Portfolio-Based Infrastructure Investment Strategy
for Railroad Company

by

Takeshi Sato

B.S., Geology and Mineralogy (1996)
University of Tokyo

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Civil and Environmental Engineering
at the
Massachusetts Institute of Technology
June 2002
© 2002 Takeshi Sato. All Rights Reserved.

The author hereby grants to MIT permission to reproduce and to distribute
publicly paper and electronic copies of this thesis document in whole or in part.

Signature of Author

Department of Civil and Environmental Engineering
May 10th, 2002

Certified by

Fred Moavenzadeh
James Mason Crafts Professor of Engineering Systems
Department of Civil and Environmental Engineering
Thesis Supervisor

Accepted by

Oral Buyukozturk
Chairman, Departmental Committee on Graduate Studies

BARKER
Portfolio-Based Infrastructure Investment Strategy
for Railroad Company

by

Takeshi Sato

Submitted to the Department of Civil and Environmental Engineering
on May 10, 2002 in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Civil and Environmental Engineering

ABSTRACT

Project based capital investment planning for developing a railroad company’s infrastructure facilities does not necessarily allow managers the optimal use of their limited capital resources, because such planning simply focuses on the required cash spending and expected return from the single project. A portfolio based investment strategy aims at increasing or maximizing the value of a company’s set of ground facilities, i.e., infrastructure portfolio, through quantifying the impact of strategic investments on the value of a portfolio.

This study makes two approaches to the measurement of the value of infrastructure portfolios and the effect of strategic investments. First, strategic investments are considered to add certain economic values to a company, which can be interpreted as residual returns from the portfolio after rewarding its investors. Then, the value of the portfolio is analogous to that of a stock price and its dividend yield. Second, the value of a portfolio can be maximized through finding optimal strategic investment timings and its amounts. Real options approach makes use of the concept of financial option pricing as capital budgeting techniques, and it allows a company to incorporate the value of managerial flexibility in its infrastructure portfolio.

Thesis Supervisor: Dr. Fred Moavenzadeh
Title: James Mason Crafts Professor of Engineering Systems
Department of Civil and Environmental Engineering
ACKNOWLEDGEMENTS

I express my gratitude to Dr. Fred Moavenzadeh for his guidance throughout this thesis. Without his insights, this thesis would not have been completed. The time he dedicated to my thesis is fully appreciated.

The assistance of my sponsor, Central Japan Railway Company, my all superiors and colleagues in JR Central, and my professors in Japan are gratefully acknowledged. My special gratitude goes to Dr. Masahiko Kunishima, Professor, Department of Civil Engineering, University of Tokyo.

I wish to thank Dr. John Miller, who gave me many hours of useful advice through his classes, Public Infrastructure Development Systems, and research seminars.

Many colleagues and friends helped me collect information essential to the research and gave me valuable suggestions about the topics. Mr. Mahdi H. Mattar gave me much advice regarding Real Options and read my draft. Mr. Koji Ishimaru provided a number of materials and comments associated with transportation business and infrastructure; Mr. Takashi Imamura gave me precious information, suggestions, and encouragements throughout this thesis research; Mr. Dominic Fung read the draft and made many helpful suggestions on this particular field; Mr. Yasuaki Moriyama helped me collect information about Japanese railway company’s business strategy; Mr. Yosuke Ando read the draft and gave me useful comments; and Mr. Bryan Goza corrected my English. I would like to thank them all. Despite those cordial supports given to me, needless to say, all the defects or errors this thesis may contain attribute to the author.

My last, but not least, acknowledgment goes to my wife, Junko. She always encouraged and supported me so that I might complete my research. This thesis is dedicated to you.

Takeshi Sato
Contents

ABSTRACT ......................................................................................................................... 2

ACKNOWLEDGEMENTS ................................................................................................. 3

List of Tables ...................................................................................................................... 6

List of Figures ................................................................................................................... 7

CHAPTER I Introduction ................................................................................................. 9

1.1 The Objective of This Research ................................................................................ 9

1.2 Organization of This Thesis ..................................................................................... 10

CHAPTER II Railroad Transportation Business and Infrastructure Portfolio ............ 13

2.1 Characteristics of Portfolio Management ................................................................. 13

2.1.1 Purpose and Objectives of Portfolio Management .............................................. 13

2.1.2 Position of Infrastructure Portfolio in a Railroad Company .......................... 15

2.1.3 Practical Aspects of Portfolio Management ....................................................... 19

2.1.4 Problems of Portfolio Management ..................................................................... 20

2.2 Investment in a Railroad Company’s Infrastructure Portfolio .............................. 23

2.2.1 Management Activities and Portfolio Investments ............................................ 23

2.2.2 Regular vs. Strategic Investment .......................................................................... 24

2.3 Portfolio Investments and Risk Estimation .............................................................. 29

CHAPTER III Economic Value Added (EVA®) and Portfolio Valuation .................. 33

3.1 Effect of Strategic Investment on the Portfolio Value ........................................... 33

3.1.1 Economic Value Added (EVA®) and Value of Project/Company .................... 33

3.1.2 EVA® and Strategic Investment ........................................................................... 37

3.2 Railtrack’s Strategic Investment .............................................................................. 41

3.2.1 Railtrack and Channel Tunnel Rail Link (CTRL) ............................................ 41

3.2.2 Railtrack’s Capital Improvement Projects ......................................................... 44

3.2.3 Strategic Investment Scheme .............................................................................. 46

3.2.4 Strategic Investment and Railtrack’s EVA® ...................................................... 48

CHAPTER IV Infrastructure Portfolio and Real Options ........................................... 52

4.1 Company’s Investment Opportunity ....................................................................... 52
List of Tables

3.1. EVA® Calculation for Simplified Financial Statements of Railtrack.............36
3.2. Costs and Performances of CTRL Project..................................................44
3.3. Railtrack's Forecasted Strategic Portfolio Investment.................................45
3.4. WCRM's Effect on the Journey Times.........................................................46
5.1. Gross Revenue and Infrastructure Charge in European Countries...............84
5.2. Estimation of Infrastructure Value in Japanese Railroad Firms.....................86
5.3. Average Volatility of Railroad Passenger Revenue......................................99
5.4. Estimated Revenue Volatility and Actual Stock Price Sigma of Japanese
      Railway Companies..................................................................................99
5.5. Value of E, F, G, H in Equation (13)......................................................105
List of Figures

1.1. Thesis Structure...........................................................................................................12
2.1. Railroad Company’s Value Chain..................................................................................16
2.2. Infrastructure Investment Activities and Typical Projects........................................25
2.3. Capital Asset Pricing Model..........................................................................................31
3.1. Implementation of Strategic Investment and Portfolio’s EVA®..................................37
3.2. Effect of Interlocking Portfolios in the Case of New Portfolio Addition [Case(a)]..................................................39
3.3. Effect of Interlocking Portfolios with Existing Sub-Portfolio Improvement [Case(b)]..............................................................................................40
3.4. Channel Tunnel Rail Link Project, UK.........................................................................42
3.5. Channel Tunnel Rail Link Project Organization.......................................................43
3.6. Location of West Coast Main Line..............................................................................45
3.7. Railtrack’s Infrastructure Management Activities and Associated Expenditures......................................................................................47
4.1. Investment and Value of Project, or Infrastructure Portfolio.................................53
4.2. Value of (a) Call Option, and (b) Infrastructure Investment Opportunity...............57
4.3. Value of Call Option...................................................................................................60
4.4. Infrastructure Investment Option..............................................................................62
4.5. Option-Based Relationship between Two Portfolios.............................................63
4.6. Geometric Brownian Motion Model..........................................................................67
4.7. Option Type and Value Curve....................................................................................75
4.8. Entry and Exit Decision Making Point.......................................................................79
5.1. Revenue and Infrastructure Maintenance Expenditure per Track Mile..................88
5.2. Hypothetical Average Infrastructure Maintenance Expenditure and Fluctuation......................................................................................89
5.3. Revenue and Infrastructure Capital Investment per Track Mile................................91
5.4. Hypothetical Average Infrastructure Capital Investment and Fluctuation.................91
5.5. Economic Depreciation of Railroad Firm’s Infrastructure.......................................93
5.6. Causes of Physical Depreciation.................................................................................94
5.7. Hypothetical Physical Depreciation Fluctuation.....................................................96
5.8. Drift of Passenger Revenue in Three Countries......................................................98
5.9. Possible Combination of Portfolio Value Creation Factors..................................102
5.10. Possible Portfolio Value Curves without Real Options Value Increment......107
5.11. Interaction between Regular Investment and Strategic Investment..........109
5.12. Portfolio Value Curve Intersection without Real Options Value Increment....111
5.13. Entry and Exit Strategic Investment Model for Railroad Infrastructure Portfolio ........................................................................................... 113
5.14. Strategic Investment and Infrastructure Portfolio Value
(Transition between Portfolio[L/H/H] and [L/L/L]).................................119
5.15. Strategic Investment and Infrastructure Portfolio Value
(Transition between Portfolio[H/H/H] and [H/L/L])....................................120
5.16. Strategic Investment and Optimal Revenue for the Transition between
Portfolio[LHH/HHH] and [LLL/HLL]...........................................................121
Chapter I

Introduction

1.1 The Objective of This Research

Infrastructure facilities or assets are the essential components for the business activities of a railroad transportation company. The railroad company’s set of facilities, i.e., the infrastructure portfolio, is characterized as vast, expensive, long-lasting, and complicated capital goods. In many large companies, its infrastructure portfolio consists of a few geographical networks, which enable a company to achieve not only economies of scale but also economies of scope.

Such huge tangible assets inevitably have the economic, social, political, and environmental impact on the environment at which they locate. Adversely, a company receives the equivalent responses from the environment in the form of the portfolio risks. Risks affect the performance of the infrastructure portfolio, and hence managers should cope with them technically, economically, socially, and politically.

Investments in an infrastructure portfolio are usually specific; that is, they are used for the construction and operation of sunken assets such as bridges, viaducts, tunnels, or stations. They are irreversible and non-deployable, and cannot be removed and resold at the secondary markets. Thus, upon making the investment, a company’s managers should have both short and long term vision, and be prepared for potential changes in the future portfolio circumstances.

From a manager’s point of view, the function of portfolio investments can be divided into two categories: investments associated with regular or day-to-day portfolio management activities, and investments focusing on the strategic development of the portfolio. Regular investments are made constantly in order to sustain current portfolio performance or condition; therefore, their budget does not
change drastically from year to year. On the other hand, strategic development requires a company to make occasional, but intensive investments, which in turn force managers to carry extra risks in exchange for shaping their desirable portfolios successfully.

The objective of this research is providing a basis for an analytical approach to the manager’s strategic portfolio investment and the portfolio value maximizing condition. The value of the strategic investment and portfolio is measured from two directions which reflect a railroad company’s economic risks: the investor’s expected return, and the manager’s flexibility. Mathematical models are applied to the actual railroad company’s capital investment in the portfolio in order to evaluate the manager’s strategy quantitatively.

1.2 Organization of This Thesis

This thesis is organized into four main chapters.

Chapter II introduces the concept of a railroad company’s infrastructure portfolio and explains its managerial roles and characteristics in the railroad transportation business. Section 2.1 defines the portfolio as an integration of a company’s variety of infrastructure facilities, and analyzes its nature, position, advantages, and problems. Section 2.2 clarifies the roles of both regular and strategic portfolio investment activities, and analyzes their impact on the company’s portfolio management. In Section 2.3, the risks, which surround the portfolio management and manager’s investment activities, are analyzed. How to cope with the economic uncertainties examined here is a background of the following three chapters.

Chapter III then applies the Economic Value Added (EVA®) approach to the valuation of the infrastructure portfolio. EVA® is the term developed by Stern Stewart & Co to assess a firm’s residual income. This approach is, in a sense, a “static” method for measuring the effect of managers’ strategic investment activities, because it analyzes the value-creating investment opportunity from the viewpoint of
the portfolio return and investor’s expected return for a fixed period of time. Section 3.1 introduces the general concept of EVA®. Section 3.2 theoretically develops the portfolio value maximizing conditions in the context of this EVA® approach. Then, an actual railroad infrastructure company’s portfolio and the strategic investments are analyzed by applying the method in Section 3.3.

Chapter IV introduces and explains the real options approach theoretically in order to apply this concept mathematically to the later case analysis in Chapter V. Using option analogy enables the managers to incorporate the value of their investment decision-making flexibility in the portfolio value. Section 4.1 provides theoretical background for determining the investment opportunity value and decision-making point. Section 4.2 develops a general mathematical model for portfolio valuation and interpretation of economic implications.

Chapter V is a case study in which the value of infrastructure portfolio and optimal strategic investment timing are analyzed through the quantification of a company’s portfolio management activities and the application of the real options valuation model. Upon the application of the real options to the railroad company’s infrastructure portfolio, Section 5.1 sets two essential assumptions: revenue flexibility, and changes in the portfolio’s operational efficiency of the port; therefore, the role of the strategic investment assumed in this chapter is not to create entirely new portfolio, but to bring more efficient operational condition to the company. Section 5.2 quantifies the three value factors that affect the value of the infrastructure portfolio: maintenance cost, regular capital investment, and physical depreciation. By using the combination of these factors, Section 5.3 first describes potential changes in the portfolio condition and its value, and then attempts to find the strategic investment opportunity that is closely related to this condition changes. Finally, the relationship between the amounts of strategic investment and manager’s optimal investment decision timing is established at a given revenue flexibility.
The structure of this thesis is shown in Figure 1.1.

**CHAPTER I**
Introduction

**CHAPTER II**
Railroad Transportation Business and Infrastructure Portfolio

- <2.1 Characteristics of Portfolio Management>
- <2.2 Portfolio Investment>
  - Regular Investment
  - Strategic Investment
- <2.3 Investments and Risk Estimation>

**CHAPTER III**
Economic Value Added (EVA®) and Portfolio Valuation

- EVA® Theory
- EVA® Application
  - <3.1 Effect of the Strategic Investment on the Portfolio Value and EVA®>
  - <3.2 Railtrack’s Strategic Investment>

**CHAPTER IV**
Infrastructure Portfolio and Real Options

- Real Options Theory
- <4.1 Company’s Investment Opportunity>
- <4.2 Mathematical Modeling>

**CHAPTER V**
Real Options Application

- Portfolio Condition Change and Strategic Investment Timing of Railroad Company
  - <5.1 Fundamentals of Real Options Application>
  - <5.2 Infrastructure Value Factor Comparison between European and Japanese Railroad Firms>
  - <5.3 Portfolio Value Maximization>

**CHAPTER VI**
Conclusion

---

Type of Valuation: “Static” Valuation
Valuation Mechanism: Risk / Return
Portfolio Value:
  = Portfolio Return
  – Investor’s Expected Return
Analogy: Stock Price and Dividend

Type of Valuation: “Dynamic” Valuation
Valuation Mechanism: Option / Opportunity
Portfolio Value:
  = Inherent Portfolio Value + Opportunity Value
Analogy: Financial Option Price

Figure 1.1. Thesis Structure
CHAPTER II

Railroad Transportation Business and Infrastructure Portfolio

Various types of capital assets are indispensable to the railroad transportation business. They are to be obtained through managers’ investment activities, and sustained by their maintenance and operation activities. Then, appropriate investment decision in terms of quality, quantity, and performance of the designed capital asset as well as its timing of implementation affects significantly upon these managerial activities. However, managers might make their investment decisions based not only on the cost and value of one project or asset, but also on a broad view of the company’s entire infrastructure condition.

Investing in the network ground facilities particularly requires such perspective, because an individual transportation facility cannot make profits by itself, and the collection of the individual facilities does create certain values for a railroad company. In other words, the integration of these facilities is required for a company to generate its revenue from these capital assets.

Portfolio-based infrastructure management is an approach to evaluate the integrity of a company’s assets in the most effective way. It helps managers to understand the effect of their activities as well as the value of their infrastructure assets through broad business perspectives.

2.1 Characteristics of Portfolio Management

2.1.1 Purpose and Objectives of Portfolio Management

A management activity has its purpose and objective. The purpose is the final goal or intended result of the activity, and the objective is the managerial hurdles that every management activity should clear during its implementation. Without clear purposes and objectives, a firm’s activities will lose their desired effect
or direction of movement.

A railroad company’s management activities which aim to develop a set of its infrastructure assets, that is, *infrastructure portfolio management*, has only a single purpose: a company’s infrastructure value maximization by integrating the effects created by a sequence of the infrastructure-related activities. Note that the word “infrastructure” in this paper refers to ground facilities.

Portfolio management requires successful short- and long-term approaches to controlling a company’s collection of facilities, as well as proper strategies and techniques for developing the portfolio. Of course, some managerial restrictions might be applied to that purpose. Portfolio management is subjected to the company’s grand strategy; therefore, it should be arranged so that the end portfolio condition could satisfy the company’s essential business needs.

The objective of portfolio management, unlike its purpose, is multiple. First, portfolio management has productivity objectives. The entire network infrastructure system, as well as an individual component facility in the network, has to be organized effectively throughout its wide-ranging management phases from planning, design, construction, to operation and maintenance, and abandonment. Budget constraints for a company require the managers to select appropriate projects or activities that allow their portfolio to demonstrate its desired performance with minimum costs, or with more advanced operational efficiency.

Second, portfolio management should take a firm’s social responsibility objectives into account. A company’s infrastructure assets, whatever the scales or types are, inevitably have economic, social, political, and environmental impact on customers, peripheral residents, regulators, and other stakeholders. This impact adversely causes external reactions against the infrastructure management. The company might forecast and perceive these reactions as the risk of portfolio management, and try to reduce them by collecting as much information as possible.

Finally, the infrastructure portfolio management should create certain profits
or returns from the portfolio, whether or not the company manages its portfolio while owning and operating the rolling stocks simultaneously. The profit will allow the company to sustain and develop its portfolio through re-investment, as well as to reward the shareholders and managers. This can be called profitability objectives of the portfolio management. The profitability objectives might provide the managers the criteria of their investment decision as well as the measures of the financial performance of the invested portfolio. However, for many railroad companies, their profitability objective does not always lead to the maximization of profit, because these companies are usually in conformity with the government regulation so that they have the obligation to contribute to the public interest.

2.1.2 Position of Infrastructure Portfolio in a Railroad Company

A company’s infrastructure portfolio needs maintenance and investment activities in order to achieve its expected performance. Some portfolio might require installing different kinds of activities all together, while other portfolio’s condition could be upheld by a single management activity. However it is sometimes difficult to measure the effects of these infrastructure-related activities without considering the interaction with other management activities.

Michael E. Porter analyzes a firm’s individual activities as well as their economic linkages inside the firm, and presents the concept of a “value chain” in *Competitive Advantage* (1985). This value chain model helps us to understand the arrangement of the railroad company’s management activities and the positioning of the infrastructure portfolio in the firm’s value creation system. Figure 2.1(a) is a railroad company’s value chain that owns and operates both ground facilities and rolling stock, and (b) describes a railroad infrastructure company’s value chain.
In the figure, the shadowed area indicates the position of the infrastructure portfolio in the railroad firm. Of course, the rolling stock, and other equipments are excluded from the portfolio here. Some value chain linkages connect the infrastructure-related activities inside the portfolio. Other linkages connect the portfolio with the non-infrastructure activities inside or outside the company. Thus, the infrastructure portfolio has both inward and outward linkages, and they determine the positioning of the portfolio in the railroad transportation business.

Porter argues that a firm’s individual value activities as well as their linkages,
i.e., the value chains, create a firm’s total value, and the differences among competitor value chains are a key source of competitive advantage. In the self-contained railroad company’s case (Figure 2.1(a)), the linkages between the company’s support activities and primary activities create its overhead firm infrastructure, which then supports other primary activities such as the train operation, marketing, or passenger service. Similarly, in the railroad infrastructure company’s case (Figure 2.1(b)), the company’s inward linkages create its competitive value, while its outward linkages affect the train operating company’s value chain.

The value of the infrastructure portfolio consists of these value activities and their linkages; therefore, upon analyzing its market or business value, it might be more convenient to evaluate all of these interactions and relations comprehensively. Changes in quality or capacity of these value activities, or in the coordination or interdependency of the linkages might cause the alteration of the portfolio value. For example, changes in construction procurement system might enhance the quality of invested capital, which in turn causes certain modification to the maintenance and operation activities. In Figure 2.1(b), the railroad infrastructure company has the supplier position against the buyer, i.e., the train operating company. Changes in the value of infrastructure portfolio directly affect the buyer performance.

Some might think that a railroad firm’s individual infrastructure facility such as a bridge, tunnel, or viaduct has no relation with the return on the invested costs, and their values are “overhead” costs in order to perform the transportation business successfully. Then, they conclude that a firm can never expect any return or profit from the infrastructure portfolio, which is a collection of these individual invested facilities. Others might say that infrastructure investment does not create high return at all; therefore a company should focus on other higher-return producing activities or businesses in order to pursue its profitability by minimizing the infrastructure investment expenditures.

It is obvious from Porter’s model that these arguments are not true. First,
as is described above, the infrastructure portfolio has a certain economic value, which
derives from the infrastructure-related value activities and their value chains.
Second, whether the portfolio creates a high return or not depends on the structure of
its value chain. Porter emphasizes the strategic implication of the cost advantage or
differentiation for determining a firm’s profitability. Economies of scale or
economies of scope, as well as capacity utilization and activity linkages are important
cost drivers for the infrastructure portfolio. The service quality provided,
technology employed, operating experience, location of portfolio, and linkages are
the drivers of uniqueness. The profitability of an infrastructure portfolio should be
argued based on the effect of the interaction or coordination between these drivers.

