¥710,650	¥691,243	¥671,059	¥650,068	¥628,238	¥605,534	¥581,923	¥557,366	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
		¥765,884	¥776,748	¥793,532	¥780,139	¥764,247	¥747,183	¥729,292	¥710,645	¥691,241	¥671,059	¥650,068	¥628,238	¥605,534	¥581,923	¥557,366	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
			¥733,919	¥779,418	¥771,902	¥760,994	¥746,298	¥729,052	¥710,580	¥691,224	¥671,054	¥650,067	¥628,238	¥605,534	¥581,923	¥557,366	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥755,619	¥752,628	¥746,887	¥738,066	¥725,802	¥709,697	¥690,985	¥670,990	¥650,050	¥628,233	¥605,533	¥581,922	¥557,366	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥724,523	¥724,923	¥723,111	¥718,808	¥711,707	¥701,473	¥687,740	¥670,111	¥649,813	¥628,170	¥605,517	¥581,918	¥557,365	¥531,828	¥505,268	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥688,164	¥691,003	¥692,077	¥691,152	¥687,967	¥682,241	¥673,664	¥661,899	¥646,577	¥627,296	¥605,283	¥581,857	¥557,350	¥531,824	¥505,267	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥648,325	¥652,794	¥655,870	¥657,355	¥657,031	¥654,661	¥649,982	¥642,710	¥632,531	¥619,105	¥602,059	¥580,990	¥557,120	¥531,765	¥505,253	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥606,610	¥612,024	¥616,349	¥619,419	¥621,054	¥621,054	¥619,200	¥615,250	¥608,941	¥599,983	¥588,062	¥572,832	¥553,918	¥530,912	¥505,031	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥564,489	¥570,281	¥575,222	¥579,179	¥582,003	¥583,528	¥583,572	¥581,936	¥578,398	¥572,714	¥564,619	¥553,821	¥539,999	¥522,807	¥501,863	¥355,654	¥322,048	¥287,097	¥90,218	¥45,993
				¥523,265	¥528,994	¥534,052	¥538,329	¥541,705	¥544,046	¥545,205	¥545,016	¥543,298	¥539,849	¥534,449	¥526,853	¥516,793	¥503,973	¥488,073	¥355,613	¥322,042	¥287,097	¥90,218	¥45,993
				¥483,993	¥489,360	¥494,177	¥498,359	¥501,806	¥504,412	¥506,056	¥506,606	¥505,915	¥503,819	¥500,138	¥494,673	¥487,202	¥477,483	¥465,245	¥354,868	¥321,877	¥287,067	¥90,218	¥45,993
				¥447,387	¥452,227	¥456,597	¥460,426	¥463,633	¥466,130	¥467,817	¥468,589	¥468,324	¥466,892	¥464,147	¥459,928	¥454,057	¥446,337	¥436,550	¥347,238	¥319,012	¥286,408	¥90,218	¥45,993
				¥413,785	¥418,044	¥421,886	¥425,248	¥428,060	¥430,247	¥431,727	¥432,408	¥432,191	¥430,967	¥428,615	¥425,004	¥419,990	¥413,413	¥405,098	¥329,953	¥306,371	¥279,189	¥90,218	¥45,993
					¥386,908	¥390,219	¥393,094	¥395,470	¥397,282	¥398,455	¥398,910	¥398,560	¥397,311	¥395,059	¥391,691	¥387,085	¥381,106	¥373,610	¥307,247	¥286,730	¥263,209	¥90,218	¥45,993
						¥361,499	¥363,914	¥365,872	¥367,312	¥368,168	¥368,369	¥367,836	¥366,485	¥364,222	¥360,947	¥356,552	¥350,918	¥343,917	¥283,107	¥264,540	¥243,352	¥88,815	¥45,993
							¥337,497	¥339,071	¥340,170	¥340,732	¥340,693	¥339,981	¥338,519	¥336,224	¥333,004	¥328,761	¥323,387	¥316,766	¥260,180	¥243,047	¥223,540	¥82,188	¥43,243
								¥314,820	¥315,609	¥315,904	¥315,647	¥314,772	¥313,210	¥310,884	¥307,711	¥303,601	¥298,458	¥292,175	¥239,330	¥223,458	¥205,423	¥75,359	¥39,633
									¥293,385	¥293,439	¥292,985	¥291,962	¥290,309	¥287,954	¥284,824	¥280,835	¥275,901	¥269,924	¥220,463	¥205,732	¥189,030	¥69,179	¥36,367
										¥273,112	¥272,479	¥271,323	¥269,587	¥267,207	¥264,115	¥260,236	¥255,491	¥249,791	¥203,392	¥189,694	¥174,197	¥63,587	¥33,412
											¥253,925	¥252,648	¥250,837	¥248,434	¥245,377	¥241,597	¥237,023	¥231,573	¥187,946	¥175,182	¥160,775	¥58,528	¥30,738
												¥235,750	¥233,872	¥231,448	¥228,422	¥224,732	¥220,312	¥215,089	¥173,969	¥162,051	¥148,631	¥53,950	¥28,318
													¥218,521	¥216,078	¥213,081	¥209,472	¥205,192	¥200,174	¥161,323	¥150,169	¥137,642	¥49,807	¥26,129
														¥202,171	¥199,199	¥195,664	¥191,511	¥186,678	¥149,880	¥139,418	¥127,699	¥46,059	¥24,148
															¥186,639	¥183,170	¥179,131	¥174,467	¥139,526	¥129,690	¥118,702	¥42,667	¥22,355
																¥171,865	¥167,930	¥163,418	¥130,157	¥120,888	¥110,562	¥39,599	¥20,734
																	¥157,794	¥153,420	¥121,680	¥112,924	¥103,196	¥36,822	¥19,266
																		¥144,373	¥114,010	¥105,717	¥96,531	¥34,309	¥17,938
																			¥107,069	¥99,196	¥90,500	¥32,036	¥16,737
																			¥100,789	¥93,296	¥85,043	¥29,979	¥15,649
																			¥95,107	¥87,957	¥80,106	¥28,118	¥14,666
																			¥89,965	¥83,127	¥75,638	¥26,433	¥13,776
																			¥85,313	¥78,756	¥71,596	¥24,910	¥12,970
																				¥74,801	¥67,938	¥23,531	¥12,241
																					¥64,628	¥22,283	¥11,582
																						¥21,154	¥10,985
																						¥20,133	¥10,445
																						¥19,208	¥9,957
																						¥18,372	¥9,515
																						¥17,615	¥9,115
																							¥8,753

Note: Years 4-12, 28-31, and 35-38 are abbreviated due to the limited space.

Table 7-15: Net Present Value of the Project without Option (Scenario 4) (f) (million)

