Public-Private Partnerships in Space Projects: An Analysis of Stakeholder Dynamics

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Abstract

In Public-Private Partnerships (PPPs), private partners assume more responsibility for public projects than in traditional approaches. The larger responsibility of the private partner is expected to improve efficiencies of the project. However, it also increases potential challenges such as conflicts of interest. If the dynamic structures which cause challenges in PPPs are identified, they will help to predict potential challenges in future PPP projects. Therefore, this research develops a dynamics model of which challenges arise in the application of PPP approaches to space projects.

The PPP dynamics model is illustrated by using system dynamics modeling. In the first step, this research develops a traditional-approach model. In the second step, it proposes the PPP model, which is a modification of the traditional-approach model. In the third step, this research tests the PPP model by applying it to four space-related PPP cases: the European navigation system Galileo, the Japanese navigation system QZSS, the Japanese launch vehicle GX, and the U.S. launch vehicle families EELV. The PPP model passes these four tests.

In the PPP model, three variables play important roles: conflicts of interest among parties, user satisfaction, and the private partner's revenue risk. The three variables represent interests of stakeholders such as the public sector, private partners, and users. Conflicts of interest among parties increase cost schedule inefficiencies. More cost schedule inefficiencies lead to less user satisfaction. Less user satisfaction results in more revenue risk for the private partner. More revenue risk for the private partner leads to more conflicts of interest among parties. Thus, the interaction of stakeholder interests forms a reinforcing loop unique to PPPs. Additionally, unexpected technical and demand problems strengthen the reinforcement. This reinforcing loop and these unexpected problems are the inherent sources of challenges in space-related PPP projects.

Lessons for improving the dynamic structures of space-related PPPs are (1) to set cost saving as the primary goal, (2) to choose the government customer market, and (3) to adopt conservative technical and demand forecasts. Based on these lessons, this research proposes that potential missions suitable for future space-related PPPs might be telecommunication, Earth observation, and meteorological monitoring for governments' use.

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1. Introduction

Public-Private Partnerships (PPPs) is an attractive approach for improving efficiencies of public projects. By choosing PPP approaches, the public sector expects to overcome budgetary constraints and private partners expect to increase profits. However, studies show that PPP approaches involve both potential efficiencies and challenges, like two sides of a coin. In fact, in the area of space, major PPP projects have experienced various challenges. These projects results in shifting to the direction of more traditional approaches. Thus, policymakers and project managers are required to carefully apply PPP approaches to space projects.

This research aims to analyze the dynamic structures by which challenges arise in the application of PPP approaches to space projects. If such dynamic structures are identified, they will help to predict potential challenges in future space-related PPP projects. Although prior work implies that characteristics unique to PPPs cause challenges in space-related PPP projects, no prior work has focused on the dynamic structures of space-related PPP projects. Therefore, the goals of this research are to develop a dynamics model of which characteristics unique to PPPs cause various challenges in space-related PPP projects, to analyze how to improve the dynamic structures, and to propose a future strategy for space-related PPPs. This chapter provides some background of this research and sets research questions. It then summarizes the conclusions of this research.

1.1 Public-Private Partnerships: Panacea or Pandora's Box?

Public-Private Partnerships (PPPs) are an arrangement whereby the private sector assumes more responsibility for the public project than in traditional approaches. In traditional approaches, facilities are built and operated with public responsibility and finance. In contrast, PPPs allow the public sector to transfer project risks and often costs to private partners. Private partners manage the risks efficiently and increases profits for themselves. In general, the private sector has the better ability and stronger incentive for risk management than the public sector. Therefore, PPPs are expected to help build and operate facilities more efficiently than traditional approaches.

In the United Kingdom, HM Treasury and the National Audit Office (NAO) present data that PPPs effectively builds and operates facilities on time and within budget [UK HM Treasury, 2003]. HM Treasury and NAO investigated 61 and 37 samples of PFI-type projects, respectively.

The PFI, Private Finance Initiative, is a form of PPP in which the private partner arranges finance for the project. The PFI was originally launched in the UK and incorporated into a broader concept of PPPs in 2000 [Spackman, 2002]. Results of HM Treasury and NAO research are illustrated in Figure 1-1. The HM Treasury research shows that 88% of the PPP projects were delivered on time and 79% were completed within budget. Similarly, the NAO research shows that 76% of the projects were delivered on time and 79% were completed within budget. In both studies, the projects in which project costs exceeded the budget were entirely due to changes in user requirements. Compared with these results, an earlier NAO research shows that only 30% of 66 projects implemented in traditional approach were delivered on time and only 27% were completed within budget [Harris, 2004]. This evidence suggests that PPPs are effective for improving efficiencies of projects.

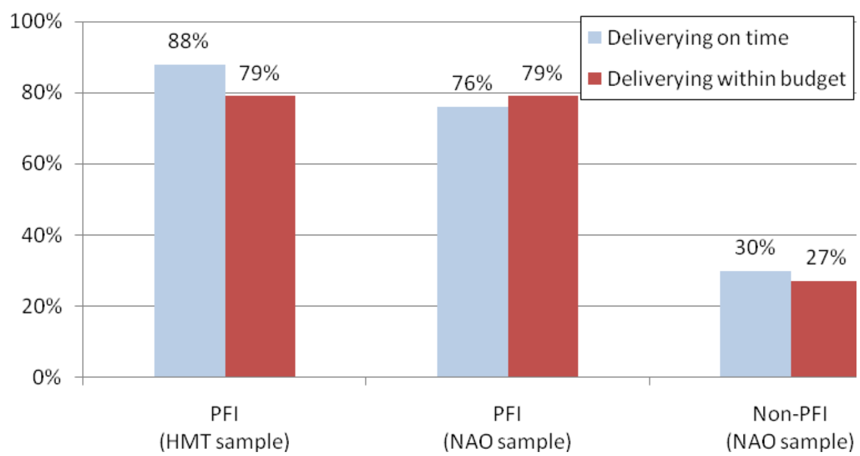

Figure 1-1: Percentage of Projects Delivering on Time and within Budget
(Source: Harris, 2004)

However, Gaffney and Pollock [1999] demonstrate that PPPs would not offset higher capital costs by cost-saving resulting from the private partner. They investigated major hospitals financed through PFI schemes in the UK and found that these hospitals experienced significant increases in estimated capital costs as shown in Figure 1-2. According to their discussion, reasons for higher capital costs might be that PFI projects include commercial interests and financing cost of the private partner. Because of the high capital costs, in 1998 the British Medical Association adopted a resolution calling for the abandonment of the PFI schemes in the health service. Thus, PFI schemes have failed in delivering within the original budgets for them.

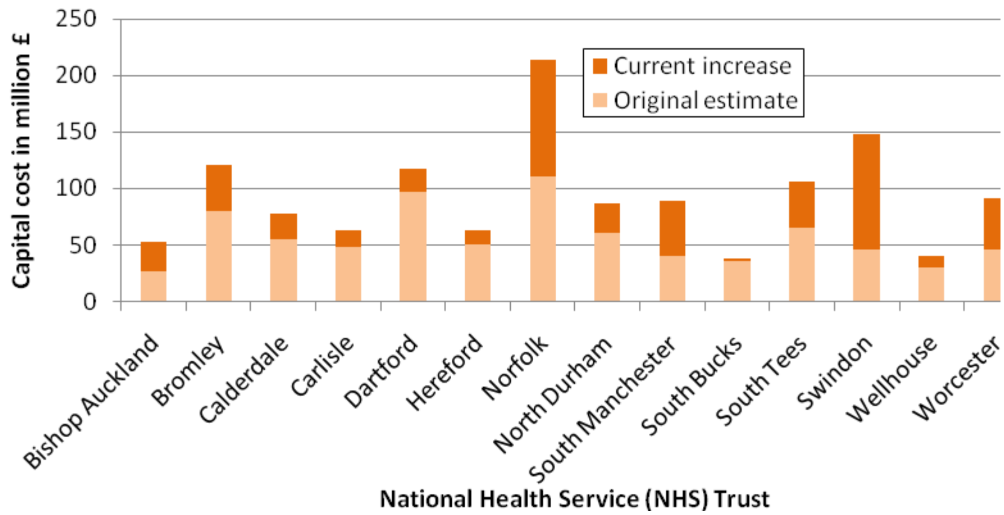

Figure 1-2: Original and Current Capital Cost Estimates for PFI Hospitals in the UK
(Source: Gaffney and Pollock, 1999)

Furthermore, in transportation, although some highway and railway PPP projects have achieved high efficiencies, other PPP projects have experienced serious challenges such as cash-flow shortfalls and conflicts of interest between the public sector and private partners. The PPPs that faced challenges have defaulted or continue the operations with public subsidies [The European Commission, 2004c].

The positive and negative evidence indicates that PPP approaches involve both potential efficiencies and challenges. Therefore, when the public sector undertakes a new project, it confronts an important choice: whether it should adopt a PPP or a traditional approach. In light of this choice, it might be useful to investigate how challenges emerge in a PPP project.

1.2 Challenges of Space-related PPPs

In space, the application of PPP approaches had not been very common until the late 1990s. Although the United States and Europe made efforts to build close partnerships between public and private sectors, private sector participation was limited because space projects include high risk. In 1980, Europe established the joint venture of national space agencies and space industries, Arianespace [Harvey, 2003]. Since then, Arianespace has offered commercial launch services by operating the European-made Ariane launch vehicle. However, the responsibility of the private partner is limited to the operational phase. In the 1980s, the U.S. government made an attempt to fully privatize the Landsat program, the U.S. land remote sensing satellite series. However, the intention to full privatization resulted in only transferring the responsibility of operation to a private company [NASA].

From the late 1990s through the early 2000s, several PPP projects emerged with the greater responsibility of the private sector. Governments expected that greater private sector participation would not only enhance efficiencies of the space programs, but also foster the competitive domestic space industry. With this expectation, the United States launched the Evolved Expendable Launch Vehicle (EELV) program. The European Union (EU) started the Galileo program, the European global navigation satellite system. Japan initiated the Quasi-Zenith Satellite System (QZSS) program, the Japanese regional navigation system. It also started the GX launch vehicle project. These PPP projects are largely different from past space PPP projects in that the private partners assume more responsibility in the development phase.

However, these PPP projects have experienced multiple challenges. Some challenges were common with traditional approaches such as schedule delays and cost increase, but other challenges were unique to PPPs such as high revenue risk and conflicts of interest. Although the above four PPP projects were expected to achieve high efficiencies, they resulted in struggling with inefficiencies. Consequently, these PPP projects have restructured or plan to restructure the partnership framework in the direction of more traditional approaches.

Since then, the public sector has seemed more skeptical about the application of PPP approaches to space projects. The challenges experienced by the four space-related PPP projects imply that there is something to learn about cooperation mechanisms between the public sector and private partners. Therefore, it might be useful to better understand how challenges arise in space-related PPP projects.

1.3 Prior Work

A limited number of papers have discussed space-related PPP projects. The reason for the small number is that it has been only about one decade since major space-related PPPs started. In particular, few papers had discussed challenges of space-related PPPs until major PPP projects such as Galileo struggled with difficulties. Moreover, prior work has mostly been done by researchers who work on Galileo or other PPP projects on either side of public agencies or private partners.

Prior work has mainly focused on case studies. Bertran and Vidal [2005] compare two major space-related PPP projects, Galileo and Skynet 5, which is the UK military satellite communication system developed in the PPP approach, with other large-scale PPP projects in the transport sector. They argue that technical and business complexity in space PPP projects is the key driver which determines financial aspects and risk allocation. Bochinger [2008] compares a non-successful experience of Galileo with a successful experience of Skynet 5. He concludes that keys for successful PPPs in the space sector are a secured market, experienced partners, and a stable policy environment. Spude and Grimard [2008] provide in-depth case studies of Galileo and Skynet 5. They also discuss PPP experiences in TerraSAR-X, the German Earth observation satellite, and Phoenix, a flight demonstrator of a future European re-usable space transportation system. They find that profitable business exists in downstream value-added service rather than direct business as a satellite operator. They also argue that the public sector's financial commitment is required even in subsequent project phases. Three papers show a broad set of lessons based on case studies and also imply that challenges experienced in PPP projects arise from unique characteristics of PPPs such as risk and cost-sharing between the public and private sectors.

However, no prior work has focused on common mechanisms by which challenges arise in space-related PPP projects. Therefore, it is not clear enough whether the lessons in prior work are applicable to other space-related PPP projects. If the mechanism is discovered, the lessons will become more useful to predict potential challenges in future space-related PPPs.

1.4 Research Questions

This research aims to analyze the common dynamic structures by which challenges arise in the application of PPP approaches to space projects. Because PPP approaches include both potential efficiencies and challenges, it is important for policymakers and project managers to reduce potential challenges. Although prior work implies that unique characteristics of PPPs cause challenges in space-related PPP projects, it has never discussed how these characteristics cause challenges. If such common dynamic structures are identified, the lessons in prior work will be more systematically applied to a wide range of cases. Moreover, the dynamic structures will contribute to additional new lessons. Therefore, identifying the dynamic structures will help policymakers predict and avoid potential challenges in future space-related PPPs. In light of the anticipated benefit from identifying the dynamic structures, this research sets up the following three questions:

(1) *What dynamic structures cause challenges in the application of PPP approaches to space projects?*
(2) *Given the dynamic structures, are there any ways to improve the dynamic structures?*
(3) *Given the ways to improve the dynamics, what is a strategy to apply PPP approaches for future space projects?*

To address these questions, this research first analyzes characteristics of PPPs and how these characteristics influence interests of stakeholders such as the public sector, private partners, and users. Then, this research analyzes space-related PPP cases. The case studies identify the type of space-related PPPs that are most likely to face challenges. Based on these analyses, this research develops a dynamics model of space-related PPP projects. In the PPP model, interests of stakeholders interact with each other. Based on this finding, this research discusses ways to improve the dynamic structures and proposes a strategy for future space-related PPPs.

1.5 Summary of Conclusions

To address the first question, this research develops a dynamics model of space-related PPP projects as shown in Figure 1-3. This PPP dynamics model includes a reinforcing loop named stakeholder interaction. The PPP-unique reinforcing loop describes the interaction of stakeholder interests such as conflicts of interest among parties, user satisfaction, and the private partner’s revenue risk. In this loop, conflicts of interest among parties enhance cost schedule inefficiencies. More cost schedule inefficiencies leads to less user satisfaction. Less user satisfaction results in more revenue risk of the private partner. More revenue risk of the private partner leads to more conflicts of interest among parties. In addition, unexpected technical and demand problems strengthen the reinforcement. This reinforcing loop and these unexpected problems are the inherent sources of challenges in space-related PPP projects. In other words, interactions among stakeholder interests lead to challenges in space-related PPP projects.