Figure 2.1 (b) describes vertical linkages of the value chain between the
supplier and buyer of the infrastructure services; that is, it depicts the vertical
separation system of the railroad transportation. This industry structure gives us a
cue to evaluate the value of infrastructure portfolio or its degree of the contribution
to the gross profit created by the entire transportation business processes.

This vertical separation system has been adopted in many European railroad
businesses, and it’s one kind of “outsourcing” of the infrastructure division by the
train operating company. Therefore, it is possible to measure the degree of the
infrastructure portfolio contribution to the gross railroad business revenue by tracking
the cash flow between these value chains. If one knows the degree of contribution,
then, the value of the portfolio can be calculated. In Chapter 5.2.1, the estimation of
this degree is attempted, and, as an approximate number, 20% is obtained for the
infrastructure contribution to the non-vertically separated company’s gross business
revenue. Therefore, if the effects of value activity, value chain, cost of capital, as
well as the investment timing in the portfolio are examined properly, it is possible for
a firm to acquire a more productive and profitable infrastructure portfolio.
2.1.3 Practical Aspects of Portfolio Management

Technically, portfolio management is a matter of a company’s capital allocation over the different types and functions of infrastructure assets, and it requires the trade-off among prospective infrastructure conditions within the budget constraint. Developing and sustaining the infrastructure portfolio is an important management issue for the profitability and sustainability of the railroad transportation business. Railroad companies begin to recognize that not a single asset or project, but an entire portfolio management provides them with an efficient set of valuable assets, which makes their business capable of generating a revenue stream that exceeds the infrastructure operating costs, and accordingly yields profit for the company.

The portfolio management discussed is not mentioned as an aggregate of individual asset managements, or as a preferred selection of higher return producing assets or projects. Setting portfolio framework might require the procedure of strategic choices of all resources available to the company as well as all opportunities accompanied by the project configuration.

John Miller developed a scenario-based approach to the simultaneous use of multiple project delivery and finance methods for more effective management of the public entity’s infrastructure portfolio in *Principles of Public and Private Infrastructure Delivery* (2000). This approach enables public owners to encourage private sector participation and cooperation for their infrastructure portfolio management. Miller’s analyses are also applicable to the highly public railroad company’s strategic infrastructure management. He refers the “five strategic variables” as the dominant factors in sustaining and improving both public and private owner’s infrastructure portfolios. The five strategic variables are: content (scope); condition assessment; sources and uses of funds; project delivery and finance methods; and pace (or level of investment). Proper management of these variables is growing to be an important issue for infrastructure owners to operate and
improve their portfolios.

Managing a railroad company’s infrastructure portfolio, also, requires simultaneous consideration of these strategic variables without exception. The cost, quality, and performance of the network facilities as the contents of infrastructure collection have to be examined strategically. The condition assessment of individual facilities is required for both short- and long-term portfolio budgeting. The sources and uses of funds considerably affect the manners of portfolio management not only in the strategic context, but also in the regulatory circumstances. Construction of the railroad infrastructure requires huge capital investments, and is usually subsidized by the government or municipalities to a certain extent; therefore, the constructed facilities as well as the company’s budgeting conditions are subjected to the scrutiny by the government auditors. With regard to the multiple use of the delivery method, many national railways’ recent privatization is an opportunity to introduce more flexible project delivery for the construction of the railroad infrastructure. The last strategic variable “pace” affects the long-term performance of the portfolio by modifying the value activities or value chains described in the Michael Porter’s model (Figure 2.1).

The combination of these strategic variables determine the nature and impact of the value activities that meet manager’s needs, which in turn shape the portfolio condition. Therefore, the strategic variables are the roots that bring certain future revenue flow to the company.

2.1.4 Problems of Portfolio Management

Consider a diversified railroad company which not only owns and operates the entire means of transportation, i.e., vehicles, machines, lands, ground infrastructures, but also has many subsidiaries that provide ancillary services to the core transportation business. In reality, the return from the infrastructure portfolio itself is rarely a performance measure for a firm’s generic business strategy.
Usually a firm does not decide to develop an infrastructure portfolio without simultaneously considering the effect of other non-infrastructure business activities that will utilize the portfolio.

For example, let us suppose a company that intends to sink capital in constructing a new route. The firm may also consider investing on land or real estate development adjacent to the new route. In this case, the construction of the new route is regarded as an infrastructure portfolio investment, while land or real estate development is a non-infrastructure investment. However, the land or real estate development will contribute to future passenger increase of the new route. Therefore, the new route investment will be ultimately decided based on the demand forecast that takes into account the revenue increases as a result of the land or real estate development.

However, the firm, at the same time, must consider the profit or return produced by the non-infrastructure investment itself. The firm may be satisfied with a future forecast which predicts the surplus of both infrastructure and non-infrastructure capitalization. But what if the forecast tells the firm that real estate and land development will achieve a sufficient rate of return while a new route will end up with considerable deficit? Or, what if the forecast tells the firm that the new route will never generate enough revenue to cover its capital cost without investing in the land development?

Let us suppose another case. A railroad firm is planning one project to improve its passenger transportation services of an existing line. This project requires a huge amount of investment in improving its ground infrastructure, vehicle accommodation, concierge service, and so on. Then, the firm will be able to calculate its return on the “total” investment from expected future revenue increase and required investment costs. However, it may never be figured out which portion of the return comes from each of the investment in the infrastructure, vehicle, or other services.
What is obvious from these examples above is that a network firm’s investment decision is extremely difficult when the gross expected return is yielded by the combination of both infrastructure and non-infrastructure investment. Eventually, a firm does not have any other approaches except for measuring the profit performance of the complex project based on the return from the whole implemented value activities including both asset and non-asset investment, not based on the return from the constructed infrastructure.

However, this railroad company’s strategy, which needs to invest in both asset and non-asset activities, has the possibility to bring the firm into an unfavorable financial condition by owning many assets which are apparently over-invested. Moreover, the invested amounts in the infrastructure will not be covered by the return from the integrated investment activities. Ironically, this situation is frequently observed when a company pays small attention to the question, “What is the return on invested network infrastructure?” A company may also lapse into this situation when it assumes that the amount of money input in the infrastructure is just a required costs for their business, and the amounts invested in other non-infrastructure business opportunity does create profit.

Of course, there are cases where profit can be created by infrastructure investment itself. Outside the railroad transportation business, Build-Own-Operate-Transfer toll roads or bridge construction projects are typical examples. However, it is common for a railroad company to combine both types of infrastructure and non-infrastructure investments, because, a network infrastructure investment usually creates other business opportunities outside the infrastructure portfolio.

It is true that the profit of a business opportunity that requires both the network infrastructure and non-infrastructure investments must be evaluated by the entire required investment amounts and their returns. However, we can also say that if a firm could determine the value and return of its infrastructure portfolio, not
only the effects of its infrastructure portfolio but also those of its other non-asset management activities on its business strategy might be evaluated based on more solid financial criteria. Porter’s model gives us the information regarding the value-based position of a railroad infrastructure portfolio. In Chapter III and V, the portfolio is treated as the objective of a company’s strategic investments that requires certain inputs and creates corresponding returns by itself.

2.2 Investment in a Railroad Company’s Infrastructure Portfolio

2.2.1 Management Activities and Portfolio Investments

Let’s go back to the Porter’s model (Figure 2.1). The infrastructure portfolio has two primary activities: capital investment activity, and facility maintenance and operation activity. These two activities are complementary; however, there are some intrinsic differences in the managerial role between them.

Maintenance activities, which are accompanied by the facility operation activities, are regularly and constantly performed in order to maintain the current physical condition of the infrastructure portfolio. On the other hand, the role of the capital investment activities can be separated into two categories: regularly performed activities for sustaining both short- and long-term physical portfolio conditions, and strategically installed activities for adding new portfolio or enhancing the ability of the existing portfolio.

The outcomes of the maintenance activities are the operating expenditures, subtracted from the company’s annual revenues. Then, the activities directly reduce the firm’s profit margin. Therefore, from an accounting point of view, the maintenance activities are items that only diminish the value of the infrastructure portfolio. On the other hand, from the manager’s long-term viewpoint, these activities have the value linkages with the capital investment activities as well as with the expected portfolio conditions. As a company’s regular management, performed maintenance or repair activity has a certain impact on the portfolio value.
The outcome of capital investment activities are a set of fixed assets, and they increase the company's asset value. From the accounting viewpoint, these activities add book value of the invested facility to the portfolio. Both the regularly performed capital investment and strategically installed investment equally increase the book value; however, their contributions to the value, behavior, return, function, and condition of the company's whole portfolio are quite different from each other. Their investment objectives, timings, and opportunities also differ in that the strategic investment has a higher flexibility.

If one considers a company's budgeting, these management or value activities above have some common features. For example, the regularly performed activities, whether they are categorized as maintenance or capital investment, have almost fixed annual budgets, and they do not show drastic fluctuations from year to year, except special needs for unexpected events. In other words, they are regularly and constantly required by the infrastructure portfolio in order to sustain its current condition both physically and economically, which assures the train operation safety and then creates passenger loyalty.

2.2.2 Regular vs. Strategic Investment

In the previous section, some functional differences between the regular and strategic investment are explained in the context of a company's infrastructure value chain. This section describes the characteristics of the capital investment activities in more detail. First, Figure 2.2 depicts the position of each value activities in the firm's capital investment activity segment.

Each investment activity in the figure is not independent, but related to each other. The relation can be interpreted as a value chain in the Porter’s model. For example, the amounts invested in the maintenance backlog reduction might affect those invested in the capital replacement. The capital replacement projects are sometimes accompanied by the capital improvement projects. These value linkages
are directly tied to the company’s capital budgeting.

The activity stream from upper left to lower right can be observed from the figure. This tendency implies that the larger the invested amount, the more strategic the investment, although there are some exceptions. A large project sometimes needs two or more different activities, however the objective of the use of capital is usually specified with respect to the activity intended. The characteristics of these investment activities are described in terms of the preformed project below.

![Type of Capital Investment Diagram](image)

**Figure 2.2.** Infrastructure Investment Activities and Typical Projects

1. Large-Scale New Project

This project is highly strategic, massive, indivisible, and time-consuming. Not all the network owner-operators can afford to invest in the project. The
project’s investment requires over 500 million dollars. Not only a railroad company but also many related-parties need to involve in the project. The project requires not only huge capital investments, but also the implementations of vast business resources and latest technologies, as well as the arrangements of institutional, social, and political stakeholders. A network firm usually decides to carry out the project based on the long-term forecast that the business opportunity would lead to substantial monopoly or achieve economies of scale with a higher expected return.

Project environment tends to change through all the phases of the project, and with other unforeseeable uncertainties, it frequently interferes with a company’s investment execution or business performance. Thus, the timing of investment should be carefully calculated with regard to these external factors. Environmental, social, and political impacts of the project are also large. In many cases, the government might grant the railroad company certain concessions, rights, and subsidies in order to promote the project, because the investment would have a potential to create employment, more convenient public services, and new footholds for the national land development. At the same time, some forms of government restriction might be applied to any phase of the project.

A very long project time-horizon is needed for planning, designing, constructing, and operating the facilities. Moreover, it will take several years before beginning to generate certain amounts of revenue, and more than ten years before recouping initial investment costs.

2. Small-Scale New Project

A network firm may consider taking business opportunities with short extensions of existing networks or construction of new business facilities that will meet the increasing customer demands. These projects here require approximately $10 to $500 million of total investments.

The same or weaker forms of financial, social, political risks as those of
large-scale new projects are subjected to this project. The construction period is much shorter compared to the facility’s long lifetime. Thus, the timing of investment is not so much emphasized as that of large-scale project. A firm might have experience in executing a number of similar small projects in the past; therefore, some typical aspects can be found in pre-construction procedures or institutional arrangements. Uncertainties are less involved in all phases of the project.

3. Capital Improvements

The purpose of this investment activity is enhancing the capability of a company’s existing facilities or portfolios. Partial infrastructure upgrading or system improvement allows a company to provide new services to its customers. This investment, for example, includes equipping existing stations with new barrier-free devices to enhance the convenience of handicapped persons’ station access, as well as improving track alignment to facilitate smooth traveling of vehicles, or retrofitting the piers of existing elevated bridges in order to augment their seismic capacity. Some investments are made in response to social or political requests, and in such cases, a firm can leverage public funds to improve its own facilities. At the same time the company can allocate its resources only to quantified benefits received from the improvement.

Generally, two types of effects are brought about to the company as a result of this capital improvement investment. Some investments might create new customers, or make customers accept higher charges for newly provided services. Others might improve a firm’s operational efficiency such as reduction in the operation and maintenance costs. There might also be some indirect effects of the investment on the existing infrastructure portfolio; that is, the improvement of one portfolio might increase or decrease the operating profits of the company’s other portfolios that are correlated to the originally improved portfolio. Upon evaluating the performance of the project, the effects above should be considered; however, a lot
of unforeseeable effects might blur the manager’s judgment on the investment amounts or timings.

4. Component Renewal/Capital Replacement

Component renewal or capital replacement has a close relationship with the maintenance and repair activities in the company’s infrastructure portfolio. Component renewal activities are performed on a divisional scale, if necessary. Capital replacement can be classified into two categories according to the objective of the investment: (1) life-cycle replacement, and (2) environment-adjusted replacement. A railroad network company is, in a sense, obliged to execute the investment projects of both categories, because these projects might not assure the company of bringing a higher return than before making the investments.

(1) Life-cycle replacement

The main objection of making this investment is to secure user or passenger transportation safety. A facility whose service time approaches its lifetime has a potential to be a failure. For a railroad company, a failure of one portion of its route or portfolio may call halt to the entire traffic flow. In order to avoid such undesirable and unexpected events, managers must take action in advance and replace facilities which have a possibility of failure. Since passengers or customers are quite sensitive to their safety, they would choose alternative transportation fleet if a company’s current services turn out to be unreliable. Thus, life-cycle replacement is, in other words, an investment activity necessary for a company to secure its current revenue stream and return level.

(2) Environmental adjusting replacement

The government or other public sectors sometimes require a company to replace its facility which fails to meet new government building standards, or is out of accordance with the benefit of local citizens. In such cases, a firm’s facilities are replaced although their lifetimes have not reached yet. Most parts of a project are
funded by the government or public sectors, however, a firm occasionally pays a portion of the investment cost, which is commensurate with the benefit the company will gain from the project. It is sometimes difficult to distinguish these investment activities from those of the capital improvement.

5. Maintenance Backlog Reduction

Backlog reduction activities and capital replacement activities are inseparably related to each other. Deferred maintenance shortens the lifetime of facilities, and its backlog builds up the zone inside the network that need to be replaced. In most of the railroad companies, their maintenance and repair activities are delayed or deferred, because these deferred maintenance backlogs are not necessarily linked directly to the facility failures, which all network companies must avoid in order to secure their business return.

6. Other Investment: Abandon, abolish, or divestiture

If the expected return from an existing business domain is very low, and a firm has no alternative way to increase the return, it can choose the exit strategy. In this case, a firm may stop providing its services or sell its business. Moreover, a firm should pay taxes for these facilities and lands, which are no more in use for its business. Exit timing and costs, the amounts of salvaged asset value are a manager’s major concerns when making this decision.

2.3 Portfolio Investments and Risk Estimation

A railroad company’s managers must cope with the risks or uncertainties that surround their infrastructure portfolio over its life cycle. They view the uncertainties as unforeseeable events, and the risks as the outcomes of these uncertainties. Capital investments, which are parts of the portfolio management activities, are also subjected to these uncertainties and risks.
According to Miller and Lessard (2000), the risks of a large engineering project are categorized as follows: (a) market risk, (b) financial risk, (c) completion risk, (d) technical risk, (e) operation risk, (f) regulatory and political risks, and (g) social acceptability. These risk categories above are accompanied by the related drivers of risks, which would affect the future performance of the invested project or portfolio. Managers are asked to pay attention to the risk drivers as well as to control them in order to avoid managerial losses incurred when these risks turn to reality.

The first step to managing investment-related risks is the identification of the risks. Then, managers need to evaluate their impacts or effects on the investment activities. Eventually, they will try to reduce the exposure of their investment activities to these identified risks. These processes often lead to the quantification of risks, i.e., statistically-based risk management. The quantified risk might give the managers a certain benchmark for their investment decision-making; however, there are no definitive measures for the quantification of the risks.

Suppose a railroad infrastructure company is all equity financed, and the company has only one infrastructure portfolio. The risks of the portfolio as well as the managers’ capital investments in the portfolio might be reflected in the firm’s market stock prices to some extent. In other words, the investors would indirectly estimate considerable portion of the risks involved in the infrastructure portfolio or managers’ investment activities. In such cases, the capital asset pricing model (CAPM) works for the quantification of the risks (Figure 2.3).

In the figure, investor’s expected return from the all equity financed railroad infrastructure company’s stock is \( r_i \). This is the value the company must reward its investors in proportion to the market risk of its stock. Since the risk free rate is \( r_f \), the portfolio’s risk premium can be described as \( r_i - r_f \).
The market risk of the company with respect to the risk of efficient market portfolio (not infrastructure portfolio) is reflected in the value of $\beta_i$. $\beta_i$ is defined as:

$$\beta_i = \frac{\text{cov}(r_m, r_i)}{\sigma_m^2},$$  

(1)

where $\sigma_m$ is the standard deviation of the market portfolio, which is equal to the risk of the market portfolio. The term $\text{cov}(r_m, r_i)$ is the covariance between the expected market return and the company’s expected stock return. Then, the investors expected reward or return $r_i$ from holding the company’s stock $i$ can be formulated as follows,

$$r_i = r_f + (r_m - r_f)\beta_i.$$  

(2)
The value of the unique risk, which is specific to the company’s infrastructure portfolio, is $\sigma_i - a_i$. Thus, for the managers, their company’s market risk $a_i$ might be a benchmark with which they could figure out how much portion of their company’s total risk should be rewarded to the investors through the stock market.

However, this capital asset pricing model assumes the efficient market portfolio; that is, each investor will choose exactly the same combination of risky assets, or stocks. The theory also neglects the existence of transaction costs, or other external economic factors which affect a company’s market risks. In order to acquire more accurate risk-return conditions of the firm’s stock, managers might well consider the application of the arbitrage pricing theory (APT), which could take such factors into consideration for deriving the company’s market risk $a_i$ as well as investors’ expected return $r_i$ from the company.

The relationship between the railroad infrastructure company’s portfolio return and its investors’ expected return would further be discussed in Chapter III.

There are other characteristics of the risks associated to the managers’ investments in the infrastructure portfolios. First, risks forecasted at the planning phase might be different from those perceived by the managers upon their investment execution. Second, as more information is available to the managers, the risks of the investment would be reduced. Thus, managers will be able to avoid some of the risks through their flexible decision-making processes.

This managerial flexibility would be discussed in Chapter IV and V with respect to the decision-making timing of strategic investment, which would enhance the infrastructure portfolio’s operational efficiency.
Economic Value Added (EVA®) and Portfolio Valuation

A shareholder of a company has to be rewarded by the company through stock dividends and the hoped-for rise in its price. In other words, a company has to produce a certain return on the shareholder’s investment as well as enhance its market value. The sources of return can be created both in and out of a company by the manager’s investing activities, which aim at incorporating some higher-return yielding projects in the firm as well as sustaining the company’s current high returns. However, that is not the end of the story. If the managers’ project produces a lower return than the investor expects, the company then has to compensate the shortfall by killing some retained earnings or some of its assets. In this situation, we might well say that the company is reducing its economic value. On the other hand, when the managers’ project or portfolio produces a higher return than expected, we might as well say that the company is adding economic value.

The argument above is also true for a company’s strategic investment in its infrastructure portfolio. Whatever the investment is, the invested infrastructure should produce a higher return than the investor’s expected reward so that a company can keep adding the economic value.

3.1 Effect of Strategic Investment on the Portfolio Value

3.1.1 Economic Value Added (EVA®) and Value of Project/Company

Economic Value Added (EVA®) is a concept propounded by Stern & Stewart Co. as a measure of a firm’s residual income, which is the result of a firm’s financing and investment activities. Simply put, it is operating profits less the cost of all of the capital employed to produce those earnings. It can also be a measure of
both the economic values and performances of a project or asset. An infrastructure asset, or portfolio, which usually has a certain capital book value, should bring some economic profits to the company; at the same time, as long as the asset or portfolio has a book value, there are costs associated with the value, that is, the cost of capital.

By judging the infrastructure’s residual income, i.e., the economic profits from the infrastructure less the cost of capital of the asset, one can evaluate the contribution of the infrastructure asset, or portfolio, to the firm’s economic value increments. Moreover, the residual income is not only a measure of a firm’s infrastructure portfolio value, but also a measure of the shareholder wealth increased by the portfolio.