Year 0	1	2	3	13	14	15	16	17	18	19	20	21	26	27	28	29	30	31	32	33	34	38	39	40
¥-184,322	¥1,032,292	¥1,055,098	¥1,077,737	¥1,262,268	¥1,271,837	¥1,278,607	¥1,282,177	¥1,282,109	¥1,277,921	¥1,269,086	¥1,255,027	¥1,235,115	¥1,036,819	¥985,112	¥931,275	¥875,269	¥817,018	¥756,437	¥693,433	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
	¥954,477	¥975,639	¥996,748	¥1,178,982	¥1,190,528	¥1,199,889	¥1,206,734	¥1,210,697	¥1,211,375	¥1,208,325	¥1,201,061	¥1,189,051	¥1,035,419	¥984,749	¥931,185	¥875,248	¥817,014	¥756,437	¥693,433	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
		¥901,390	¥920,771	¥1,094,691	¥1,107,061	¥1,117,734	¥1,126,439	¥1,132,876	¥1,136,711	¥1,137,576	¥1,135,068	¥1,128,739	¥1,020,890	¥979,549	¥929,822	¥874,905	¥816,935	¥756,421	¥693,430	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
			¥850,431	¥1,012,031	¥1,024,327	¥1,035,290	¥1,044,703	¥1,052,321	¥1,057,875	¥1,061,066	¥1,061,560	¥1,058,992	¥984,468	¥953,414	¥915,452	¥869,806	¥815,630	¥756,109	¥693,365	¥627,897	¥559,762	¥258,810	¥175,901	¥89,675
				¥933,156	¥944,756	¥955,277	¥964,543	¥972,358	¥978,503	¥982,738	¥984,795	¥984,376	¥932,314	¥908,765	¥879,564	¥844,056	¥801,522	¥751,174	¥692,154	¥627,633	¥559,716	¥258,810	¥175,901	¥89,675
				¥859,541	¥870,101	¥879,747	¥888,332	¥895,696	¥901,660	¥906,028	¥908,583	¥909,084	¥870,439	¥851,943	¥828,825	¥800,546	¥766,511	¥726,064	¥678,482	¥622,969	¥558,655	¥258,810	¥175,901	¥89,675
				¥791,915	¥801,316	¥809,908	¥817,565	¥824,151	¥829,514	¥833,487	¥835,890	¥836,522	¥804,636	¥789,196	¥769,905	¥746,334	¥718,008	¥684,398	¥644,923	¥598,936	¥545,719	¥258,810	¥175,901	¥89,675
				¥730,367	¥738,629	¥746,157	¥752,839	¥758,553	¥763,166	¥766,532	¥768,492	¥768,872	¥739,802	¥726,062	¥708,994	¥688,249	¥663,444	¥634,160	¥599,936	¥560,265	¥514,590	¥258,344	¥175,901	¥89,675
				¥674,586	¥681,792	¥688,325	¥694,082	¥698,955	¥702,823	¥705,553	¥707,004	¥707,019	¥679,074	¥666,350	¥650,645	¥631,661	¥609,068	¥582,513	¥551,611	¥515,947	¥475,069	¥248,959	¥173,756	¥89,675
				¥624,099	¥630,346	¥635,972	¥640,885	¥644,987	¥648,166	¥650,305	¥651,272	¥650,927	¥623,642	¥611,687	¥597,023	¥579,378	¥558,458	¥533,945	¥505,495	¥472,736	¥435,267	¥229,081	¥160,829	¥84,696
				¥578,416	¥583,794	¥588,599	¥592,748	¥596,151	¥598,707	¥600,308	¥600,836	¥600,163	¥573,441	¥562,167	¥548,423	¥531,963	¥512,520	¥489,806	¥463,508	¥433,288	¥398,783	¥209,564	¥147,076	¥77,427
				¥537,080	¥541,671	¥545,734	¥549,192	¥551,962	¥553,954	¥555,069	¥555,200	¥554,230	¥528,017	¥517,359	¥504,448	¥489,061	¥470,954	¥449,867	¥425,515	¥397,594	¥365,771	¥191,904	¥134,631	¥70,850
				¥499,677	¥503,558	¥506,949	¥509,781	¥511,978	¥513,460	¥514,135	¥513,906	¥512,668	¥486,916	¥476,815	¥464,658	¥450,241	¥433,344	¥413,729	¥391,139	¥365,296	¥335,901	¥175,925	¥123,371	¥64,898
				¥465,834	¥469,071	¥471,854	¥474,120	¥475,800	¥476,819	¥477,097	¥476,543	¥475,061	¥449,726	¥440,130	¥428,654	¥415,115	¥399,312	¥381,029	¥360,034	¥336,072	¥308,873	¥161,466	¥113,182	¥59,513
					¥437,866	¥440,099	¥441,853	¥443,064	¥443,666	¥443,583	¥442,734	¥441,033	¥416,076	¥406,936	¥396,077	¥383,332	¥368,519	¥351,442	¥331,888	¥309,629	¥284,418	¥148,384	¥103,963	¥54,641
						¥411,366	¥412,656	¥413,444	¥413,667	¥413,258	¥412,143	¥410,243	¥385,627	¥376,900	¥366,600	¥354,574	¥340,657	¥324,670	¥306,422	¥285,703	¥262,289	¥136,546	¥95,621	¥50,232
							¥386,238	¥386,642	¥386,523	¥385,819	¥384,464	¥382,383	¥358,076	¥349,723	¥339,928	¥328,552	¥315,446	¥300,446	¥283,378	¥264,053	¥242,267	¥125,835	¥88,073	¥46,243
								¥362,391	¥361,962	¥360,992	¥359,418	¥357,174	¥333,147	¥325,132	¥315,794	¥305,007	¥292,634	¥278,527	¥262,528	¥244,464	¥224,149	¥116,143	¥81,243	¥42,633
									¥339,739	¥338,527	¥336,756	¥334,364	¥310,590	¥302,881	¥293,957	¥283,702	¥271,992	¥258,694	¥243,661	¥226,739	¥207,756	¥107,373	¥75,064	¥39,367
										¥318,200	¥316,250	¥313,725	¥290,180	¥282,748	¥274,197	¥264,425	¥253,316	¥240,748	¥226,591	¥210,700	¥192,923	¥99,438	¥69,472	¥36,412
											¥297,696	¥295,050	¥271,712	¥264,530	¥256,319	¥246,982	¥236,416	¥224,510	¥211,144	¥196,188	¥179,502	¥92,258	¥64,412	¥33,738
												¥278,152	¥255,002	¥248,046	¥240,141	¥231,199	¥221,125	¥209,818	¥197,168	¥183,057	¥167,357	¥85,762	¥59,834	¥31,318
													¥239,881	¥233,131	¥225,503	¥216,918	¥207,289	¥196,523	¥184,521	¥171,175	¥156,368	¥79,883	¥55,692	¥29,129
													¥226,200	¥219,635	¥212,258	¥203,996	¥194,769	¥184,494	¥173,078	¥160,424	¥146,426	¥74,564	¥51,944	¥27,148
													¥213,820	¥207,424	¥200,274	¥192,303	¥183,441	¥173,609	¥162,724	¥150,696	¥137,429	¥69,751	¥48,552	¥25,355
													¥202,619	¥196,374	¥189,430	¥181,724	¥173,191	¥163,760	¥153,355	¥141,894	¥129,288	¥65,397	¥45,483	¥23,734
													¥192,484	¥186,377	¥179,618	¥172,151	¥163,916	¥154,849	¥144,878	¥133,930	¥121,922	¥61,456	¥42,707	¥22,266
														¥177,330	¥170,739	¥163,489	¥155,524	¥146,785	¥137,208	¥126,723	¥115,257	¥57,891	¥40,194	¥20,938
															¥162,706	¥155,651	¥147,931	¥139,489	¥130,267	¥120,203	¥109,227	¥54,665	¥37,921	¥19,737
																¥148,560	¥141,060	¥132,887	¥123,987	¥114,302	¥103,770	¥51,745	¥35,864	¥18,649
																	¥134,843	¥126,914	¥118,305	¥108,964	¥98,832	¥49,104	¥34,002	¥17,666
																		¥121,508	¥113,163	¥104,133	¥94,365	¥46,714	¥32,318	¥16,776
																			¥108,511	¥99,762	¥90,322	¥44,552	¥30,794	¥15,970
																				¥95,807	¥86,664	¥42,595	¥29,415	¥15,241
																					¥83,355	¥40,824	¥28,168	¥14,582
																						¥39,222	¥27,039	¥13,985
																						¥37,773	¥26,017	¥13,445
																						¥36,461	¥25,093	¥12,957
																						¥35,274	¥24,257	¥12,515
																							¥23,500	¥12,115
																								¥11,753

Note: Years 4-12, 22-25, and 35-37 are abbreviated due to the limited space.

7.5.3 Net Present Value of the Project with Option

As a result of the calculation based on Equation 7-6 and the criteria of Equation 7-7, project managers can develop the net present value of the project with option to expand capacity. Table 7-16 and Table 7-17 show the total net present value of the projects with options, in Scenarios 3 and 4 respectively in case the initial demand is (f) 22,500 with the inaccuracy rate of -10%.

Table 7-16: Net Present Value of the Project with Option (Scenario 3) (f) (million)