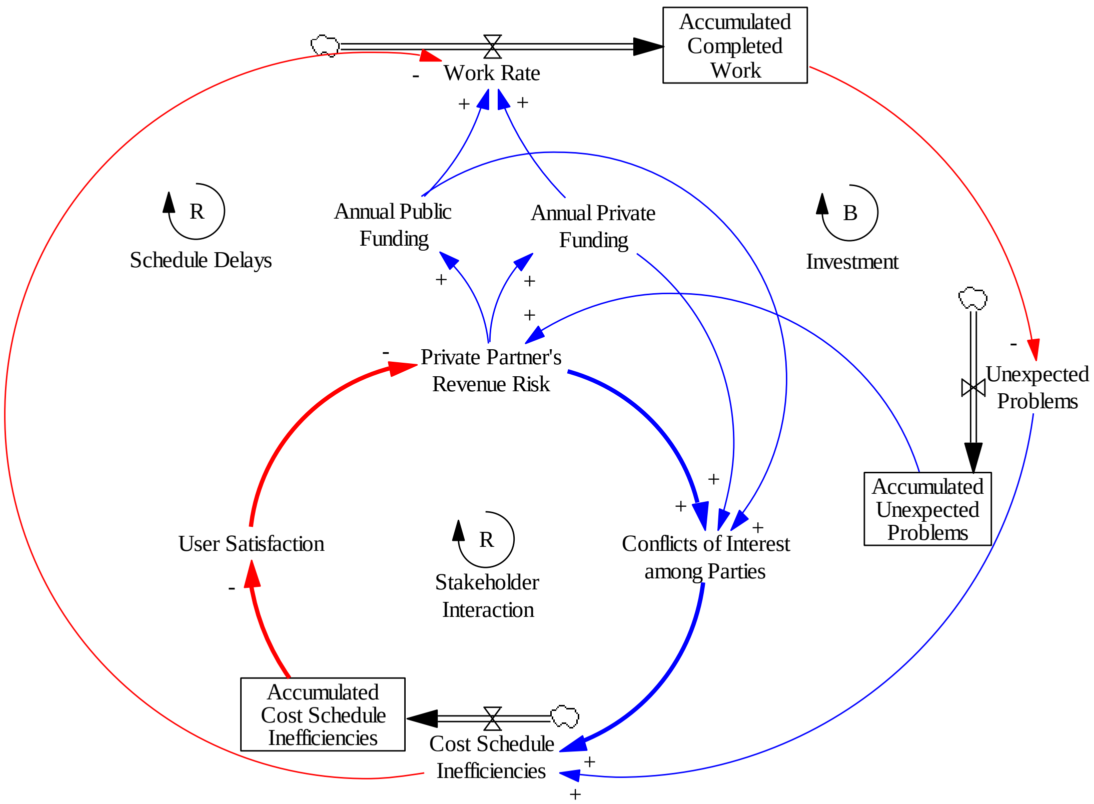

Figure 1-3: A Dynamics Model of Space-related PPP Projects (Source: Author)

To answer the second question, this research identifies three new lessons for improving the dynamic structures. The lessons are shown in Table 1-1. They should be used together with lessons developed in prior work.

Table 1-1: Lessons for Improving the Dynamic Structures (Source: Author)

The primary goal of space-related PPP projects should be cost saving.
The government customer market is more suitable for space-related PPP projects than the commercial customer market.
Space-related PPP projects should adopt conservative technical and demand forecasts.

To address the last question, a strategy for future space-related PPPs might be to apply PPPs in the government customer market. Potential missions might be telecommunications, Earth observation, and meteorological monitoring for governments' use.

1.6 Thesis Structure

Chapter 2 develops a framework for this research and analyzes mechanics of PPPs. It starts by defining and categorizing PPPs. It then argues that the rationale of PPPs is to address budgetary constraints. It identifies four characteristics of PPPs: risk transfer, high cost schedule efficiencies, high transaction cost, and higher pricing risk. The analysis reveals that PPPs cause trade-offs among interests of stakeholders such as the public sector, private partners, and users.

Chapter 3 studies space-related PPP cases. It categorizes the cases based on the types of PPPs introduced in Chapter 2. The categorization shows that space-related PPPs are more likely to face challenges when PPPs choose the commercial customer market and ask private partners to participate in the development phase.

Chapter 4 proposes and tests a dynamics model of space-related PPP projects. The proposed PPP model includes a reinforcing loop that describes the interaction of stakeholder interests: conflicts of interest among parties, user satisfaction, and the private partner's revenue risk. The model is tested by four space-related PPP cases: Galileo, QZSS, GX, and EELV. These tests demonstrate that the proposed PPP model explains the challenges that emerged in the four PPP projects. The analysis also simulates a behavior of the PPP model. The simulation demonstrates that PPPs are likely to face cost schedule inefficiencies more than traditional approaches.

Chapter 5 analyzes ways how to improve the dynamic structures. It focuses on variables included in the reinforcing loop. It also reviews existing lessons found in prior work. The analysis results in three new lessons: (1) to set cost saving as the primary goal, (2) to choose the government customer market, and (3) to adopt conservative technical and demand forecasts.

Chapter 6 discusses policy implications for future space-related PPPs. It proposes a strategy for the application of PPPs to future space projects. Potential missions might be telecommunications, Earth observation, and meteorological monitoring for governments' use.

Chapter 7 concludes the discussion. It summarizes findings of this research and suggests areas for future study.

2. Trade-off Analysis of Public-Private Partnerships

This chapter has two purposes. First, it aims to provide a framework with this research. To develop the framework, this research defines PPPs. The definition indicates that PPPs require more responsibility from private partners than traditional approaches. Because PPPs have a broad spectrum, this analysis categorizes PPPs into four types based on market and on the degree of private sector participation.

Second, this analysis aims to investigate the rationale and characteristics of PPPs. The rationale of PPPs is that PPPs allow the public sector to address budgetary constraints while traditional approaches often conflict with them. Based on this rationale, PPPs are designed to transfer risk to private partners. This risk transfer is the source of high cost schedule efficiencies for the public sector. However, PPPs also include some disadvantages such as high transaction cost and higher pricing risk. Thus, PPPs are characterized by four factors: risk transfer to private partners, high cost schedule efficiencies for the public sector, high transaction cost between the public sector and private partners, and higher pricing risk to users. These characteristics can be described as trade-offs among interests of stakeholders such as the public sector, private partners, and users. This analysis provides a basis for discussion in later chapters.

2.1 PPP Defined

There is no widely accepted, single definition of a PPP because PPP remains an evolving concept. Therefore, this research sets a definition of a PPP that fits the purpose of this research. The definition that this research looks at should refer to differences between PPPs and traditional approaches because this research aims to analyze the PPP-unique dynamic structures. The Congressional Research Service (CRS) provides such a definition in a simple form: a PPP, broadly defined, is any arrangement whereby the private sector assumes more responsibility than is traditional for infrastructure planning, financing, design, construction, operation, and maintenance [Mallett, 2008]. Arranging this definition, this research defines a PPP as follows:

A PPP refers to any arrangement whereby the private sector assumes more responsibility for the public project than in the traditional approach.

A similar term to PPP is the Private Finance Initiative (PFI). The PFI refers to a form of PPP in which the private partner assumes the responsibility of finance for the project [Allen, 2001]. Although the PFI was originally invented in the UK, it was gradually incorporated into PPPs which are a broader concept, including public-partner collaboration without private finance [Spackman, 2002].

The definition of a PPP requires the definition of a traditional approach. There is no single definition of the traditional approach, either. Engel et al. [2008] define a traditional approach as an arrangement whereby the firm that builds the infrastructure takes no responsibility for its long-term performance. In addition to his definition, the definition of a traditional approach should clarify the responsibility of financing and operating. Therefore, this research defines a traditional approach as follows:

A traditional approach refers arrangements whereby the firm builds a new facility with public funding, but takes no responsibility for the facility's long-term performance and the public sector operates the facility.

PPPs are a form of enterprise placed between the public enterprise and the private enterprise. The public enterprise represents public projects under traditional approaches. The private enterprise represents commercial business in free market. Between these two ends, PPPs sometimes include a state of privatization. Privatization is referred to the movement from the public enterprise to the private enterprise. In contrast, the movement toward the other direction is referred to as nationalization. Figure 2-1 illustrates relationships of the key terms. [Savas, 2000]

Figure 2-1: Relationships of Key Terms (Source: Author)

2.2 Spectrum of PPPs

PPPs include various degrees of private partners' responsibility in their broad spectrum. How much responsibility private partners assume is on a case-by-case basis. Typically, private partners assume responsibilities of two or more phases, such as designing, building, operating, maintaining, and financing. Combining multiple phases is called "bundling"; this is a source of high cost schedule efficiencies, a characteristic of PPPs. Figure 2-2 shows some of the most common PPP models. Names of PPP models often describe responsibilities of the private partner such as Design-Build-Maintain. Table 2-1 also shows brief descriptions of the PPP models. It also includes some additional models which do not appear on the spectrum.

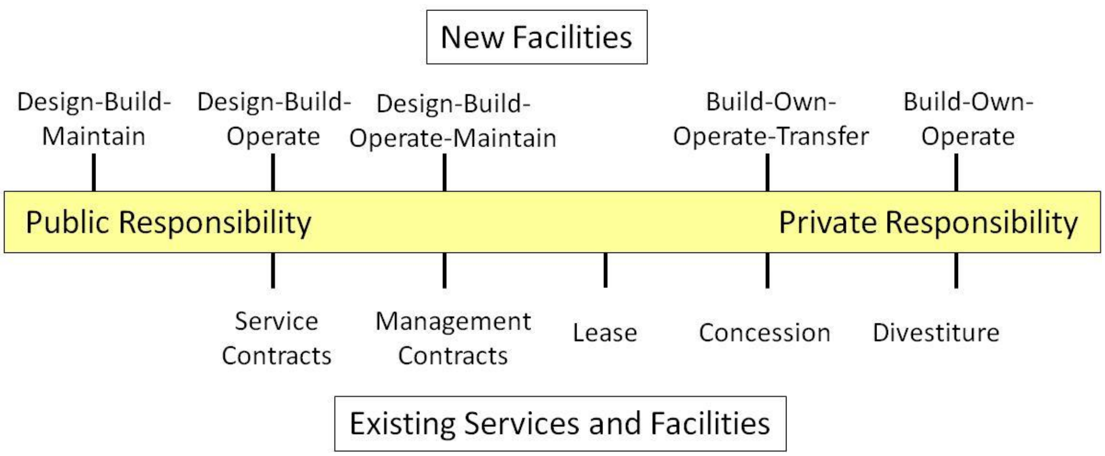

Figure 2-2: PPP Models with Responsibilities of Private Partners (Source: Deloitte, 2006)

Taking into consideration this existing classification, this research introduces four simple categories for later discussion. Although PPP models are arranged on a case-by-case basis, these new categories help to establish a stable framework for this research. Two criteria for the new categories are described below:

(1) For which market does the private partner provide the service, the commercial customer market or the government customer market?

In Figure 2-2, PPP models on the right, such as Build-Own-Operate, Build-Own-Operate-Transfer, divestiture, and concession, usually provide services for commercial customers. On the other hand, PPP models on the left, such as Design-Build-Maintain, usually provide services for government customers. Some cases of other types may also offer service for commercial customers.

Table 2-1: Descriptions of PPP Models (Source: Deloitte, 2006)

Design-Build-Maintain (DBM): This model is similar to Design-Build except that the private partner also maintains the facility. The public sector retains responsibility for operations.

Design-Build-Operate (DBO): The private partner designs and builds a facility. Once the facility is completed, the title for the new facility is transferred to the public sector, while the private partner operates the facility for a specified period.

Design-Build-Operate-Maintain (DBOM): This model combines the responsibilities of design-build models with the operations and maintenance of a facility for a specified period by a private partner. At the end of the period, the operation of the facility is returned to the public sector.

Design-Build-Finance-Operate/Maintain (DBFO, DBFM, or DBFO/M): The private partner designs, builds, finances, operates, and maintains a new facility under a long-term lease. At the end of the lease term, the facility is transferred to the public sector.

Build -Own-Operate-Transfer (BOOT): The public sector grants a franchise to a private partner to finance, design, build, and operate a facility for a specific period of time. Ownership of the facility is transferred back to the public sector at the end of that period.

Build -Own-Operate (BOO): The public sector grants the right to finance, design, build, operate, and maintain a facility to the private partner. The private partner is not required to transfer the facility back to the public sector.

Service Contract: The public sector contracts with a private partner to provide services the public sector previously performed.

Management Contract: A management contract differs from a service contract in that the private partner is responsible for all aspects of operations and maintenance of the facility.

Lease: The public sector grants a private partner a leasehold interest in the facility. The private partner operates and maintains the facility in accordance with the terms of the lease.

Concession: The public sector grants a private partner exclusive rights to provide operate and maintain a facility over a long period of time in accordance with performance requirements set forth by the public sector. The public sector retains ownership of the original facility, while the private partner retains ownership over any improvements made during the concession period.

Divestiture: The public sector transfers a facility, either in part or in full, to the private partner. Generally, the public sector will include certain conditions with the sale of the facility to ensure that improvements are made and citizens continue to be served.

Alliancing: The public sector and private partner agree to jointly design, develop, and finance the project. In some cases, they also work together to build, maintain, and operate the facility.

(2) In which phase or phases does the private partner assume the responsibility, both the development and operational phases or only the operational phase?
Developing a new facility requires larger investments and higher technology levels than operating an existing facility. In addition, a new facility usually includes higher demand uncertainties than an existing facility.

According to these two criteria, PPPs fall into one of the four categories shown in Table 2-2. In Table 2-2, development indicates design and building work. Operation indicates operating and maintaining work.

Table 2-2: Categorization of PPPs (Source: Author)

Category	Description
Type I	Commercial market-based PPPs in development and operation
Type II	Government market-based PPPs in development and operation
Type III	Commercial market-based PPPs in development and operation
Type IV	Government market-based PPPs in development and operation

In general, type I PPPs are likely to include Build-Own-Operate, Build-Own-Operate-Transfer. Some cases of Design-Build-Operate and Design-Build-Operate-Maintain may also fall into this type. Similarly, type II PPPs are likely to include Design-Build-Maintain. Some cases of Design-Build-Operate and Design-Build-Operate-Maintain may be included in this type. Type III PPPs are likely to include lease, concession, and divestiture. Finally, type IV PPPs are likely to include service contracts and management contracts. However, exact categorization depends on cases. These categories are important because space-related PPP cases are analyzed based on this categorization in Chapter 3.

2.3 Why PPPs? – Addressing Budgetary Constraints

This section discusses the rationale of PPPs. As we saw in this chapter so far, PPPs are significantly different from traditional approaches in that the private partner assumes large responsibility in public projects. However, why does the public sector choose PPPs? How does the public sector justify allowing the private sector to assume part of its responsibility? This section argues that the public sector chooses PPP approaches to address budgetary constraints and justifies PPPs as a tool to improve efficiencies of the public service.

The goal of the public sector is to maximize social welfare. Social welfare is sometimes referred to as total quality of life in the entire society. Thus, the public sector is accountable to society, or citizens [Viscusi et al., 2005]. The social welfare includes the quality of environment, the level of crime and the availability of services essential for life. To maximize the social welfare, the public sector procures new facilities from the private sector and delivers services by itself. In other words, the public sector usually adopts traditional approaches. Although services delivered by the public sector vary depending on countries and times, public services in many developed countries today includes education, health care, military, police service, fire service, public transportation, and water services.

However, the public sector has its limitation: it often faces budgetary constraints to deliver public services. Although public services increase social welfare, these services also require financial responsibility of the public sector. Additionally, as the social welfare increases, citizens do not want to accept the degradation of the quality of life. On the contrary, they desire higher quality of life. Therefore, the public sector often cannot find funding to respond to their needs. As a result, it takes a long time for the public sector to start a new project or upgrade an existing facility. Then, citizens have to wait until the response for their needs materializes. The delays in service delivery pose significant economic loss.

On the other hand, the goal of private companies is to maximize their own profits, or shareholders’ profits. Thus, the private sector is accountable to shareholders. Because of this goal, private companies generally have a stronger incentive to work efficiently and the better ability of managing risk than the public sector. Therefore, when financial returns from public service are likely to occur, private companies are willing to invest their own resource in the public service on behalf of the public sector. By cooperating with a private company, the public sector can overcome the problem of budgetary constraints and to response social needs quickly. Thus, partnerships between the public sector and private partners help the public sector to improve efficiencies of public service.