If the designed infrastructure project is expected to produce more profits than the cost of capital invested in the asset, the project can be considered to add a positive EVA® to the company. The economic value earned is to be retained in a firm as an increment of the shareholder wealth; therefore, the project is worth the investment of capital when the expected EVA® is larger than zero. On the contrary, if the designed infrastructure project is likely to incur more cost of capital than the expected profits, the infrastructure project will add a negative EVA®. In such a case, when the economic value would be subtracted from the firm’s total value, the project should be cancelled. The concept of the Economic Value Added can be formulated as follows:

\[
\text{Economic Value Added} = \text{NOPAT} - \text{Dollar Amount of Cost of Capital}, \tag{1}
\]

where NOPAT is the project’s net operating profits after taxes, and Capital is the total capital employed in operations. Thus, equation (1) can also be expressed in the following form:

\[
\text{Economic Value Added} = \text{Income Earned} - \text{Income Required} \tag{1'}
\]
These equations above might be more familiar to us if we divide the both sides by the capital invested in the project.

\[
\frac{\text{Economic Value Added}}{\text{Invested Capital}} = \frac{\text{Income Earned}}{\text{Invested Capital}} - \frac{\text{Income Required}}{\text{Invested Capital}}
\]

Net Rate of Return \( (R) \) = Return on the Project \( (r) \) - Cost of Capital, \( (\rho) \)  \hspace{1cm} (2)

where the term \( r \) is a firm’s return from operating the project or asset, while the term \( \rho \) is the investor’s expected return. Thus, for a firm, the project is worth investing in and carrying out when \( r \) is larger than \( \rho \), because some portions of the return on the project can be retained in the firm even after it rewards its investors. On the other hand, it is obvious that the project is not worth investing when \( r \) is smaller than \( \rho \), because a firm eventually overpays its investors beyond the solvency margin of the project. Shareholders might be pleased with earning the expected return \( \rho \) from the firm; however, they will actually lose some of the value of the firm. In this section, the weighted average cost of capital (WACC) is used for the value of \( (\rho) \).

NOPAT as used here is not pure “net operating profits after taxes” in accounting terms, but it makes adjustments when used for EVA\(^\circledR\) calculation in order to give a clear financing picture. First, tax shields of the debt interest expenses are added back to NOPAT. Furthermore, preferred dividends, minority interest provisions as well as increases in equity equivalents must also be added into the NOPAT. Similarly, the “Capital” in the equations above has to be adjusted so that it can include common equities, equity equivalents, preferred stocks, minority interests and all of the debts. For the derivation of a year’s return, the capital at the beginning of the year is used because it is assumed that newly invested capital requires a full year to become fully productive.
Table 3.1 is an example of the Economic Value Added calculated by using the simplified financial statements of the year 2000's Railtrack in the United Kingdom. Railtrack had lost the economic value during one year ended at March 31, 2000, since its EVA® is negative $58.6 million.

**Table 3.1. EVA® calculation for simplified financial statements of Railtrack**

<table>
<thead>
<tr>
<th>[NOPAT (year ended at 31 March 2000)]</th>
<th>[Beginning Capital (1 April 1999)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating revenue</td>
<td>Debits due within one year (1)</td>
</tr>
<tr>
<td>3,859</td>
<td>48</td>
</tr>
<tr>
<td>Operating costs</td>
<td>Debits due after more than one year (2)</td>
</tr>
<tr>
<td>(3,309)</td>
<td>2,453</td>
</tr>
<tr>
<td>Operating profits</td>
<td>Equity shareholder's funds</td>
</tr>
<tr>
<td>550</td>
<td>5,323</td>
</tr>
<tr>
<td>Other profits</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Net interest expense</td>
<td></td>
</tr>
<tr>
<td>(89)</td>
<td></td>
</tr>
<tr>
<td>Net operating profits before taxes</td>
<td>Total Capital</td>
</tr>
<tr>
<td>545</td>
<td>7,824</td>
</tr>
<tr>
<td>Taxes</td>
<td>Weighted average interest rate</td>
</tr>
<tr>
<td>(98)</td>
<td>of (1) and (2)</td>
</tr>
<tr>
<td>Income available to common</td>
<td>(*) Calculated by Railtrack</td>
</tr>
<tr>
<td>447</td>
<td>6.39%</td>
</tr>
<tr>
<td>Tax(30%) shield of interest expenses</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Net Operating Profits After Taxes</td>
<td>Expected average Railtrack equity return</td>
</tr>
<tr>
<td>474</td>
<td>7.00%</td>
</tr>
<tr>
<td>(Million US$)</td>
<td></td>
</tr>
<tr>
<td>NOPAT/Total Capital</td>
<td>Weighted Average Cost of Capital</td>
</tr>
<tr>
<td>0.061</td>
<td>(WACC)</td>
</tr>
<tr>
<td>Economic Value Added</td>
<td>0.068</td>
</tr>
<tr>
<td>(Million US$)</td>
<td></td>
</tr>
<tr>
<td>-58.6</td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 EVA® and Strategic Investment

As was discussed in Chapter II, a railroad company’s infrastructure investment activities can be classified into two categories; one is the regular capital investment, and the other is the strategic investment. In terms of the managerial roles of these investments, the former regular investments are usually made in order to assure the safety of the train operations, that is, in order to sustain the company’s current business return level. The latter strategic investments should bring higher returns to the company. Given these managerial roles of both types of investment, we can say that the regular capital investments are made in order to keep the company’s EVA® at the same level as that up to the present year, while the strategic investments should add the positive EVA® to the company. The regular investments might sometimes add such positive EVA®, but should not lower the current EVA® level. Thus, this section assumes these regular capital investments add zero EVA®.

\[ X: \text{EVA}^\circ \text{ created by the original portfolio} \]

\[ Y: \text{EVA}^\circ \text{ created by the portfolio after the completion of the strategic investment} \]

\[ Z: \text{EVA}^\circ \text{ created by the portfolio while the construction-in-progress} \]

\[ \Delta 1: \text{Changes in EVA}^\circ \text{ before and after the implementation of the strategic investment} \]

\[ \Delta 2: \text{Changes in EVA}^\circ \text{ due to the capital construction-in-progress} \]

\[ \Delta 3: \text{Changes in EVA}^\circ \text{ due to the operation start-up of the implemented infrastructure} \]

*Figure 3.1. Implementation of strategic investment and portfolio’s EVA®*

Figure 3.1 shows the simplified concept of value-adding strategic investment and its contribution to the gross EVA® created by the infrastructure portfolio. This
model assumes that (a) the original portfolio’s NOPAT remains constant during the construction period; (b) the assets construction-in-progress do not provide any services but are capitalized every year; therefore, (c) the original portfolio’s EVA® is reduced by the amounts of (cost of capital)×(invested capital in Year \( n - b \)) during the construction period; and finally that (d) the implementation of the strategic investment is completed at Year \( n \). At that time the assets start operation and create a profit inflow.

The EVA®, after the implementation of the strategic investment, is not necessarily larger than that of the original portfolio; that is, \( \Delta I \) in Figure 3.1 can be positive or negative. This is because \( \Delta I \) is an outcome of strategic investment, and if the NOPAT of the newly implemented assets is smaller than the required dollar cost of capital of the assets, the value of \( \Delta I \) becomes negative.

Two different types or roles of strategic investment will be made in a firm’s infrastructure portfolio in accordance with the manager’s decision: (a) the strategic investment creating a new portfolio; (b) the strategic investment enhancing the operational efficiency of the existing portfolio. In Case (a), the conditions \( X \) and \( Y \) in Figure 3.1 may be expressed as follows:

\[
X + N (= EVA^\circ of new portfolio) = Y. \tag{3}
\]

In fact, equation (3) neglects the effect of the new portfolio on the existing portfolio. By taking this effect into consideration, equation (3) can be changed to the following form:

\[
X' + N = Y. \tag{3'}
\]

\[
X' = X + x
\]

where \( x \) is the increment of EVA® of the original portfolio caused by the effect of the new portfolio. This factor \( x \) might be thought of as an interlocking effect between the
original portfolio and the new portfolio. For example, a newly constructed line, i.e., a new portfolio, not only attracts new customers but also boosts the numbers of customers of the existing line, i.e., the existing portfolio. Figure 3.2 depicts the conditions of equation (3) and (3)'. Upon making the investment decision, managers have to choose the most desirable new portfolio so that the value of $N + x$ can be maximized. As a minimum required condition, the value of $N + x$ should be positive, and also the new portfolio’s net present value (NPV) is larger than zero.

(a) Equation (3)  
(b) Equation (3)'

![Figure 3.2. Effect of interlocking portfolios in the case of new portfolio addition]  

In Case (b), strategic investment does not add a new portfolio, but improves the existing portfolio’s operational efficiency. Suppose that a part of the existing portfolio, i.e., a sub-portfolio $(i)$, achieves operational efficiency as a result of this strategic investment. The operational efficiency will bring larger NOPAT than before to the sub-portfolio $i$. Given that the original sub-portfolio’s EVA® is $X_i$ and that the EVA® enhanced by additional strategic investment is $E'$, we get the following equation,
\[(X_i + E) + X_j = Y,\]  \hspace{1cm} (4)

\[X = X_i + X_j,\]

where the second term \(X_j\) is EVA\(^\text{®}\) created by the other original sub-portfolio \((j)\), which will not be improved by the strategic investment. This portfolio \(j\) is subjected to changes in its EVA\(^\text{®}\) by the effect of the interlocking with its counterpart sub-portfolio \(i\). By taking this effect into account, equation (4) can be modified as follows,

\[(X_i + E) + X'_j = Y.\] \hspace{1cm} (4')

\[X'_j = X_j + x\]

where \(x\) is again the increment of EVA\(^\text{®}\) created by the interlocking. The conditions of equation (4) and (4)’ are shown in Figure 3.3.

**Figure 3.3.** Effect of interlocking portfolios with existing sub-portfolio improvement [Case(b)]
The kind of strategic investment that would enable a company’s managers to maximize their infrastructure portfolio value as well as their shareholder wealth might be found if the managers could correctly estimate the value of \((x + N)\) or \((x + E)\) according to the type of the designed investment. Both the direct and indirect effects of strategic investment, which results from the portfolio’s interaction, are reflected in these two terms \((x + N)\) or \((x + E)\). Sometimes, a railroad company’s strategic investment might only bring negative \(N\) or \(E\) as a directly created EVA\(^\text{®}\); however, it could induce large positive \(x\) as an indirect EVA\(^\text{®}\). Remember that these strategic investments should have both positive NPV and positive EVA\(^\text{®}\).

### 3.2 Railtrack’s Strategic Investment

#### 3.2.1 Railtrack and Channel Tunnel Rail Link (CTRL)

Upon the division and privatization of the British Railways (BR), Railtrack PLC was formed as the unique owner and operator of Britain’s railroad infrastructure, such as the tracks, signals, tunnels, bridges, viaducts, and level crossings as well as stations. The company also manages fourteen of the largest stations in the United Kingdom in which passenger travel services as well as diversified commercial services are provided. The company has issued franchises to twenty-five train-operating companies (TOCs), which now run all the train services.

After the opening of the Channel Tunnel, London was directly connected to the continental cities such as Paris, or Brussels by the railroad. However, the existing rail tracks and other facilities between London and Dover are still not adequate for either the high-speed Eurostar trains at their maximum speed, or the large volume of freight traffic between British Island and the Continent.
In 1996, authorization for the construction, operation and maintenance of the new line, Channel Tunnel Rail Link (CTRL), was provided by the Channel Tunnel Rail Act, and in the same year, the private consortium, London & Continental Railways Limited (LCR), was selected by the Government as an operator of this project following an international competition. Work began in October 1998 to build the first section of CTRL between the Channel Tunnel and Fawkham Junction (Figure 3.4). Then, an agreement was reached for Railtrack PLC to purchase this section from the LCR subsidiary, Union Railways (South) Ltd, and this subsidiary was operated under the management control of Railtrack. The section was scheduled to open in 2003. For Railtrack, it was an opportunity to incorporate the new infrastructure portfolio into the company.

Construction work on Section 2 began in July 2001. Union Railways (North) is the LCR’s subsidiary responsible for the construction of this section, which connects Section 1 to central London. The project was to be completed by 2007. Railtrack had an option, exercisable until July 2003, to commit to taking management control over the construction of Section 2 and to purchasing the section following completion, on a similar basis to the arrangements for Section 1. However,
in early 2001, Railtrack decided not to exercise the option, and would only operate and maintain Section 2. Figure 3.5 shows the organizational chart of this CTRL project.

![Organizational Chart of CTRL Project](image)

**Figure 3.5. Channel Tunnel Rail Link Project Organization**

The effects and construction costs of the project are presented in Table 3.2. In fact, CTRL is Britain’s first high-speed railway line. Upon the completion of Section 1, the journey time between Waterloo, London, and Channel Tunnel boundary is to be reduced from 68 minutes to 51. When Section 2 is completed, the journey will take only 35 minutes. The railway capacity, too, is increased. Twice the numbers of Eurostars will be able to run between St. Pancras and Paris or Brussels. The estimated gross construction costs for the project are 7.88 billion US dollars, of which 2.88 billion is for Section 1 as well as 5.00 billion is for Section 2 (1 USD = 0.66 GBP). This gross construction costs include 3.33 billion US dollars of government grants.
Table 3.2. Costs and Performances of CTRL project

<table>
<thead>
<tr>
<th>Route</th>
<th>Distance</th>
<th>Estimated Cost (Including land)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Tunnel to St. Pancras</td>
<td>68 miles</td>
<td>7.88 million US$</td>
</tr>
<tr>
<td>Channel Tunnel to Fawkham Junction (Section 1)</td>
<td>46 miles</td>
<td>2.88 million US$</td>
</tr>
<tr>
<td>Southfleet Junction to St. Pancras (Section 2)</td>
<td>24 miles</td>
<td>5.00 million US$</td>
</tr>
<tr>
<td>[Distance in tunnel] 25% of route -</td>
<td>16 miles</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>Current</th>
<th>After Section 1 completion</th>
<th>After whole line completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey times</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(London - Channel Tunnel)</td>
<td>68min</td>
<td>51 min</td>
<td>35 min</td>
</tr>
<tr>
<td>(London - Paris)</td>
<td>168min</td>
<td>151 min</td>
<td>135 min</td>
</tr>
<tr>
<td>Maximum Usage</td>
<td>Up to 4 Eurostars per hour each way</td>
<td>8 Eurostars per hour each way</td>
<td></td>
</tr>
</tbody>
</table>

Data Source: http://www.ctrl.co.uk

3.2.2 Railtrack’s Capital Improvement Projects

Besides the CTRL Section 1 portfolio, Railtrack has been making investments in the company-wide strategic portfolio improvements, which are to be delivered between 1996 to 2008 in tandem with their route maintenance and renewal activities. The largest and most complex project among them is the West Coast Route Modernization (WCRM), which is intended to upgrade the company’s main arterial route between London and Glasgow (Figure 3.6).

The estimated total cost of WCRM is 7.9 million US dollars, which consists of $5.1 million renewal expenditures as well as $2.8 million of capital improvement investments (Table 3.3). The renewal expenditures will be kept making beyond the project completion year, 2007, since they are regular management activities. On the other hand, very small or no capital improvement investments, i.e, the strategic investments, will be made after finishing the portfolio improvement. The combination of this regular renewal investment and the strategic investment will allow the company to spend less regular renewal investments after the completion of the project.
The objective of this WCRM project is to deliver a high-capacity and high-speed route that meets the needs of Train Operating Companies (TOCs) and their customers. The effects that Railtrack expects upon the project completion are as follows: improved safety on the railway, increased passenger and freight numbers, reduced journey times, increased frequency of service, identifying and adopting new technologies, and enhanced passenger services. Table 3.4 presents the forecasted journey times between London and other cities along the West Coast Main Line, which will be achieved after the implementation of this mixed regular and strategic investment project.

Table 3.3. Railtrack’s forecasted strategic portfolio investment

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Strategic Investment</th>
<th>Total Expenditure Including Regular Investment</th>
<th>Expected Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>2,621</td>
<td>2,621</td>
<td>2003</td>
</tr>
<tr>
<td>WCRM</td>
<td>2,827</td>
<td>7,892</td>
<td>2007</td>
</tr>
<tr>
<td>Others</td>
<td>2,041</td>
<td>2,123</td>
<td>2002-2008</td>
</tr>
</tbody>
</table>

(US million dollars: 1USD = 0.66 GBP)
Data Source: 2001 Network Management Statement, Railtrack
Table 3.4. WCRM’s Effect on the journey times

<table>
<thead>
<tr>
<th>Route</th>
<th>Current position</th>
<th>Achieved by WCRM</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>London Euston - Glasgow</td>
<td>5hr 18min</td>
<td>4hr 12min</td>
<td>66min</td>
</tr>
<tr>
<td>London Euston - Birmingham</td>
<td>1hr 35min</td>
<td>1hr 18min</td>
<td>17min</td>
</tr>
<tr>
<td>London Euston - Manchester</td>
<td>2hr 35min</td>
<td>1hr 59min</td>
<td>36min</td>
</tr>
</tbody>
</table>

Data Source: 2001 Network Management Statement, Railtrack

3.2.3 Strategic Investment Scheme

The Railtrack’s investment expenditures or activities might be classified into two categories following the role of the investments; one is the regular investments including maintenance backlog reductions as well as capital renewals, and the other is the strategic investments, i.e, both CTRL Section 1 purchasing and the company-wide improvement project represented by WCRM. Note that improvement investments are distributed for upgrading the tracks, signallings, structures, electrifications, and stations.

Some renewal investments might be considered as the strategic investments, because they are closely tied to the current strategic improvement investments as was explained in WCRM case (Table 3.3). However, they are treated here as the regular investment activities, because the renewal activities will still last even after the completion of the strategic improvement program. The aim of this strategic investment is to achieve the operational efficiency of the existing infrastructure portfolio, and the future regular investment are to be reduced but not to become zero as a result of the capital improvement investments.

Figure 3.7 (a) presents the company’s expenditures for both the regular and strategic infrastructure portfolio investment activities. The figure also depicts the company’s annual depreciation and maintenance costs. As was discussed in Chapter II, the company’s total infrastructure portfolio value is strongly affected by these
economic value factors associated with the company’s infrastructure management. Maintenance expenditure as well as depreciation cost can be treated as the operation costs having negative values, on the other hand, the investment expenditures, which add the asset book values to the company, can be treated as the items having positive values. Thus, the figure was drawn so that it could reflect the conditions of these value factors.

(a) Railtrack’s infrastructure expenditures

(b) Breakdown of Capital Investments

Figure 3.7. Railtrack’s infrastructure management activities and associated expenditures

Since 1998, Railtrack has been annually outlaying approximately $400 million for the purchase of Channel Tunnel Rail Link Section 1 (Figure 3.7 (a)), which is the company’s “portfolio-adding” strategic investment. On the other hand, the company has made annually $315 to 980 million of capital improvement expenditures. This can be considered as the company’s “portfolio-improving” strategic investment.

General framework for describing the effects of both the portfolio-adding and portfolio-improving strategic investments on the company’s EVA® is already discussed in the previous section. These numbers above might tell us the magnitude of the impact that Railtracks’ investment strategies could have on the company’s current and future economic value. The following sub-section estimates the relations between these strategic investments and their contributions to the company’s overall EVA®.

### 3.2.4 Strategic Investment and Railtrack’s EVA®

Railtrack’s EVA® in the 99/00 year were calculated as −58.6 million US dollars (Table 3.1). On the previous year (ending at March 31 1999), the company made a total of $863 (= $417 for CTRL + $445 for the improvement projects) million of the strategic investments, which might not create next year’s operating profit until the completion of those strategic projects. In the same year, the company had made a total of $1,803 million of the regular investments, i.e., the capital renewals and maintenance backlog reductions, which are required in order for the company to sustain current profit flows from the operation. The regular investments are supposed here to produce next year’s EVA® immediately after their installation.

As already discussed in Section 3.2.2, the regular investments should not add negative EVA® to the company; that is, the operating profit less the cost of the regular investments should not be negative, because the major objective of these investments are to assure the safety of the train operations, which result in sustaining
the company’s current business return level. In other words, this paper assumes the managers determine the amounts of the annual regular investments so that these investments bring them current profit level through the safe and stable train operations without spending additional operation costs. Thus, the EVA® created by these regular investments are also supposed to be zero, not to say positive.

Similarly, the negative effects of the on-going strategic investments on the company’s EVA® are already described in Figure 3.1. The negative values result from their “zero-contribution” to the company’s current operating profit creation. This is because the invested amounts in the projects are added to the firm’s asset book value while they do not produce profits until they are completed and start operation. The negative effects can be calculated as follows:

Strategic investment’s effect on the company’s EVA® in the year 99/00

\[
\text{Strategic investment's effect on the company's EVA®} = (\text{NOPAT}) - (WACC) \times \left( \text{Strategic investment made in the year 98/99} \right)
\]

\[
= 0 - 0.068 \times $863 \text{ million} = -$58.7 \text{ million.}
\]

This value is almost equal to the Railtrack’s negative EVA® in the 99/00 year. Thus, the company’s negative EVA® in the year can be reduced to the negative EVA® created by the strategic investments.