Year 0	1	2	3	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	32	33	34	39	40
¥-39,817	¥865,542	¥879,538	¥892,800	¥964,982	¥971,837	¥978,607	¥982,177	¥982,109	¥977,921	¥969,086	¥955,027	¥935,115	¥908,662	¥874,916	¥833,062	¥786,312	¥736,819	¥685,112	¥393,433	¥327,908	¥287,097	¥90,218	¥45,993
	¥810,005	¥823,354	¥836,037	¥899,752	¥900,647	¥902,897	¥906,734	¥910,697	¥911,375	¥908,325	¥901,061	¥889,051	¥871,710	¥848,404	¥818,436	¥781,050	¥735,419	¥684,749	¥393,433	¥327,908	¥287,097	¥90,218	¥45,993
		¥771,909	¥784,195	¥847,142	¥844,286	¥840,695	¥837,909	¥836,485	¥836,711	¥837,576	¥835,068	¥828,739	¥818,100	¥802,612	¥781,687	¥754,681	¥720,890	¥679,549	¥393,430	¥327,908	¥287,097	¥90,218	¥45,993
			¥736,139	¥801,212	¥798,914	¥794,365	¥787,381	¥779,435	¥772,114	¥766,039	¥761,571	¥758,992	¥752,955	¥743,002	¥728,640	¥709,326	¥684,468	¥653,414	¥393,365	¥327,897	¥287,097	¥90,218	¥45,993
				¥761,651	¥760,406	¥756,902	¥750,935	¥742,303	¥730,808	¥717,925	¥705,273	¥693,541	¥683,212	¥674,759	¥664,794	¥650,809	¥632,314	¥608,765	¥392,154	¥327,633	¥287,097	¥90,218	¥45,993
				¥725,352	¥726,038	¥724,609	¥720,821	¥714,412	¥705,107	¥692,623	¥676,671	¥658,629	¥640,016	¥621,433	¥603,304	¥586,101	¥570,439	¥551,943	¥378,482	¥322,969	¥287,097	¥90,218	¥45,993
				¥688,164	¥691,003	¥692,077	¥691,152	¥687,967	¥682,241	¥673,664	¥661,899	¥646,577	¥627,296	¥605,283	¥581,857	¥557,350	¥531,824	¥505,267	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥648,325	¥652,794	¥655,870	¥657,355	¥657,031	¥654,661	¥649,982	¥642,710	¥632,531	¥619,105	¥602,059	¥580,990	¥557,120	¥531,765	¥505,253	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥606,610	¥612,024	¥616,349	¥619,419	¥621,054	¥621,054	¥619,200	¥615,250	¥608,941	¥599,983	¥588,062	¥572,832	¥553,918	¥530,912	¥505,031	¥355,656	¥322,049	¥287,097	¥90,218	¥45,993
				¥564,489	¥570,281	¥575,222	¥579,179	¥582,003	¥583,528	¥583,572	¥581,936	¥578,398	¥572,714	¥564,619	¥553,821	¥539,999	¥522,807	¥501,863	¥355,654	¥322,048	¥287,097	¥90,218	¥45,993
				¥523,265	¥528,994	¥534,052	¥538,329	¥541,705	¥544,046	¥545,205	¥545,016	¥543,298	¥539,849	¥534,449	¥526,853	¥516,793	¥503,973	¥488,073	¥355,613	¥322,042	¥287,097	¥90,218	¥45,993
				¥483,993	¥489,360	¥494,177	¥498,359	¥501,806	¥504,412	¥506,056	¥506,606	¥505,915	¥503,819	¥500,138	¥494,673	¥487,202	¥477,483	¥465,245	¥354,868	¥321,877	¥287,067	¥90,218	¥45,993
				¥447,387	¥452,227	¥456,597	¥460,426	¥463,633	¥466,130	¥467,817	¥468,589	¥468,324	¥466,892	¥464,147	¥459,928	¥454,057	¥446,337	¥436,550	¥347,238	¥319,012	¥286,408	¥90,218	¥45,993
				¥413,785	¥418,044	¥421,886	¥425,248	¥428,060	¥430,247	¥431,727	¥432,408	¥432,191	¥430,967	¥428,615	¥425,004	¥419,990	¥413,413	¥405,098	¥329,953	¥306,371	¥279,189	¥90,218	¥45,993
					¥386,908	¥390,219	¥393,094	¥395,470	¥397,282	¥398,455	¥398,910	¥398,560	¥397,311	¥395,059	¥391,691	¥387,085	¥381,106	¥373,610	¥307,247	¥286,730	¥263,209	¥90,218	¥45,993
						¥361,499	¥363,914	¥365,872	¥367,312	¥368,168	¥368,369	¥367,836	¥366,485	¥364,222	¥360,947	¥356,552	¥350,918	¥343,917	¥283,107	¥264,540	¥243,352	¥88,815	¥45,993
							¥337,497	¥339,071	¥340,170	¥340,732	¥340,693	¥339,981	¥338,519	¥336,224	¥333,004	¥328,761	¥323,387	¥316,766	¥260,180	¥243,047	¥223,540	¥82,188	¥43,243
								¥314,820	¥315,609	¥315,904	¥315,647	¥314,772	¥313,210	¥310,884	¥307,711	¥303,601	¥298,458	¥292,175	¥239,330	¥223,458	¥205,423	¥75,359	¥39,633
									¥293,385	¥293,439	¥292,985	¥291,962	¥290,309	¥287,954	¥284,824	¥280,835	¥275,901	¥269,924	¥220,463	¥205,732	¥189,030	¥69,179	¥36,367
										¥273,112	¥272,479	¥271,323	¥269,587	¥267,207	¥264,115	¥260,236	¥255,491	¥249,791	¥203,392	¥189,694	¥174,197	¥63,587	¥33,412
											¥253,925	¥252,648	¥250,837	¥248,434	¥245,377	¥241,597	¥237,023	¥231,573	¥187,946	¥175,182	¥160,775	¥58,528	¥30,738
												¥235,750	¥233,872	¥231,448	¥228,422	¥224,732	¥220,312	¥215,089	¥173,969	¥162,051	¥148,631	¥53,950	¥28,318
													¥218,521	¥216,078	¥213,081	¥209,472	¥205,192	¥200,174	¥161,323	¥150,169	¥137,642	¥49,807	¥26,129
														¥202,171	¥199,199	¥195,664	¥191,511	¥186,678	¥149,880	¥139,418	¥127,699	¥46,059	¥24,148
															¥186,639	¥183,170	¥179,131	¥174,467	¥139,526	¥129,690	¥118,702	¥42,667	¥22,355
																¥171,865	¥167,930	¥163,418	¥130,157	¥120,888	¥110,562	¥39,599	¥20,734
																	¥157,794	¥153,420	¥121,680	¥112,924	¥103,196	¥36,822	¥19,266
																		¥144,373	¥114,010	¥105,717	¥96,531	¥34,309	¥17,938
																			¥107,069	¥99,196	¥90,500	¥32,036	¥16,737
																			¥100,789	¥93,296	¥85,043	¥29,979	¥15,649
																			¥95,107	¥87,957	¥80,106	¥28,118	¥14,666
																			¥89,965	¥83,127	¥75,638	¥26,433	¥13,776
																			¥85,313	¥78,756	¥71,596	¥24,910	¥12,970
																				¥74,801	¥67,938	¥23,531	¥12,241
																					¥64,628	¥22,283	¥11,582
																						¥21,154	¥10,985
																						¥20,133	¥10,445
																						¥19,208	¥9,957
																						¥18,372	¥9,515
																						¥17,615	¥9,115
																							¥8,753
Year 0	1	2	3	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	32	33	34	39	40
Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Stay	Stay	
	Stay	Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Stay	Stay	
		Stay	Stay	Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Stay	Stay	
			Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Expand	Expand	Expand	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Expand	Expand	Expand	Expand	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
				Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
					Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
						Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
							Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
								Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
									Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
										Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
											Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
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													Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
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																		Stay	Stay	Stay	Stay	Stay	
																			Stay	Stay	Stay	Stay	
																			Stay	Stay	Stay	Stay	
																			Stay	Stay	Stay	Stay	
¥-39,817																			Stay	Stay	Stay	Stay	
¥-63,541																			Stay	Stay	Stay	Stay	
¥23,725																				Stay	Stay	Stay	
																					Stay	Stay	
																						Stay	
																						Stay	
																						Stay	
																						Stay	
																						Stay	

Note: Years 4-12, 28-31, and 35-38 are abbreviated due to the limited space.

Table 7-17: Total Net Present Value of the Project with Option (Scenario 4) (f) (million)

Year 0	1	2	3	13	14	15	16	17	18	19	20	21	26	27	28	29	30	31	32	33	34	38	39	40
¥-184,311	¥1,032,306	¥1,055,117	¥1,077,762	¥1,262,757	¥1,272,494	¥1,279,490	¥1,283,364	¥1,283,703	¥1,280,063	¥1,271,964	¥1,258,895	¥1,240,312	¥1,059,581	¥1,015,697	¥972,371	¥922,390	¥862,085	¥790,292	¥705,738	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
	¥954,477	¥975,639	¥996,748	¥1,178,982	¥1,190,528	¥1,199,889	¥1,206,734	¥1,210,697	¥1,211,375	¥1,208,325	¥1,201,061	¥1,189,051	¥1,035,419	¥984,749	¥931,185	¥875,248	¥817,014	¥756,437	¥693,433	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
		¥901,390	¥920,771	¥1,094,691	¥1,107,061	¥1,117,734	¥1,126,439	¥1,132,876	¥1,136,711	¥1,137,576	¥1,135,068	¥1,128,739	¥1,020,890	¥979,549	¥929,822	¥874,905	¥816,935	¥756,421	¥693,430	¥627,908	¥559,763	¥258,810	¥175,901	¥89,675
			¥850,431	¥1,012,031	¥1,024,327	¥1,035,290	¥1,044,703	¥1,052,321	¥1,057,875	¥1,061,066	¥1,061,560	¥1,058,992	¥984,468	¥953,414	¥915,452	¥869,806	¥815,630	¥756,109	¥693,365	¥627,897	¥559,762	¥258,810	¥175,901	¥89,675
				¥933,156	¥944,756	¥955,277	¥964,543	¥972,358	¥978,503	¥982,738	¥984,795	¥984,376	¥932,314	¥908,765	¥879,564	¥844,056	¥801,522	¥751,174	¥692,154	¥627,633	¥559,716	¥258,810	¥175,901	¥89,675
				¥859,541	¥870,101	¥879,747	¥888,332	¥895,696	¥901,660	¥906,028	¥908,583	¥909,084	¥870,439	¥851,943	¥828,825	¥800,546	¥766,511	¥726,064	¥678,482	¥622,969	¥558,655	¥258,810	¥175,901	¥89,675
				¥791,915	¥801,316	¥809,908	¥817,565	¥824,151	¥829,514	¥833,487	¥835,890	¥836,522	¥804,636	¥789,196	¥769,905	¥746,334	¥718,008	¥684,398	¥644,923	¥598,936	¥545,719	¥258,810	¥175,901	¥89,675
				¥730,367	¥738,629	¥746,157	¥752,839	¥758,553	¥763,166	¥766,532	¥768,492	¥768,872	¥739,802	¥726,062	¥708,994	¥688,249	¥663,444	¥634,160	¥599,936	¥560,265	¥514,590	¥258,344	¥175,901	¥89,675
				¥674,586	¥681,792	¥688,325	¥694,082	¥698,955	¥702,823	¥705,553	¥707,004	¥707,019	¥679,074	¥666,350	¥650,645	¥631,661	¥609,068	¥582,513	¥551,611	¥515,947	¥475,069	¥248,959	¥173,756	¥89,675
				¥624,099	¥630,346	¥635,972	¥640,885	¥644,987	¥648,166	¥650,305	¥651,272	¥650,927	¥623,642	¥611,687	¥597,023	¥579,378	¥558,458	¥533,945	¥505,495	¥472,736	¥435,267	¥229,081	¥160,829	¥84,696
				¥578,416	¥583,794	¥588,599	¥592,748	¥596,151	¥598,707	¥600,308	¥600,836	¥600,163	¥573,441	¥562,167	¥548,423	¥531,963	¥512,520	¥489,806	¥463,508	¥433,288	¥398,783	¥209,564	¥147,076	¥77,427
				¥537,080	¥541,671	¥545,734	¥549,192	¥551,962	¥553,954	¥555,069	¥555,200	¥554,230	¥528,017	¥517,359	¥504,448	¥489,061	¥470,954	¥449,867	¥425,515	¥397,594	¥365,771	¥191,904	¥134,631	¥70,850
				¥499,677	¥503,558	¥506,949	¥509,781	¥511,978	¥513,460	¥514,135	¥513,906	¥512,668	¥486,916	¥476,815	¥464,658	¥450,241	¥433,344	¥413,729	¥391,139	¥365,296	¥335,901	¥175,925	¥123,371	¥64,898
				¥465,834	¥469,071	¥471,854	¥474,120	¥475,800	¥476,819	¥477,097	¥476,543	¥475,061	¥449,726	¥440,130	¥428,654	¥415,115	¥399,312	¥381,029	¥360,034	¥336,072	¥308,873	¥161,466	¥113,182	¥59,513
					¥437,866	¥440,099	¥441,853	¥443,064	¥443,666	¥443,583	¥442,734	¥441,033	¥416,076	¥406,936	¥396,077	¥383,332	¥368,519	¥351,442	¥331,888	¥309,629	¥284,418	¥148,384	¥103,963	¥54,641
						¥411,366	¥412,656	¥413,444	¥413,667	¥413,258	¥412,143	¥410,243	¥385,627	¥376,900	¥366,600	¥354,574	¥340,657	¥324,670	¥306,422	¥285,703	¥262,289	¥136,546	¥95,621	¥50,232
							¥386,238	¥386,642	¥386,523	¥385,819	¥384,464	¥382,383	¥358,076	¥349,723	¥339,928	¥328,552	¥315,446	¥300,446	¥283,378	¥264,053	¥242,267	¥125,835	¥88,073	¥46,243
								¥362,391	¥361,962	¥360,992	¥359,418	¥357,174	¥333,147	¥325,132	¥315,794	¥305,007	¥292,634	¥278,527	¥262,528	¥244,464	¥224,149	¥116,143	¥81,243	¥42,633
									¥339,739	¥338,527	¥336,756	¥334,364	¥310,590	¥302,881	¥293,957	¥283,702	¥271,992	¥258,694	¥243,661	¥226,739	¥207,756	¥107,373	¥75,064	¥39,367
										¥318,200	¥316,250	¥313,725	¥290,180	¥282,748	¥274,197	¥264,425	¥253,316	¥240,748	¥226,591	¥210,700	¥192,923	¥99,438	¥69,472	¥36,412
											¥297,696	¥295,050	¥271,712	¥264,530	¥256,319	¥246,982	¥236,416	¥224,510	¥211,144	¥196,188	¥179,502	¥92,258	¥64,412	¥33,738
												¥278,152	¥255,002	¥248,046	¥240,141	¥231,199	¥221,125	¥209,818	¥197,168	¥183,057	¥167,357	¥85,762	¥59,834	¥31,318
													¥239,881	¥233,131	¥225,503	¥216,918	¥207,289	¥196,523	¥184,521	¥171,175	¥156,368	¥79,883	¥55,692	¥29,129
													¥226,200	¥219,635	¥212,258	¥203,996	¥194,769	¥184,494	¥173,078	¥160,424	¥146,426	¥74,564	¥51,944	¥27,148
													¥213,820	¥207,424	¥200,274	¥192,303	¥183,441	¥173,609	¥162,724	¥150,696	¥137,429	¥69,751	¥48,552	¥25,355
													¥202,619	¥196,374	¥189,430	¥181,724	¥173,191	¥163,760	¥153,355	¥141,894	¥129,288	¥65,397	¥45,483	¥23,734
													¥192,484	¥186,377	¥179,618	¥172,151	¥163,916	¥154,849	¥144,878	¥133,930	¥121,922	¥61,456	¥42,707	¥22,266
														¥177,330	¥170,739	¥163,489	¥155,524	¥146,785	¥137,208	¥126,723	¥115,257	¥57,891	¥40,194	¥20,938
															¥162,706	¥155,651	¥147,931	¥139,489	¥130,267	¥120,203	¥109,227	¥54,665	¥37,921	¥19,737
																¥148,560	¥141,060	¥132,887	¥123,987	¥114,302	¥103,770	¥51,745	¥35,864	¥18,649
																	¥134,843	¥126,914	¥118,305	¥108,964	¥98,832	¥49,104	¥34,002	¥17,666
																		¥121,508	¥113,163	¥104,133	¥94,365	¥46,714	¥32,318	¥16,776
																			¥108,511	¥99,762	¥90,322	¥44,552	¥30,794	¥15,970
																				¥95,807	¥86,664	¥42,595	¥29,415	¥15,241
																					¥83,355	¥40,824	¥28,168	¥14,582
																						¥39,222	¥27,039	¥13,985
																						¥37,773	¥26,017	¥13,445
																						¥36,461	¥25,093	¥12,957
																						¥35,274	¥24,257	¥12,515
																							¥23,500	¥12,115
																								¥11,753