However, the private sector also has its limitation: private companies and shareholders pursue their profits, not social welfare. Therefore, when the private sector increases its responsibility in public projects, it might decrease interests of citizens. For example, the private sector may deliver service only to rich people at high price without paying attention to equity. The private sector may sell high technologies to foreign countries without paying attention to national security. The private sector may limit the available time of service without paying attention to liberty. In general, public policy requires balancing four goals: equity, efficiency, security, and liberty [Stone, 2001]. However, the limitation of the private sector makes it difficult to balance the four goals of the public sector.

In conclusion, the public sector chooses PPPs to address budgetary constraints. The rationale of PPPs lies in improving efficiencies of public service. However, PPPs cause trade-offs between efficiencies and other social interests such as equity, security, and liberty. Therefore, the trade-offs must be done carefully. The next section analyzes the detail of trade-offs.

2.4 Characteristics of PPPs

This section analyzes four characteristics which arise in the trade-offs of PPPs: risk transfer to private partners, high cost schedule efficiencies for the public sector, high transaction cost between the public and private sectors, and higher pricing risk to users. Risk transfer to private partners helps to achieve the optimal risk allocation between the public and private sectors. High cost schedule efficiencies allow the public sector to address budgetary constraints. However, high transaction cost is inevitable because private partners gain larger bargaining power than in traditional approaches. In addition, higher pricing risk reduces benefits for users. These characteristics appear in any type of PPPs regardless of types I, II, III, and IV. In the following, this research analyzes each characteristic.

2.4.1 Risk Transfer to Private Partners

In traditional approaches, the public sector assumes most responsibility of project risk. Although projects include a wide range of risks such as technical risk, construction risk, operating risk, and financial risk, the responsibility of the private contractor is limited to the construction of the facility.

In PPPs, the public sector transfers part of the risks to private partners. Private partners are often responsible for not only construction risk, but also technical risk, operating risk and part of financial risk. Poschmann [2003] classifies risks of PPP projects into nine types. Table 2-3 shows the typical project risks and hypothetical allocations. The private sector usually creates a special purpose vehicle (SPV) as the organization that manages these risks. The special purpose vehicle is often established as a consortium of several private companies. A typical PPP project structure is illustrated in Figure 2-3.

Table 2-3: Typical Project Risks and Hypothetical Allocations (Source: Poschmann, 2003)

Risk Category	Examples	Partner Likely to Suited to Bear Risk*
Technical risk	Engineering and design failures	Private
Construction risk	Cost escalation owing to faulty technique or delays	Private
Operating risk	Costly operation and maintenance	Private
Revenue risk	Deficient revenue owing to low volume or price of delivered service	Public/Private
Financial risk	Costs of inadequate revenue hedging, debt management	Private
Force majeure	Losses from war, acts of God	Public/Private
Regulatory/Political risk	Changes in law or policy that undermine project finances	Public
Environmental risks	Damage through adverse environmental impacts/liability	Private
Project default	Failure through any combination of the above or other factors	Public/Private

* “Private” partner includes outside banks or investors.

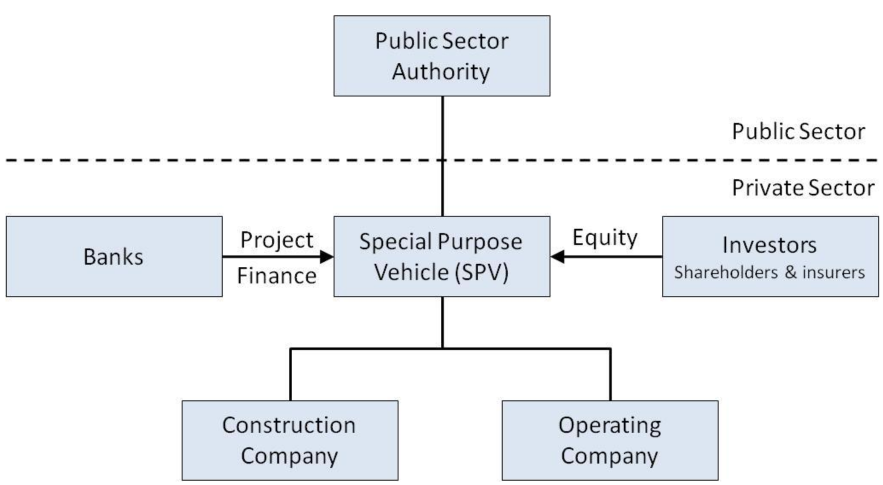

Figure 2-3: Typical PPP Project Structure (Source: Harris, 2004)

The purpose of the risk transfer is to achieve the optimal risk allocation. First, the optimal risk allocation is to minimize total project risk. Private partners generally have the better ability of managing risks than the public sector. Therefore, by transferring part of risk to private partners, the project is more likely to be completed successfully. Second, the optimal risk allocation maximizes incentives of private partners to work efficiently. When private partners' profits rely on their risk management, private partners are willing to make efforts to manage the risk effectively. In light of the second aspect, the risk allocation is closely related to incentive management [de Bettignies and Ross, 2004].

The optimal risk allocation can be achieved when project risk is allocated to the party who can better manage it than the other. If a risk cannot be managed by the private partner, there is no advantage to transfer such a risk to the private partner. In general, private partners cannot manage exogenous or political risks effectively. For example, although a storm may destroy a bridge when it is under construction, the private partner cannot manage the risk better than the public sector. Therefore, there are no advantages in transferring such risks to private partners [Dewatripont and Legros, 2005].

In summary, PPPs transfer part of project risks to private partners. The risk transfer helps to allocate risk optimally between the public sector and private partners. The optimal risk allocation minimizes total project risk and maximizes incentives of private partners. However, a risk should be transferred to private partners only when private partners can better manage it than the public sector.

2.4.2 High Cost Schedule Efficiencies for the Public Sector

In PPPs, the public sector can gain high cost schedule efficiencies. The high cost schedule efficiencies may occur in three ways: flat payment profile, cost reduction incentives of private partners, and the private partner's investment.

First, flat payment profile emerges when PPPs bundle development and operational phases. Figure 2-4 contrasts public sector payment profiles between traditional approaches and PPPs [PricewaterhouseCoopers, 2005]. In a traditional approach, a new project typically has high construction costs and low operating costs. However, strict budgetary constraints of the public sector often become a barrier to pay the high construction costs. Therefore, the public sector has to postpone the project until the budgetary constraints are relaxed. On the other hand, in PPP, the public sector spreads construction costs over the project lifetime and makes annual payment in the operational phase. Thus, PPPs make the payment profile flat. Accordingly, the project becomes affordable within annual budgets of the public sector.

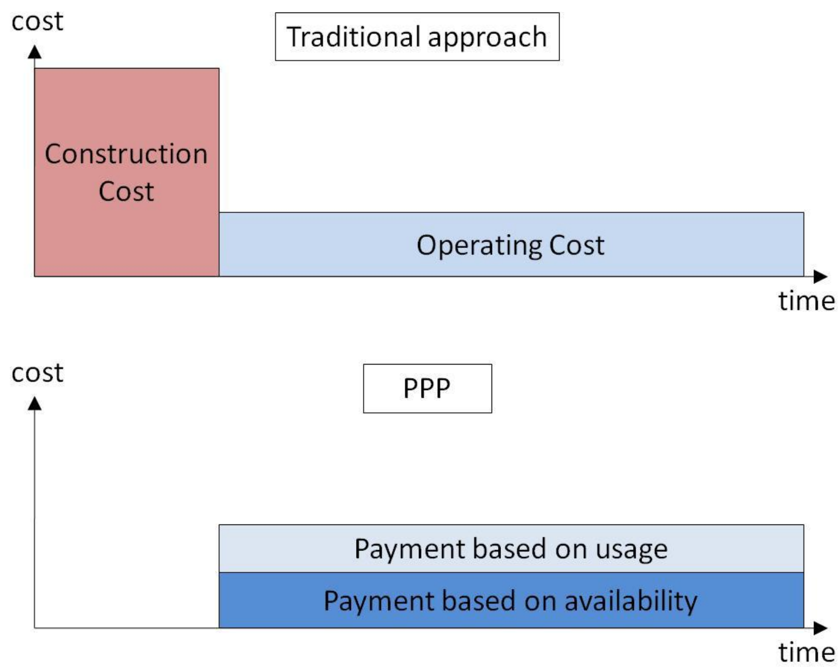

Figure 2-4: Public Sector Payment Profiles of Traditional Approaches and PPPs
(Source: PricewaterhouseCoopers, 2005)

Secondly, cost reduction incentives of private partners occur when private partners' profits rely on their performance [de Bettignies and Ross, 2004]. In particular, a strong cost reduction incentive appears when the PPP bundles development and operational phases. In a traditional approach, the builder has little incentive to reduce operating costs because it has no responsibility for the operational phase after the short term construction warranty has expired. Consequently, in the operational phase, the operator may face high operating costs which arise from inefficient designs. In contrast, when a PPP bundles development and operational phases, and when the private partner is required to invest its own funding in the development phase and to retrieve the investment in the operating phase, the private partner makes efforts to reduce lifetime costs. These efforts reduce total project costs as well as increase profits of the private partner.

Thirdly, when private partners provide their own funding, the public sector can enjoy high cost schedule efficiencies. This case usually occurs when PPPs aim to deliver service to the commercial customer market. Private partners gain revenues from the commercial customer market in the operational phase and retrieve their investment. Such private partners' self-motivated investment rarely happen when PPPs deliver service to government customers because expected revenues of private partners are often determined by political circumstances, not by economic principles.

The high cost schedule efficiencies allow the public sector not only to complete the project at low cost, but also to deliver the service to society earlier. Early delivery of the service leads to reduce the economic loss of society due to the lack of the service. In addition, the high cost schedule efficiencies help the public sector to launch other important projects earlier. Therefore, the public sector can respond more needs of society. These benefits gained by adopting PPP approaches are called Value for Money (VFM).

2.4.3 High Transaction Cost between the Public and Private Sectors

High transaction cost emerges when the public sector and private partners arrange and enforce agreements of PPPs. PPPs increase transaction cost because of two reasons. One is that part of right to decide is transferred to private partners. The other is that projects often require relationship-specific investment. This section discusses these two factors.

Transfer of right to decide

In a traditional approach, the public sector makes most important decisions over design, construction and finance as well as operation and maintenance. Accordingly, the private partner has little right to decide. Thus, the public sector has strong initiatives on the project while the private partner retains low bargaining power.

In contrast, a PPP transfers part of the public sector's right to decide to the private partner. When the public sector transfers project risk to the private partner, some right to decide is also transferred from the public sector to the private partner. Thus, the private partner gains its bargaining power and the public sector relatively reduces its bargaining power. As a result, both parties retain certain amount of bargaining power. This relationship implies that when two parties arrange the PPP agreement or when one party requests to change it, they need to negotiate with each other until they reach an agreement. However, as discussed in Section 2.3, the public sector and private partners pursue different goals. Therefore, PPPs tend to incur high transaction costs such as conflicts of interest and cost renegotiation. [de Bettignies and Ross, 2004]

Relationship-specific investment

Relationship-specific investment is referred to as the investment made between two parties who receive more benefits from the other party rather than outside parties. For example, construction projects often require relationship-specific investments regardless of whether the projects use PPPs or traditional approaches [de Bettignies and Ross, 2004]. Once the construction project starts, the public sector and the private partner gain more benefits from working together toward the completion of the project than terminating the project. The reason is that construction projects usually include specific design requests such as location, performance, and time schedule. Therefore, if negotiation between the two parties breaks down, the private partner can hardly find another customer. The public sector also has to spend additional cost to find another builder. Thus, the public sector and the private partner make relationship-specific investments in the project. In contrast, a supermarket and a customer are not relationship-specific. They can gain the same amount of benefits from other customers or supermarkets.

Relationship-specific investment leads to bilateral monopoly unless the public sector and the private partner have outside alternatives. In other words, the public sector becomes the only customer for the private partner, and the private partner becomes the only supplier for the public sector. In such a situation, both parties tend to behave opportunistically in order to gain its own surplus. Their opportunistic behavior makes it difficult to arrange and enforce agreements of the PPP. Therefore, relationship-specific investment increases transaction costs.

However, traditional approaches are less affected by relationship-specific investments than PPPs. Because traditional approaches do not allow the private sector to have large bargaining power, the private sector cannot behave opportunistically. In contrast, PPPs transfer right to decide to private partners. Therefore, relationship-specific investments result in higher transaction costs in PPPs than in traditional approaches.

2.4.4 Higher Pricing Risk to Users

Higher pricing risk to users occurs when private partners deliver services to users. For example, a highway project under the PPP approach may introduce a toll to a non-tolled highway. In addition, the private partner may raise the highway toll after it starts the operation [Prud'homme, 2005]. This problem can occur even in the government customer market.

In traditional approaches, higher pricing risk does not occur. The public sector operates highways, bridges, and public transportations without user charges or at low prices because the goal of the public sector is to maximize social welfare. However, zero or low user charges often lead to deficit balance in the operation. Therefore, the public sector injects tax revenue into many facilities to compensate for the deficits.

In PPPs, the higher pricing risk to users occurs partly because private partners aim to maximize revenue. In many PPP cases, the public sector transfers the responsibility of service delivery to private partners. Then, private partners pursue profit maximization in delivering service. If user demand is high, private partners may set higher service price. Although the public sector oversees the service price, it is difficult for the public sector to strictly exclude profit pursuing behavior of private partners.

Moreover, higher pricing risk to users occurs because many private partners do not have enough financial source of compensation like the public sector has tax revenue. Although some private partners receive direct compensation from the public sector, the amount of the compensation is unlikely to reach that of the public sector because the public sector justifies PPPs by reducing cost for the public sector. Specifically, the public sector often chooses PPPs, expecting the private partner to gain revenue from user charges. However, public services which private partners are asked to deliver are inherently less profitable than pure commercial service although these services are essential to society. Therefore, service delivered under PPPs tends to have higher price than service delivered under traditional approaches.

As a result, PPPs include higher pricing risk to users. Users have to pay user charges in addition to tax. Users may think that they have a right to receive the service without user charges because their tax is invested in the project to a certain degree, unless the facility was fully privatized [Sadka, 2006].

2.5 Stakeholder Analysis

This section analyzes the four characteristics of PPPs from the view of stakeholders. In PPPs, key stakeholders include the public sector, private partners, and users. Table 2-4 summarizes advantages and disadvantages of the PPP characteristics for each stakeholder. The public sector gains benefits from risk transfer and high cost schedule efficiencies while it receives negative influence from high transaction cost and higher pricing risk. Private partners may gain higher incentives and flexibilities from risk transfer although it may face greater loss due to excessive risk transfer. In addition, high transaction cost is a disadvantageous factor for private partners. Users expect earlier service provision under PPP approaches. However, it may be affected by higher price of service.