After these projects are completed, they will start operation and produce a certain profit. The CTRL portfolio’s forecasted total asset book value is $2,621 million from Table 3.3. Therefore, given that the WACC of the company still remains the same and no depreciation costs are incurred, the amounts of NOPAT that will not cause any EVA® changes in the firm are,

\[
\text{EVA} = \text{NOPAT from CTRL portfolio} - WACC \times [\text{CTRL's asset book value}]
\]

\[
0 = \text{NOPAT from CTRL portfolio} - 0.068 \times $2,621 \text{ million}
\]

\[
\therefore (\text{Minimum required}) \text{NOPAT from CTRL portfolio} = $178.2 \text{ million.}
\]
The WCRM project is aiming at the facility improvement of the existing portfolio. The asset book value added by the strategic investment is $2,827 million. Although this project includes total $5,065 million of regular investments, they are supposed to produce next year’s profits immediately after installation. As was discussed above, these profits are supposed to equal the cost of the investment, since the regular investments are required to sustain the company’s current return level; therefore, the EVA® created by the regular investments on the WCRM project is zero. The NOPAT which makes the EVA® of the WCRM strategic investment zero can be calculated making the same assumption as the CTRL case,

\[
\text{EVA} = \text{Increased NOPAT by WCRM improvement} - \text{WACC} \times \left(\text{WCRM’s improved asset book value}\right)
\]

\[
0 = \text{Increased NOPAT by WCRM improvement} - 0.068 \times 2,827 \text{ million}
\]

\[
:\text{(Minimum required) Increased NOPAT by WCRM improvement} = 192.2 \text{ million}
\]

For the company’s managers, these NOPAT values calculated above might be the benchmarks for their business conditions and firm’s value. They could draw their business strategy so that the actual increments in NOPAT achieved by the strategically acquired or improved portfolios would become larger than the minimum required NOPAT values obtained above. The larger the actual NOPAT increments less the calculated NOPAT, the higher the firm’s value. The values of NOPAT obtained above can be considered as the minimum hurdles that the managers should clear by making the active use of their overall business strategy.

However, the discussion above assumes no effects of: (A) changes in WACC by issuing the new equities or corporate bonds, (B) depreciation of the acquired or improved portfolios and its impact on the NOPAT and portfolio’s book value, and (C) EVA® created by the portfolio interlocking. The effects of (A) depend on the manager’s decision. (B) could be calculated using the following equation
assuming that the strategic investments \( C \) are depreciated during \( i \) years with the salvage value of \( S \).

\[
\text{EVA}^\circ \text{ in year } j \ (j \geq 1) = \left( \text{Increased NOPAT by the Strategic Investment} \right) - \left( \frac{\text{Annual Depreciation of the Strategically Installed Assets}}{i} \right) - (\text{WACC}) \times \left( \frac{\text{Value of Strategically Installed Assets}}{i} \right)
\]

\[
= \text{Increased NOPAT} - \frac{(C - S)}{i} - (\text{WACC}) \times (C - j \times \frac{(C - S)}{i})
\]

\[
= \text{Increased NOPAT} - (\text{WACC}) \times C - \frac{(C - S)}{i} (1 - j \times (\text{WACC})).
\]

Thus, if \((1 - j \times (\text{WACC})) > 0\), the original \( \text{EVA}^\circ \) value before the depreciation adjustment will lose some depreciation related values. On the other hand, if \((1 - j \times (\text{WACC})) < 0\), then, the original \( \text{EVA}^\circ \) will add them. In the Railtrack's case, WACC is calculated as 0.068; therefore, the effects of the depreciation will add positive \( \text{EVA}^\circ \) to the company from 15 years \( (= 1/0.068 \) ) after the completion of the strategic investment.

The effects of \((C)\), i.e., the portfolio interlocking, is already explained in Section 3.2.2, and they also depends on the managers business strategies. It might be possible to attract more customers and make larger operation profits by combining the enhanced services of the new or improved portfolios with those of existing portfolios. Taking these effects into account will allow the managers to draw their optimum business strategy so that the company's value can be maximized.
Chapter IV

Infrastructure Portfolio and Real Options

This chapter prepares theoretical background for the valuation of the infrastructure portfolio as well as the optimal decision-making point of the company’s strategic investment activity. The concept of real options, which is an analogy of financial option valuation model, is applied to the portfolio management strategy here.

Section 4.1 compares the valuation of a call option with that of an infrastructure portfolio. Investors pursue the optimal timing for exercising the option, which maximizes the net payoff from the exercising. Similarly, a company’s managers try to find the optimal investment timing in order to maximize both the value of the infrastructure portfolio and the effect of the strategic investment.

Section 4.2 focuses on the mathematical modeling of the infrastructure portfolio valuation with using the option analogy discussed in Section 4.1. Black-Scholes option value formula is the basis of the portfolio value equations obtained in this section. Economic interpretation of these equations allows us to incorporate the value of investment opportunity in the company’s portfolio value maximizing strategy.

4.1 Company’s Investment Action and Opportunity

4.1.1 Finding Investment Opportunity via Real Options

What should be the investment opportunity for a railroad network owner-operator company to develop, expand and maximize the value of its entire infrastructure portfolio? Various types of answer might be considered, however, the economically rational and acceptable reason for investing in any opportunity that is to be created within a network company is that whatever investment is made in a
company’s portfolio, it must raise the value of the company’s expected set of infrastructure assets as well as the expected gross cash flow associated with the portfolio.

(a) Project or Commodity Development

\[
V(R) - I = N(R) - I
\]

(b) Infrastructure Portfolio Investment

\[
V_1(R) = V_0(R) + I
\]

Figure 4.1. Investment and Value of Project, or Infrastructure Portfolio

(Note that both figures are just conceptual models, and do not reflect any real numbers or situations.)
Previous real options research puts an emphasis on finding investment opportunities in developing one project or commodity by which new variable revenue stream $R$ is promised to the developer*. In such cases, required initial investment amount ($I$) is predetermined and treated as sunk cost, and then subtracted from the gross cash flow ($N(R)$) of the new project or commodity. Then, the value of the newly developed project or commodity ($V(R)$) and its most appropriate investment opportunity ($\hat{R}$) are analyzed and evaluated using real options approach. Figure 4-1(a) is a conceptual framework describing the relationship between the value of a project or a commodity and required investment.

In the following discussion of this paper, however, the investment is not treated as described above. The invested amount itself is not subtracted from the value of the portfolio here, but is added to it. After figuring out the values of the two portfolio types ($V_0(R)$, $V_1(R)$), the most appropriate investment opportunity ($\hat{R}$) and required investment amount ($I$) are evaluated using option analogy (Figure 4-1-(b)).

In fact, both types of real options analyses described in Figure 4-1(a) and (b) use numerically the same equation at the most appropriate investment opportunity point $\hat{R}$. At this point, the former equation becomes,

$$N(\hat{R}) - I = V(\hat{R}),$$

and the latter equation is,

$$V_1(\hat{R}) = V_0(\hat{R}) + I.$$

---

Intuition tells us that these value equations can be solved in the same way, and they actually can. However, the value decline or increment accompanied by the investment in either case has quite different economic meanings.

According to the nature of infrastructure of railroad firm, the portfolio as an aggregate of these infrastructure assets has both “disbursement cost type” (Figure 4-1(a)) and “value adding type”(4-1(b)) of investment. Ideally, any investment decision should count them both so that the investment can enhance the firm’s value as a whole. However, in this paper, the former type of investment project or activity aiming to provide entirely new service will not be analyzed as real options application to the infrastructure portfolio.

This is because this investment form is quite uncommon for private railroad firms except for constructing such large infrastructures as the Channel Tunnel Rail Link in UK or high speed Shinkansen line in Japan. Moreover, government policy or financing decisions rather than a firm’s investment opportunity or decision play a core role in such cases for the development of an infrastructure portfolio.

Thus, on using real options approach, this paper focuses on the portfolio value maximization by increasing the portfolio’s operational efficiency, which can be achieved through the arrangement of a company’s regularly executing infrastructure management activities---maintenance, investment for maintenance backlog reduction, capital renewal, improvement or replacement. The paper also focuses on the firm’s strategic investment. This large-scale investment considered in the following discussion is not used for bringing the firm new portfolios, i.e., sources of revenue, but used for improving or changing the value or quality of those regular management activities above.

Consider that the value of a portfolio can be expressed by its revenue, operation cost, depreciation cost, and capital investment. Making infrastructure investment does increase the value of the infrastructure portfolio by the invested amount. However, the invested projects might incur annual maintenance costs or
other operation costs. Thus, investment opportunity should balance them.

The expected revenue might increase by the invested project, and in such situations, the increment can be added to the portfolio value. On the other hand, as was mentioned above, there would be cases in which investment is made just for the sake of assuring the level of current revenue or return: investment for maintenance backlog reduction or replacement activities.

4.1.2 Investment Opportunity and Option Value

A real options application for analyzing a firm’s infrastructure portfolio value makes use of the following general natures that infrastructure investment has in common. First, for most types of infrastructure investment, it goes without saying that these investments are, once made, irreversible. In other words, most infrastructure investments become sunk costs. Constructed facilities cannot be easily moved and relocated because they have been designed specifically for the construction site. Furthermore, each constructed facility is usually specialized for the use of the network operation, and cannot be separated from the network or traded in the commodity market.

The second feature of infrastructure investment is its timing and opportunity value. If the opportunity can be expressed as some dollar amount, the quantity would change according to the economic condition in which the investing firm is situated. When the future revenue increases so much that a firm is likely to reap benefits from the intended investment, it might invest in the project at that point. On the other hand, if the future forecast looks blue, a firm can wait until the economic condition improves, and after some time it might finally decide to invest in the attractive project.

The application of real options to a firm’s investment strategy enables us to consider comprehensively these essential features accompanied by investing in infrastructure assets. The value of the investment opportunity mentioned above is
just the analogy of real put or call options value (Figure 4-2(a)). A financial option is the right to sell or purchase underlying stocks at a certain predetermined price or an exercise price \( E \) before the option’s expiration date.

![Diagram of Financial Option and Infrastructure Investment Option](image)

**Figure 4.2. Value of (a) Call Option, and (b) Infrastructure Investment Opportunity**

(Note that both figures are just conceptual models, and do not reflect any real numbers or situations.)

Firms also have rights to invest a certain amount of money in exchange for the intended assets at the most preferable timing. Just as the put or call options could be exercised in order to get the underlying stock at the strike price, so the investment opportunity could be exercised, or killed, in order to invest in and acquire some projected infrastructure whose value is \( I \) (Figure 4-2(b)).

An investor holding call options might buy a firm’s financial security by exercising the option when the stock price goes up to such a high level that the net gain could compensate the value of call options. She/he could wait to exercise without losing the right to do so even if the stock price level still moves far below the strike price before the expiration. Therefore, a financial option has a certain market value unless the underlying stock value is zero. However, once the option is exercised, the action is irreversible and an investor can never buy back the original...
option in exchange for its purchased stocks.

Similarly, a firm holding a real options opportunity associated with its infrastructure portfolio might invest in certain selected projects by exercising the opportunity when its business environment gets profitable enough to acquire designed new portfolio value \( V_1(R) \), which could compensate for both the exercised opportunity value \( V_0(R) \) and invested amount \( I \). In fact, at the most appropriate investment timing \( \hat{R} \), the equilibrium equation becomes,

\[
V_1(\hat{R}) = V_0(\hat{R}) + I, \tag{2}
\]

namely, the new portfolio value equals to the old portfolio plus the invested amount. If one regards the investment \( I \) as expenditure, the equation can be expressed as follows,

\[
V_1(\hat{R}) - I = V_0(\hat{R}),
\]

A firm could wait to invest without losing its right to invest if the revenue level remains low, although it might miss the timing of investment. Investment irreversibility is also similar to the financial options because, as mentioned above, it is difficult to relocate or trade the invested infrastructure assets of a firm.

In either case of exercising the financial options or exercising investment opportunities, it is important to determine what is the potential value of options or opportunities first, and then to decide the appropriate timing of paying cost price for underlying stocks or making investment in projects. Note that in case of financial option, the value of the option, and the exercising timing could be expressed in terms of underlying stock price and expiration date of the options. On the other hand, the value of the investment opportunity for the infrastructure portfolio and the timing of investing would be expressed as a function of revenue and costs associated with the firm’s infrastructure.
4.1.3 Decision-Making Differences Between NPV Rule and Option Approach

The traditional capital budgeting rule says that if an intended project’s net present value (NPV) is larger than 0, then invest immediately. If the project’s NPV is less than 0, then never invest and abandon the project planning. However, the real options approach for investment decision-making gives us another conceptual framework.

Trigeorgis (1996) explains that traditional “static” NPV approach makes implicit assumptions concerning an “expected scenario” of cash flows, while in the real world of uncertainty and competitive interactions the realization of cash flows will probably differ from what management originally expected. In order to take this managerial flexibility into account and reflects it in the real project opportunity, he suggests using the “expanded” NPV using option approach.

In his argument, the expanded (strategic) net present value is described in the following form:

\[
\text{Expanded (strategic) NPV} = \text{Standard (static) NPV of expected cash flows} + \text{Option premium}
\]

where “Option premium” indicates the value of operating and strategic options from active management and interaction effects of competition, synergy, and interproject dependence. By introducing this expanded NPV concept, Trigeorgis has incorporated the flexibility value into the total project value. Thus, even though one project has negative NPV of static cash flows, the project is not necessarily abandoned immediately or never invested in, because it may still have some flexibility or opportunity value as well as positive expanded NPV.

However, suppose the expanded NPV is positive, is it optimal to invest in the project immediately? The answer is, “you can invest if the static NPV is at the
same time larger than zero, but even in such a situation, it might not be optimal to invest immediately."

In order to explain the implications of this answer, it is useful to quote the example of financial options. Again the valuation of a call option is described below. The value of a call option $V(S)$ is denoted as a function of stock price $S$ and its exercise price $E$ here.

![Figure 4.3. Value of Call Option](image)

It is obvious that if stock price were below $E$, no one would exercise her/his call option, as she/he does not want to pay a higher price than the obtained stock price. Assume that current stock price is $S_a$. Then, current call option value and net payoff if exercising the option is $V(S_a)$ and $S_a - E$, respectively. As is shown in Figure 4.3, the value of the call option is apparently larger than the net payoff, i.e., $V(S_a) > S_a - E$, and an investor who exercises this option will lose as much value as $V(S_a) - (S_a - E)$ by the exercising. Therefore, she/he would never exercise the call option when the stock price is $S_a$.  

60
The stock price where an investor is willing to exercise her/his option is \( \hat{S} \) in Figure 4.3. At this price, the value of the call option agrees completely with net payoff from exercising the option. In Figure 4.3 the call option value curve meets tangentially to the payoff curve when the underlying stock price is \( \hat{S} \). The stock price at this tangent point can be called a threshold-exercising price.

The same things happen in the real option valuation for an infrastructure investment portfolio. Suppose one situation in which currently laying-up railroad line can start operation with no activation cost and just incurs constant annual operation costs \( C \) upon activation. The annual revenue \( R \) is uncertain. In this situation, the opportunity value of having the railroad line, or the line’s capital appreciation, can be interpreted as the financial call value \( V(S) \) in Figure 4.3, because once a firm exercises its activation opportunity, it will obtain a certain amount of cash flow from the assets. Stock price \( S \) and strike price \( E \) can be interpreted as \( R \) and \( C \), respectively.

Even though the railroad line has not started operation yet, its opportunity value, or capital appreciation of the laying-up infrastructure, continues increasing as the expected annual revenue goes up. The break-even point is \( R = C \), however, the value of capital appreciation is still higher than the net payoff from the operation \( R - C \) when the value of \( R \) is between \( C \) and the activation threshold value \( \hat{R} \), i.e., \( C < R < \hat{R} \). Note that \( \hat{R} \) corresponds with \( \hat{S} \) in Figure 4.3. Therefore, for the asset owner, it is better to keep the asset halted rather than to start operation when the expected revenue level is lower than \( \hat{R} \).

We can also say that even though current expanded NPV (e.g., \( V(S_a) \) in Figure 4.3.) is positive, a firm might not invest in the project immediately, because current static NPV (e.g., \( S_a - E \)) might be smaller than the expanded NPV. If a firm invests in the project immediately, it might lose the value equal to the difference between expanded NPV and static NPV (\( V(S_a) - (S_a - E) \)).
4.1.4 Decision Making Point in Infrastructure Portfolio Investment

The optimal infrastructure portfolio investment, like optimal call option exercising, should be made at the revenue threshold where one portfolio value curve, which includes both investment opportunity and inherent portfolio value, meets tangentially with another value curve, which reflects another portfolio value condition. The relationship between these two value curves is shown in Figure 4.4 in the context of infrastructure portfolio value maximization process.

![Figure 4.4. Infrastructure Investment Option](image)

Assume that investment $I$ is an absolutely essential amount so that a firm’s portfolio condition can change from Portfolio 0 to Portfolio 1. At one revenue point $\hat{R}$, the value of Portfolio 0 ($V_0(\hat{R})$) is $\bar{a} \cdot d$, which is larger than the value of Portfolio 1 minus investment $I$ ($b \cdot d = V_1(\hat{R}) - I$). In other words, if a firm makes investment $I$ here, the value of the portfolio changes from $V_0(\hat{R})$ to $V_1(\hat{R})$, while
the value increment \( V_1(\hat{R}) - V_0(\hat{R}) \) is less than \( I \).

The reason why a firm failed to incorporate the entire invested amount \( I \) into its portfolio at the revenue point \( \hat{R} \) is that it had allowed some of the investment opportunity value to drain out of its portfolio upon making the investment. The wasted opportunity value is shown in the figure as a distance \( a \cdot b \), while the total opportunity value is \( a \cdot c \). Provided a firm is to make the same amount of investment \( I \) at any discretionary revenue level, Figure 4.4 tells us that the lower the revenue, the higher the wasted opportunity value \( (a \cdot b) \).

Thus, the relationship between the value of Portfolio 0 and Portfolio 1 can be expressed in the following form:

\[
V_0(\hat{R}) - (a \cdot b) + I = V_1(\hat{R})
\]

\[
\begin{align*}
&\text{Value of Portfolio 0} \quad \text{Wasted Opportunity Value} \quad \text{Required Investment} \quad \text{Value of Portfolio 1} \\
&\text{(a} \cdot c\text{)} + \text{(c} \cdot d\text{)} \\
&\text{Opportunity Value Increment} \quad \text{Inherent Portfolio Value}
\end{align*}
\]

Figure 4.5. Option-Based Relationship between Two Portfolios

Therefore, it is obvious that if managers want to incorporate the entire investment value \( I \) upon making their decision, they should invest when the value of wasted opportunity is minimum, or zero. The wasted value \( a \cdot b \) approaches zero as the revenue level goes to \( \hat{R} \), where the value curve of Portfolio 0 \( V_0(\hat{R}) \) and that of Portfolio 1 \( V_1(\hat{R}) \) meet tangentially. At this point, the equation above becomes,
\[ V_0(\hat{R}) + I = V_1(\hat{R}), \]

since \( a \cdot b = 0. \)

This is the very point where managers never fail to capture the entire invested amount in a firm’s infrastructure portfolio. However, in return for obtaining optimal investment opportunity, managers have to wait to invest until a firm’s revenue rises to this point.

### 4.1.5 Mathematical Implications of the Decision-Making Point

The agreement condition of the two portfolio value curves at the decision-making point obtained at the previous section is mathematically analyzed by Dixit (1989a, 1989b), and Dixit and Pindyck (1996). They explain that these decision making points should have both “value-matching” and “smooth-pasting” conditions.

The value-matching condition implies the continuity of two portfolio curves at the point, while the smooth-pasting condition connotes the continuity of the slope of two curves. These two conditions are followed by the next two equations that must be effective at the revenue threshold \( \hat{R} \) in the previous example:

for value-matching condition,

\[ V_0(\hat{R}) + I = V_1(\hat{R}), \quad (4) \]

and for smooth-pasting condition,

\[ \left. \frac{dV_0(R)}{dR} \right|_{\hat{R}} = \left. \frac{dV_1(R)}{dR} \right|_{\hat{R}}. \quad (5) \]

In fact, whatever types of value curves of real options analogy, the value-maximizing decision-making point has these two conditions. For the example of the financial call option, an investor would exercise her/his option and purchase the
underlying stock when the stock price is \( \hat{S} \), where both the slope of call option value curve \( V(S) \) and net payoff curve \( S - E \) has the same value, that is, 1. At this point, both (4) and (5) are satisfied at once.

If equation (4) were satisfied but (5) were not, one could do better by exercising the investment at a different point.

Note that once investment \( I \) is made, it is irreversible, that is, a firm might never return to have the original portfolio \( V_0(R) \) after making an intended investment.
4.2 Mathematical Modeling

4.2.1 Basic Modeling Equation and Black-Scholes Option Valuation

A general model of calculating both the optimal portfolio value and the decision-making point with using real options analogy was theoretically developed by McDonald and Siegel (1986), Dixit (1989a, 1989b, 1992), and Dixit and Pindyck (1996, 1998). This section briefly describes their methods and interprets their results in an economic context so that it might be easier to apply multifarious real options techniques for estimating an actual firm’s both total infrastructure portfolio value and the effect of investment at the critical decision-making point.