Year 0	1	2	3	13	14	15	16	17	18	19	20	21	26	27	28	29	30	31	32	33	34	38	39	40
Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	***Expand***	***Expand***	***Expand***	***Expand***	***Expand***	Stay	Stay	Stay	Stay	
	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
		Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	Stay	
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Note: Years 4-12, 22-25, and 35-37 are abbreviated due to the limited space.

7.5.4 Summary of the Project Evaluation

Table 7-18 shows the summary of the project evaluation, including expected net present value of the project with and without option for each scenario, and the expected value of the option to expand the capacity. Figure 7-17 shows the value at risk and gain distribution for each scenario, and Table 7-19 shows the comparison of economic value of each scenario.

Table 7-18: Result of the Analysis (million)

Scenario			Initial Demand		Value of Project			Value of Option		
			Inaccuacy Percentage	Percentage of Projects (a)	Net Present Value (b)	(a) * (b)	Expected Net Present Value of Project	Net Present Value of Option (c)	(a) * (c)	Expected Net Present Value of Option
Without Option	Base Scenario (4 Lanes)	a	150.0%	3.4%	¥581,851	¥19,783	¥-66,261	-	-	-
		b	102.1%	5.4%	¥470,161	¥25,389		-	-	-
		c	59.3%	8.3%	¥290,378	¥24,101		-	-	-
		d	30.0%	12.0%	¥118,454	¥14,214		-	-	-
		e	10.0%	21.2%	¥-23,519	¥-4,986		-	-	-
		f	-10.0%	28.3%	¥-184,322	¥-52,163		-	-	-
		g	-30.0%	13.6%	¥-359,374	¥-48,875		-	-	-
		h	-53.0%	7.7%	¥-567,855	¥-43,725		-	-	-
	Scenario 1 (2 Lanes)	a	150.0%	3.4%	¥50,338	¥1,711	¥-51,955	-	-	-
		b	102.1%	5.4%	¥50,337	¥2,718		-	-	-
		c	59.3%	8.3%	¥50,214	¥4,168		-	-	-
		d	30.0%	12.0%	¥40,226	¥4,827		-	-	-
		e	10.0%	21.2%	¥3,866	¥820		-	-	-
		f	-10.0%	28.3%	¥-63,541	¥-17,982		-	-	-
		g	-30.0%	13.6%	¥-166,269	¥-22,613		-	-	-
		h	-53.0%	7.7%	¥-332,529	¥-25,605		-	-	-
	Scenario 2 (6 Lanes)	a	150.0%	3.4%	¥688,618	¥23,413	¥-312,721	-	-	-
		b	102.1%	5.4%	¥421,276	¥22,749		-	-	-
		c	59.3%	8.3%	¥118,850	¥9,865		-	-	-
		d	30.0%	12.0%	¥-121,216	¥-14,546		-	-	-
		e	10.0%	21.2%	¥-296,583	¥-62,876		-	-	-
		f	-10.0%	28.3%	¥-476,796	¥-134,933		-	-	-
		g	-30.0%	13.6%	¥-658,590	¥-89,568		-	-	-
		h	-53.0%	7.7%	¥-867,853	¥-66,825		-	-	-
With Option	Scenario 3 (2 Lanes) + Add 2 Lanes (If necessary)	a	150.0%	3.4%	¥593,389	¥20,175	¥51,648	¥543,051	¥18,464	¥103,603
		b	102.1%	5.4%	¥481,700	¥26,012		¥431,362	¥23,294	
		c	59.3%	8.3%	¥311,313	¥25,839		¥261,099	¥21,671	
		d	30.0%	12.0%	¥184,523	¥22,143		¥144,297	¥17,316	
		e	10.0%	21.2%	¥78,623	¥16,668		¥74,757	¥15,849	
		f	-10.0%	28.3%	¥-39,817	¥-11,268		¥23,725	¥6,714	
		g	-30.0%	13.6%	¥-164,092	¥-22,316		¥2,177	¥296	
		h	-53.0%	7.7%	¥-332,529	¥-25,605		¥0	¥0	
	Scenario 4 (4 Lanes) + Add 2 Lanes (If necessary)	a	150.0%	3.4%	¥775,173	¥26,356	¥-51,358	¥193,322	¥6,573	¥14,903
		b	102.1%	5.4%	¥564,973	¥30,509		¥94,812	¥5,120	
		c	59.3%	8.3%	¥319,027	¥26,479		¥28,649	¥2,378	
		d	30.0%	12.0%	¥124,121	¥14,894		¥5,667	¥680	
		e	10.0%	21.2%	¥-22,816	¥-4,837		¥703	¥149	
		f	-10.0%	28.3%	¥-184,311	¥-52,160		¥11	¥3	
		g	-30.0%	13.6%	¥-359,374	¥-48,875		¥0	¥0	
		h	-53.0%	7.7%	¥-567,855	¥-43,725		¥0	¥0	