Table 2-4: Advantages and Disadvantages of PPP Characteristics (Source: Author)

Characteristics of PPP	Stakeholders		
	Public Sector	Private Partners	Users
Risk transfer	+	+ / –	
High cost schedule efficiencies	+		+
High transaction cost	–	–	
Higher pricing	–		–

+: advantage, –: disadvantage

2.5.1 The Public Sector

In traditional approaches, the public sector assumes most responsibility over project risk. However, some risks might be better managed by the private partner. In addition, the public sector has little incentive and expertise to improve efficiencies of the project. These factors may lead the public sector to experience cost increases and schedule delays in the project. Furthermore, the public sector is supposed to finance the whole project. However, in most cases, the growth rate of annual budgets in the public sector is only a few percent or even less. Therefore, the public sector cannot bear high start-up costs and lifetime costs. Accordingly, strict budgetary constraints become a major barrier to starts a new project. As a result, the public sector often has to postpone the project. The delayed delivery of the service may result in economic losses of society.

PPPs can reduce these disadvantages. Risk transfer helps the public sector to achieve the optimal risk allocation, which minimizes total project risk and maximizes incentives of the private partner. Furthermore, high cost efficiencies make the payment profile of the public sector flat and reduce lifetime costs of the project. Therefore, the project becomes affordable within annual budgets of the public sector. As a result, PPPs helps the public sector to deliver more services earlier to society.

However, PPPs involve some negative characteristics for the public sector: high transaction cost and higher pricing risk to users. In PPPs, the public sector may be concerned about complicated negotiation with the private sector in decision processes of the project. If the negotiation goes worse, high transaction cost may outweigh benefits from cost schedule efficiencies and risk transfer. However, it is difficult for the public sector to forecast how much transaction costs are required because of uncertainties. Furthermore, the public sector may be concerned about the higher pricing risk to users. When this risk becomes high, the public sector needs to regulate the service price.

To put the above discussion together, the public sector expects PPPs to deliver services earlier at lower cost and risk, but subject to higher transaction cost and higher pricing risk than traditional approaches. However, because high transaction cost includes high uncertainties, it is difficult for the public sector to evaluate transaction cost before choosing PPP approaches.

2.5.2 Private Partners

In traditional approaches, private partners assumes little risk and responsibility. Little risk and responsibility result in low profits. In addition, it has little right to decide. Therefore, the private partner does not have flexibilities in project management. The lack of flexibilities results in low efficiencies of the project. When the public sector postpones the project due to its budgetary constraints, the private contractor loses the business opportunity.

In PPPs, private partners are responsible for larger risk of the project than in traditional approaches. First, the larger risk leads to greater potential profits. Therefore, private partners gain higher incentives to projects. They also increase flexibilities. The higher incentives and flexibilities make the project more efficient. However, if excessive risk is transferred to private partners, the larger risk results in greater loss than in traditional approaches. Second, private partners receive more right to decide. However, more right to decide causes higher transaction cost in coordination with the public sector.

The private partner may confront decisions unique to a PPP. It may be concerned about whether it can manage transferred risk efficiently. In the case that the private partner cannot manage it, the traditional approach is more beneficial for the private partner than the PPP. It also may be concerned about how much transaction cost the PPP includes. In the case that high transaction cost is expected, the traditional approach might be more suitable for the private partner. The private partner has to make a decision on these issues before participating in the PPP.

In pure private enterprises, the private company assumes full risk and responsibility of the whole project. Therefore, it retains all right to decide and high flexibilities in project management. Full right to decide leads to high incentives to the efficiencies of the project. However, the company also potentially has large financial loss as well as high return.

In summary, private partners expect PPPs to provide more incentives and flexibilities subject to higher risk and transaction cost than traditional approaches. Compared to pure private enterprises, private partners also expect PPPs to make less profit at less risk and to provide less flexibility.

2.5.3 Users

When private partners collect user charges from users, users' decisions have influence on revenues of the project. Users prefer PPPs in terms of earlier service delivery. However, they prefer traditional approaches in terms of higher pricing risk to users. Thus, users are willing to accept PPPs if PPPs deliver services to users at lower prices and earlier than traditional approaches.

2.6 Trade-offs between PPPs and Traditional Approaches

This chapter so far analyzed the rationale and characteristics of PPPs. It also discussed the influence of these characteristics on stakeholders. The analysis identified advantages and disadvantages of PPPs in comparison with traditional approaches. This section summarizes the overall trade-off between PPPs and traditional approaches.

The rationale of PPPs is that the public sector can overcome budgetary constraints. By choosing PPP approaches, the public sector leverages incentives and investments of the private sector. The incentives and investments of the private partner allow the public sector to build and operate facilities at lower cost and earlier than in traditional approaches. Therefore, PPPs are expected to increase social welfare.

Risk transfer is the tool of PPPs to address budgetary constraints. It helps to achieve optimal risk allocation between the public and private sectors because private partners can manage some risks better than the public sector. Risk transfer also helps to maximize incentives of private partners because private partners' profit relies on how they manage the risk. In this light, risk transfer is beneficial to the public sector. The risk transfer is also beneficial to private partners in terms of potential higher profits while high risk to private partners may lead to greater loss.

High cost schedule efficiencies are the advantageous effects of risk transfer. Risk transfer helps to reduce project cost and to deliver service early. It also makes the public sector's payment profile flat and encourages private partners' efficiency-enhancing efforts. If private partners invest their own funding in projects, the investment also helps the public sector to save cost and to deliver service early. Therefore, high cost schedule efficiencies are advantageous for the public sector. Users also receive benefit from high cost schedule efficiencies in terms of early service provision.

However, high transaction cost arises from risk transfer when the public sector and private partner arrange and enforce agreements of PPPs. Private partners gain more bargaining power while the public sector relatively reduce bargaining power. Therefore, they tend to spend more cost and time to negotiate with each other than in traditional approaches. The high transaction cost is disadvantageous for both the public sector and private partners.

Another disadvantage of risk transfer is higher pricing risk to users. Private partners may raise service prices. Although private partners may secure their revenue by higher pricing, users reduce their benefit from service. The public sector is also concerned about this risk.

In light of these influences on stakeholders, successful trade-offs for PPPs are to retain high cost schedule efficiencies, avoiding high transaction cost and higher pricing risk. Figure 2-5 illustrates trade-off between PPPs and traditional approaches.

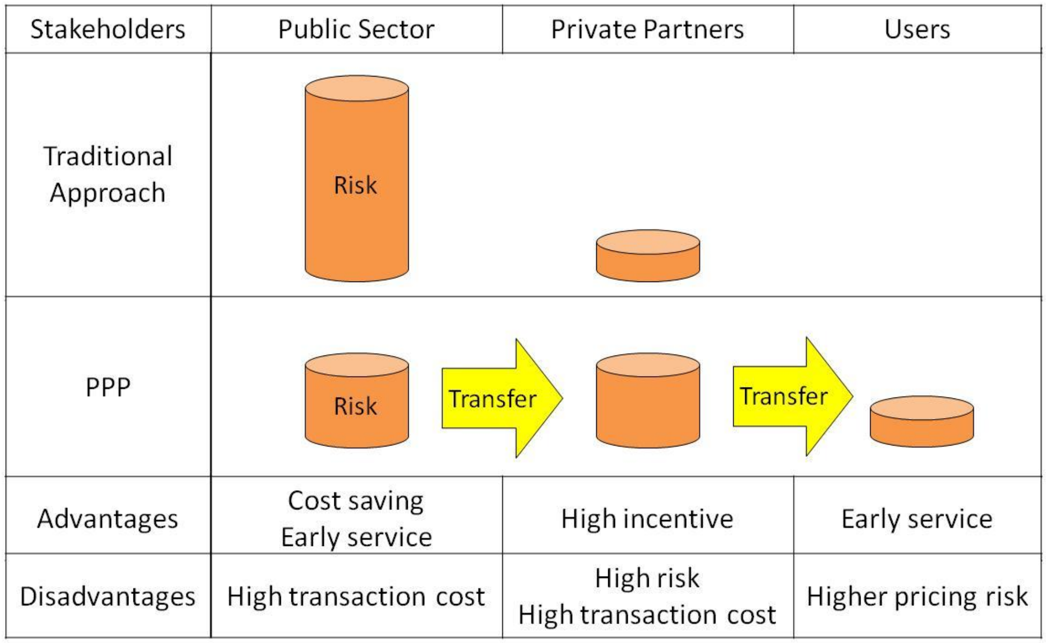

Figure 2-5: Trade-offs between PPPs and Traditional Approaches (Source: Author)

3. Case Studies of Space-related Public-Private Partnerships

This chapter analyzes space-related PPP cases for two purposes. One purpose is to understand what types of PPPs are likely to face challenges in space projects. The other purpose is to identify challenges that occur in the space-related PPP projects. The analysis of this chapter provides a basis for developing a dynamics model of PPPs, improving the model, and discussing a future strategy for space-related PPPs in later chapters.

For the first purpose, the analysis categorizes twelve space-related PPPs into the four types of PPPs, which were introduced in Chapter 2. These twelve cases are the best available ongoing space-related PPP projects in the United States, Europe, and Japan. The categorization of the cases shows that type I PPPs, commercial market-based PPPs in development and operation, are more likely to face challenges than any other type of PPPs.

For the second purpose, this analysis reviews each space-related PPP case. The case studies include motivation, structure, and major challenges of space-related PPP projects. The analysis shows that many type I PPPs tend to face multiple challenges rather than a single challenge. Additionally, while some of the challenges are common in both PPPs and traditional approaches, PPP-unique challenges, such as conflicts of interest and revenue risk, also emerge. This trend indicates that space projects are more likely to face multiple challenges as private partners assume larger responsibility than in traditional approaches.

3.1 Overview of Space-related PPP Cases

This section categorizes twelve space-related PPP projects in the United States, Europe, and Japan. These PPP projects are best available cases for this research. Each of them is in either of the planning, developing, or operating stage. To categorize these cases, this research adopts the four categories developed in Section 2.2. The four categories are shown in Table 3-1.

Based on the categories shown in Table 3-1, the twelve space-related PPP projects are categorized as described in Table 3-2. In addition, Figure 3-1 shows the space-related PPP projects with their current status.

Table 3-1: Four Categories of PPPs (Source: Author)

	Government Customer Market	Commercial Customer Market
PPPs in development and operation	Type II	Type I
PPPs in operation	Type IV	Type III

Table 3-2: Categorization of Space-related PPPs (Source: Author)

Types of PPP	Space Projects	Missions	Country or Region
Type I	Galileo	Navigation	Europe
	QZSS	Navigation	Japan
	GX	Space Transportation	Japan
	EELV	Space Transportation	US
	TerraSAR-X	Earth Observation	Germany
Type II	Skynet 5	Telecommunication	UK
	COTS	Space Transportation	US
Type III	Ariane 5	Space Transportation	Europe
	H-IIA	Space Transportation	Japan
Type IV	Space Shuttle	Space Transportation	US
	Kibo	International Space Station	Japan
	GMS-8 and 9	Meteorological Monitoring	Japan

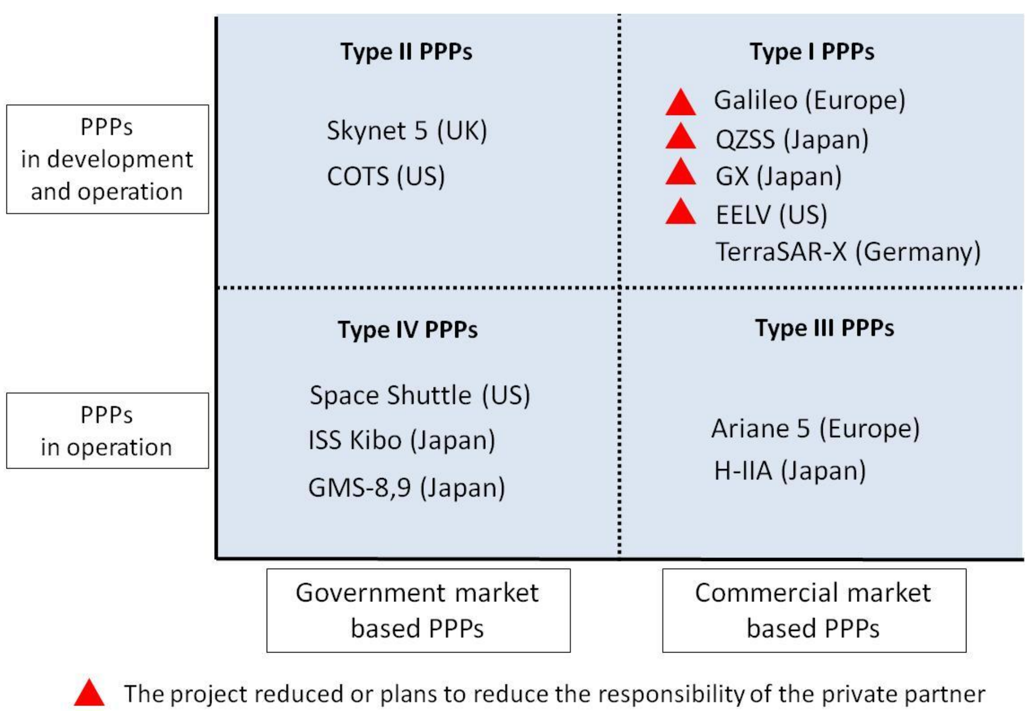

Figure 3-1: Categorization of Space-related PPPs with Current Status (Source: Author)

In Figure 3-1, four of five projects in the type I have reduced or plan to reduce the responsibility of the public partners. As discussed in the next section, the decisions to reduce the responsibility were made because the four PPP projects, Galileo, QZSS, GX, and EELV, faced multiple challenges rather than a single challenge. These challenges are not only common challenges in traditional approaches such as cost increase and schedule delay, but also challenges unique to PPPs such as conflicts of interest and revenue issues. These challenges made the PPP projects shift or plan to shift in the direction of more traditional approaches. This trend indicates that space projects more increasingly face multiple challenges as the private partners assume larger responsibility than in traditional approaches.

In the rest of this chapter, this research reviews each space-related PPP shown in Figure 3-1. The case studies include motivation, structure, and major challenges of the space-related PPP projects.

3.2 Type I: Commercial Market-based PPPs in Development and Operation

This section reviews Galileo, QZSS, GX, EELV, and TerraSAR-X. The first four cases faced multiple challenges while TerraSAR-X is too early to evaluate the success of the PPP.

3.2.1 Galileo: European Global Navigation Satellite System

Table 3-3: PPP in the Galileo Case (Source: The European Commission, 2007)

Type I PPP		
Project		Galileo
Country/Region		Europe
Mission		Navigation
PPP Start		2002
Funding	Public	Development cost and 1/3 of deployment cost
	Private	2/3 of deployment cost and full operating cost
PPP Structure	Public	European Union (EU), European Space Agency (ESA)
	Private	8-member consortium
Major Challenges		Conflicts of interest, schedule delays, and revenue risk

Galileo, the European global navigation satellite system, is a constellation of 30 satellites. It enables users to determine their locations and set a course between the location and a desired destination. The Galileo program was launched in 2002 by the European Union (EU). The start of the service was originally scheduled in 2008 [The European Commission, 2007].

The total cost of constructing Galileo is estimated to reach 3.2 billion euro ($ 4.2 billion; 1 euro = $1.3 USD). The EU planned to construct Galileo in three steps: development and in-orbit validation phase, deployment phase, and operational phase. The consortium was supposed to finance two-thirds of the deployment cost. The consortium will also operate Galileo with its funding. Therefore, it planned to gain profits by collecting royalties for navigation receivers and delivering high accuracy service for user charges.

However, the PPP experienced negotiation breakdown because conflicts over work distribution occurred among parties. Then, the schedule delayed. The consortium was also concerned about revenue risk. As a result, the public sector decided in 2007 to fully finance the deployment phase with the public funding. The EU expects the full operation of Galileo in 2012.