Dixit and Pindyck (1996) expressed a project’s value \( V(R) \) as a function of variable profit or revenue \( R \), constant operating cost \( C \), and investment \( I \). Their first assumption, which plays an important role in calculating a project’s investment opportunity value as an analogy of financial option valuation, is that the variable \( R \) evolves according to the following diffusion process, called geometric Brownian motion:

\[
dR = \alpha R \cdot dt + \sigma R \cdot dz,
\]  

(6-a)

where \( \alpha \) and \( \sigma \) are constants called the drift parameter and the variance parameter, respectively. The coefficient \( \alpha \) indicates the expected annual growth rate of a project’s revenue or profit, and \( \sigma \) is a standard deviation of variable \( R \) per year. The differential factor \( dz \) represents the increment of standard Wiener process by,

\[
dz = \varepsilon \cdot \sqrt{dt},
\]  

(6-b)

where \( \varepsilon \) has zero mean and unit standard deviation; therefore, \( \mathbb{E}(dz) = 0 \), and its variance is \( \mathbb{E}[(dz)^2] = dt \).

The conceptual model of this diffusion process is explained in Figure 4.6. This model is frequently used to describe economic or financial variables such as...
interest rates or stock prices.

\[ dR = \alpha R \, dt + \sigma R \, dz \]

Figure 4.6. Geometric Brownian Motion Model

Under the assumption with regard to the revenue or profit movement described above, the value of a project or an asset which expects annual revenue \( R \) and the fixed operating cost \( C \) at time \( t \) can be expressed as the sum of the profit \( R - C \) over the time interval \((t, t + dt)\) and the expected present value of the project or asset whose value is \( V(R + dR) \) at time \( t + dt \). Thus,

\[
V(R) = (R - C) \cdot dt + \mathbb{E}[V(R + dR)e^{-\rho \cdot dt}]. \tag{7-a}
\]

The right-hand side of the equation can be expanded by using Ito’s Lemma:

\[
V(R) = (R - C)dt + \frac{1}{2} \sigma^2 R^2 \cdot V''(R) + \alpha R \cdot V'(R)dt + (1 - \rho dt)V(R) + o(dt), \tag{7-b}
\]

where \( V'' = d^2V/dR^2 \), \( V' = dV/dR \) and \( \rho \) is the opportunity cost of capital of the project. The term \( o(dt) \) collects terms that go to zero faster than \( dt \) when \( dt \to 0 \). Therefore, by dividing (7-b) by \( dt \), and proceeding to the limit as \( dt \to 0 \), the following differential equation can be obtained:
\[
\frac{1}{2} \sigma^2 R^2 \cdot V''(R) + \alpha R \cdot V'(R) - \rho R \cdot V(R) + R - C = 0
\]  \hspace{1cm} (7-c)

This is very similar to the Black-Scholes model equation for the valuation of an European call option where the value of a call option \(V_c(S)\) satisfies the following differential equation with respect to the risk-free interest rate \(r_f\), the underlying stock price \(S\) with an option exercise price \(E\), and the stock’s annual dividend yield rate \(\delta\),

\[
\frac{1}{2} \sigma^2 S^2 \cdot V''(S) + (r_f - \delta) S \cdot V'(S) - r_f \cdot V_c(S) + \frac{\partial V_c(S)}{\partial t} = 0.
\]  \hspace{1cm} (8)

According to Trigeorgis (1996), the mathematical solution for this dividend-yield European type call option value equation can be expressed as,

\[
V_c(S) = S \cdot e^{-\delta t} N(d_1) - E \cdot e^{-r_f t} N(d_2).
\]  \hspace{1cm} (9)

where

\[
d_1 = \frac{\ln(S/E) + [(r_f - \delta) + \frac{1}{2} \sigma^2] \cdot t}{\sigma \sqrt{t}},
\]  \hspace{1cm} (10)

\[
d_2 = d_1 - \sigma \sqrt{t}
\]  \hspace{1cm} (11)

Time factor \(t\) is a remaining time before the expiration of the call option, and \(N(d)\) is the cumulative probability distribution function for a standard normal random variable \(d\).

### 4.2.2 Step in the Solution to the Basic Option Valuation Model

Equation (7-c) in the previous section might be solved with the same procedure as the Black-Scholes solution shown above. However, this section tries
to take an alternative approach to obtain the value $V(R)$ of a project or an asset shown in (7-c) because of the difficulty in determining the project’s remaining time $t$, which is usually predetermined in the case of a financial call option valuation. Moreover, it would be convenient to take another approach for more complex case discussion later. In fact, the value of a project or an asset in the differential equation (7-c) can be generally expressed as,

$$V(R) = A_1 R^{\beta_1} + A_2 R^{\beta_2} + F \cdot R + G \cdot C,$$

where $A_1, A_2, \beta_1, \beta_2, F, G$ are the constants to be determined. $R$ and $C$ are a project’s revenue and cost, respectively. In order to obtain these constants, we differentiate (12-a) by $R$ and derive the following first and second order differentiation equations:

$$V'(R) = A_1 \beta_1 R^{\beta_1-1} + A_2 \beta_2 R^{\beta_2-1} + F$$

(12-b)

$$V''(R) = A_1 \beta_1 (\beta_1 - 1) R^{\beta_1-2} + A_2 \beta_2 (\beta_2 - 1) R^{\beta_2-2}$$

(12-c)

Then, by substituting equation (7-c) with the right hand side of (12-a,b,c), it becomes,

$$\frac{1}{2} \sigma^2 R^2 \cdot (A_1 \beta_1 (\beta_1 - 1) R^{\beta_1-2} + A_2 \beta_2 (\beta_2 - 1) R^{\beta_2-2})$$

$$+ \alpha R \cdot (A_1 \beta_1 R^{\beta_1-1} + A_2 \beta_2 R^{\beta_2-1} + F) - \rho \cdot (A_1 R^{\beta_1} + A_2 R^{\beta_2} + F \cdot R + G \cdot C) + R - C = 0$$

(13-a)

and this equation can be summarized and changed into the next form,

$$A_1 R^{\beta_1} \left( \frac{1}{2} \sigma^2 \beta_1 (\beta_1 - 1) + \alpha \beta_1 - \rho \right) + A_2 R^{\beta_2} \left( \frac{1}{2} \sigma^2 \beta_2 (\beta_2 - 1) + \alpha \beta_2 - \rho \right) + R(\alpha F - \rho F + 1) - C(\rho G + 1) = 0$$

(13-b)

From (13-b) it is clear that the constants $\beta_1, \beta_2, F, G$ are irrelevant to the value of
variable \( R \); therefore, they can be obtained here individually. On the other hand, \( A_1 \) and \( A_2 \) are dependent on the value of \( R \), so they cannot be determined without providing other information related to these constants. This means that additional asset value equations, which express different project conditions from those described by equation (13-b), must be provided when deriving these two constants. In Section 4.2.4, these constants will be fixed based on four equations obtained in an example case. In order for the convenience of understanding economic implication of the value equation \( V(R) \), the constants \( \beta_1, \beta_2, F, \) and \( G \) are determined first in this section.

As was analyzed in Dixit and Pindyck (1996), and Trigeorgis (1996), \( \beta_1 \) and \( \beta_2 \) are respectively a positive and negative solution of the following equation. Note that all the numerical components are extracted from (13-b).

\[
\frac{1}{2} \sigma^2 \beta (\beta - 1) + \alpha \beta - \rho = 0, \quad (14)
\]

therefore,

\[
\beta_1 \equiv \left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right) + \sqrt{\left( \frac{\alpha}{\sigma^2} - \frac{1}{2} \right)^2 + 2\rho / \sigma^2} > 1, \quad (15)
\]

\[
\beta_2 \equiv \left( \frac{1}{2} - \frac{\alpha}{\sigma^2} \right) - \sqrt{\left( \frac{\alpha}{\sigma^2} - \frac{1}{2} \right)^2 + 2\rho / \sigma^2} < 0. \quad (16)
\]

\( F \) and \( G \) are solutions of the next equations respectively.

\[
\alpha F - \rho F + 1 = 0, \quad (17)
\]

\[
\rho G - 1 = 0. \quad (18)
\]

Thus, we get \( F = \frac{1}{\rho - \alpha} \) and \( G = \frac{1}{\rho} \), which is independent of the value of revenue.
Having determined the four constants in the previous section, the original value equation defined in (12-a) is finally expressed as follows:

\[ V(R) = A_1 R^\beta_1 + A_2 R^\beta_2 + \frac{R}{\rho - \alpha} - \frac{C}{\rho}, \quad (19) \]

Again, \( A_1 \) and \( A_2 \) are constants remained to be determined. \( \beta_1 \) and \( \beta_2 \) are a positive and a negative solution of (14), respectively. \( \rho \) is the opportunity cost of capital of the project or the asset, \( \alpha \) is the expected growth rate of the project revenue \( R \), and \( C \) is the fixed annual operating cost.

**4.2.3-A No Option Case**

Each of the terms in equation (19) has individual economic implication. In fact, the terms \( \frac{R}{\rho - \alpha} - \frac{C}{\rho} \) in (19) indicate the difference between the expected present value of the perpetual sum of annual revenue steam \( R \) coupled with its growth rate \( \alpha \) and the expected present value of the perpetual sum of the fixed operating cost.

Judging from the interpretation of the terms above, the value of the project or the asset \( V(R) \) excluding any option value increment should be expressed as the next equation (20). This equation can be applied to the case where the project or the asset has to keep operation despite any losses, and therefore it has no opportunity to add option-like value increments derived from the flexibility of revenue \( R \),

\[ V_{(0)}(R) = \frac{R}{\rho - \alpha} - \frac{C}{\rho}, \quad (20) \]
Therefore, the terms $A_1 R^{\beta_1} + A_2 R^{\beta_2}$ in (19) can be interpreted as the real options value increment obtained by the changes in expected revenue $R$. Furthermore, it must be emphasized that state or conditional changes in the project are the prerequisite for creating real options value increment accompanied by the flexibility of revenues. In other words, these two mathematical terms are to be generated according to the changes in the project state or condition, for example, condition changes between laying-up, operating, and operating limit due to a price ceiling. Since equation (20) represents a case in which a project or an asset does not have any option of changing the state from one to another, there will be no option value increment in it. Therefore, both $A_1$ and $A_2$ have to be 0.

4.2.3-B Entry Option Case

If a project or an asset is in the state of laying-up, there is no chance of getting revenue inflow or paying operating expenses unless the project exercises “entry” option and starts operation. On the other hand, its potential value is increasing with the increase in potential expected revenue flow. Thus, the laying-up project having just an option to enter into the operating state might exercise the right to start operation when the expected revenue inflow grows large enough to keep the project alive. Consequently, such a project or an asset value during an idling state can be described as follows,

$$V_{(i)}(R) = A_{1(i)} R^{\beta_1} + A_{2(i)} R^{\beta_2}. \quad (21-a)$$

From (15) and (16) $\beta_1 > 1$, and $\beta_2 < 0$. The possibility of exercising an entry option whose value is described as equation (21-a) should approach 0 when the expected revenue $R$ is getting very small. This means that the constant $A_{2(i)}$ in equation (21-a) corresponding to the negative index $\beta_2$ should be zero so that the term $A_{2(i)} R^{\beta_2}$ cannot increase to the larger value when $R$ is very small. Thus, the
value of the activation option of the laying-up project is,

\[ V_{(t)}(R) = A_{i(t)} R^{\beta_i}, \]  

(21-b)

where \( A_{i(t)} \) is a positive constant to be determined. Having positive \( A_{i(t)} \) and \( \beta_i \), equation (21-b) tells us that the option value increases with the increase of expected revenue inflow.

### 4.2.3-C Exit Option and Operating Condition Change Option Case

As was mentioned in 2.2.3-A, as long as the project has to keep current operation regardless of declining or increasing in its revenue, the value of the project or asset has a form of equation (20). However, if the project or asset can be abandoned or changed into other different operational states, there are chances of making decision to exercise such rights or options. In this sub-section, the exit option case is treated first and an option accompanied by an operating condition change is analyzed next. First, we start from equation (19):

\[ V(R) = A_1 R^{\beta_1} + A_2 R^{\beta_2} + \frac{R}{\rho - \alpha} - \frac{C}{\rho}. \]  

(19)

From the interpretation of the terms in the previous sub-sections, the first two terms imply the project or the asset’s option, or opportunity value, whatever it is. Suppose that one project just has an exit option, namely, the project can be abandoned if the expected revenue flow decreases, while it is kept current operation forever without any options when the expected revenue increases. In this case, the value of the option terms \( A_1 R^{\beta_1} + A_2 R^{\beta_2} \) should be getting higher with the decrease in revenue \( R \) and, on the contrary, approaching 0 with the increase in \( R \). The condition where \( A_1 \) equals 0 and \( A_2 \) is a positive number matches this exit option case, because, once again, the indices \( \beta_1 > 1 \) and \( \beta_2 < 0 \). Thus, (19) becomes,
Next, if a project can change into another operation state where the fixed operating expense can be lowered and therefore the project or asset value is higher than the state described by (22), then, the project does have an “entry” option into the state. On the other hand, if a project’s or asset’s maximum revenue is limited at a certain level, e.g., by government price restriction or upper price limit due to competition, its value should also have a ceiling. In either case equation (19) holds, but \( A_i \) gets positive number for the “entry” case and negative for the “ceiling” case. Therefore,

\[
V_{(3)}(R) = A_{(3)}R^{\beta_1} + A_{(2)}R^{\beta_2} + \frac{R}{\rho - \alpha} - \frac{C}{\rho},
\]  

(23)

where

\[ A_{(3)} > 0, A_{(2)} > 0 \quad \text{for having “low exit” and “high entry” options, or,} \]

\[ A_{(3)} < 0, A_{(2)} > 0 \quad \text{for having “low exit’ and “high ceiling” options.} \]

**Summery of equations**

The discussion above is summarized and graphically shown below. Here, equations (20), (21-b), (22), (23) are calculated considering a project whose expected annual revenue ranges from $0 to $60. \( C = $40, \sigma = 0.2, \rho = 0.04, \) and \( \alpha = 0.01. \) (Thus \( \beta_1 = 1.686, \) and \( \beta_2 = -1.186. \)) The factor \( A_{(j)} \) here is set arbitrarily as \( A_{(1)} = 0.5, \ A_{(3)} = \pm 0.2, \ A_{(2)} = A_{(3)} = 1.0 \times 10^{-4}; \) therefore these factors do not have any relationship with each other.
4.2.4 Determination of Option Value

Having mathematically introduced the value of the real options opportunity created in an asset or portfolio value equation, both the optimal investment decision making point and the value of the asset or portfolio at this point might be acquired, too, by utilizing these value equations. Dixit (1989a, 1989b, 1992), and Dixit and Pindyck (1996) argued an entry-exit model for the option valuation between an idle and active condition of the project. Here, their procedures are modified and applied to the valuation of a firm’s managerial condition change.

This section examines the value of one hypothetical firm whose current revenue $R$ follows geometric Brownian motion with an annual growth rate of 2% ($\alpha = 0.02$) and 20% of volatility ($\sigma = 0.2$). The firm’s opportunity cost of capital is 5% ($\rho = 0.05$). As a current condition, the firm incurs its annual operation expenses amounting to 50% of the revenue. These expenses are paid in proportion to the total amount of revenue. The firm is now considering another management strategy with which annual operation costs will change into 10% of the revenue plus $3$ million
annual fixed cost.

Under the firm's current business condition, its asset value can be expressed as follows using equation (7-a),

\[ V_0(R) = R \cdot dt - 0.5R \cdot dt + \mathbb{E}[V_0(R + dR)e^{-0.05 \cdot dt}] \]  \hspace{1cm} (24)

where \( R \) follows geometric Brownian motion, i.e., equation (6-a). Thus,

\[ dR = 0.02R \cdot dt + 0.2R \cdot dz. \]

Then, by expanding the right hand side of equation (24) using Ito's Lemma, we get,

\[ \frac{1}{2} \cdot (0.2)^2 R^2 V_0''(R) + 0.02R \cdot V_0'(R) - 0.05V_0(R) + 0.5R = 0 \]  \hspace{1cm} (25)

Equation (25) can be solved by applying the same procedure as (12-a, b, c) and (13-a, b). Therefore, we get,

\[ V_0(R) = A_1 R^{\beta_1} + A_2 R^{\beta_2} + \frac{0.5R}{0.05 - 0.02}, \]  \hspace{1cm} (26)

where \( A_1 \) and \( A_2 \) are constants remained to be determined. \( \beta_1 \) and \( \beta_2 \) are solutions of equation (14), with \( \rho = 0.05, \quad \sigma = 0.2, \) and \( \alpha = 0.02. \) Thus,

\[ \beta_1 = 1.58, \quad \text{and} \quad \beta_2 = -1.58. \]

If another management strategy were in place, then the value equation could be figured out as follows,

\[ V_1(R) = R \cdot dt - (0.1R + 3) \cdot dt + \mathbb{E}[V_1(R + dR)e^{-0.05 \cdot dt}]. \]  \hspace{1cm} (27)

By utilizing the same procedure as above, the value equation of the new strategy can be obtained:
\[ V_i(R) = B_1 R^{\beta_1} + B_2 R^{\beta_2} + \frac{0.9R}{0.05 - 0.02} - \frac{3}{0.05}, \quad (28) \]

where \( B_1 \) and \( B_2 \) are constants to be determined. \( \beta_1 \) and \( \beta_2 \) are exactly the same value as those of (26).

Suppose there is no future revenue uncertainty and thus no option terms in the two value equations. The break-even point between current condition and new strategy can be obtained by equating the last two terms of (26) and (28). The point and the value of the firm at the point is,

\[ R = \$4.5\text{million}, \text{and} \ V(R) = \$75\text{million}. \]

Managers of the firm now realize that $10 million additional irreversible investment would allow them to change their management strategy from the current one to another if the revenue level rose to a certain point. This situation can be interpreted as an entry option to the new strategy. On the other hand, they also realize that if the revenue were lowered to some point, additional $1 million reinvestment would return them from the new strategy to the current business condition. This is an exit option to the current business, and the reinvestment is a substantial exit cost. Managers further know that the current business cannot be abandoned even though the revenue goes down to zero, and moreover, they do not have any strategies other than the current one and another newly considered one.

In the context above, the constant \( A_2 \) and \( B_1 \) in (26) and (28) should be zero. This is because \( A_2 \) is associated with the negative index \( \beta_2 \), while \( B_1 \) is associated with the positive \( \beta_1 \) as was discussed in section 4.2.3-B and C. Assume that the entry threshold revenue is \( \hat{R} \), and the exit threshold is \( \bar{R} \). Then, by using the value-matching and smooth-pasting condition equations described previously as equation (4) and (5), the next four equations are immediately formulated.
\[ V_0(\tilde{R}) + 10 = V_1(\tilde{R}), \quad (29) \]

\[ V_0'(\tilde{R}) = V_1'(\tilde{R}), \quad (30) \]

\[ V_0(\tilde{R}) = V_1(\tilde{R}) + 1, \quad (31) \]

\[ V_0'(\tilde{R}) = V_1'(\tilde{R}), \quad (32) \]

By solving these equations, we determine the value of \( A_i, B_2, \tilde{R}, \) and \( \bar{R}. \) The calculation procedures are so tedious that they are omitted here. They could be obtained by using mathematical calculation software. The approximate solutions for the undetermined constants are \( A_i = 1.852, \) and \( B_2 = 204.5, \) and the exit and entry threshold revenues are \( \bar{R} = $4.47 \) million, and \( \bar{R} = $12.80 \) million, respectively.

The relationship of the firm’s two management strategies with regard to real options value is shown in Figure 4.8. It is obvious that managers might do better by waiting with their $10 million investment until the firm’s revenue rises up to $12.8 million annually in order to change their business strategy into a new one and maximize the value of the firm. On the other hand, once managers make $10 million investment and choose another strategy, it is better to keep the strategy as long as the revenue is more than $4.47 million, and return to the current strategy by making $1 million investment only when the annual revenue reaches $4.47 million. In other words, once they open up another strategy, they should not abandon it until the revenue reaches this amount.

These numbers are very different from those at the break-even point obtained above. Although the firm value is $75 million at the point without any option value increment, the firm value at the entry and exit threshold is about $320 million and $94 million, respectively. This difference results from the real options value increment, and therefore, the firm’s value curves are shifted upward compared
to those with no option value increments.

(a) Entry and Exit Investment

\[ V_{0}(\tilde{R}) + I_{\text{entry}} = V_{1}(\tilde{R}) \]
\[ \tilde{R} = 12.80 \]

(b) Exit Threshold and Investment

\[ V_{0}(\tilde{R}) = V_{1}(\tilde{R}) + I_{\text{exit}} \]
\[ \tilde{R} = 4.47 \]

Figure 4.8. Entry and Exit Decision Making Point
CHAPTER V

Real Option Application

Railroad Company’s Portfolio Condition Change and Strategic Investment Timing

This chapter analyzes European and Japanese railroad company’s infrastructure investment strategy from the viewpoint of real options. The company’s infrastructure portfolio value maximization strategy is mathematically described with focus on both the firm’s regularly, or in a sense routinely, executed portfolio management activities and its strategically performed large-scale investment.

Upon the application of the real options analysis, the conditional changes in the infrastructure portfolio associated with a firm’s infrastructure management policy are explained in Section 5.1. Then, these changes are statistically estimated using the current railroad firm’s data in Section 5.2. More specifically, the magnitude of the infrastructure portfolio contribution to the railroad firm’s gross business revenue is determined first, and then the infrastructure-related value factors that affect the portfolio value are analyzed with respect to the infrastructure maintenance expenditure, regular capital investment, and physical depreciation. Conditional changes in infrastructure portfolios are a prerequisite for creating the real options value increment, and they might be obtained by combining these value factors.