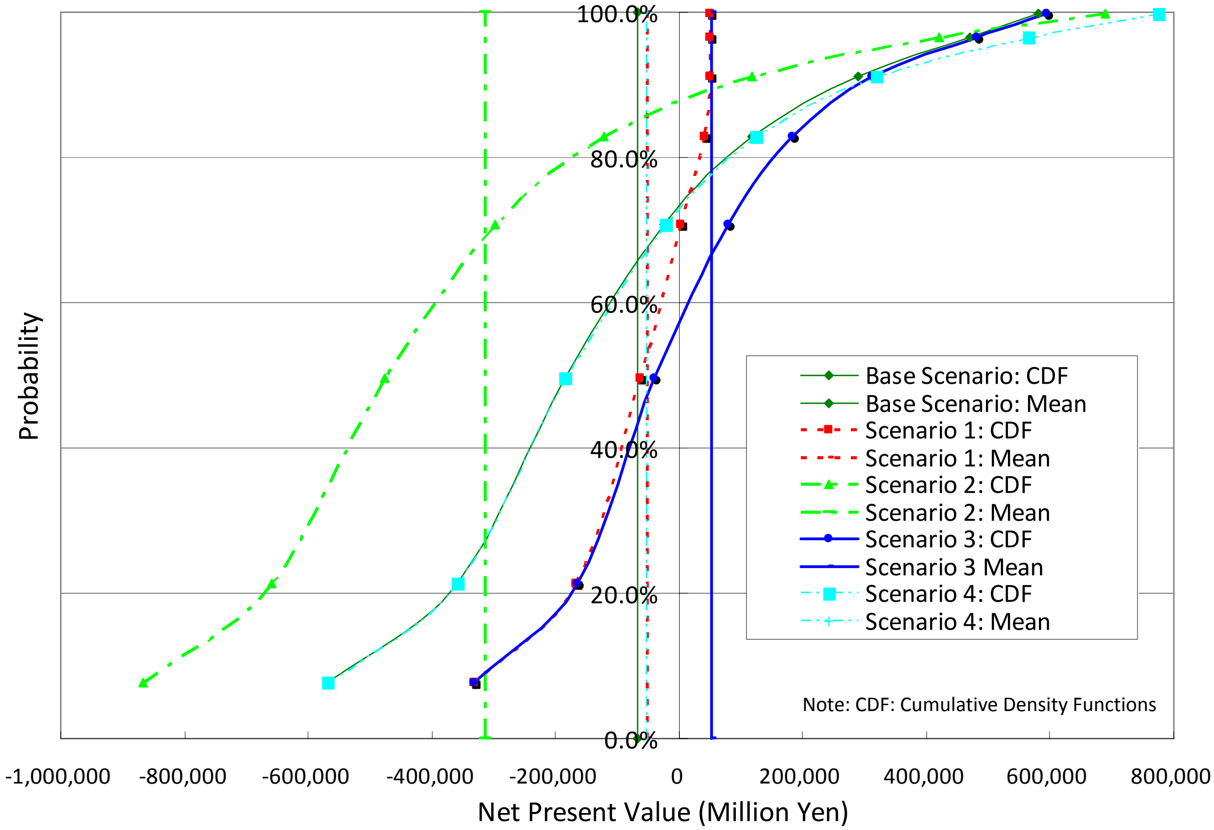

Figure 7-17: Value-At-Risk and Gain Distribution for Five Scenarios

Table 7-19: Comparison of Economic Values of Five Scenarios

Criteria	Base Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Expected Net Present Value (Million)	¥-66,261	¥-51,955	¥-312,721	¥51,648	¥-51,358
Standard Deviation (NPV) (Million)	¥390,894	¥129,857	¥526,704	¥309,584	¥448,766
Flexibility Value (Million)	-	-	-	¥103,603	¥14,903
Initial Cost (Million)	¥1,160,000	¥860,000	¥1,460,000	¥860,000	¥1,160,000
Maximum Value (NPV) (Million)	¥581,851	¥50,338	¥688,618	¥593,389	¥775,173
Minimum Value (NPV) (Million)	¥-567,855	¥-332,529	¥-867,853	¥-332,529	¥-567,855

Firstly, the value of the project in Scenario 1 is the least negative among Base Scenario and Scenarios 1 and 2. This is because the scale of the initial construction in Base Scenarios (4 lanes, 2 tunnel) and 2 (6 lanes, 3 tunnels) are too large for their traffic demand. Secondly, the project value of Scenario 4 (¥-51,358 million) is less negative than that of Base Scenario (¥-66,261 million). This is because Scenario 4 has the option to expand capacity if the traffic demand exceeds the capacity of the initial facility and its expansion benefits exceed its costs, at which point it will exercise the option. Thus, holding options enables project managers to enhance the value of the project. Thirdly, in the same way as the comparison of Scenario 4 and Base Scenario, the project value of Scenario 3 (¥51,648 million) is larger than that of Scenario 1

(¥-51,955 million). Finally, the value of the project of Scenario 3 is larger than that of Scenario 4. This is because Scenario 3 reduces the initial construction cost, and this avoids the downside risk of traffic demand. Furthermore, the value of the option to expand of Scenario 3 is larger than that of Scenario 4. Thus, Scenario 3 can provide the largest project value and the value of option to expand. Therefore, Scenario 3 is the best strategy for project companies. Table 7-20 shows the performance improvements achieved with flexible design. This result clearly shows that scenarios with flexibility is better than the one without flexibility, and thus this case study demonstrates that flexibility reduces risks and enhances the value of the project.

Table 7-20: Performance Improvements Achieved with Flexible Design

Criteria	Design		Comparison
	Base Scenario (No Flexibility)	Scenario 3 (Flexible)	
Expected Net Present Value (Million)	¥-66,261	¥51,648	Flexibility Better
Initial Cost (Million)	¥1,160,000	¥860,000	Flexibility Better
Maximum Value (NPV) (Million)	¥581,851	¥593,389	Flexibility Better
Minimum Value (NPV) (Million)	¥-567,855	¥-332,529	Flexibility Better
Flexibility Value (Million)	-	¥103,603	-

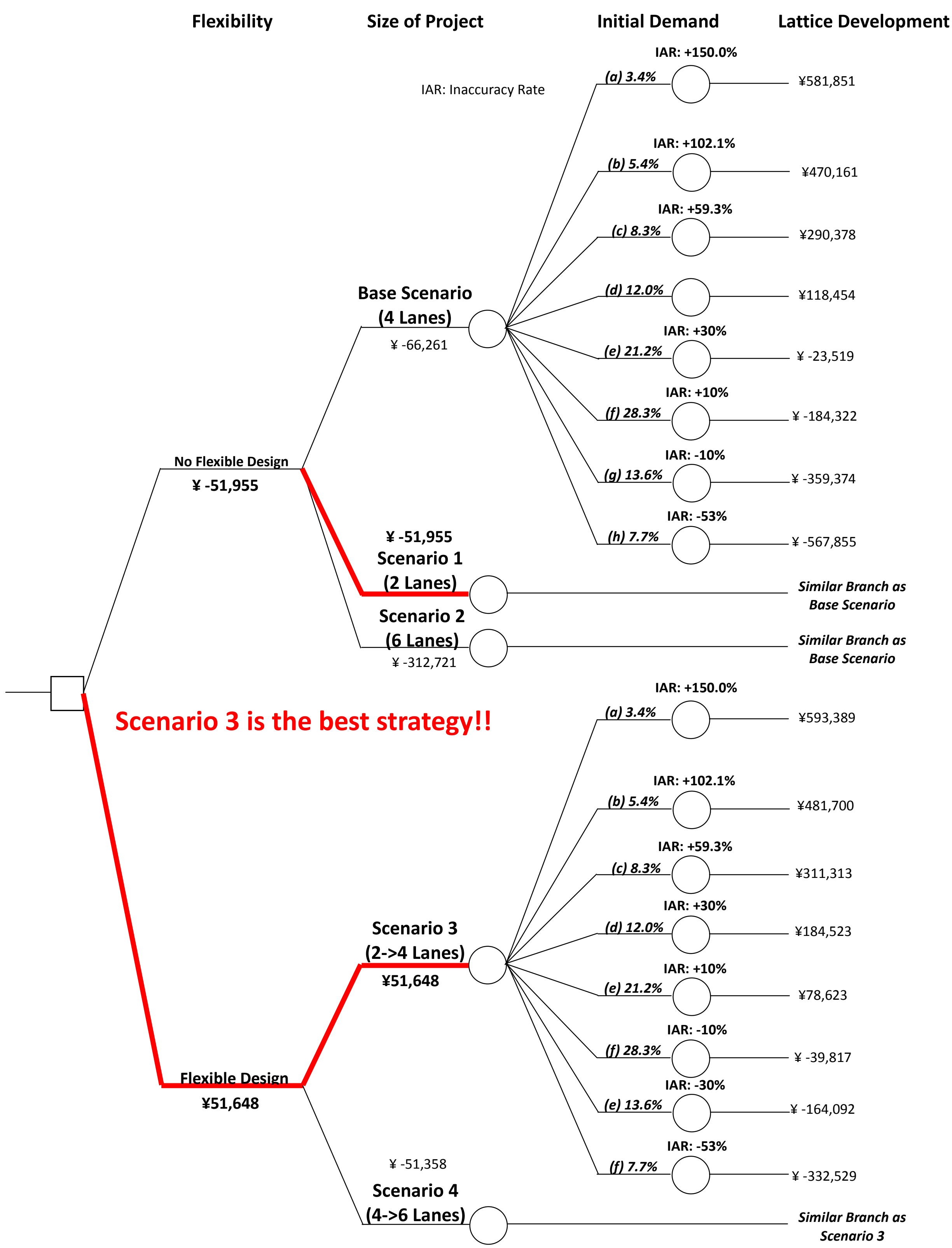

Figure 7-18: Result of Analysis (million)

7.6 Alternatives of Enhancing the Value of Projects

Under a conventional delivery method, due to the restricted budget and separate issuance of orders for the private sector to perform design work, construction, operation, and maintenance, projects have not been optimized in terms of project life. However, under PFI, project companies are able to consistently manage projects throughout their lifecycle. Therefore, as this chapter demonstrates, PFI enables project companies to incorporate flexibility into design using real options analysis, which reduces risks and enhances the value of the project. In addition to real options approach, under PFI, project managers can apply alternatives to enhance the value of projects with their management skills, originality and ingenuity, such as managing toll, shortening of construction period, and reduction of operational and maintenance costs. This section introduces the examples of effective alternatives of enhancing the value of the project other than real options approach.

7.6.1 Management of Toll

Toll is the direct source for the cash flows for the project during operation period. By managing toll appropriately, project managers are able to increase traffic volume. For example, in order to solve the situation where the traffic was much less than forecast, the toll was reduced after 2 years operation by 25% from the initial price (i.e. from ¥4,000 to ¥3,000 for standard-sized car). As a result, the number of vehicles increased by about 38% from 9,600 vehicles per day in 1999 to 13,300 vehicles per day in 2001. But this increment included the natural growth of the traffic demand.