3.2.2 QZSS: Japanese Regional Navigation Satellite System

Table 3-4: PPP in the QZSS Case (Source: Council for Science and Technology Policy, 2002)

Type I PPP		
Project		QZSS
Country/Region		Japan
Mission		Navigation
PPP Start		2002
Funding	Public	90 billion yen ($ 900 million; 100 yen = $1 USD)
	Private	80 billion yen ($ 800 million)
PPP Structure	Public	Ministry of Education, Culture, Sports, Science and Technology (MEXT) Ministry of Economy, Trade and Industry (METI) Ministry of Internal Affairs and Communications (MIC) Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Japan Space Exploration Agency (JAXA)
	Private	6-member consortium
Major Challenges		Conflicts of interest, schedule delays, and revenue risk

QZSS, Quasi-Zenith Satellite System, is a three-satellite regional navigation satellite system. These satellites are arranged to make one of them visible around the zenith of Japan for 24 hours. Because QZSS work with GPS cooperatively, QZSS will fill uncovered areas of GPS. The program started in 2002. The start of the service was originally scheduled in 2008 [Japan, Council for Science and Technology Policy, 2002].

Four Japanese ministries committed $900 million (90 billion yen) in this program and a consortium planned to invest $800 million. The ministries aimed at the complement navigation service, which fills the gap of the GPS service. The consortium planned commercial value-added services combining navigation, broadcasting, and communications for user charge.

However, in 2006, the public sector and consortium failed in negotiation. One reason for the breakdown was that the revenue risk was too high. Another reason was a lack of legal framework in the operational phase. Because QZSS was the first Japanese navigation system, it was difficult for the four ministries to decide the agency responsible for the operational phase.

As a result, the public sector announced to deploy QZSS in traditional approach. In the first step, the public sector will launch only one satellite with the public funding. After the assessment of the first step, the public sector will move to the second step, in which the public sector will launch the remaining two satellites and the private sector will provide funding if it starts business.

3.2.3 GX: Japanese Medium-class Launch Vehicle

Table 3-5: PPP in the GX Case (Source: JAXA, 2006)

Type I PPP		
Project		GX
Country/Region		Japan
Mission		Space transportation
PPP Start		2001
Funding	Public	30 billion yen ($ 300 million)
	Private	15 billion yen ($ 150 million)
PPP Structure	Public	MEXT, METI, JAXA
	Private	9-member consortium
Major Challenges		Conflicts of interest, cost increase, and schedule delays

The GX launch vehicle aims at launching medium-to-small satellites into low Earth orbit. It was designed to use the Atlas III first stage for its first stage. For the upper stage, JAXA is developing the liquefied natural gas (LNG) engine. LNG has combined advantageous characteristics of kerosine and liquefied hydrogen: low cost, easy to handle, and high propulsive [JAXA, 2006].

The GX project started in 2001 with the private sector initiative as the revised project of the advanced technology demonstration rocket. Although the rocket project was publicly funded, it was suspended because another Japanese launch vehicle, H-II, failed in launching in 1999. The budgetary constraint changed the publicly funded advanced technology demonstration rocket to the private sector initiative GX project. The start of the service was originally foreseen in 2006.

In this project, each of two ministries and the consortium committed to investing $150 million, respectively. The consortium procures the first stage and integrates the system. It planned to start commercial launch business. METI financially supported the consortium. JAXA develops the upper stage and transfers the technology to the consortium. MEXT financially supported JAXA.

However, JAXA experienced technological challenges in developing the LNG engine. Because the original engine design was required design changes, significant cost increase and schedule delays occurred. Therefore, the consortium asked JAXA to increase its responsibility and funding [IHI, 2008]. Currently, the expected start of the service is foreseen in 2011.

3.2.4 EELV: U.S. Evolved Expendable Launch Vehicle

Table 3-6: PPP in the EELV Case (Source: RAND, 2006)

Type I PPP		
Project		EELV
Country/Region		United States
Mission		Space transportation
PPP Start		1995
Funding	Public	$1 billion
	Private	$5 billion (Boeing: $2.3B, Lockheed Martin: $1.6B)
PPP Structure	Public	Department of Defense (DoD)
	Private	Boeing and Lockheed Martin
Major Challenges		Conflicts of interest and cost increase

EELV, the evolved expendable launch vehicle program, aims at reducing the government's unit launch cost by 25-50% over previous U.S. launch vehicles [U.S. LA Air Force Base]. The EELV program consists of Delta IV developed by Boeing and Atlas V developed by Lockheed Martin. The cost reduction was expected because these two families used common components and infrastructure such as standardized launch pads. Moreover, the commercial acquisition strategy of the U.S. government was expected to reduce launch costs. In this strategy, the U.S. government procures launch services from contractors who supply launch services in the commercial launch market. The government would be the secondary user. Therefore, if a strong commercial launch demand emerges, the commercial revenue will help to reduce government launch costs.

The EELV program began in 1995. Initially, DoD planned to gradually reduce contractors, choosing four contractors in the initial stage, two contractors in the second stage, one single contractor in the final stage. However, in the final stage, DoD retained two contractors because higher commercial demand was foreseen. Although DoD expected that high commercial demand would support the two-contractor strategy, the large commercial customer market did not materialize. As a result, the government and two contractors faced significant cost increases. In 2006, Boeing and Lockheed Martin announced that they would merge their service division for the government.

3.2.5 TerraSAR-X: German Earth Observation Satellite

Table 3-7: PPP in the TerraSAR-X Case (Source: Spude and Grimard, 2008)

Type I PPP		
Project		TerraSAR-X
Country/Region		Germany
Mission		Earth observation
PPP Start		2002
Funding	Public	185 million euro ($241 million)
	Private	37 million euro ($ 48 million)
PPP Structure	Public	German Aerospace Center (DLR)
	Private	EADS Astrium
Major Challenge		N/A

TerraSAR-X, a German Earth observation satellite, is the first PPP space project in Germany with considerable financial contribution by the private partner. The PPP agreement was signed in 2002 between DLR and Astrium, one of the European leading space manufacturers. TerraSAR-X was launched in 2007 and has successfully started the operation. This satellite carries a synthetic aperture radar (SAR) with as high as 1 meter resolution. Data taken by this satellite are used for commercial and scientific purposes.

DLR provides 80% of the TerraSAR-X manufacturing costs. The remaining 20% is provided by Astrium. 50% of data are obtained by DLR for scientific use. The other 50% are obtained by Infoterra, a wholly-owned subsidiary of Astrium. The prime target of TerraSAR-X is military and civil government customers. Inforterra expects to gain annual revenues of more than 200 million euro during the five years of the satellite lifetime [Spude and Grimard, 2008].

This PPP started because Astrium's analysis showed that the potential commercial customer market of remote sensing data would have high demand. DLR could start this project with the private funding. DLR and Astrium also agreed to launch another Earth observation satellite, TanDEM-X, under the framework of PPP. DLR provides 105 million euro for TanDEM-X and Astrium provides 40 million euro. If the commercial service is successful, the PPP agreement allows TerraSAR-X2 to be launched in 2012. Infoterra estimates the replacement costs will be 100 million euro. A series of PPPs seem to be going well. However, it has been only two years since the launch. Therefore, it is too early to evaluate the success of the PPPs [Infoterra].

3.3 Type II: Government Market-based PPPs in Development and Operation

Skynet 5 is a successful case of the type II PPP. Although COTS is too early to evaluate, this program facilitates competition among contractors and is effectively managed so far.

3.3.1 Skynet 5: U.K. Military Communication System

Table 3-8: PPP in the Skynet 5 Case (Source: Spude and Grimard, 2008)

<table>
<tr><th colspan="3">Type II PPP</th></tr>
<tr><td colspan="2">Project</td><td>Skynet 5</td></tr>
<tr><td colspan="2">Country/Region</td><td>United Kingdom</td></tr>
<tr><td colspan="2">Mission</td><td>Telecommunication</td></tr>
<tr><td colspan="2">PPP Start</td><td>1998</td></tr>
<tr><td rowspan="2">Funding</td><td>Public</td><td>3.7 billion pound</td></tr>
<tr><td>Private</td><td>Up-front investment</td></tr>
<tr><td rowspan="2">PPP Structure</td><td>Public</td><td>Ministry of Defense (MOD)</td></tr>
<tr><td>Private</td><td>Paradigm Secure Communications</td></tr>
<tr><td colspan="2">Major Challenge</td><td>Asset insurance</td></tr>
</table>

Skynet 5 is a military communication system, which provides MOD with secure telecommunication services. This project aimed at replacing the existing Skynet 4 system [McLean, 1999]. MOD chose the PPP option in comparison with the traditional approach and international cooperation.

Paradigm Secure Communications, wholly owned subsidiary of EADS, developed two satellites, Skynet 5A and 5B, and operates them as well as the existing Skynet 4. In the development phase, MOD reimbursed the development and launch costs when Paradigm Secure Communications passed milestones. The contract sets financial penalties in case of schedule delays. In the operational phase, Paradigm gains revenue from MOD's assured capacity, which meets MOD projected nominal and surge requirements. In addition, Paradigm gains revenue from the open capacity, which is free for sale to third party users with the approval of MOD. First customers for the open capacity have been NATO and the Portuguese and Canadian militaries [Paradigm].

Skynet 5 has been going well so far. MOD added Skynet 5C to the contract, waiving the asset insurance. The contract continues until 2020 [Spude and Grimard, 2008].

3.3.2 COTS: U.S. Commercial Orbital Transportation Services

Table 3-9: PPP in the COTS Case (Source: NASA, 2007)

Type II PPP		
Project		COTS
Country/Region		United States
Mission		Space transportation
PPP Start		2006
Funding	Public	$500 million
	Private	N/A
PPP Structure	Public	National Aeronautics and Space Administration (NASA)
	Private	Space X and Orbital Sciences
Major Challenge		Contractual default

COTS, the commercial orbital transportation services, was designed by NASA to privatize the transportation services to the international space station (ISS). Although the transportation services have been provided by the Space Shuttle, the U.S. government announced in 2004 that it would retire the Space Shuttle by 2010. To fulfill the government's demand for the delivery after 2010, NASA decided to finance the development of commercial transportation services and to acquire the commercial services. NASA also expects private sector involvement to reduce transportation costs of ISS. This program was announced in 2006. NASA anticipates that the commercial services will be necessary through 2015 [NASA, 2007].

NASA intends to spend $500 million through 2010 to support the demonstration of the orbital transportation service capabilities. In addition, NASA started financing for the crew transportation capabilities in 2009. Private contractors were supposed to provide the rest of the costs.

NASA started COTS phase I in 2006, financially supporting two contractors, Space Exploration Technologies (Space X) and Rocketplane Kistler (RpK). Phase I is designed to develop and demonstrate commercial service capabilities. The COTS agreement defined milestones for the development. However in 2007, NASA terminated the agreement with RpK because the contractor failed in raising sufficient private funding. NASA withdrew remaining funding from RpK and awarded $170 million in 2008 to the new contractor, Orbital Sciences. In 2008, NASA awarded commercial resupply service contracts to Space X and Orbital Sciences.

3.4 Type III: Commercial Market-based PPPs in Operation

Ariane 5 and H-IIA are both launch vehicle projects. Their major challenge is launch failures. Launch failures have significant impacts on their commercial activities.

3.4.1 Arian 5: European Heavy-lift Launch Vehicle

Table 3-10: PPP in the Ariane 5 Case (Source: Isakowitz, 2004)

Type III PPP		
Project		Ariane 5
Country/Region		Europe
Mission		Space transportation
PPP Start		1997
Funding	Public	8-9 billion euro ($10.4-11.7 billion) for development
	Private	125-155 million euro ($163-$202 billion) per launch
PPP Structure	Public	24-shareholder joint venture
	Private	
Major Challenge		Launch failures

Ariane 5 is a latest version of the European expendable launch vehicle family. By operating this launch vehicle, Europe aims at securing its independent access to space as well as penetrating the commercial launch market.

Ariane 5 was developed by European Space Agency (ESA) with public funding. Then, the operation of Ariane 5 was transferred to Arianespace, the world’s first launch service company. Arianespace was established in 1980 as a consortium by the European public and private sectors, soon after Europe first succeeded in launching Ariane 1. Since then, Arianespace has provided the commercial launch services. It has 24 shareholders from 10 European countries. FAA estimates the price per launch 125-155 million euro [Isakowitz, 2004].

Arianespace encountered significant financial difficulties from 2000 through 2002 partly because the commercial launch market declined and partly because Ariane 5 failed in launching in 2001 and 2002. Therefore in 2003, European countries agreed to the EGAS program, European Guaranteed Access to Space, which covers Arian 5’s launch-pad and other fixed costs between 2005 and 2009 in order to place European space industry on a level playing field compared to competitors. The amount of subsidy is 960 million euro.

3.4.2 H-IIA: Japanese Heavy-lift Launch Vehicle

Table 3-11: PPP in the H-IIA Case (Source: Isakowitz, 2004)

Type III PPP		
Project		H-IIA
Country/Region		Japan
Mission		Space transportation
PPP Start		2007
Funding	Public	115 billion yen ($1.15 billion) for development
	Private	10 billion yen ($100 million) per launch
PPP Structure	Public	JAXA
	Private	Mitsubishi Heavy Industry
Major Challenge		Launch failures

H-IIA is the Japanese primary launch system developed by Japan Space Exploration Agency (JAXA). JAXA designed H-IIA to enhance the reliability and to halve the manufacturing costs of its predecessor, the H-II launch vehicle. By doing so, Japan aims at fostering the competitive commercial launch business. In 2002, the Japanese government announced to privatize the H-IIA launch vehicle. Following the announcement, JAXA solicited applications of companies for the ownership of H-IIA and selected Mitsubishi Heavy Industry (MHI), the prime contractor of the H-IIA launch vehicle [JAXA, 2002].

In 2007, MHI succeeded the first launch of the privatized H-IIA. MHI manufactures and markets H-IIA and JAXA operates the safety assurance. When JAXA launches its own satellites, it procures H-IIA launch vehicles from MHI.

Challenges of MHI are customers' trust and price setting. Although H-IIA has succeeded 15 of 16 launches so far, it has not yet gained enough customers' trust to H-IIA. In the global launch market, competitors have more accumulated records of launch success. In addition, although the unit price of H-IIA was initially estimated $85 million, the unit price has increased up to $100 million after the sixth H-IIA flight failed in its launch. Therefore, the price of H-IIA is higher than other competitors such as Russian and Chinese launch vehicles. However in 2008, MHI first agreed to a launch contract with the Korea Aerospace Research Institute (KARI) for launching its optical Earth observation satellite, KOMPSAT-3, as a sub-payload in 2012. [MHI, 2009]

3.5 Type IV: Government Market-Based PPPs in Operation

In the Space Shuttle case, responsibilities of operation and maintenance were successfully transferred to the private partner. Kibo and GSM-8 and 9 aim at similar responsibility transfer.

3.5.1 Space Shuttle: U.S. Manned Space Transportation System

Table 3-12: PPP in the Space Shuttle Case (Source: Isakowitz, 2004)

Type IV PPP		
Project		Space Shuttle
Country/Region		United States
Mission		Space transportation
PPP Start		1995
Funding	Public	$5.5 billion for development
	Private	$450-750 million per launch
PPP Structure	Public	NASA
	Private	United Space Alliance (USA)
Major Challenge		N/A

The Space Shuttle, the world's first reusable spacecraft, has been used for U.S. human spaceflight programs for nearly 30 years. Although NASA initially expected to operate the Shuttle approximately 50 times per year [Tylko, 2009], the actual launch times were four to seven per year. Therefore, the operating costs ranged from $450 million to $750 million per launch although the expected operating costs were $56 million per launch. In this context, PPPs were a possible approach to improve efficiencies of the flight operation.