The strategic investment discussed in this chapter enables a railroad company’s managers to increase their operational efficiencies in a portfolio, while maximizing its economic value. Section 5.3 applies those mathematical procedures of the real options asset valuation analyzed in Chapter 4 to finding the optimal timing for making the strategic investment decision associated with the portfolio value maximization. The analyses are based on the statistical data processed in Section 5.2.
5.1 Fundamentals of Real Options Application to the Railroad Firm

Generally, the real options approach is preferably applied to analyzing the value of investment opportunities when these opportunities are surrounded by uncertainties. For example, a railroad firm’s investment in an individual infrastructure component might be able to capture the option-like value increment when the expected future cash flow from this asset is uncertain. The real options theory tells us that future uncertainty and flexibility for investment decision does create the option value.

This uncertainty-based aspect of the real options approach is an important concept. However, the discussion in the previous chapter depicts another important thing; in order for an investment decision to capture the value-increasing opportunity created by uncertainties, the target project or investment objective must undergo some state changes in its cash flow condition accompanied by making the investment decision. For example, currently laid-up state infrastructure asset will be converted to the operation state as a result of certain opening investments. Likewise, a revenue-decreasing railroad line will be abandoned as a result of paying required exit costs or sold to other operator by receiving some transfer value.

If an investment incorporated in a company’s infrastructure portfolio brings no change in future cash flow, the investment is independent of its timing and amount, and there will be no opportunity for the portfolio to gain real options value increment. On the other hand, suppose that the strategic investment allows managers to lower the maintenance expenditures of the portfolio, and/or the regular capital investment. The portfolio management condition definitely changes, and it might create an opportunity value increment in terms of real options. Such strategic investment can be deferred or postponed until a firm’s revenue goes up to such a high level that the company can incorporate the real options opportunity value in its portfolio.
According to the nature of the railroad industry, each railroad company ordinarily outlays its large portion of infrastructure investments for managing the condition of its existing portfolio: partial capital improvement, maintenance backlog reduction, capital renewal and replacement of the network infrastructure. Sometimes large-scale investment is planned and performed inside the company for the construction of a new line, or station. In such cases, government subsidies or grants are usually provided since the new project might bring considerable services and benefits to the public. Thus, these funds play an important role in executing the project.

These new lines or station constructions are clearly aimed at increasing the firm's revenue, and therefore, profit margin. In other words, they are creating independent new portfolios and the value of each portfolio is added to the original portfolio. Of course, as was discussed in the previous chapter, there might be an interaction between the original portfolio and a newly created portfolio, which might furthermore add an "interaction value" to the total portfolio. Creating a new portfolio, a new project, or a service might be easily analyzed with using real options.

However, this chapter analyzes another aspect of the infrastructure portfolio and its value maximization. It rather focuses on more conservative portfolio management: regularly performed maintenance expenditures, and capital investment. These management activities are indispensable for a company to assure the safety of train operations and to maintain its current level of profits or returns from the infrastructure portfolio. Safety is not a definition of a railroad company's success, but a mission for the company's business. Thus, what is important for managing a company's infrastructure portfolio is to achieve the operational efficiency of these regularly performed management activities without any losses to the company. One of the methods that would bring a company this operational efficiency by modifying its regular activities is a large-scale extra investment on the existing infrastructure portfolio. This chapter defines them as a strategic investment and tries to analyze
its optimal investment timing as well as the value of a portfolio which is to be maximized by the real options application.

Although a railroad company’s investment decision for regularly performed capital improvements or replacement activities will not be analyzed here, it should be changed or modified through the strategic investment decision. We might also find that if a new portfolio or project creation such as a new short distance line or a small station were regularly performed and it brought a company similar returns as that of existing infrastructure portfolio, it could be classified as a “regularly preformed infrastructure investment”, not as a “strategic investment”. From the definition here, the strategic investments are performed not regularly or constantly, but timely and concentratedly, and thus, strategically.

A company’s manager gathers financing resources from its annual account, and allocates them over many required “regular” projects, although some projects are benefited from government grants, subsidies, or tax postponings. The total amount of these regular activities will not change drastically from year to year, though some fluctuations are allowed to it. On the other hand, the amount of the required strategic investment depends on the project that is going to change the condition of these regular activities.

This chapter’s real options analysis, therefore, puts an emphasis on making it visible so that the strategic investment opportunities and timings are actually existing accompanied by a firm’s conditional changes in its infrastructure portfolio management. A firm’s infrastructure asset is subjected to the regular maintenance, the capital investment, and the physical depreciation. There is an option-like optimum investment timing and an appropriate investment amount at the threshold of changing these activities. Of course, the firm must balance financially both the regular activities and the strategic investments within its limited budget. The role of the strategic investment and its effects on the infrastructure portfolio is further analyzed in Section 5.3.5 from the viewpoint of this budget constraint.
5.2 Infrastructure Value Factor Comparison between European and Japanese Railroad Firms

5.2.1 Contribution of a Firm’s Infrastructure to its Operating Revenue

Railroad Infrastructure firms in four European countries (Sweden, Germany, France, and the United Kingdom) are compared here in order to analyze how many portions of the railroad passenger revenue obtained by a train operating company could be substantially created by an infrastructure asset firm’s contribution. Table 5.1 compares the gross train passenger and freight revenue with the franchise revenue or the infrastructure fees of the railroad infrastructure firms in European countries.

Table 5.1. Gross revenue and infrastructure charge in European countries.

<table>
<thead>
<tr>
<th></th>
<th>Sweden</th>
<th>Germany</th>
<th>France</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross passenger and freight revenue(1*)</td>
<td>1,127</td>
<td>13,403</td>
<td>7,858</td>
<td>5,173</td>
</tr>
<tr>
<td>Infrastructure charge(2*)</td>
<td>229</td>
<td>3,147</td>
<td>1,300</td>
<td>3,535</td>
</tr>
<tr>
<td>Infrastructure contribution (%)</td>
<td>20.31%</td>
<td>23.48%</td>
<td>16.54%</td>
<td>68.34%</td>
</tr>
</tbody>
</table>

(A) US Million Dollars. 1USD=9.16SEK=1.12EUR=0.66GBP
(B) France: 1999 data. Sweden, Germany and UK: 2000 data.
(C) Data Source: Annual report of each railroad company
(1*) Gross revenue is collected by train operation companies. Train operating companies are, SJ in Sweden, DB(Reise&Touristik, Regio, Cargo, Station&Service) in Germany, SNCF in France, and 25 Train Operating Companies in UK.
(2*) Infrastructure charges are collected by infrastructure companies. Infrastructure companies are, Banverket in Sweden, DB Track Infrastructure in Germany, RFF in France, and Railtrack in UK.

By law, these countries introduce the vertical separation system for the
railroad service management, and therefore, one might recognize it more explicitly for how many portions of the gross revenue should be reduced to the railroad infrastructure asset contribution. Of course, these proportions are usually determined and restricted by the government’s judgment, or they are affected by the existence of government grants and subsidies, but this paper assumes that the proportion economically reflects the essential value of both the train operating business and the infrastructure management business, and this value strongly relates to the firm’s ability to create its revenue flow.

In Table 5.1, the proportion of infrastructure contribution in the United Kingdom seems outstanding (68.34%) compared to other European countries. The main reason of this phenomenon is that the UK Railtrack not only owns and operates Britain's railway infrastructure -- the tracks, signals, tunnels, bridges, viaducts, and level crossings -- but also provides passenger services at its stations. Other countries’ infrastructure firms do not need to manage and provide such services at their stations. Therefore, the extra personnel expenses and other charges are incurred to the Railtrack. Furthermore, Railtrack business is independent as a listed enterprise and government subsidy is allocated not to Railtrack but to the train operating franchises. This indicates that the infrastructure fees collected by the firm might be set at a higher level compared to other countries’ infrastructure firms so that the firm’s business could yield some rewards to its shareholders. On the other hand, Banberket (Sweden) and RFF (France) are directly subsidized by the government or states, and DB Track Infrastructure is aided by its parent company, Deutsche Bahn.

From the three countries’ data in Table 5.1, this paper adopts 20% of the infrastructure contribution to the total passenger and freight revenue, and applies it to other “non-vertically separated” Japanese railroad firms. Although this proportion has no clear ground for applying to other non-vertically separated firms, it is likely to be a good approximation if one finds that the book value of Japanese railroad firm’s infrastructure assets, i.e., tracks, routes, structures, signaling systems, electrification,
stations and depots is approximately the present value of 20% of annual revenue flow minus present value of annual maintenance cost flow.

Table 5.2 compares Japanese railroad firm’s (A): 20% of passenger revenue, (B): infrastructure maintenance expenditure, (C): net present value of (A) minus (B) expecting that current revenue and cost flow lasts over 40 years, and (D): book value of infrastructure assets in 2000-2001. As an annual cost of capital, 4% is adopted here. From Table 5.2 data, the book values of Japanese railroad firm’s infrastructure are approximately equal to the difference of the expected present value between 20% of the revenue and its infrastructure operating costs over forty years.

Thus, the assumption of 20% infrastructure contribution to the total passenger and freight revenue is, not to say a completely true value, but might be a fairly advisable one. This assumption is also used in the following analyses.

Table 5.2. Estimation of infrastructure value in Japanese railroad firms.

<table>
<thead>
<tr>
<th></th>
<th>JR-West</th>
<th>JR-Central</th>
<th>JR-East</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) 20% passenger and freight revenue(^{(1)}) = assumed infrastructure contribution</td>
<td>1,437</td>
<td>1,827</td>
<td>3,088</td>
</tr>
<tr>
<td>(B) Maintenance expenditure(^{(2)})</td>
<td>1,149</td>
<td>726</td>
<td>2,067</td>
</tr>
<tr>
<td>(C) NPV of (A-B) over 40 years</td>
<td>4,980</td>
<td>19,036</td>
<td>20,219</td>
</tr>
<tr>
<td>(D) Book value of infrastructure assets(^{(3)})</td>
<td>6,119</td>
<td>17,890</td>
<td>19,323</td>
</tr>
</tbody>
</table>

(A) US Million Dollars. 1USD=120YEN


\(^{(3)}\) Numbers are book value of buildings and structures for the use of transportation such as stations, viaducts, bridges, or distribution lines. Lands are excluded. Data source: “JRW/JRC/JRE financial securities report” (2001), Ministry of Finance, Japan (in Japanese)
5.2.2 Portfolio Value Factor Analysis

Although the maintenance activity relates to the operating costs and expenses in the corporate income statements and the investing activity is an item of cash flow statements, a railroad firm’s infrastructure asset closely ties them together. If a firm’s annual infrastructure maintenance is restrained at the minimum required level that just needs to assure the safety of train operation, maintenance backlog is likely to be cumulating every year. In such a case, investing in the backlog reduction will growing to a significant level, and then there will be an earlier and more recurrent need for investing in the capital renewals or replacements.

Similarly, if a firm’s maintenance expenditure is enough to inhibit maintenance backlog from building up, not only its infrastructure assets will be maintained at a good condition but also the average amount of investing in capital replacement will be saved. Therefore, it is essential to manage these financial items above simultaneously in order to find certain change in the condition of the cash flow or the value of the total infrastructure portfolio that leads to creating a real options value increment opportunity.

The value of total infrastructure portfolio—not the investment portfolio—is chiefly affected by the extent of the following three factors: (1) maintenance expenditure (2) capital investment (3) physical asset depreciation. The necessity of the maintenance expenditure reduces the value of the asset, while the maintenance backlog reduction, capital renewal, replacement and investing in capital improvement increases its value. The physical depreciation certainly reduces the portfolio value, but it is difficult to obtain its exact value directly. Therefore, it is estimated by modifying the actual economic depreciation value in the European and Japanese railroad firms.

This section illustrates each of these factors using actual data obtained from the European and Japanese railroad firms. These factors will provide us an approach to analyze the relationship between the regularly performed infrastructure
management and the strategic investment of a railroad firm in Section 5.3.

**Value Factor 1: Infrastructure Maintenance Expenditure**

In Figure 5.1, Japanese railroad company's revenue is adjusted to 20% of total passenger revenue as was discussed in the previous section. These figures below are per track mile and not per route mile so that the gap of asset volume between single and double track can be filled up. Japanese railroad company’s expenditure is for track, signaling system, and electrification maintenance, but vehicle maintenance is excluded.

![Figure 5.1. Revenue and infrastructure maintenance expenditure per track mile](image)

Data source: BV/RFF/DB/RT Annual reports 1999/2000


Theoretically, if every company has the same asset volume per track mile, its maintenance expenditure may not be different from one company to another. However, it is evident that the maintenance expenditure increases at a certain rate as
the revenue increases. This increment might be regarded as deterioration equivalence due to the increasing in the frequency of traffic usage.

As a next step of analysis, the line of the average maintenance expenditure per track mile is assumed in Figure 5.2. The average annual maintenance cost per track mile is supposed to follow the line (A) in the figure as the revenue changes. Then, fluctuation of this average line is considered in Figure 5.2. The average maintenance expenditure ±20% level is shown as broken lines represented by (B) and (C). These lines do not indicate the minimum and maximum limit of a firm's expenditure ability. The upper line is assumed to be an amount "average" value a company is able to spend regularly for the maintenance activity every year. Likewise, the lower line is the minimum on-going spending criteria which is acceptable for assuring the safety of train operation if a firm pays at least this amount constantly every year. Therefore, a firm may spend more beyond line (C), or spend less than (B), if necessary.

![Figure 5.2. Hypothetical average infrastructure maintenance expenditure and fluctuation](image)

\[ C_{m(H)} = 1.20C_{m(AVE)} \]
\[ C_{m(AVE)} = 7.5R^{0.65} - 10R^{0.45} \]
\[ C_{m(L)} = 0.80C_{m(AVE)} \]
The equations of these lines are,

\[(A)\] Average expenditure: \[C_{m(AVE)} = 7.5R^{0.65} - 10R^{0.45}, \tag{1}\]

\[(B)\] Lower level maintenance expenditure: \[C_{m(L)} = 0.80C_{m(AVE)}, \tag{2}\]

\[(C)\] Higher level maintenance expenditure: \[C_{m(H)} = 1.20C_{m(AVE)}, \tag{3}\]

Note that equation (1) describes the average line (A) designed for the convenience of solving the differential equations of asset valuation in the latter section, and does not necessarily represent the exact average of these points plotted. The number \(\pm 20\%\) for the upper and the lower line (2) and (3) is also assumed arbitrarily here because the aim of this case analysis is to find the infrastructure value increasing opportunity using real options, not to evaluate each firm’s actual management efficiency or rationality.

**Value Factor 2: Infrastructure Capital Investment**

Each railroad company’s infrastructure capital investment is also shown in Figure 5.3. Because of the data availability, only limited firms’ infrastructure investment values are plotted on the figure.

Infrastructure capital investment, like maintenance expenditure, has a tendency of increasing its amount as a company’s revenue rises. There might be several reasons for this; (a) supporting the large volume transportation and sustaining the high service quality require better asset conditions, and it leads to more frequent capital renewal and replacements; (b) high revenue enables a firm to make larger amounts of investments for new facility construction. Note that even though the new facility construction might have a strategic aspect in terms of a firm’s business, this section treats them as a regular investment activity performed within the existing infrastructure portfolio.
Figure 5.3. Revenue and infrastructure capital investment per track mile

Data Source: Same as Figure 5.1

\[ C_{c(U)} = 1.20C_{c(AVE)} \]
\[ C_{c(AVE)} = 30 + 5.0R^{0.65} - 6.0R^{0.45} \]

Figure 5.4. Hypothetical average infrastructure capital investment and fluctuation
As was already done at the maintenance expenditure analysis, the average capital investment trend line (D) and ±20% lines (E and F) are hypothesized in Figure 5.4 so that they might represent the approximate fluctuation of the regular infrastructure capital investment. The equations obtained from this figure are,

\[(D) \text{ Average capital investment: } C_{c(AVE)} = 30 + 5R^{0.65} - 6R^{0.45}, \quad (4)\]

\[(E) \text{ Lower level capital investment: } C_{c(L)} = 0.80C_{c(AVE)}, \quad (5)\]

\[(F) \text{ Higher level capital investment: } C_{c(H)} = 1.20C_{c(AVE)}. \quad (6)\]

Equation (4) describes the average trend line (D) designed again for the convenience of solving the differential equations of asset valuation in the latter section, and does not necessarily represent the exact average of these points plotted. The ±20% fluctuations for the upper and the lower line ((5) and (6)) are also assumed arbitrarily here. Equation (5) and (6) do not indicate a firm’s acceptable capital investment limit, but represent a firm’s hypothetized lower and higher sustainable degree of continuous annual investment. For example, continuous annual capital investment at a lower-level (E) could ensure the required safety standard for the railroad firms in terms of the maintenance backlog reduction, renewal, and capital replacement. Similarly, regularly made higher level annual capital investments (F) would enable a firm to boost and improve its asset quality, or to construct new infrastructure assets.

**Value Factor 3: Physical Depreciation**

The last factor which affects a firm’s total infrastructure portfolio value is its physical depreciation. In order to approximate this value, each railroad firm’s economic depreciation is plotted first in Figure 5.5, and then its physical depreciation is hypothetically determined based on the trend.
It is true that the degree of economic depreciation depends on the book value of each infrastructure that a firm currently holds. But a tendency that the higher the revenue, the higher the degree of economic depreciation can be observed from Figure 5.5. This paper will not analyze the reason of this correlativity, since the objective of this section is to estimate the degree of physical depreciation. However, we are able to assume that the degree of the physical depreciation, too, will have a similar trend in its revenue correlativity.

Upon estimating the trend of both the minimum and the maximum degree of the physical depreciation, we utilize the relationship between a firm's physical asset volume, the frequency of infrastructure usage, and their effects on the magnitude of the physical depreciation. First, suppose that the relation can be described as Figure 5.6. Two links can be observed in it. Links (A) and (B) explain the effect of the
frequency of infrastructure usage on the depreciation, and that of the physical asset quality on the depreciation, respectively. In fact, link (A) is already recognized as the revenue correlativity of the depreciation in the discussion above. Therefore, utilizing the trend expressed in Figure 5.5 for estimating both the minimum and the maximum degree of the physical depreciation might be a reasonable way to explain this first link.

![Figure 5.6. Causes of Physical Depreciation](image)

The maximum physical depreciation line is supposed to be drawn approximately corresponding with the economic depreciation line (Figure 5.7) because infrastructure assets are, in general, economically depreciating faster than its actual physical depreciation. The equation would be $D_{(h)} = 0.5R$.

On the other hand, the minimum physical depreciation line cannot be found from current information with respect to the infrastructure portfolio, and therefore, it has to be hypothesized by utilizing the relationship shown as link (B) in Figure 5.6. Since link (A) has already been considered and quantified when drawing the maximum depreciation line, it might be of importance to find the relationship between the maximum and the minimum depreciation in order to obtain the
minimum depreciation trend. First, we assume the next relation from Figure 5.6:

\[ \text{Physical depreciation} = \Delta \text{Physical asset quality} \].

This "\(\Delta \text{Physical asset quality}\)" should be replenished by an annual capital investment. We further assume the case where all the capital investments are made for the replenishments. In such a case,

\[ \Delta \text{Physical asset quality} = \text{Capital investment} \].

Then, we combine these two relational expressions and obtain the next hypothetical correlations:

<table>
<thead>
<tr>
<th>Higher rate physical depreciation</th>
<th>Faster change in asset quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower rate physical depreciation</td>
<td>Slower change in asset quality</td>
</tr>
</tbody>
</table>

\[ \text{Higher level capital investment } [C_{c(H)} = 1.20(30 + 5.0R^{0.65} - 6R^{0.45})] \]

\[ \text{Lower level capital investment } [C_{c(L)} = 0.80(30 + 5.0R^{0.65} - 6R^{0.45})] \]

Of course this correlation above assumes the most extreme case where all the capital investments are outlayed for recovering the physical depreciation. In reality, the higher rate physical depreciation does not necessarily relate to the higher-level capital investment, and also a firm who invests small amounts of money in infrastructure does not necessarily own the infrastructure portfolio of which physical depreciation rates are also low.

However, we assume the proportion of the regularly performed capital investment \( C_{c(H)}/C_{c(L)} = 1.5 \) as that of the physical depreciation rate here. The rate of the higher physical depreciation has already been obtained above \( D_{(H)} = 0.5R \). Therefore \( D_{(L)} = D_{(H)}/1.5 = 0.3333R \). The equations are summarized below and shown in Figure 5.7. From the figure, both the lower- and the higher-rate physical depreciation seem to correspond with the actual firms' economic depreciation trend:
(G) Lower rate physical depreciation: \( D_{(L)} = 0.3333R \), \( (7) \)

(H) Higher rate physical depreciation: \( D_{(H)} = 0.5R \). \( (8) \)

\[
\begin{align*}
\text{Figure 5.7. } & \text{Hypothetical physical depreciation fluctuation} \\
\text{One might also assume that the lower rate physical depreciation relates to} & \text{the expected present value of constant lower level capital investment flow. This} \\
\text{means that constantly made lower-level capital investments will only increase the} & \text{present value of physical asset quality at a lower rate, while constantly performing} \\
\text{higher-level capital investments will lead to better asset qualities with higher} & \text{expected present values.} \\
\text{The proportion of the expected present value of investment flow between the} & \text{lowest- and the highest-level constant capital investment might also reflect the rate of} \\
\text{physical depreciation. The value is the same as above, that is,} & \text{physical depreciation. The value is the same as above, that is,} \\
\frac{(\text{Expected present value of constant } C_{c(H)} \text{ flow})}{(\text{Expected present value of constant } C_{c(L)} \text{ flow})} & = 1.5 .
\end{align*}
\]
5.3 Portfolio Value Maximization---Strategic Investment and Portfolio Condition Change

In the preceding section, a railroad firm’s fundamental variable factors that affect the value of a firm’s infrastructure portfolio were hypothetically obtained from the actual firm’s data. This section uses these factors in order to describe the conditional change in the portfolio value mathematically. The portfolio condition changes create both the optimal strategic investment opportunity and the real options value increment, which lead to the value maximization of the firm’s infrastructure portfolio.