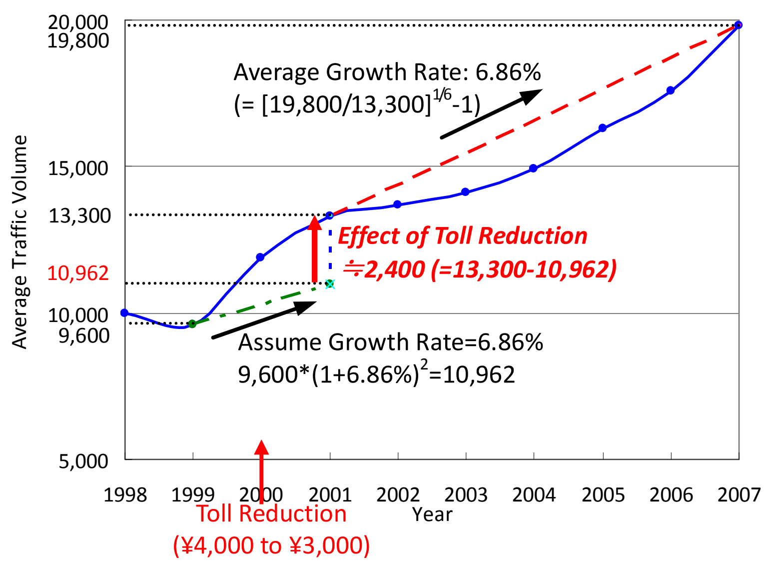

Figure 7-19: Effect of Toll Reduction

Figure 7-19 shows the effect of the toll reduction. After the reduction of the toll in 2001, the traffic demand seemed to increase without the effect of reduction of toll. The growth rate between in 2001 and in 2007 can be calculated as 6.86%. If there had not been toll reduction after the first 2 years operation, the traffic demand might have increased with the growth rate above, and the traffic demand in 2001 might have been about 10,962 vehicles per day. Therefore, the effect of the toll reduction can be calculated as increment of about 2,400 vehicles per day, which means that the number of vehicles increased by about 25% from 9,600 vehicles per day in 1999 to 12,000 vehicles per day in 2001.

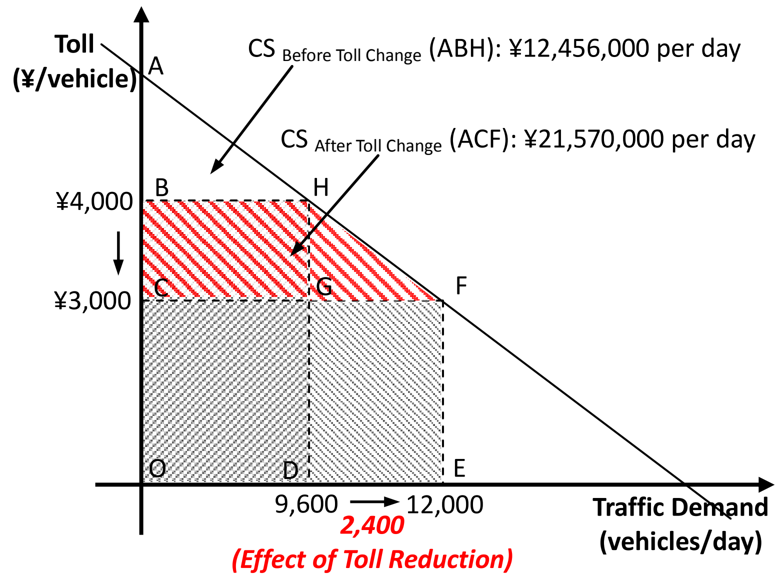

Figure 7-20: The Relationship between Toll and Traffic Demand on the Demand Curve

Figure 7-20 shows the relationship between toll and traffic demand on the demand curve. The percentage of change in toll is -25%, and the percentage of change in traffic demand is about 25%, which means that the price elasticity equals to about -1.00. As Figure 7-20 shows, the revenue before the reduced toll can be shown as square BODH (¥4,000 * 9,600 = ¥38,4 million per day), as well as the revenue after the reduced toll is square COEF (¥3,000 * 12,000 = ¥36.0 million per day), both of which are almost the same amount. In the meanwhile, the consumer surplus before the reduced toll can be shown as triangle ABH (¥12,456,000 per day), while the consumer surplus after the reduced toll can be shown as triangle ACF (¥21,570,000 per day). Thus, the consumer surplus was increased by 73.2% as a result of the reduced toll. From this analysis, although the revenue for the project company has been changed little, consumers can benefit from the reduced toll. Furthermore, although increased consumers does not increase the benefits for project companies in terms of cash flow during operation, the more the consumers increases, the more the benefits of gift shops, restaurants, and amusement shop at the Umi-Hotaru is, all of which are also revenue sources for project companies. Also, the more vitalized the economy both in Kisarazu and Kawasaki cities are. Moreover, increase in traffic at Aqua-Line can contribute to the traffic mitigation at the expressway along the Tokyo Bay, which is one of the objectives of the Tokyo Bay Aqua-Line Project. Thus, from the perspective of public policy, managing toll appropriately can not only create consumers profits but also contributes to socioeconomics without providing loss to the project companies.

7.6.2 Shortening of Construction Period

Construction period for this project was 10 years. For the actual project, since the government issued orders to the private sector to perform design work, construction, operation, and maintenance separately, as well as the government issued orders part by part, the construction process was not effective compared to the one under PFI. If the project had been conducted under PFI, the construction period could have been shortened by effectiveness from private sector's management skills, ingenuity, and efforts. Shortening construction period can enhance the value of the project. In other words, it can increase the cash flows during operation period, which means that the net present value of the cash flows during operation period can be improved.

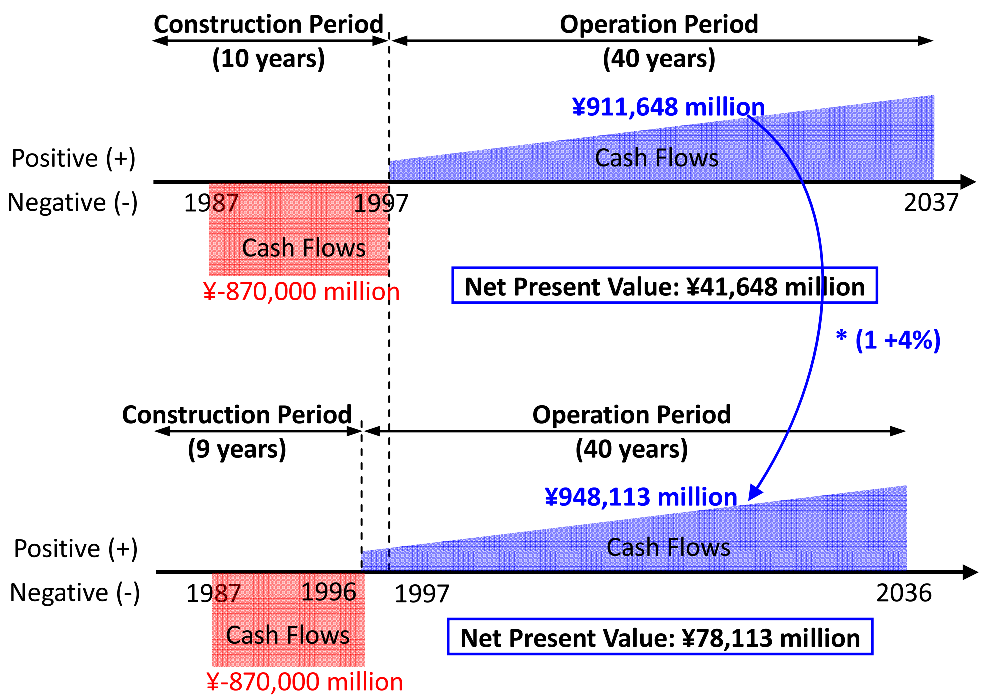

Figure 7-21: Comparison of Net Present Value of the Project with the One with Shorter Construction Period (Scenario 3)

Figure 7-21 compares the net present value of the project with the one with construction period 1 year shorter in case of Scenario 3. The figure above shows the cash flows structure with 10 years construction period, and the figure below shows the cash flows structure with 9 years construction period. The present value of cash flows obtained from the operation in the figure above is ¥911,648 million, while the present value of the cash flows obtained from the operation in the figure below is ¥948,113 million. This can be calculated as the cash flows of ¥911,648 multiplied by (1+4%) equals to ¥948,113. Therefore, the net present value of the project becomes ¥78,113 million, which is the enhancement of ¥36,465 million in project total. Thus, project company's efforts, such as shortening of construction period, can enhance the value of the project.

7.6.3 Reduction of Operation and Maintenance Costs

If the project had been conducted under PFI, the operational and maintenance costs could have been reduced by effectiveness from project company's efforts. The operational and maintenance costs during operation period is a main resource for the expenditure, but effective management of operation and maintenance can reduce the fixed costs of total costs, which can contributes to the improvement of the cash flows.

Table 7-21 Project Value and Increase Rate of Project Value by Cost Reduction (Scenario 3)

Costs Reduction Rate	Project Value (¥ million)	Increase Rate of Project Value
5%	54,898	6.3 %
10%	58,149	12.6%
15%	61,400	18.9 %
20%	64,650	25.2 %

Table 7-21 shows the project value and increase rate of project value by cost reduction in Scenario 3. The reduction of operational and maintenance costs by 5%, 10%, 15%, and 20% can increase the value of project by 6.3%, 12.6%, 18.9%, and 25.2% respectively. Thus, the cost reduction can have a significant impact on the value of the project. In PFI, project companies can reduce the operational and maintenance costs by their efforts and thus it enhances the value of the project.

7.7 Conclusion of the Case Study of the Tokyo Bay Aqua-Line Project

This chapter demonstrates how the proposed methodology, which is different from the Case Study 1, can be applied in real-world projects using the case study of the Tokyo Bay Aqua-Line Project.

Firstly, this case study demonstrates how project managers and designers can model the analysis of the project, calculate the value of the project and evaluate it, including setting up various scenarios with or without options to expand, modeling demand development, building cash flows pro forma, and developing the calculation and evaluation process. The case study selects the combination of binomial lattice model and decision analysis as a project valuation methodology. The binomial lattice model is useful for developing traffic demand, which is the only uncertainty in this case study. But because the traffic demand does not exist until the open of this expressway, it is necessary not only to find out the past trend from comparable and similar projects in the past to set up the growth rate and the volatility, but also consider the inaccuracy of the forecast of initial demand based on the past research result. Decision analysis can not only deal with various scenarios but also consider as many possible outcomes for each scenario as possible, which can treat the various inaccuracy rates for the initial demand forecast. Thus, this case study deals with the uncertainty of traffic demand by applying binomial lattice model and the inaccuracy of the forecast of the initial demand by applying decision analysis.