In 1995, NASA awarded the contract to United Space Alliance (USA), which was formed by Lockheed Martin and Rockwell (acquired by Boeing later) with each firm a 50 percent owner. Under the cost reimbursement contract, USA had overall responsibility for processing the Shuttle hardware. It was also rewarded for performance successes and personalized for its performance failures. Cost reductions achieved by USA were shared with NASA taking 65 percent of the savings and United Space Alliance 35 percent [CAIB, 2003].

The contract has saved NASA a total of more than $1 billion for the six years. NASA exercised options for two-year extensions twice. The contract was concluded in 2006 after the 10-year enforcement. In 2006, NASA and USA started another contract. It will be concluded in 2010, when the Shuttle retires, but extendable up to 2015 [USA].

3.5.2 Kibo: Japanese Experiment Module of International Space Station

Table 3-13: PPP in the Kibo Case (Source: JAXA, 2007)

Type IV PPP		
Project		Kibo
Country/Region		Japan
Mission		International Space Station
PPP Start		2007
Funding	Public	N/A
	Private	N/A
PPP Structure	Public	JAXA
	Private	Japan Manned Space Systems (JAMSS) Japan Space Forum (JSF)
Major Challenge		N/A

Kibo is the Japanese experiment module of the International Space Station (ISS). In the ISS program, the United States, Russia, Europe, Japan and Canada provide one or more modules or equipment for the station and cooperate in assembling. Japan provided Kibo, which is equipped with space experiment facilities in the field of pharmacy, biochemistry, and microgravity.

One concern about Kibo was that operating costs would be expected up to $400 million per year. To reduce the operating costs, JAXA intends to involve the private sector and to transfer JAXA's responsibility to the private sector.

In 2007, JAXA awarded a contract to Japan Manned Space Systems (JAMSS) and Japan Space Forum (JSF), respectively [JAXA, 2007]. Under the contracts, JAMSS gradually increases its responsibility for the operation of Kibo and JSF expands its responsibility for the customer support. The payments may change based on their performance. The contracts started in 2007 and will continue until 2015.

3.5.3 GMS: Japanese Geostationary Meteorological Satellites 8 and 9

Table 3-14: PPP in the GMS Case (Source, JMA, 2008)

Type IV PPP		
Project		GMS-8 and 9
Country/Region		Japan
Mission		Meteorological monitoring
Operation Start		2014 and 2016
Funding	Public	N/A
	Private	N/A
PPP Structure	Public	Japan Meteorological Agency (JMA)
	Private	N/A
Major Challenge		N/A

GMS 8 and 9 are Japanese geostationary meteorological satellites which Japanese Meteorological Agency (JMA) currently plans to launch in 2014 and 2016, respectively. JMA has operated GMS series for more than 30 years and has provided critical weather information including anticipated paths of typhoons and heavy rains. Although JMA currently operates GMS 6 and 7, they will reach the end of the design life around 2014 [JMA, 2008].

One challenge for JMA is severe budgetary constraints. Because of the budgetary constraints, JMA developed GMS 6 and 7 as joint projects with Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) to share project costs. Therefore, GMS 6 and 7 have not only meteorological observation functions, but also aerial navigation functions provided by MLIT. However, MLIT is not going to collaborate with JMA for GMS 8 and 9 because they have not decided the next generation flight control system, yet. JMA could not find other partners in the public sector.

After discussing possible alternatives, JMA decided to pursue a PPP approach in which JMA will finance the development and launch of the satellites and the private sector will own ground stations and provide observation services to JMA. This PPP approach is expected to allow JMA to reduce project costs in the operational phase.

4. Developing a Dynamics Model of Space-related Public-Private Partnerships

This chapter is the main part of this research. It addresses the first research question. The goal of this chapter is to develop a dynamics model that explains how challenges occur in the application of PPP approaches to space projects.

To achieve the goal, this research uses three modeling steps. First, this analysis develops a traditional-approach model that describes the dynamics of traditional approaches in space projects. In the second step, it proposes a dynamics model of space-related PPPs based on the traditional-approach model. The proposed PPP model reflects on the trade-off analysis in Chapter 2 and the case studies in Chapter 3. However, the proposed PPP model is purely hypothetical at this point. Therefore in the third step, this analysis tests whether the PPP model explains challenges that emerged in actual space-related PPP cases. Specifically, this research selects four cases of type I space-related PPP projects: Galileo, QZSS, GX and EELV. As we saw in Chapter 3, these four space-related PPP projects have experienced multiple challenges.

The analysis shows that the PPP model explains the challenges that emerged in the four space-related PPP projects. In the PPP model, challenges emerge from a reinforcing loop. The loop consists of four variables: conflicts of interest among parties, cost schedule inefficiencies, user satisfaction, and the private partner's revenue risk. While the cost schedule inefficiencies are included in the traditional-approach model, the rest of them are variables unique to PPPs that represent stakeholder interests in PPPs. The reinforcing loop indicates that the interaction of stakeholder interests is the inherent source of multiple challenges in space-related PPPs. In addition, unexpected technical and demand problems enhance the reinforcement. Finally, a simple numerical simulation describes that the PPP model causes more cost schedule inefficiencies than the traditional-approach model.

4.1 Modeling Methodology: System Dynamics Modeling

This research uses System Dynamics which is a modeling technique useful to understand complex systems. Before starting to develop models, this section briefly introduces the concept of System Dynamics. It also discusses the rationale of choosing this methodology and modeling steps.

4.1.1 Introduction to System Dynamics Modeling

System Dynamics is a modeling technique to analyze systems with nonlinear behaviors. Most complex behaviors in systems usually arise from the interactions among the components of the system, not from the complexity of the components themselves. Therefore this modeling technique focuses on capturing such complex feedback structures of systems. For this purpose, System Dynamics is grounded in the theory of nonlinear and feedback control developed in mathematics, physics, and engineering [Sterman, 2000].

System Dynamics helps decision makers to learn about the structure and dynamics of complex systems. This methodology was initially developed at MIT by Professor Jay Forrester in the 1950s. In its early stage, he applied System Dynamics to management problems such as decision making for inventory [Forrester, 1989]. Since then, System Dynamics has been gradually applied to broader policy issues such as economic growth, technology diffusion, and system safety. Thus, System Dynamics helps to gain useful insight into relationships between dynamic complexity and its control policy [Sterman, 2000].

The first stage for building a System Dynamics model usually begins by selecting key variables for the problem [Ahn, 1999]. This step requires analyzing which variables are likely to have significant influences on the problem. To keep the model intuitively understandable, the number of key variables should be as small as possible, say no more than twenty.

In the second stage, the model developer connects two of these variables with a causal link, analyzing cause-and-effect between them. Each causal link must have either a positive (+) polarity or a negative (–) polarity. A positive polarity indicates that if the cause increases, the effect increases, and if the cause decreases, the effect decreases [Sterman, 2000]. A negative polarity indicates that if the cause increases, the effect decreases, and if the cause decreases, the effect increases. A group of causal links creates either a reinforcing loop or a balancing loop. A reinforcing loop enhances the original change. Figure 4-1 describes a reinforcing loop with the loop polarity identifier R: an increase in the chicken population causes the number of eggs laid each day to rise above what it would have been. In contrast, a balancing loop opposes the original change. Figure 4-2 describes a balancing loop with the loop polarity identifier B: The more chickens, the more road crossings they will attempt. If there is any traffic, more road crossings will lead to fewer chickens.

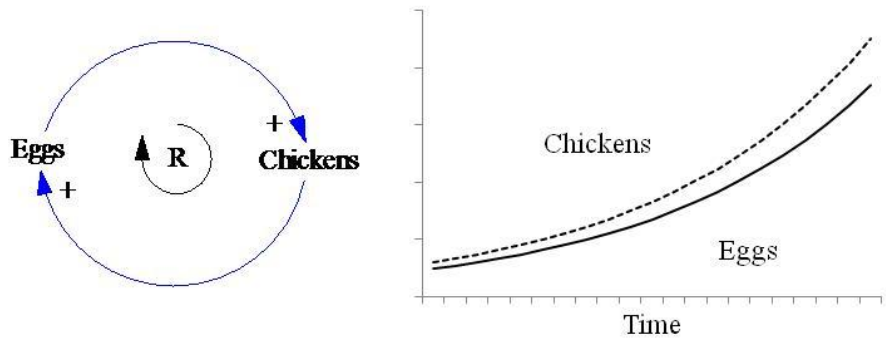

Figure 4-1: A Reinforcing Loop and its Behavior (Source: Sterman, 2000)

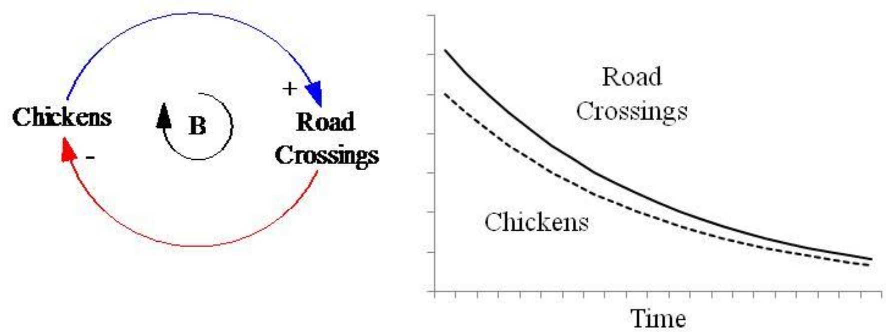

Figure 4-2: A Balancing Loop and its Behavior (Source: Sterman, 2000)

In a System Dynamics model, the system is described as a group of reinforcing loops and balancing loops. This causal loop diagram is very useful in grasping the characteristics of the system. The causal loop diagram helps not only to discuss the system qualitatively, but also to describe the model structure intuitively.

In the final stage, once a causal loop diagram is developed, one can transfer the conceptual causal loop model into a time-based numerical model by defining differential equations for each causal link [Sturtevant, 2008]. Simulating such a model allows one to test detailed behaviors of the model and to provide quantitative discussion closely connected with the real world system's behavior. However, this is not always possible when causal links in the conceptual model cannot be mathematically formulated.

4.1.2 The Rationale of Selecting System Dynamics Methodology

System Dynamics fits this research because it aims to analyze the dynamic structures by which challenges arise in space-related PPP projects. As mentioned in Section 1.4, prior work has never discussed the dynamics although it implies that unique characteristics of PPPs cause various challenges in space projects. Therefore, the focus of this research suggests that it use methodologies to analyze the dynamics of systems.

In addition, case studies of space-related PPP projects in Chapter 3 show that space projects increasingly face multiple challenges rather than a single challenge, as private partners assume larger responsibility than in traditional approaches. This trend seems to indicate that challenges grow in the complex feedback system of space-related PPP projects. Therefore, this research calls on methodologies suitable to analyze complex feedback systems.

In light of these two reasons, System Dynamics modeling is the methodology most suitable to the purpose of this research. This research expects System Dynamics to help to make new contributions. It would be difficult to achieve the purpose of this research without System Dynamics modeling.

4.1.3 Modeling Steps

Approach to develop the space-related PPP model is divided into three steps. In Step 1, this research builds a traditional-approach model of space projects. This traditional-approach model provides the basis for later steps.

In Step 2, this research proposes a hypothetical dynamics model of space-related PPPs. This PPP model consists of key variables selected based on analysis in Chapter 2. The model describes dynamic structures by which challenges arise from characteristics of PPPs.

In Step 3, this research tests whether the PPP model explains challenges that caused actual space-related PPP projects. To test the model, this research applies the proposed PPP model to Galileo, QZSS, GX, and EELV cases, which are type I PPP cases.

After these three steps, this research finally concludes that the PPP model appropriately explains the dynamics by which challenges arise in the application of PPP approaches to space projects. To better understand the behavior of the dynamics, this analysis also provides results of a simple simulation of the PPP model.

4.2 Step One: Developing a Traditional-Approach Model

This section develops a traditional-approach model of space projects. The purpose of modeling the traditional-approach model is to provide a basis for a PPP dynamics model of space projects, not to analyze the traditional approach itself. Therefore, this analysis seeks a simple model to contrast differences between traditional approaches and PPPs. The developed traditional-approach model is shown in Figure 4-3. Each variable is defined in Table 4-1.

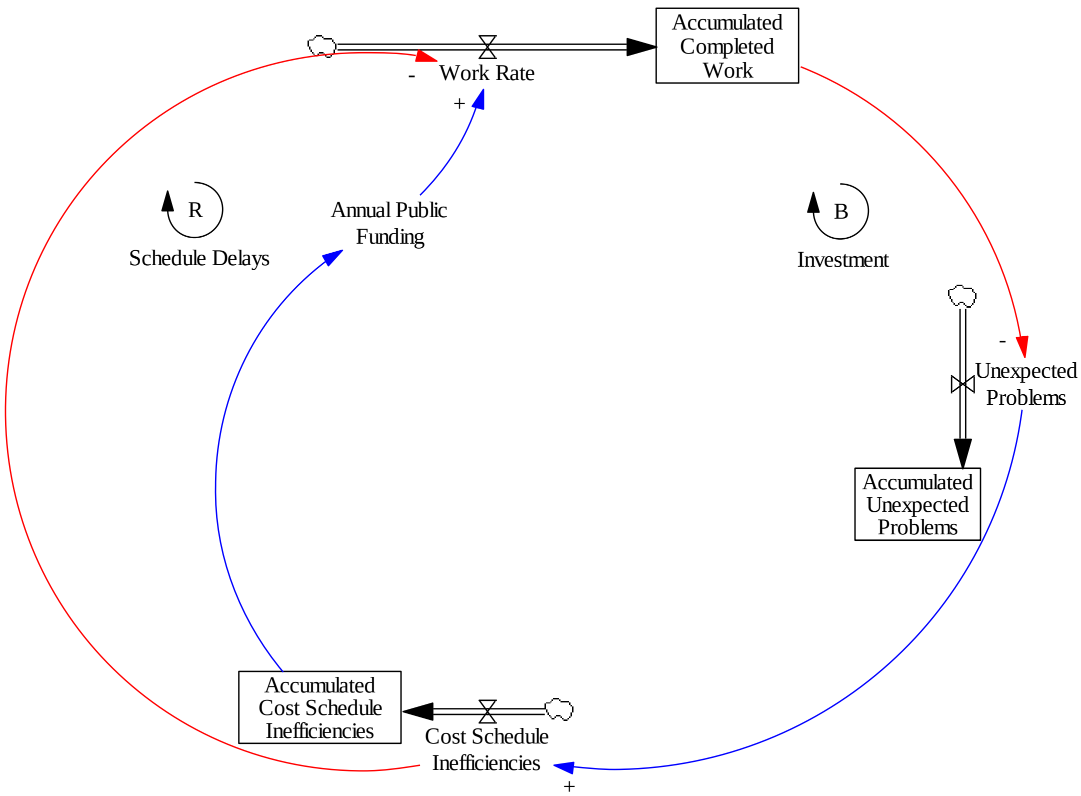

Figure 4-3: A Traditional-Approach Model of Space Projects (Source: Author)

First, the progress of the project is described by two variables: work rate and accumulated completed work. The accumulated completed work accumulates work rate until the project reaches its completion. It should be noted that work rate is illustrated with an arrow and accumulated completed work is put in a box. The arrow represents a flow which is defined as the volume of the fluid that moves through a specific point per unit time. The box represents a stock which is defined as the accumulation of a flow. Thus in the above model, work completed accumulates work rate.