5.3.1 Revenue Drift

We start from one assumption for the modeling of a railroad firm’s infrastructure portfolio and determining its option value. The assumption is that the portfolio’s future revenue drift follows the geometric Brownian motion explained in Chapter 4.2.1:

\[ dR = \alpha \cdot R \cdot dt + \sigma \cdot R \cdot dz, \]

where

- \( R \): Annual revenue created by the infrastructure portfolio contribution,
- \( \alpha \): Annual growth rate of the revenue,
- \( \sigma \): Volatility or standard deviation of the revenue.

In the following discussion, the drift of the revenue created by a railroad firm’s infrastructure portfolio is supposed to follow this geometric Brownian motion, with its annual growth rate \( \alpha \). This value \( \alpha \) might be acquired from the data of the actual firm’s revenue fluctuation over a few years. Since the range of the drift is considerably affected by the nation’s inflation rate or business condition, it might be better to compare the revenue by the nation. Thus, the gross passenger revenue in
the United Kingdom, Germany, and Japan are compared in Figure 5.8, and the trend line of $\alpha = 0.01$, which satisfies the equation $R = R_0 \cdot e^{\alpha t}$, where $R_0$ is a revenue in year 0, is assumed to be appropriate and shown on the figure.

![Figure 5.8. Drift of passenger revenue in three countries](image)

($^1$) UK national railways' receipts  
($^2$) DB Group total passenger revenues  
($^3$) JR Group total passenger revenues  

Data source: ($^1$) Transport statistics Great Britain 2001, Department for Transport, Local Government and the Regions, UK  
($^2$) DB annual report 2000  
($^3$) Railway figures 2001, Institute for Transport Policy Studies, Japan

The average volatility of the revenue ($\sigma$) is also estimated in Table 5.3 by comparing these three nations above, although the three countries' data might not be enough to determine the actual railroad firm's overall revenue volatility.

The average standard deviation of the revenue divided by the mean is 0.065. Therefore, this paper applies $\sigma = 0.07$ to the latter term of the geometric Brownian motion equation ($dR = \alpha \cdot R \cdot dt + \sigma \cdot R \cdot dz$). Furthermore, the estimated average revenue volatility $\sigma = 0.07$ and actual Japanese railway company's stock volatilities are compared in Table 5.4 in order to check whether or not the obtained revenue
volatility is apart from actual managerial figures which reflect a firm’s business condition through the stock market. Although there might be a small relationship between the volatility of passenger revenue and that of actual firm’s market security prices, these two values show as almost the same number in the table. Therefore, we will apply this estimated revenue volatility to the real options analysis later.

**Table 5.3.** Average volatility of railroad passenger revenue

<table>
<thead>
<tr>
<th></th>
<th>UK</th>
<th>Germany</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Revenue (1994-2000)*</td>
<td>4,025</td>
<td>13,714</td>
<td>34,487</td>
</tr>
<tr>
<td>Standard Deviation*</td>
<td>641.5</td>
<td>232.2</td>
<td>629.9</td>
</tr>
<tr>
<td>SD/Mean Revenue</td>
<td>0.1594</td>
<td>0.0169</td>
<td>0.0183</td>
</tr>
<tr>
<td><strong>Average Volatility (σ)</strong></td>
<td></td>
<td></td>
<td><strong>0.065</strong></td>
</tr>
</tbody>
</table>

*US million dollars: 1USD = 0.66GBP = 1.12EUR = 120YEN

**Table 5.4.** Estimated revenue volatility and actual stock price Sigma of Japanese railway companies

<table>
<thead>
<tr>
<th>Estimated Volatility</th>
<th>Stock Price Sigma*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>West Japan Railway</td>
</tr>
<tr>
<td><strong>0.065 = 0.07</strong></td>
<td>0.0723</td>
</tr>
</tbody>
</table>

* Stock volatility sigma (σ) is calculated based on the stock price data of recent 30 or more but less than 60 months before 9/2001.

Data Source: TOPIX β value (9/2001), Tokyo Stock Exchange, Japan
Infrastructure Management Scenario Construction

As was mentioned before, this real options application chapter aims to describe railroad firm’s infrastructure portfolio management and its value maximization strategy. The research target is not a new large project creating higher expected return on assets, but an entire infrastructure portfolio on which a firm’s essential transportation business stands. Portfolio value maximization might be possible through both a firm’s regular infrastructure management and its strategic investment decision. The regular management usually includes asset maintenance and maintenance backlog reduction as well as capital improvement, renewal, and replacement activities, while the strategic investment changes and rearranges the combination of these regular management activities.

A firm’s physical asset condition, which is the fundamental portion of the infrastructure portfolio value, depends heavily on this regular management; therefore, if a firm desires to change or improve its portfolio value, it is essential to reconsider what these regular activities should be. The strategic investment decision helps managers to achieve their desirable set of the portfolio management activities. The best investment decision-making rests on the best consideration of the portfolio condition configured by the current or the future regular management activities.

In terms of a firm’s budget planning, amounts of the expenditure or the investment allocated for these regularly performed fundamental activities do not change drastically from year to year, and usually are predetermined, with the exclusion of spending for urgent needs against unexpected events. Thus, these regular activities have a certain annual budget basis, which in turn affects or determines a certain portion of a firm’s infrastructure portfolio value.

However, a firm might be able to change this budget basis by considering extra strategic investment that could modify its entire infrastructure portfolio condition and value. For example, a firm is now considering one strategic project. If this project were adopted and completed, a firm’s annual maintenance expenditure
would fall to two-thirds of the current basis. In such a case, it might be possible to find the optimal investment point where the firm’s revenue is high enough to invest in the costly project at the same time maximizing its infrastructure portfolio value.

This strategic investment does not necessarily create new facilities that would bring the firm higher annual revenue or profit. Rather, the investment might be used to assure a firm’s current revenue with lowering the operating cost, that is, the investment might enhance a firm’s operational efficiency. Such operational efficiency, e.g., decrease in the maintenance expenditure or in the physical depreciation, could raise a firm’s profit margin as well as its portfolio value. The strategic investment is also used to increase the quality of the infrastructure that might not be achieved by the regularly performed investment activities such as maintenance backlog reduction or capital replacement. At least, we can say that the strategic investment would bring some conditional changes to a firm’s portfolio management.

The hypothesis that strategic investment could change a firm’s management condition would enable us to quantify the effect of the investment on the infrastructure assets as well as the optimal timing of the investment by applying real options approach to the portfolio valuation. The first step to the quantification is to obtain the portfolio value at the starting and the ending portfolio conditions across the strategic investment.

The strategic investment is a one-time intensive spending, while regularly performed management activities are accompanied by continuous and constant cash outlay. Generally, the latter types of cash flow constitute the large portion of infrastructure portfolio value in a railroad firm; therefore, the starting and ending conditions mentioned above have to be quantified by the measures associated with these regular management activities. In Section 5.2, we have already examined three measures, or portfolio value factors, that directly reflect these regular portfolio management activities. By combining the fluctuation of these factors, some
portfolio conditions could be available.

Figure 5.9 describes a firm’s possible infrastructure portfolio condition expressed by its value creation factors that are closely related to a firm’s regularly performed portfolio management activities. The average level of each value factor is not shown here in order to describe the portfolio condition changes more explicitly.

* Portfolio value factor combination
  \[ (\text{Maintenance expenditure}/\text{Capital investment}/\text{Physical depreciation}) = (M/C/P) \]

*For example, a portfolio condition with \( (M/C/P) = H/L/L \) indicates that a firm manages its portfolio by regularly outlaying "High-level" maintenance expenditure, "Low-level" capital investment with annual "Low-rate" physical depreciation condition. The combination \([H/L/L]\) should be determined or required by the portfolio’s current condition.

For a given business situation, the regular management activities are to
follow the portfolio condition, accompanied by one of the combinations of these value factors, so that the portfolio can be managed at the most preferable state. Once the activities are taken by the managers, they might be kept over many years because the infrastructure portfolio condition can not be changed easily and the managers might keep their regular management policy on the basis of the condition. Remember that from the discussion in Section 5.2, managers could spend less or more than the assumed high- or low-level maintenance expenditure and capital investment line, if necessary. An assumed level is the "mean" of the expenditures or the investments over many years.

However, the regular activity basis could be altered if the portfolio condition and the associating value factor combination were changed drastically. In this situation the converted portfolio with another combination of associating value factors has to be followed by another regular management activities.

Suppose that a firm's portfolio, which is accompanied by the value factor combination of high-level maintenance expenditure, low-level capital investment and high-rate physical depreciation, is currently managed by some constant management policy that meets to sustain the portfolio without any losses to the firm. As a result of a large-scale strategic investment, the portfolio no longer incurs high-level maintenance expenditure. In such a case, will the managers still keep the original management policy alive? The answer is no, because the managers might not spend excessively on the maintenance activities.

From Figure 5.9, 8 (= 2^3) types of the portfolio condition are obtained. Based on these conditions and utilizing the equation (7-a) in Chapter 4, the value of the portfolio can be expressed as follows:

\[ V(R) = Rdt - C_m dt + C_c dt - D dt + \mathcal{E}[V_0(R + dR)e^{-\rho dt}], \]  \hspace{1cm} (10)

where

\[ V(R) \]: infrastructure portfolio value,
$R$: annual revenue created by infrastructure portfolio contribution
of which drift is expressed by equation (9),

$C_m$: annual maintenance expenditure of which fluctuation is expressed by
equation (2) and (3),

$C_c$: annual capital investment of which fluctuation is expressed by
equation (5) and (6),

$D$: physical depreciation of which fluctuation is expressed by
equation (7) and (6),

$\mathcal{E}[a \cdot e^{-\rho t}]$: expected present value of $a$ at time $t$,

$a = (\text{value of total portfolio at time } dt) = V_0 (R + dR)$

$\rho$: opportunity cost of capital.

As was already discussed in Chapter 4, the right-hand side of the equation can be
expanded by using Ito’s Lemma:

$$V(R) = (R - C_m + C_c - D)dt + \frac{1}{2} \sigma^2 R^2 \cdot V''(R) + \alpha R \cdot V'(R)dt + (1 - \rho dt)V(R) + o(dt).$$

(11)

This equation can also be simplified by applying the same procedure explained in
Chapter 4. Then,

$$\frac{1}{2} \sigma^2 R^2 \cdot V''(R) + \alpha R \cdot V'(R) - \rho \cdot V(R) + R - C_m + C_c - D = 0.$$

(12)

Substituting $C_m$ by equation (2) or (3), $C_c$ by equation (5) or (6), and $D$
by equation (7) or (8) in compliance with the portfolio condition obtained in Figure
5.9, eight equations are formulated. They can be solved in terms of portfolio value
$V(R)$. Generally, as was discussed in Chapter 4, $V(R)$ is expressed as the
following form,
\[ V(R) = A_1 R^\beta_1 + A_2 R^\beta_2 + E \cdot R + F \cdot R^{0.65} + G \cdot R^{0.45} + H , \]  
\[ \text{where } A_1 \text{ and } A_2 \text{ are constants remained to be determined later. From Chapter 4.2.2, } \beta_1 \text{ and } \beta_2 \text{ must be a positive and a negative solution to the following equation:} \]
\[ \frac{1}{2} \sigma^2 \beta (\beta - 1) + \alpha \beta - \rho = 0. \]  
\[ \text{The value of a railroad firm's revenue volatility } \sigma \text{ is 0.07 from Table 5.4, annual revenue growth rate } \alpha \text{ is 0.01 by Figure 5.8, and both satisfy equation (9). With using } \rho = 0.04 \text{ we get,} \]
\[ \beta_1 = 2.78, \text{ and } \beta_2 = -5.87 \]

Then, the constants E, F, G, and H are determined and shown in the Table 5.5.

**Table 5.5. Value of E, F, G, H in equation (13)**

<table>
<thead>
<tr>
<th>Portfolio value factor combination (M/C/P)</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>H/H/H</td>
<td>16.67</td>
<td>-88.09</td>
<td>132.94</td>
<td>900</td>
</tr>
<tr>
<td>H/H/L</td>
<td>22.22</td>
<td>-88.09</td>
<td>132.94</td>
<td>900</td>
</tr>
<tr>
<td>H/L/H</td>
<td>16.67</td>
<td>-146.81</td>
<td>199.41</td>
<td>600</td>
</tr>
<tr>
<td>H/L/L</td>
<td>22.22</td>
<td>-146.81</td>
<td>199.41</td>
<td>600</td>
</tr>
<tr>
<td>L/H/H</td>
<td>16.67</td>
<td>0.00</td>
<td>22.16</td>
<td>900</td>
</tr>
<tr>
<td>L/H/L</td>
<td>22.22</td>
<td>0.00</td>
<td>22.16</td>
<td>900</td>
</tr>
<tr>
<td>L/L/H</td>
<td>16.67</td>
<td>-58.72</td>
<td>88.63</td>
<td>600</td>
</tr>
<tr>
<td>L/L/L</td>
<td>22.22</td>
<td>-58.72</td>
<td>88.63</td>
<td>600</td>
</tr>
</tbody>
</table>

As was discussed in Chapter 4.2.2, the first two terms in equation (13) imply
the real options opportunity value of a portfolio if it has a chance to transfer to another portfolio condition. For example, consider a portfolio whose value factor combination (M/C/P) is H/H/H, or just Portfolio[H/H/H], and another portfolio whose value factor combination is H/H/L, or Portfolio[H/H/L]. Portfolio[H/H/H] requires a firm to take a certain regular management activities which meets to sustain the portfolio condition, that is, a firm has to spend regularly the higher-level maintenance expenditure and the higher-level capital investment while allowing higher-rate physical depreciation. Then, the value of Portfolio[H/H/H] would be an outcome of a firm’s regular management activities.

Similarly, the value of Portfolio[H/H/L] is an outcome of a firm’s regularly making higher-level maintenance expenditures and higher-level capital investments with lower-rate annual physical depreciation. If these two portfolios had an opportunity to switch each other, both Portfolio[H/H/H] and Portfolio[H/H/L] would have their own values for constant \( A_1 \) and \( A_2 \) in equation (13).

If there were no opportunity for a portfolio to switch to another one, the values of both \( A_1 \) and \( A_2 \) would be 0. In such cases, the portfolio value can be expressed as follows:

\[
V_0(R) = E \cdot R + F \cdot R^{0.65} + G \cdot R^{0.45} + H
\]  

(15)

Equation (15) is graphically shown in Figure 5.10 by substituting E, F, G, and H with the values calculated in Table 5.5. Again, these portfolio value creation factors in Table 5.5 are only possible combinations. Moreover, not all of them have an opportunity to switch to other portfolio conditions. Thus, we have to judge which portfolio has an opportunity to create real options value increments and optimal investment timing.

Figure 5.10 shows some portfolio value curves that intersect with each other. On the other hand, other curves do not have any intersections. When two curves are intersecting at one point, managers might be able to alter their portfolio’s conditions.
by changing its value factors (M/C/P). Such value factor modification enables a portfolio value curve to switch from one to another.

![Diagram of possible portfolio value curves without real options value increment](image)

*Figure 5.10. Possible portfolio value curves without real options value increment*

For example, managers currently manage their infrastructure portfolio by regularly making lower-level maintenance expenditures and lower-level capital investments accompanied by the portfolio’s annual higher-rate physical depreciation. These levels or rates are measured in accordance with the revenue collected by the portfolio. Thus, the managers currently have Portfolio[L/L/H] (line6). They might observe an intersection between line 5 and line 6 at the point where the revenue is approximately $870 thousand/track mile.

Assume that any two portfolios having the same value at a revenue level, i.e., any two portfolios at the intersecting point can change their value factor combination freely between themselves at this point. The combinations L/L/H and H/L/L are inter-exchangeable with each other only at $870 thousand of the revenue level. This
means that the portfolio’s condition at this value and revenue point requires either $L/L/H$ or $H/L/L$ for the value factor combination; that is, outlaying high maintenance expenditure would allow the portfolio to physically depreciate at the lower rate without changing any portfolio value, given that the revenue level remains constant at that level.

Now the managers own a Portfolio$[L/L/H]$ with $870$ thousand of revenue level. Below the level, managers would choose current Portfolio$[L/L/H]$ (line 6) in which the combination of required value factors ($M/C/P$) is $L/L/H$. Above this revenue level, on the other hand, managers would choose Portfolio$[H/L/L]$ (line 5) by regularly making higher-level maintenance costs and lower-level capital investments with lower-rate annual physical depreciation so that a firm’s portfolio always has a higher value at any time.

Note that the example above does not consider the portfolio’s real options opportunity value increment that is to be created by the revenue flexibility.

5.3.3 The Role of Strategic Investment

Possible infrastructure portfolio conditions associated with the various combinations of value factors are presented in the previous section. However, two more things should be added here: that is, the treatment of value factor change and the selection of the any portfolio value curves. First, with regard to the portfolio’s value creation factors, their trends and fluctuations were hypothesized in Section 5.2.2. For instance, the maximum physical depreciation curve was determined to have the same trend and value as that of economic depreciation, while its rate of fluctuation was assumed, based on the proportion of regular capital investment outlays.

The example at the end of the last section assumed that any two portfolios having the same value at a revenue level, i.e., any two portfolios at the intersecting point could exchange their value factor combinations freely at this point. Under this
assumption, managers could freely modify their regular management activities following the change in the value factor combination between $L/L/H$ and $H/L/L$. However, in reality, the portfolio conditions cannot be exchanged freely without any extra impact from the firm’s managers. The managers should not be managed by the portfolio’s condition, but they must manage the portfolio, although they need a certain amount of investment which is large enough to have an impact on the entire portfolio’s condition.

Therefore, we treat this extra impact as the strategic investment in the following analyses. In other words, the strategic investment here is a driving force which would enable managers to achieve their portfolio’s operational efficiencies through modifying the portfolio’s condition as well as their regularly performed infrastructure management activities. The strategic investment made at the optimal timing would create maximum value of infrastructure portfolio in accordance with the firm’s revenue level.

Trigeorgis (1996) describes the relationship between this strategic investment (in his words, “strategic project”) and regularly performed capital investment (in his words, “normal project”). The analysis focuses on the interaction between these two investment categories from the viewpoint of a firm’s financial aspects such as investment growth, budget constraints or return on assets (Figure 5.11). Then, he concludes, “The outcome of this strategic-investment-mix analysis will be the value-maximizing strategy and the optimal growth path (how much should be invested in each broad project category over time).”

A railroad infrastructure portfolio has to be invested by the regular capital investment activities such as capital replacement, maintenance backlog reduction, or component renewal, while it also has to be managed through the strategic investments, which facilitate the efficiency of these regularly performed current management activities. This situation matches with Trigeorgis’s explanation well. Both the regular and the strategic investment have to be balanced within a firm so
that the firm could take the greatest advantage of these investments. Thus, it might be helpful to understand the interaction between the two investment categories within the railroad infrastructure portfolio by using his figures.

![Graph showing interaction between regular investment and strategic investment](image)

*Figure 5.11. Interaction between regular investment and strategic investment (from Trigeorgis(1996))*

### 5.3.4 Scenario Selection

Several value curves that did not intersect with each other were observed in Figure 5.10. Curve 1 whose value factor combination is \((M/C/P) = L/H/L\) never intersects with Curve 8 whose value factor combination is \((M/C/P) = H/L/H\). In such cases, managers have few chances to switch the portfolio’s condition between non-intersecting value curves. This is because the amount of required strategic investment discussed above might be getting too large in such cases.

For example, portfolio value curves 1 (\(Portfolio[L/H/L]\)) and 2 (\(Portfolio[L/L/L]\)) in Figure 5.10 never intersect with each other. If managers who are currently managing \(Portfolio[L/L/L]\) at the $600 thousand/track mile of annual revenue want to enhance its portfolio value by changing the condition into \(Portfolio[L/H/L]\), they will
need the strategic investment amount of $2,870 thousand/track mile ($14,630 – $11,760). Assume the firm’s total number of track miles is 4,000. Then, the gross required strategic investment is $2,870,000 \times 4,000 = $11.48 billion. Even if this amount of investment would bring conditional changes in a firm’s infrastructure portfolio, managers might not make such a decision.

Thus, portfolio condition changes between any two non-intersecting value curves might be unrealistic, let alone considering opportunities for real options value increments between them. Given this situation, Figure 5.12 summarizes the conditional changes worth examining by real option application.