Secondly, the case study demonstrates that incorporating flexibility into design can reduce risks and enhance the value of projects. As Section 7.5.4 shows, Scenario 3, of which initial capacity is minimum size and which has the option to expand the capacity, can minimize the initial cost, avoiding the downside risk of traffic demand, and can maximize the value of the project, taking advantage of the upside opportunity. Thus, applying the combination of binomial lattice model and decision analysis enables project managers to find out the best scenario under future uncertainties. Because under PFI, project managers can apply their management skills and technical capabilities, they can apply flexible design to large scale infrastructure development, and thereby they can manage risk in PFI as this chapter demonstrates.

Finally, as Section 7.6 demonstrates, there are alternatives to enhance the value of projects under PFI other than real options analysis. By applying project company's management skills, originality, and ingenuity, they can not only enhance the value of projects but also contribute to the consumer's benefits without losing project companies' profits. Therefore, the project company can achieve not only their successful project but also contribution to socioeconomic from the perspective of public policy.

Thus, the proposed concepts and methodologies demonstrated in both this case study and the previous case study can contribute to the improvement of the VFM described in Section 2.3.2, which results in public infrastructure with higher quality at reduced costs and realizes the idea of PFI.

Chapter 8 Barriers to Implementation of the Proposed Methodologies and Policy Recommendation

This thesis has demonstrated how flexible design is useful for reducing risks and uncertainties in large-scale infrastructure development projects, and the proposed concepts and methodologies introduced in this thesis are expected to be applied in future real-world projects. However, there are significant barriers to the implementation of these proposed concepts and methodologies. Both the public and private sectors prefer to maintain the status quo. They are generally uncomfortable accepting new concepts, new environment, new rules, new systems, or new methodologies, all of which can significantly alter the current situation. This is generally because they do not want the added burden of mastering skills or obtaining tools necessary for these new concepts and methods. These barriers discourage both public and private sectors from adopting these new and useful concepts and methodologies. This chapter first demonstrates the degree to which the proposed methodology has been applied as a valuation method in the real world thus far. It also describes barriers to the implementation of those proposed concepts and methodology, and lastly makes recommendations to alleviate these barriers.

8.1 Current Status of Adoption of Proposed Methodology

There are a variety of methodologies for project valuation, including the ones that this thesis introduces in Chapter 4, such as NPV, DCF, and real options. Figure 8-1 and Figure 8-2 show the adoption ratio of evaluation methodologies applied by companies in the U.S., and in Japan [68] [69]. Graham and Harvey conducted the survey by investigating 392 CFOs in major companies in the U.S. in 1999. The result of this survey shows that the adoption ratio of traditional evaluation methods such as IRR and NPV were more than 75%, followed by hurdle rate, payback period and several other methodologies. Real options analysis was adopted by about 25% of companies. The Ministry of Economy, Trade and Industry in Japan conducted a similar survey investigating 2,204 companies in Japan in 2004, and receiving responses from 1,147 companies. This result shows that traditional methodologies such as financial statement analysis are used by about 50% of respondents as their first ranked methodology. Payback Period analysis is used by about 25% as the first ranked methodology and by about 50% as the second ranked methodology. NPV and IRR were used by about 10% as the first ranked methodology and by about 30% as the third ranked methodology. Real options analysis has not been used as the first and the second methodology at all, and used by only 0.3% as the third methodology. This methodology has been introduced and recommended in numerous academic works not only in the U.S but also throughout the world. Based on those works, it has also been introduced in Japan, has been discussed by a many researchers, and several organizations have been launched, such as the establishment of the Japan Association Real Options and Strategy. Nevertheless, the actual application is very limited, as the survey shows.

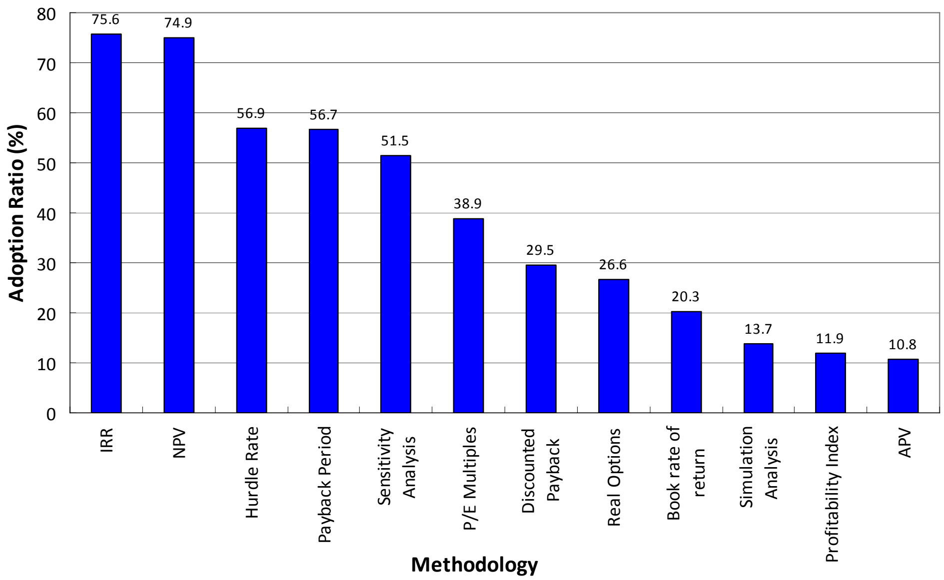

Figure 8-1: Adoption Ratio of Evaluation Methodology Applied by companies in the U.S.
Source: Graham, Harvey (2001) [68]

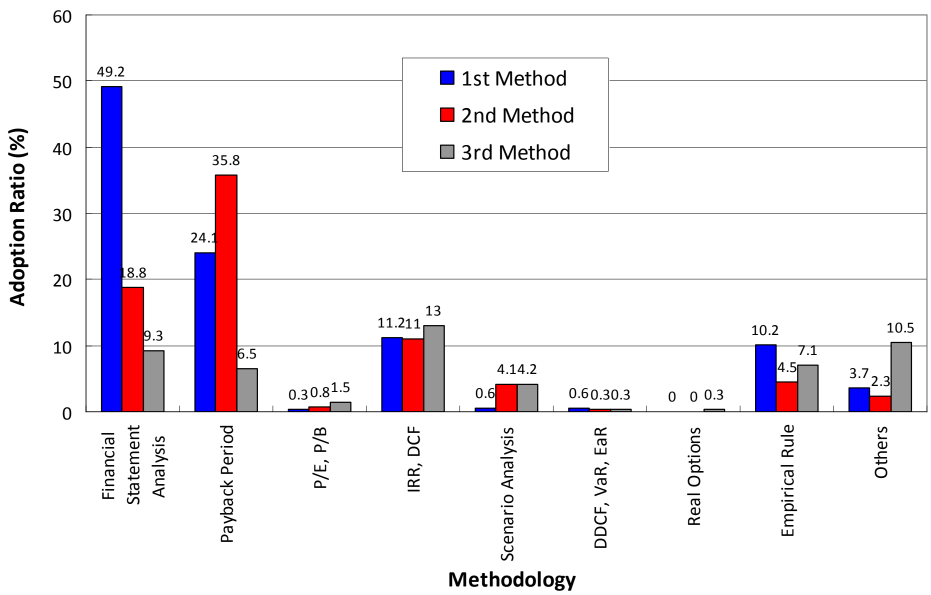

Figure 8-2: Adoption Ratio of Evaluation Methodology Applied by Companies in Japan
Source: Japan, Ministry of Economy, Trade and Industry, (2004) [69]

8.2 Barriers to Implementation of New Concepts and New Methodologies

Technological innovation and economic development has been achieved by applying various types of new concepts and methodologies. It might be true that both public and private sectors recognize that these new concepts and methodologies can improve or strengthen their current economic situations or potential value of their projects. Nevertheless, some of them tend to not want to change. This tendency discourages them from challenging the status quo, and introducing new and useful concepts and methodologies.

One barrier to implementing new concepts and new methodologies is the conservative comfort with existing situations, including concepts and methodologies which have been working satisfactorily for them. As long as the existing methodologies function well, they think those methodologies are the best option, and they do not think to continuously challenge themselves to use even better concepts and methodologies. However, this tendency often leads to reluctance in employing new approaches, even if those that would be employing them knew that they would be more useful and effective than existing ones. In some cases though, these persons may not even be up-to-date on these new concepts and methodologies.

Another barrier to the introduction of new concepts and new methodologies is the arduousness that is imposed on project managers, who are required to spend a lot of energy and effort in learning a new system. If they do not have a good background regarding the new methodologies, it takes a lot of time to master them. For instance, complicated evaluation methods using binomial lattice model requires an understanding of advanced financial theory. This discourages project managers from trying to applying them. Moreover, they have to convince those who are around them such as executive officers, subordinates, and governments, of the validity of these concepts and methodologies. This process is very time-consuming, and requires that project managers spend a lot of extra energy.

For these reasons, real options analysis might have not been widely applied as the evaluation method in many Japanese companies. Traditional methodologies, such as DCF, IRR, and payback period, are very easy to calculate, do not require advanced financial theory, and they have worked so well so far. Therefore, many project managers are comfortable with the existing methodologies, and they think it is unnecessary to apply new concepts and approaches as their evaluation methodology for potential projects. They believe that applying new concepts and methodologies such as real options analysis, will requires too much additional time and energy.

Another example is PFI itself. As Section 3.1.2 describes, the survey conducted by the central government in Japan shows that both public and private sectors have had several concerns and complaints about the implementation of PFI so far [13]. The public sector insists that since the implementation process of PFI requires a huge amount of time, it is very hard for those in government who have gotten used to a conventional delivery system to apply PFI. Also, some people in management positions tend to not want to apply PFI, stating that they think it is unclear how effective PFI is.