Table 4-1: Definitions of Variables for the Traditional-Approach Model (Source: Author)

Variables	Units	Definitions
Work Rate	Unit/Time	The rate of completing work per unit time
Accumulated Completed Work	Unit	The accumulated amount of completed work
Unexpected Problems	1/Time	The number of problems which had not been expected to occur, but have actually occurred per unit time
Accumulated Unexpected Problems	Dimensionless	The accumulated number of unexpected problems
Cost Schedule Inefficiencies	1/Time	The average of two ratios: cost increase per unit time to original total cost; and schedule delays per unit time to original total schedule
Accumulated Cost Schedule Inefficiencies	Dimensionless	The accumulation of cost schedule inefficiencies
Annual Public Funding	Currency/Time	The amount of funding annually invested in the project by the public sector

Next, as more work is completed, fewer unexpected problems occur per unit time. Because it is impossible to anticipate in advance every single problem that occurs during the project, some unexpected problems may arise in any phase of the project. However, they are less likely to occur as the project comes closer to its completion. In this light, unexpected problems have a negative causal link from accumulated completed work.

Thirdly, more unexpected problems cause more cost schedule inefficiencies. When unexpected problems occur, the problems require additional cost and time to solve. Then, cost increase and schedule delays emerge. Therefore, cost schedule inefficiencies have a positive causal link from unexpected problems.

Annual public funding increases as cost schedule inefficiencies increase. The public sector must provide additional funding to keep the original plan. The public sector sometimes decreases priorities of projects that face cost increase or schedule delays. In such cases, annual public funding may decrease as cost schedule inefficiencies increases. However, this dynamics model focuses on project management rather than on such policy decision. Therefore, annual public funding is connected by a positive causal link with cost schedule inefficiencies.

Finally, the work rate has a negative causal link from cost schedule inefficiencies and a positive causal link from annual public funding. As cost schedule inefficiencies emerge, they decrease work rate. However, as the public sector offers more annual funding, the work rate increases.

As a result, a reinforcing loop and a balancing loop appear in the traditional-approach model. Thus, the reinforcing loop indicates that cost schedule inefficiencies cause additional cost schedule inefficiencies. However, the balancing loop indicates that more annual public funding reduces cost schedule inefficiencies and results in less additional investment later. These reinforcing and balancing loops are named schedule delays and investment, respectively.

4.3 Step Two: Proposing a Space-related PPP Model

This section proposes a hypothetical dynamics model of space-related PPPs, in which multiple challenges emerge from characteristics unique to PPPs. Figure 4-4 shows the proposed model. The feature of the PPP model is the reinforcing loop which does not exist in the traditional-approach model. This reinforcing loop not only increases cost schedule inefficiencies, but also enhances conflicts of interest and revenue risk. It also decreases user satisfaction. In the following, the development process of this model is detailed.

First, this research selects key variables unique to PPPs based on the analyses of Chapters 2 and 3. Chapter 2 identified four characteristics of PPPs: risk transfer, high cost schedule efficiencies, high transaction cost, and higher pricing risk. This analysis refines these four characteristics to fit in the case studies in Chapter 3. The case studies shows that revenue risk is a typical risk transferred to the private partner. In many cases, high cost schedule efficiencies are achieved by the private partner’s investment. Furthermore, some cases face high transaction cost that emerged from conflicts of interest among parties. Higher pricing risk to users is part of user satisfaction. Therefore, this analysis chooses four key variables: private partner’s revenue risk, annual private funding, conflicts of interest among parties, and user satisfaction. Table 4-2 gives definitions of these variables.

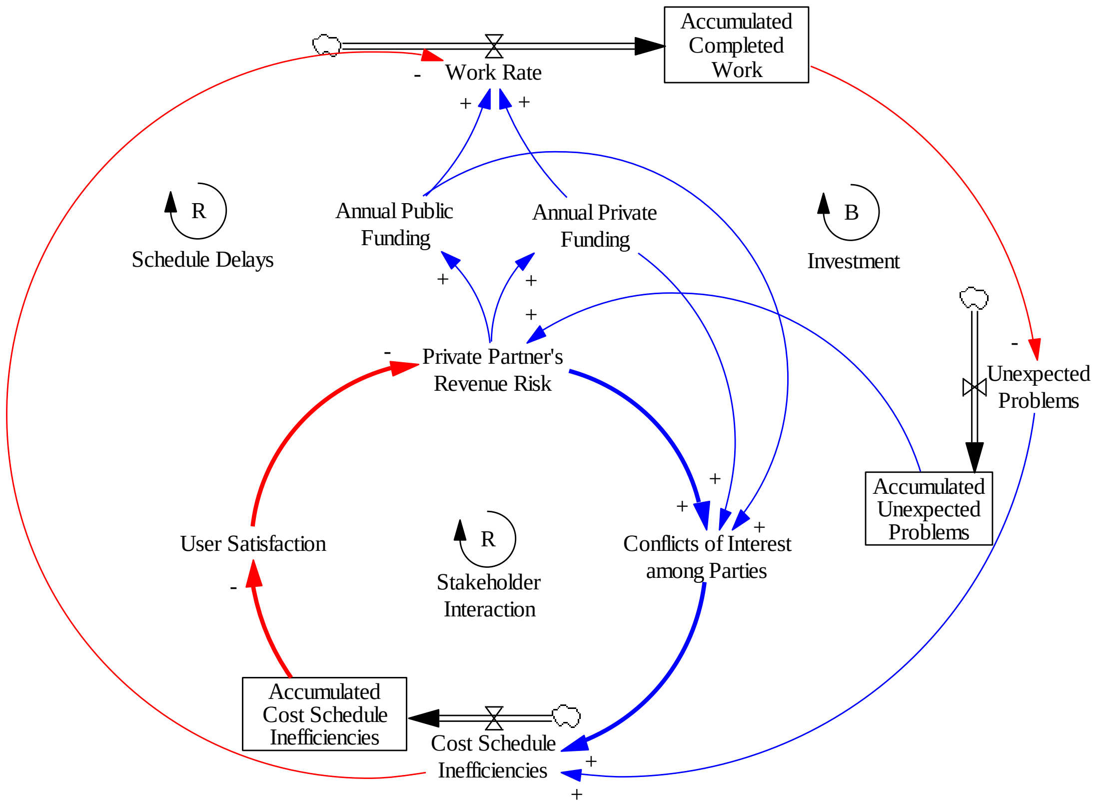

Figure 4-4: A PPP Model of Space Projects (Source: Author)

Table 4-2: Definitions of Variables Unique to the PPP Model (Source: Author)

Variables	Units	Definitions
Annual Private Funding	Currency/Time	The amount of funding annually invested in the project by the private partner
Conflicts of Interest among Parties	Currency*Time	The amount of cost and time to solve the conflicts among parties
User Satisfaction	Dimensionless	The average of two ratios: original service price to current service price; and original length to current length of development phase
Private Partner's Revenue Risk	Currency	Potential financial loss for the private partner

Next, this research connects these variables by causal links based on cause-and-effect analysis. To begin with, conflicts of interest are connected to cost schedule inefficiencies by a positive causal link. When parties have conflicts of interest, they need to spend additional cost and time to address conflicts. Therefore, as parties confront more conflicts of interest, more cost increases and schedule delays are likely to occur.

Cost schedule inefficiencies have a negative causal link to user satisfaction. As cost schedule inefficiencies increase, the project results in delivering service at higher price and behind the original schedule. The higher price and schedule delays degrade benefits of users from the project. Thus, user satisfaction decreases.

User satisfaction has a negative causal link to the private partner's revenue risk. When services of competitors are available earlier and at lower price than the service of this project, users may choose these services rather than the service of this project. They will choose competitors that deliver services at lower price and earlier. Therefore, the private partner is likely to face higher revenue risk.

The private partner's revenue risk sometimes becomes higher because of the accumulated unexpected problems. Specifically, unexpected problems consist of demand decrease and technology risk. Regarding with the private partner's revenue risk, the demand for the project may go below the originally expected demand. In such a case, accumulated unexpected problems increase the private partner's revenue risk. Therefore, the private partner's revenue risk is connected with accumulated unexpected problems by a positive causal link. Furthermore, the private partner's revenue risk also has positive causal links to annual public and private funding, respectively.

Finally, conflicts of interest among parties receive positive causal links from the private partner's revenue risk, annual public funding, and annual private funding. Conflicts of interest are often closely connected with financial issues. Therefore, as these three variables increase, conflicts of interest are likely to take additional cost and time to be solved.

As a result, variables unique to PPPs form a reinforcing loop. The reinforcing loop consists of conflicts of interest among parties, cost schedule inefficiencies, user satisfaction, and the private partner's revenue risk. It should be noted that these variables describes interests of stakeholders. In this model, when one stakeholder faces a problem, the problem incurs additional problems connected with other stakeholder interests. Each problem grows through influence from other stakeholder interests. Therefore, this reinforcing loop might explain the dynamics by which multiple challenges arise in the application of PPP approaches to space projects. Because this reinforcing loop consists of interests of stakeholders, the loop is named as stakeholder interaction.

4.4 Step Three: Testing the PPP Model

This section tests whether the hypothetical PPP model proposed in Section 4.3 explains actual challenges faced in cases of space-related PPP projects. To test the PPP model, this research applies the model to four space-related PPP projects: Galileo, QZSS, GX, and EELV. The analysis discusses whether the dynamic structures of the stakeholder interaction are consistent with these cases. Specifically, this section focuses on five variables: conflicts of interest among parties, cost schedule inefficiencies, user satisfaction, the private partner's revenue risk, and unexpected problems. The results of the analysis show that each case includes the key structures illustrated in Figure 4-5.

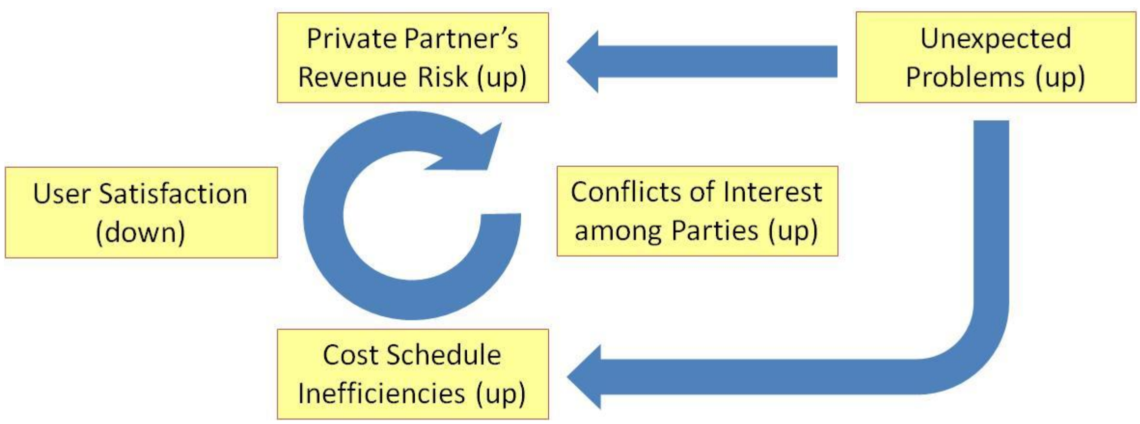

Figure 4-5: The Key Structures of the PPP Model

4.4.1 Galileo: European Global Satellite Navigation System

PPP Background

The Galileo program started as a joint initiative of the European Union (EU) and European Space Agency (ESA), assuming collaboration with the private sector. The EU is responsible for the political dimension and the high-level mission requirements. It investigated the overall architecture, the user needs, and standardization issues. ESA's responsibility covers the definition, development, and in-orbit validation of the Galileo system. ESA has worked on the new technologies needed for the satellite constellation such as high precision clocks onboard satellites.

In the EU, the European Commission has the political leadership of the Galileo program. It implements EU policies and spends EU budget as an executive arm of the EU. It also drafts proposals for new European laws. Activities of the European Commission are authorized by the European Parliament and Council of the European Union. The European Parliament consists of 785 members elected every five years by the people of Europe. The Council of the European Union consists of ministries from the national government of all the European counties [The European Union].

ESA is an international organization with 18 European countries. While ESA's mandatory activities such as space science programs and basic activities are funded by all member countries on a scale based on their Gross Domestic Product (GDP), other programs known as optional programs are funded by member countries which are interested in the programs. The Galileo program falls into the categories of optional programs [European Space Agency].

The private partner was expected to invest in the deployment of Galileo, operate Galileo, and gain revenues from user charges. The private partner was intended to collect user charges in two ways. One way was to charge manufacturers of the Galileo receiver for royalties of Galileo's intellectual property right. The other way was to collect direct access fees for value-added commercial services. By doing so, the EU expected the private partner to offset operating costs of Galileo.

Public and Private Funding

When the EU initiated the Galileo program in 2002, the EU estimated that the cost of establishing Galileo was 3.2 billion euro ($4.2 billion). According to a report of the European Commission, this cost summed up each cost for the first two of the following three phases [The European Commission, 2004b]:

- Development and validation phase

  This phase runs from 2002 to 2005 and covers the development of the satellites and related components. The cost is 1.1 billion euro. This phase should be financed entirely by the public sector.
- Deployment phase

  This phase covers 2006 and 2007 and involves the building and launching of the satellites.

The cost is 2.1 billion euro. The public sector finances a maximum of one-third of the cost in this phase. The private sector was intended to provide the two-thirds of the deployment cost and offset it with commercial revenues in the operational phase.

- Commercial operating phase

  This phase begins in 2008 and covers the management of the system. The private partner was supposed to fully finance this phase. It is estimated that the operating cost of Galileo will be 220 million euro per year.

Conflicts of Interest among Parties

Conflicts over work distribution arose in relation with public funding. The public funding came from the national governments of the EU and ESA member countries. Major financial sources of Galileo were French, German, Italian, British, and Spanish governments [Space News, 2005a]. As financial supporters, these national governments desired to receive return to their domestic space industries from the EU.

Initially, the EU planned to choose one consortium based on proposals from the private sector. Two major consortia competed in the bidding process for the Galileo concession contract [Space News, 2005a]. One consortium, iNavsat, was led by EADS of France, Germany, and Britain; Inmarsat of Britain; and Thales Group of France and Britain. The other consortium, Eurley, was led by Alcatel Space of France, Finmeccanica of Italy, Hispasat of Spain, and Arena of Spain.

However, the EU found that it was difficult to select one single contractor because the choice of the private partner was tightly connected to the work distribution to the countries. Specifically, neither of the two consortia had geographically balanced member distribution. iNavsat had no significant Italian and Spanish participation. Eurely had little German participation. If the EU chose one of the two consortia, countries with little participation in the consortium had to bear little work return from their public funding. Therefore, governments reportedly supported one consortium which involved their companies over the other. This conflict over work distribution prevented the EU from selecting one single consortium. In addition, proposals from the two consortia were equally attractive. Therefore in 2005, the EU finally asked the two consortia to merge in order to solve the conflicts [Space News, 2005a].

Even after the merger, another conflict over work distribution continued in connection with the public funding [Space News, 2005b]. Members of the merged consortium insisted that they would not agree to the Galileo concession contract until ESA member countries approved ESA's budget to start the development and validation phase of Galileo. This problem was rooted in ESA's geographical return rule. As mentioned above, ESA must collect funding from member countries to implement optional programs. To attract funding of member countries, ESA guaranteed that it would return work to each country in proportion to its government investment. Based on this rule, major member countries such as France, Germany, Italy, the UK, and Spain desired to build Galileo control centers and other infrastructures on their own territories. However, ESA did not guarantee the geographical return because such political decisions should not be made by ESA, but by the EU [Space News, 2005b]. Therefore, member countries delayed the approval of ESA's budget, insisting on their returns.