![Figure 5.12. Portfolio value curve intersection without real options value increment](image-url)
Figure 5.12 presents seven intersections with respect to conditional changes in portfolios and their value factors. The location of the intersection implies the presence of a real options value increment opportunity. A firm with an infrastructure portfolio revenue per track mile of around $130 thousand might be able to change its portfolio value curve at the neighborhood of Point B or Point E in accordance with the revenue flexibility, given that the firm’s portfolio is currently managed by one of following value factor combinations: [L/L/L], [H/H/L], [L/L/H], or [H/H/H]. Similarly, a firm with its revenue created by its infrastructure contribution of around $388 thousand/track mile might be able to let its portfolio value curve to switch at the neighborhood of Point C or Point F in accordance with the revenue flexibility, given that the firm’s current portfolio management condition is controlled by one of following value factor combinations: [L/L/L], [L/H/H], [H/L/L], or [H/H/H].

Remember that these intersecting value curves in Figure 5.12 are calculated based on the assumption that the fluctuation of portfolio value factors (Maintenance expenditure/ Capital investment/ Physical depreciation) has just two positions: high-level (high-rate) or low-level (low-rate). If other positions, e.g., average-level, were also supposed and added, the number of value curves would be multiplied in accordance with the numbers of combinations of these positions. Such an assumption might increase the number of value curve intersections, which implies the increase in the opportunities of real option value increments for a firm.

5.3.5 Portfolio Value Maximizing Condition

In order to examine the optimal strategic investment timing for changing the portfolio value conditions, this section analyzes two cases selected from seven intersecting conditions shown in Figure 5.12. The first case is a conditional change between Portfolio[L/L/L] and Portfolio[L/H/H]. The intersection of these two value curves is Point C in the figure if one neglects real options opportunity value increments. The second case is the one between Portfolio[H/L/L] and Portfolio[H/H/H].
Their intersection is Point F. Upon starting the analysis, we have to assume the value of strategic investments with which a firm’s managers might be able to modify its portfolio value factors, as discussed in Section 5.3.4. In fact, the strategic investments in this case study are classified into two categories. One is an “entry option” type investment, and the other is “exit option” type investment.

For example, if the transition is between Portfolio[L/L/L] and Portfolio[L/H/H], a manager might do well to change his or her portfolio from [L/H/H] to [L/L/L] by making the strategic investment when the future revenue increases to a certain point. This is an “entry option” type investment (Figure 5.13). On the other hand, a manager should prepare changing his or her portfolio from [L/H/H] to [L/L/L] when the future revenue goes down. This can be considered as an “exit option” type investment.

We can say that either Portfolio[L/H/H] or Portfolio[H/H/H] has just an entry option, while either Portfolio[L/L/L] or Portfolio[H/L/L] has just an exit option. The mathematical option valuation models for these two investment categories have
already developed in Chapter 4.2.3. In addition, the smooth-pasting and the value-matching conditions explained in Chapter 4.1.5 are required for these decision-making points. This case study hypothesizes that a certain amount of the strategic investment is needed depending on the type of the intended project in case of the entry option type transitions, while no exit investment, or exit cost is incurred for the exit transition. Figure 5.13. (b) is a conceptual model which describes this hypothetical situation. Note that the investment is, once made, irreversible.

Just as the regularly performed infrastructure management activities depend on the firm’s both the financial condition and the current quality of its infrastructure portfolio, so the objective and the required quantity of its strategic investment reflect both a firm’s financial condition and the envisioned effect on the regular management activities. Here, we arbitrarily predetermine the amount of the required “entry” investment as each one of $50, $100, $200, $300, and $400 thousand per track mile. At one situation, a firm’s managers might realize that only $50 thousand/track mile of strategic investment could allow them to modify the portfolio value factors. On the other hand, another situation requires them to make over $300 thousand/track mile of the extra investment in order to change these portfolio factors.

In the context above, four portfolio value curves are mathematically examined in the following Case A and B for the derivation of optimal timing to make these strategic investments. The value curves without real options value increment have already been obtained in Table 5.5. For describing the transition between Portfolio[L/L/L] and Portfolio[L/H/H] we use the next equations;

\[
V_{LHH}(R) = A_1 R^{\beta_1} + A_2 R^{\beta_2} + 16.67 R + 22.16 R^{0.45} + 900, \tag{16}
\]

\[
V_{LLL}(R) = B_1 R^{\beta_1} + B_2 R^{\beta_2} + 22.22 R - 58.72 R^{0.65} + 88.63 R^{0.45} + 600, \tag{17}
\]

and for the transition between Portfolio[H/L/L] and Portfolio[H/H/H] we use,
\[ V_{hhh}(R) = X_1 R^\beta_1 + X_2 R^\beta_2 + 16.67R - 88.09R^{0.65} + 132.94R^{0.45} + 900, \quad (18) \]
\[ V_{hll}(R) = Y_1 R^\beta_1 + Y_2 R^\beta_2 + 22.22R - 146.81R^{0.65} + 199.41R^{0.45} + 600. \quad (19) \]

\( \beta_1 \), and \( \beta_2 \) are a positive, and a negative solution of equation (14), respectively. Thus, we have \( \beta_1 = 2.78 \), and \( \beta_2 = -5.87 \). As was explained in Chapter 4.2.4, the constants \( A_2 \) and \( X_2 \) associated with the negative index \( \beta_2 \) have zero value, because Portfolio\([L/H/H]\) and Portfolio\([H/H/H]\) have only an entry option into Portfolio\([L/L/L]\) and Portfolio\([H/L/L]\), respectively. Similarly, \( B_1 \) and \( Y_1 \) associated with the positive index \( \beta_1 \) are zero, since Portfolio\([L/L/L]\) and Portfolio\([H/L/L]\) have only an exit option. The constants \( A_1 \), \( B_2 \), \( X_1 \), and \( Y_2 \) are remained to be determined.

**Case A  Transition between Portfolio\([L/L/L]\) and Portfolio\([L/H/H]\).**

First, we examine the option value to be created in the transition between Portfolio\([L/L/L]\) and Portfolio\([L/H/H]\). As was examined in Chapter 4 (4.1.5 and 4.2.4) equation (16) and (17) should have the smooth-pasting and the value-matching conditions at the entry and the exit thresholds. Suppose the strategic “entry” investment were made at the point \( \hat{R} \) where the revenue level would be high enough to make the investment. From the smooth-pasting condition, we get,

\[ \left. \frac{dV_{lhh}}{dR}(R) \right|_{\hat{R}} = \left. \frac{dV_{lll}}{dR}(R) \right|_{\hat{R}}. \quad (20) \]

The predetermined strategic “entry” investment has a value of each one of $50, $100, $200, $300, or $400 thousand per track mile. We represent it as \( I \), and the value-matching condition can be expressed as follows:

\[ V_{lhh}(\hat{R}) + I = V_{lll}(\hat{R}). \quad (21) \]
The required strategic "exit" investment at the revenue point \( \bar{R} \) is zero, as was hypothesized in the discussion above. The smooth-pasting and value-matching conditions at this point can be written in the same forms as above:

\[
\left. \frac{dV_{LH}}{dR} \right|_{\bar{R}} = \left. \frac{dV_{LL}}{dR} \right|_{\bar{R}},
\]

\[
V_{LH}(\bar{R}) = V_{LL}(\bar{R}) + 0.
\]

By solving these four equations, we could obtain the constants \( A_1 \), and \( B_2 \). The mathematical procedures are so tedious that they are omitted here. The solutions could be obtained by using mathematical calculation software, and just their results are presented in Figure 5.14.

Figure 5.14 [a] presents the optimal investment timing and the infrastructure portfolio values at this timing with $100 thousand$/track mile of the required strategic investment. Suppose that a firm's current revenue created by its infrastructure contribution is $600 thousand/track mile, and the infrastructure portfolio is regularly managed with the combination of the lower-level maintenance cost, the higher-level capital investment (not strategic investment), with its annual higher-rate physical depreciation. The managers know that a firm-wide track improvement project which requires $100 thousand$/track mile of the investment would allow them to acquire a new portfolio condition that will be regularly managed with lower-level maintenance cost, lower-level capital investment accompanied by the annual lower-rate physical depreciation. The new portfolio is going to have a higher value than the current one.

However, if the managers made the $100 thousand strategic investment at lower revenue level than the optimal point, they would lose some portion of the invested amount, i.e., not all of the investment would be incorporated in the value of the new portfolio. This is because such hasty investments lose some opportunity
value in terms of the real options. On the other hand, if the managers missed the optimal investment timing and invested at a higher revenue than the optimal point, they could not acquire a new portfolio because the predetermined $100 thousand would not be enough to change the portfolio condition.

Figure 5.14 [a] tells us that the optimal revenue threshold is approximately $710 thousand/track mile. At that point the value of the current portfolio is $13,800 thousand/track mile, and that of the new portfolio is $13,900 = $13,800 + $100 thousand/track mile. This $100 thousand strategic investment is irreversible. Therefore, once the managers make an investment and acquire the new portfolio, they cannot return to the original portfolio as long as the revenue level remains high. The managers can return to the original portfolio only when the revenue goes down to approximately $430 thousand/track mile. This is an exit revenue threshold from Portfolio[UL] to Portfolio[UH]. The value of the portfolio at this threshold is approximately $8,540 thousand/track mile.

Since no extra investment is required at the exit threshold, the managers might be able to choose either Portfolio[UL] or Portfolio[UH] depending on the condition of the portfolio and/or a firm’s business environment. The managers would select the preferable portfolio condition which requires the value factor combination of either lower-level capital investments with lower-rate physical depreciation or higher-level capital investments with higher-rate physical depreciation. Of course, the regular management policy should meet the requirement by the portfolio condition.

**Case B**  *Transition between Portfolio[H/L/L] and Portfolio[H/H/H].*

A firm’s infrastructure portfolio is currently managed with the value factor combination of either [H/L/L] or [H/H/H]. When the revenue level grew up, managers would try to change the combination from [H/H/H] to [H/L/L] in order to enhance the portfolio value by making a required amount of the strategic investment. On the
other hand, if the revenue level went down to a certain level, they might change the combination from [H/L/L] to [H/H/H] without any exit investment. The amount of the required strategic investment \( I \) depends on the project designed by the managers, which is predetermined here as each one of $50, $100, $200, $300, $400 thousand per track mile.

The same mathematical procedures as Case A are applied to obtain the optimal strategic investment timing and the portfolio value incorporated with the option value increment. From the smooth-pasting and the value-matching condition we get,

\[
\frac{dV_{HHH}(R)}{dR} \bigg|_{\tilde{R}} = \frac{dV_{HLL}(R)}{dR} \bigg|_{\tilde{R}},
\]

\[
V_{HHH}(\tilde{R}) + I = V_{HLL}(\tilde{R}),
\]

\[
\frac{dV_{HHH}(R)}{dR} \bigg|_{\tilde{R}} = \frac{dV_{HLL}(R)}{dR} \bigg|_{\tilde{R}},
\]

\[
V_{HHH}(\tilde{R}) = V_{HLL}(\tilde{R}) + 0.
\]

By solving these four equations, we could obtain the constants \( X_1 \), and \( Y_2 \). The mathematical procedures are, once again, omitted here. Their results are presented in Figure 5.15.

From Figure 5.14 and 15, one might recognize that these two cases have the same revenue threshold for the inter-portfolio “entry” and “exit” decision-making points. For example, both cases have $663 thousand/track mile of the higher revenue threshold for making the strategic investment, as well as $450 thousand/track mile of the lower revenue threshold for selecting optimal portfolio with $50 thousand/track mile of the strategic investment. This accidental coincidence derives from the numerical components in the equation (16)-(19).
CASE A

Solution of equation (20)-(23) for different values of $I$

<table>
<thead>
<tr>
<th>$I$</th>
<th>$A_i \times 10^8$</th>
<th>$B_2/10^{15}$</th>
<th>$\tilde{R}$</th>
<th>$V_{LL} (\tilde{R}) = V_{LHH} (\tilde{R}) + I$</th>
<th>$V'<em>{LL} (\tilde{R}) = V'</em>{LHH} (\tilde{R})$</th>
<th>$\tilde{R}$</th>
<th>$V_{LL} (\tilde{R}) = V_{LHH} (\tilde{R})$</th>
<th>$V'<em>{LL} (\tilde{R}) = V'</em>{LHH} (\tilde{R})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>799.48</td>
<td>253.23</td>
<td>663.16</td>
<td>12,995</td>
<td>19.35</td>
<td>450.92</td>
<td>8,957</td>
<td>18.22</td>
</tr>
<tr>
<td>100</td>
<td>734.99</td>
<td>206.80</td>
<td>710.51</td>
<td>13,904</td>
<td>19.43</td>
<td>428.48</td>
<td>8,536</td>
<td>18.03</td>
</tr>
<tr>
<td>200</td>
<td>635.38</td>
<td>161.82</td>
<td>790.80</td>
<td>15,468</td>
<td>19.53</td>
<td>404.70</td>
<td>8,090</td>
<td>17.82</td>
</tr>
<tr>
<td>300</td>
<td>559.71</td>
<td>138.73</td>
<td>864.78</td>
<td>16,915</td>
<td>19.61</td>
<td>391.14</td>
<td>7,836</td>
<td>17.70</td>
</tr>
<tr>
<td>400</td>
<td>499.72</td>
<td>124.46</td>
<td>933.61</td>
<td>18,267</td>
<td>19.66</td>
<td>382.08</td>
<td>7,667</td>
<td>17.61</td>
</tr>
</tbody>
</table>

Figure 5.14. Strategic Investment and Infrastructure Portfolio Value (Transition between Portfolio[L/H/H] and [L/L/L])
CASE B

Solution of equation (24)-(27) for different values of $I$

<table>
<thead>
<tr>
<th>$I$</th>
<th>$X_1 \times 10^4$</th>
<th>$Y_2 / 10^{15}$</th>
<th>$\tilde{R}$</th>
<th>$V_{HLL}(\tilde{R}) = V_{HHH}(\tilde{R}) + I$</th>
<th>$V_{HLL}(\tilde{R}) = V_{HHH}(\tilde{R}) \cdot \tilde{R}$</th>
<th>$V_{HLL}(\tilde{R}) = V_{HHH}(\tilde{R})$</th>
<th>$V_{HLL}(\tilde{R}) = V_{HHH}(\tilde{R})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>799.48</td>
<td>253.22</td>
<td>663.16</td>
<td>9,037</td>
<td>14.86</td>
<td>6,012</td>
<td>13.20</td>
</tr>
<tr>
<td>100</td>
<td>734.99</td>
<td>206.80</td>
<td>710.51</td>
<td>9,744</td>
<td>15.03</td>
<td>5,704</td>
<td>12.95</td>
</tr>
<tr>
<td>200</td>
<td>635.38</td>
<td>161.82</td>
<td>790.80</td>
<td>10,960</td>
<td>15.26</td>
<td>5,380</td>
<td>12.66</td>
</tr>
<tr>
<td>300</td>
<td>559.71</td>
<td>138.73</td>
<td>864.77</td>
<td>12,095</td>
<td>15.45</td>
<td>5,197</td>
<td>12.48</td>
</tr>
<tr>
<td>400</td>
<td>499.72</td>
<td>124.46</td>
<td>933.61</td>
<td>13,164</td>
<td>15.59</td>
<td>5,075</td>
<td>12.35</td>
</tr>
</tbody>
</table>

**Figure 5.15.** Strategic Investment and Infrastructure Portfolio Value (Transition between Portfolio[H/H/H] and [H/L/L])
Although the two cases have the same revenue thresholds, they have different portfolio values at these critical points. In Case A, the portfolio value would be approximately $13,900 thousand/track mile as a result of $50 thousand/track mile of the strategic investment, while it would be $9,740 thousand/track mile in Case B. This is because both cases have different combination of regularly performed portfolio management value factors (maintenance expenditure, capital investment, and physical depreciation).

In both cases, we have assumed that the amount of the strategic investment is each one of $50, $100, $200, $300, $400 thousand per track mile. The relationship between these numbers and the values of obtained investment threshold revenue gives us the overall information regarding the amount of the required strategic investment and its optimal investment timing, or the optimal revenue level. Figure 5.16 describes this strategic investment – optimal revenue threshold correlation.

![Figure 5.16 Strategic investment and optimal revenue for the transition between Portfolio [LHH/HHH] and [LLL/HLL]](image)
5.3.6 Summary of the Case

Through the conditional changes in the portfolio and the portfolio-related regular management activities, the optimal strategic investment timing and associated portfolio value increment have been found out by the real options application in this case study. The regularly performed management activities are, in a sense, required items by the portfolio in order to sustain its current condition and value. The strategic investment forces the portfolio to change its condition, which in turn brings a firm another set of required management activities.

Any strategic investment at the optimal timing allows managers to maximize their portfolio value. In fact, it does not matter whether the source of fund is a government, municipal, or a company itself for both the value equations and the portfolio values obtained in this case study. The value equation incorporates any kind of the invested amount into the portfolio as an increment of the portfolio value, although government grants and subsidies might lower the firm’s cost of capital.

The amount of the strategic investment shown in Figure 5.14, and 5.15 is quite small compared to the value of the total infrastructure portfolio; however, these values are that of a track mile. Suppose that a railroad company, which has approximately 2,070 miles of track extension and its current passenger revenue is $9.15 billion, is planning $400 thousand/track mile (= $828 million in total) of the strategic investment by which the company’s current portfolio value factor combination [H/H/H] could be modified into [H/L/L]. The total $828 million of the extra investment might not be so small a value for the company. Note that this company currently outlays approximately $724.5 million (= $350 thousand/track mile [Figure 5.4] x 2070 miles) of capital investment per annum.

From Figure 5.15 the strategic investment should be made when the revenue level increases to $933.6 thousand/track mile, which implies that $9.66 billion ($933.6 thousand x 2,070 miles + 20% of infrastructure contribution) of annual passenger revenue is required for the company in order to incorporate all the
opportunity value into its portfolio by making the strategic investment. The value of the company’s infrastructure portfolio after the investment at that point is $13,164 thousand per track mile, which is equal to $27.25 billion ($=13,164 thousand \times 2,070 miles) in total.

Through this case study, we have found that in order for any strategic investment to obtain the real options value increment, a firm’s infrastructure portfolio must undergo certain condition changes, i.e., changes in the portfolio value factors. In other words, if no condition changes are achieved despite the strategic investment, no real options value increment will happen in the portfolio. In such a case, just an invested amount is added to the original portfolio value. Therefore, upon making the strategic investment, a firm’s managers have to assess carefully whether the intended investment might bring certain changes in the portfolio value factors or not.

Finally, this case study has utilized hypothesized portfolio value factor fluctuations from the data available (Section 5.2.2). The more abundant the data, the more accurate the fluctuations. Then, the firm’s managers could capture more accurate positioning (i.e. either higher-, lower-, or average-level) of their regularly performed activities from the viewpoint of the overall railroad infrastructure management business. Recognizing the accurate positioning is crucial for the evaluation of the real options opportunity value increment during the infrastructure portfolio condition change.
CHAPTER VI

Conclusion

Portfolio based infrastructure investment analysis enables a railroad company to acquire more comprehensive perspectives of its infrastructure asset management and strategic investment decision. The premise of this perspective is that the individual facility’s economic value factors, i.e., the construction costs, book values, market-related risks, returns, and the degrees of contribution to the transportation business, differ from one facility to another, but their total economic value can be improved or maximized more effectively by evaluating them as a whole than focusing on individual facility’s economic value behavior.

Managing Infrastructure-Related Activities

Instead of focusing on individual facilities or assets, managers are required to understand the value linkages between individual portfolio management activities. These linkages as well as a company’s entire value chain create a valuable infrastructure portfolio. Then, managers have to consider changing these value activities and linkages in order to make their portfolio more sustainable and profitable.

Strategic investments might be a driving force that enables the managers to modify their value activities, e.g., constantly performed maintenance or capital investment activities, or introduction of new technologies, which lead to an improved portfolio operational efficiencies. Strategic investments might also add new portfolios to a company that yields higher returns than the existing portfolios.

EVA® and Portfolio Valuation

Economic Value Added (EVA®) discussed in Chapter III can be a method of measuring profit return of an entire portfolio as well as that of strategic investments. Although this indicator does not tell us a portfolio’s value maximizing profile, it
explains whether a portfolio or a strategic investment could create the manager’s expecting economic value or not. A company’s shareholders as well as its managers are rewarded when the company incorporates positive economic value into the company.

**Improving a Portfolio’s Operational Efficiency via Real Options**

Real Options theory can be applied to find the value maximizing condition and optimal decision-making point of both portfolio-adding and portfolio-improving strategic investments. Preceding research focuses on the project evaluation associated with the former type of investment. This study analyzed the latter type of investment decision in Chapter IV and V, and could find the optimal strategic investment timing that brings increased operational efficiency to a portfolio while maximizing its economic value.

**Issues in the Manager’s Decision-Making**

However, further analyses are required particularly for understanding the value increment effect of the interlocking portfolios discussed in Chapter III. Strategic investments not only create a new portfolio or enhance an existing portfolio’s operational efficiency, but also affect the value of other non-invested existing portfolios in the company. The portfolio value maximization strategy cannot be completed until managers have appropriately estimated and evaluated the effects of interlocking upon making their investment decision. The economic behavior of a company’s portfolio is not as simple as it looks. Sound, and reliable estimation of the interlocking effects is crucial to sustaining and developing the infrastructure portfolio.
Bibliography


Copeland, T., and Antikarov, V. (2000) “Real Options, a practitioner’s guide.” Texere