8.3 Recommendation to Alleviate Barriers

It is crucial to alleviate those barriers so that the proposed methodology could not only be widely used for evaluating PFI but also so that PFI could be applied to large-scale infrastructure development projects. One way to alleviate barriers is to clearly demonstrate how the new concepts and methodologies are more effective than existing ones and that their benefits outweigh the required costs. This can be achieved by applying the concepts and methodologies to real case studies, like the ones conducted in this thesis, and showing how useful and effective considering uncertainties and incorporating flexibility into design are. This has been a major goal of this thesis. As case studies in Chapters 6 and 7 show, the proposed methodology reduces risks and enhances the value of the projects, over the ones not incorporating flexibility into design.

As Section 3.1.2 explains, the investigation conducted by the central government in Japan pointed out the fact that "The Guideline for Risk Allocation of PFI Projects" does not include specific methodologies of evaluating risks and the countermeasures against the risks; hence, specific directions about the evaluation of risks and methodologies of handling them should be shown in the guideline [13]. One proposal is thus that an official organization such as the "Private Finance Initiative Promotion Office" should demonstrate case studies to which the proposed methodologies are applied, as this thesis conducted, in order to solve the current issue described in the investigation above. By showing the effectiveness and incentives of the methodology, both public and private sectors are able to look to long-term strategies for managing and designing projects.

Another way to alleviate barriers is to introduce a user-friendly methodology that project managers could understand and use relatively easily. Regarding the evaluation methodology, because the method of simulations, such as Monte-Carlo simulations using Excel®, can be not only the most user-friendly methodology introduced in this thesis but also a powerful methodology, it should be applied to large-scale infrastructure development projects as a means of project evaluation. It is relatively easy for project managers to conduct this methodology and explain the concepts, process and results of the analysis, compared to a methodology that requires advanced financial methodologies, such as the binomial lattice model. Furthermore, this methodology can be widely used, in that it explains the results of the analysis by using various graphs and charts.

The original reason why PFI was introduced in Japan was to stimulate the stagnant Japanese economy and to achieve higher values, efficiency, and effectiveness in public works projects. This objective represents introducing new concepts and methodologies, and replacing existing ones. By keeping this objective firmly in mind, both public and private sectors should make efforts to apply new concepts and methodologies that could improve the current situation.

Chapter 9 Conclusion

9.1 Conclusion of the Thesis

PFI was introduced in Japan in order to encourage the stagnant Japanese economy and to provide public services with higher quality while reducing costs to the country and the local authority. It has been about 10 years since its introduction, and PFI has been applied to many public works projects so far, but not to large-scale infrastructure development projects, such as toll road and airport projects. One of the main reasons for this is that specific methodologies of handling risks and uncertainties involved in long-term projects have not been introduced and demonstrated, and both public and private sectors do not have methodologies of responding to risks and uncertainties.

By proposing a methodology that can reduce risks involved in PFI projects and demonstrating how they can apply it, this thesis aims to help those involved in large-scale infrastructure development projects apply PFI to those projects.

The first goal is to propose a quantitative methodology so that project managers can handle uncertainty and reduce risks in large-scale infrastructure projects. Chapter 3 proposes the application of flexible design to handle risks and enhance the value of projects in large-scale infrastructure projects. Chapter 4 explains the basic concepts for a valuation methodology, and Chapter 5 introduces the concepts of financial options, and real options approaches, such as binomial lattice model, simulation and decision analysis, as methodologies that can be applied in large-scale infrastructure development projects.

Demand risk is one of the crucial risks in large-scale infrastructure development projects. It is impossible to forecast demand accurately, because there are a lot of uncertainties in large-scale engineering projects and they can make a big impact on the past trends on which forecasting methodologies rely. Therefore, forecast is always wrong. It should be emphasized not how accurately project managers forecast demand in large-scale infrastructure development projects, but how they can handle risks and uncertainties in them.

Key to handling demand risks should be the incorporation of flexibility into design. PFI projects can explicitly provide project managers with the opportunity to use flexibility, unlike the conventional delivery system, because they can consistently utilize the private sector's managerial skills and technical capabilities over the entire long-term contractual period. Therefore, by managing risks and uncertainty appropriately, PFI can be applied to large-scale infrastructure development projects. Real options analysis is a significantly useful way to reduce risks and enhance the value of projects in that it can consider future uncertainties and incorporate flexibility into design. Project managers have to choose one or a combination of the proposed methodologies so that they can appropriately apply them to the characteristics of their projects, considering the advantage and disadvantage of the proposed methodologies.

The second goal is to demonstrate how project managers can apply the proposed methodology practically to real-world projects, including how to model analysis, calculate the value of projects, and evaluate them. Also, its goal is to demonstrate how the proposed methodology is useful for reducing risks and enhancing the value of projects by using two case studies, the "Tokyo International Airport New Runway Extension Project" in Chapter 6, and the "Tokyo Bay Aqua-Line Project" in Chapter 7. Each case study applies different methodologies. Using two real-world case studies also enables this thesis to demonstrate the effectiveness and advantage of different types of real options analysis. Also, both case studies demonstrate that project managers could have considered future uncertainties and incorporated flexibility into design, and thereby reduced risks and enhanced the value of projects, provided that those projects had been conducted under PFI instead of a conventional project delivery system. This is because project companies can consistently manage an entire project over its useful life under PFI.

In the case study of the Tokyo International Airport New Runway Extension Project, this thesis applied Monte-Carlo simulations using Excel®. This case study demonstrates that the flexibility, such as options to expand capacity can reduce the excessiveness of facility, minimize the possible losses, and enhance the value of the project, compared to an inflexible approach. The biggest advantage of Monte-Carlo simulations is that it does not require advanced financial theory, and thus project managers who are not familiar with advanced finance theory are able to apply it. In addition, by using Excel®, this methodology can illustrate the result of the analysis graphically. Therefore, this approach is the most user-friendly methodology of all applicable real options approaches.

The case study of the Tokyo Bay Aqua-Line Project also demonstrates how project managers can model and analyze the project and how the flexibility can enhance the value of the project and thereby obtain the best scenario quantitatively. This case applies the combination of decision analysis and binomial lattice model as an evaluation methodology. As long as the demand develops along past trends, the binomial lattice model is very useful to consider single uncertainty and to incorporate flexibility into design. However, when project managers plan and design a new project, since there is no past trend of demand, they have to manage to model demand. This case study demonstrates that comparable past projects can provide the design conditions necessary for the binomial lattice development, such as the growth rate and the volatility of demand. In addition, forecasts are always wrong, and project managers have to recognize the inaccuracy of forecasts. Therefore, this case study demonstrates the inaccuracy of forecasted traffic demand for road projects based on the past research, and considers and applies the distribution of the inaccuracy to the initial demand. Beyond the proposed methodology, this case study also demonstrates several alternatives to enhance the value of projects by proposing managing tolls, shortening the construction period, and reducing the operational and maintenance costs, all of which can be achieved by project companies' ingenuity and efforts. Managing tolls appropriately, especially, can create benefits for consumers without losing project companies' profits, and thereby it can contribute socioeconomically from the perspective of public policy.

The proposed concepts and methodologies demonstrated in both case studies can contribute to the improvement of the VFM, which results in public infrastructure with higher quality at reduced costs and realizes the idea of PFI.

The third goal is to recommend ways to alleviate the barriers to implementation of the proposed methodology. Both public and private sectors prefer to maintain status quo, generally because they do not want the added burden of mastering skills or obtaining tools necessary for new concepts and methodologies. There are two barriers to implementation of new concepts and methodologies. One is the conservative comfort with existing situations, including concepts and methodologies which have been working satisfactorily for public and private sectors. The other barrier is the arduousness that is imposed on project managers, who are required to spend a lot of energy and effort in learning a new system.

One way to alleviate barriers is to clearly demonstrate how the new concepts and methodology are more effective than existing ones and that their benefits outweigh the required costs. This can be achieved by applying the concepts and methodology to real case studies, like the ones conducted in this thesis and showing how useful and effective considering uncertainties and incorporating flexibility into design are. Therefore, it would be desirable if these were demonstrated in official guidelines. Another way to alleviate barriers is to introduce a user-friendly methodology that project managers could understand and use relatively easily, such as Monte-Carlo simulations, which is able to alleviate arduousness of their situation.

The concepts and methodologies in this thesis enable project companies to reduce risks and enhance the value of project in large-scale infrastructure development projects. Under PFI, project companies can apply proposed concepts and methodologies, and therefore the proposed concepts and methodologies can help both public and private sectors apply PFI to large-scale infrastructure development projects. Successful application of PFI to large-scale infrastructure development projects can contribute to socioeconomics in terms of the idea of PFI.

9.2 Future Work

Firstly, it is necessary to research how project managers can handle the range of risks involved in PFI. This thesis focuses only on demand risks, but it might be possible to deal with and reduce other risks by considering uncertainties and incorporating flexibility into design. The concepts and methodologies described in this thesis are enough for introducing project managers to how they can reduce risks involved in PFI projects, but is not enough to be used in official guidelines, such as "The Guideline for Risk Allocation of PFI Projects" because this thesis discusses only demand risks. Therefore, it is important and necessary to research the concepts and methodologies to reduce risks other than demand risks.

Secondly, the case study in this thesis includes many assumptions and thus the results are only rough estimates. Therefore, when project managers work on an actual project, they have to consider and deal with more detailed data and information. For example, the case studies in this thesis use the discount rate of 4% for the projects, which is the interest rate of long-term government bonds in accordance with the practice of the Japanese government for large-scale public works. However, when a new company is established as a project company in PFI, it is necessary to set the discount rate appropriate not only for the company's opportunity cost of capital, but also the specific project, by using the CAPM or the WACC introduced in Chapter 4 of this thesis.

The author of this thesis would like to express deep gratitude for readers of this thesis. It would be the greatest pleasure if the ideas and concepts presented in this thesis could be useful for readers and be applied in real-world projects in the very near future.

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