Furthermore, another conflict of interest occurred regarding the private funding due to the merger of the two consortia [Space News, 2007a]. In the Galileo program, the consortium was required to invest in the deployment phase and to offset it in the operational phase. However, because of the merger, eight members of the consortium had divergent interests and different expectations with the lack of a joint vision. This complex partnership resulted in internal disagreement over work and responsibility distributions.

Cost Schedule Inefficiencies

Schedule delays accumulated from the conflicts of interest. Public and private sectors spent a significant amount of time negotiating the merger. After the two consortia were merged, national governments negotiated the locations of Galileo control centers. Because of these negotiations, the EU had to change the timeline of signing from the end of 2005 to mid-2006. In spite of this change, the EU and the consortium still could not reach an agreement by the end of 2006. Then, the negotiation came to a stop in 2007 [The European Commission, 2007].

Another reason for cost schedule inefficiencies is that Galileo required additional technology development. ESA found that it would need a series of hardware and software modifications for the development and validation phase [Space News, 2004c]. In addition, ESA was required to add encryption and other security-related functions to Galileo. Such modifications and additional development caused schedule delays and cost increases. As a result, the initial operation of Galileo was postponed from 2008 to 2013. The total cost is reported to have reached 3.9 billion euro compared to initial cost of 3.2 billion euro [Space News, 2006].

User Satisfaction

Galileo is designed to provide five services as shown in Table 4-3. Features of Galileo are high accuracy service of less than one meter and integrity service [The European Commission, 2003]. Accuracy is the ability to determine the location precisely. Integrity is the ability to guarantee the reliability of the service. These two features are advantageous over other satellite navigation systems in the world. For example, the GPS of the United States, the most widely used system in the world, offers accuracy of 30-meter or less and it has no integrity function [U.S. DoD, 2008].

Table 4-3: Services of Galileo (Source: The European Commission, 2003)

Services	Descriptions
Open Service (OS)	This service provides accuracy of less than 15m, which is slightly better or similar to current GPS's accuracy. It will provide signals at no cost.
Safety of Life Service (SoL)	This service provides accuracy of 4-6m. It will be used for transport applications where human lives could be endangered if the performance of navigation systems is degraded without notice. Unlike the Open Service, the performance of this service has integrity.
Commercial Service (CS)	This service provides accuracy of less than 1m. It is aimed at market applications requiring higher performance. It also has integrity. The signals will be encrypted to allow access only by users who pay access fees.
Public Regulated Service (PRS)	This service provides accuracy of 6.5m. It will be used for governmental applications. Access will be limited to groups such as the police and the fire departments.
Search and Rescue Service (SRS)	This service relays distress beacons. It is aimed at Europe's contribution to the international cooperation in humanitarian search and rescue.

However, schedule delays of Galileo services degraded user benefits from its high accuracy and integrity. The Galileo program experienced five-year schedule delays. The EU's analysis predicted that unless the EU reacts quickly and decisively, the current delays may have a domino effect in terms of the investments in the downstream applications and service markets which rely on the certainty of the time schedule by which the Galileo will be put in place [The European Commission, 2007].

Additionally cost increases risked higher pricing to potential Galileo users. Because the private partner was supposed to invest two-thirds of the deployment cost and to offset it in the operational phase, the increase of the deployment cost is likely to lead to higher royalties and higher access charge.

The Private Partner's Revenue Risk

The low user satisfaction with Galileo led to increase in the private partner's revenue risk because users are likely to choose services of competitors with the service of Galileo. The EU's analysis projects that significant revenue losses can be expected resulting from a late arrival on the market in the face of the emerging global competition such as GPS III. [The European Commission, 2007] GPS III is the upgraded GPS of the United States, which will provide similar accuracy to Galileo without user charge. In addition, Russia, China, Japan, and India will start the operation of their satellite navigation systems before the operation of Galileo. Because the consortium is supposed to make profits from collecting royalties and access charges, users' choice will directly affect the revenue of the consortium.

The high revenue risk affected conflicts of interest. The consortium said that part of the conflict resulted from the difficulties of allocating Galileo risks [Space News, 2007b], including risks of financial difficulties, between the public sector and consortium. Space News argued that it was fair to assume that if the industry consortium truly felt confident of the profit-making potential of the enterprise, the negotiations would not have dragged out for this long [Space News, 2007c]. Thus, the higher the revenue risk, the more conflicts of interest occur.

Unexpected Problems

Unexpected problems in demand forecasting also made the revenue risk higher. Spude and Grimard [2008] argue that the demand forecast made in 2003 was overoptimistic regarding the business prospects for the Galileo operator. When the EU investigated user demand in 2003, the study anticipated that the total annual sales of navigation-enabled devices such as in-car navigation systems would approach just under 180 billion euro by 2020 [The European Commission, 2003]. However, as Spude and Grimard contend, it appeared that the revenue for the Galileo operator would not be as high as that for direct service to users downstream. This view suggests that the private partner's revenue risk became higher than expected because of unexpected demand errors.

Finally, in 2007, the EU announced that it would end the current PPP negotiations with the consortium and would procure all 30 Galileo satellites and associated ground segments by a traditional approach with public funding. The EU then expects the PPP to restart in the operational phase [The European Commission, 2007]. The EU also decided to divide the consortium into two consortia for competitive bidding [Space News, 2007d].

As analyzed in this section, challenges faced in the Galileo program have the same dynamics described in the PPP model. Therefore, this section concludes that the PPP model is consistent with the Galileo case.

4.4.2 QZSS: Japanese Regional Satellite Navigation System

PPP Background

The QZSS program was launched under the PPP among four Japanese ministries, MEXT, MIC, METI, and MLIT, and the private consortium, Advanced Space Business Corporation (ASBC). Both of the public and private sectors expected that the public sector's R&D efforts and public service in this program would help the private sector to develop a new market for navigation service. In addition, they expected to save project cost by sharing launch and operating costs between the two sectors [The Mainichi Daily News, 2006].

The public sector was responsible for R&D for navigation technologies and the complementary navigation service and part of the reinforced navigation service. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) aimed at demonstrating navigation systems in orbit. The Ministry of Internal Affairs and Communications (MIC) aimed at researching timing technologies for navigation systems. The Ministry of Economy, Trade and Industry (METI) aimed at developing hardware for lighter spacecraft and longer lifetime. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) aimed at developing reinforcement technologies of navigation signals. Since 2005, The Cabinet Secretariat has been responsible for the coordination among the four ministries to facilitate close collaboration.

ASBC was established by six private firms including Mitsubishi Electric and Hitachi. This consortium was responsible for the reinforced navigation service and system integration as well as telecommunication and broadcasting services [Japan MEXT, 2006]. Specifically, it envisioned to add reinforced navigation, telecommunication, and broadcasting functions to QZSS so that the consortium could provide value-added combined services such as personal navigation, car security monitoring, and traffic information services [ASBC, 2004].

Public and Private Funding

The total cost of QZSS was estimated $1.7 billion (170 billion yen). The consortium committed $800 million (80 billion yen). The public sector committed $900 million (90 billion yen). The commitment of the public sector included $200 million for common expense for four ministries and the same amount of cost for the system operation. The operating cost was supposed to be paid by the operating agency of QZSS, which would be determined later by four ministries. Each ministry must independently request budget for its own commitment. These ministries annually invested $60 to 90 million [The Mainichi Daily News, 2006].

Conflicts of Interest among Parties

A conflict over the operating agency arose from public funding. Although four ministries initially planned to determine the operating agency of QZSS by mid-2006, they could not reach an agreement. One reason for the conflict was the severe financial situation of the Japanese government. Because financial constraints were unlikely to allow ministries to increase their annual budgets, the ministry that would become responsible for the operational phase of QZSS would have to reduce the budget for its other space projects in order to add the budget for the operation of QZSS [Space News, 2004f]. Another reason for the conflict was that navigation services were new and available to a wide range of areas [Tech-on!, 2004]. Thus, no one could foresee the clear legal framework for applications of QZSS. Such high uncertainties prevented the ministries from determining the operating agency of QZSS.

Accordingly, the consortium insisted that it would not be able to commit its investment before the ministries agreed to the operating agency [Space News, 2004e]. The consortium desired to exclude financial uncertainties from the project because it realized that the project may include high business risk.

Cost Schedule Inefficiencies

Negotiations among parties led to cost schedule inefficiencies. The public sector announced in 2004 that the operating agency would be determined by the end of the in-orbit demonstration phase of QZSS, which would last from 2008 to 2011 [Japan Cabinet Secretariat, 2004]. Subsequently, the consortium postponed to decide its business plan. Although it initially planned to decide the business plan by 2004 [ASBC, 2003], the decision had not been made until 2006. As a result, launch years of QZSS were also postponed from 2008 and 2009 to 2009 and 2010, respectively. The current launch year of the first QZSS satellite is planned in 2010.

User Satisfaction

Schedule delays decreased user satisfaction with QZSS. Expected users faced increasing economic loss which emerged from longer waiting time. In addition, similar to the Galileo case, schedule delays were likely to affect investment in the downstream applications. Therefore, fewer applications would be available to users than originally expected.

The Private Partner's Revenue Risk

The low user satisfaction led to increase the revenue risk of the consortium. While the consortium agreed to invest $800 million in QZSS, it estimated in 2006 that the revenue would be only $200 million from 2010 through 2021 [ASBC, 2006]. This revenue was significantly lower than the 2004 estimate of $810 million [ASBC, 2004].

The consortium explained the reason, saying that terrestrial telecommunication and broadcasting network expanded rapidly. This terrestrial network transmitted reinforced GPS signals via GPS based control station on the ground [ASBC, 2006]. Therefore, users were willing to choose these ground based services rather than wait for QZSS.

Unexpected Problems

Another reason for the increased revenue risk would be unexpected cost and demand change. As of 2003, it was difficult to accurately forecast cost estimate and user demand between 2010 and 2021. Therefore, as the project progresses, user demand decreased and cost estimate increased. For example, while the consortium assumed the total project cost of $1.7 billion in

2003, it reached up to $2.23 billion in 2006 [ASBC, 2006]. Although the forecast of user demand is not disclosed, similar forecasting error might have occurred.

As a result, the consortium asked the public sector to provide the additional public funding of $1.13 billion. Because the public sector could not accept the proposal, it decided to develop QZSS by traditional approach. This modified plan consists of two steps. In the first step, it will launch only the first QZSS satellite for technology demonstration purpose. JAXA, a R&D agency of MEXT, will be the agency responsible for the operation of QZSS in this step. In the second step, after evaluating the result in the first step, the public sector will discuss the feasibility of the PPP approach with the private sector. Based on this modified plan, four ministries jointly established the non-profit organization, Satellite Positioning Research and Application Center (SPAC). This organization coordinates user needs instead of ASBC. The launch of the first satellite is scheduled in 2010.

This section demonstrated that the PPP model explained challenges faced in the QZSS program. Therefore, it concludes that the dynamic structures in the PPP model are included in the QZSS case.

4.4.3 GX: Japanese Medium-size Launch Vehicle

PPP Background

In the GX launch vehicle project, MEXT and METI collaborate with the private sector under private sector initiatives. This collaboration allows the private sector to receive technical and financial support from the public sector. It also allows the public sector not only to save cost for the in-orbit demonstration, but also to immediately transfer new technologies to the industry.

The private sector aims at a commercial launch business for medium-to-small satellites. For this purpose, it desires high-performance, low-cost and high-reliability launch vehicles. In 2001, nine companies led by IHI established the consortium, Galaxy Express Corporation (GALEX). GALEX is responsible for the project. It arranges to procure the first stage of Atlas III and to integrate the system.

JAXA, a R&D agency of MEXT, is committed to develop and transfer the upper stage of GX to the consortium. JAXA selected a liquefied natural gas (LNG) engine as the upper stage.

METI is committed to finance the system integration of GALEX. MEXT and METI request their budget independently.

Public and Private Funding

The total cost of GX was estimated $450 million (45 billion yen) except costs for test flights and a launch pad. GALEX, MEXT, and METI were committed to invest $150 million (15 billion yen), respectively. They were supposed to decide cost allocation for test flights and the launch pad later. The GX project undertook the development in 2002 and was scheduled to launch the first test vehicle in 2005.

Unexpected Problems

Multiple technical problems occurred from 2002 through 2005 when JAXA developed the upper stage of GX. First, the tank made by composite material flaked because of insufficient strength. Additionally, the specific impulse of the engine and the engine weight could not meet the original specification. To solve these problems, JAXA changed the composite tank to the metal tank. In addition, JAXA added a boost pump to the propulsion system. Although the upper stage initially aimed at a simple and efficient design, the design changes increased the complexity of the design. Furthermore, irregular combustion pressure occurred in this modified engine. All of these problems had not been foreseen at the beginning of the project.

Cost Schedule Inefficiencies

A series of unexpected technical problems gradually delayed the schedule and increased the development cost. The first test flight was postponed from 2005 to 2006, then to 2011. According to the current plan, it is scheduled in 2012. While JAXA estimated the development cost of $100 million at the starting point of the project, the current estimate is approximately $300 million.

Schedule delays in the upper stage development affected the development plan of the overall project. Although the consortium planned to procure the first stage of Atlas III for the first stage of GX, Atlas III was retired in 2005. Therefore, the consortium had to adopt the first stage of Atlas V, a successor of Atlas III. Moreover, schedule delays caused additional costs for contract payment and infrastructure maintenance. Consequently, the total cost of the project increased from the original $450 million plus cost for test flights to somewhere between $830 million and $1380 million [JAXA, 2008b].

User Satisfaction

Schedule delays decreased user satisfaction for GX. Potential users lost expected benefits from GX because of the schedule delays. They were concerned about uncertainties of launch schedules. The consortium stated that an urgent issue for the consortium was to secure the trust of medium-to-small satellite operators [IHI, 2006].

Furthermore, the increase of the development cost is likely to raise the service price of GX. The cost of the first test flight is forecasted $150 million, which is high for a launch of a medium-to-small satellite [JAXA, 2008a]. Although the consortium does not disclose the unit price for a commercial launch of GX, the cost increase would affect the launch price. However, the consortium states that because test flights are very costly in general, the cost for a test flight could be more than twice of the price for a commercial launch [Japan Space Activities Commission, 2008b].

The Private Partner's Revenue Risk

While the consortium says that GX's launch business is feasible based on its current market analysis and launch cost, it also admits that additional investment would degrade the feasibility [Japan Space Activities Commission, 2008a]. To avoid the additional cost increase, the consortium proposed in 2008 to shift the GX project from the private sector initiative to the public sector initiative. According to the proposed plan, JAXA is intended to extend its responsibility to cover the overall project including the first stage and the system integration. The public sector is also supposed to finance all cost for test flights and the launch pad. In this plan, the consortium states that it will support the public sector in the development phase and do the planned commercial launch business in the operational phase.

Conflicts of Interest among Parties

The consortium's proposal causes conflicts of interest between the public and private sectors. Because the consortium aims at entering into the commercial launch market, the important factors for GX are high performance, low cost, and high reliability. However, the public sector aims at not only fostering commercial space business, but also developing advanced technologies and securing assured access to space.

First, the public sector needs to confirm whether the public sector's investment in GX will lead to create new space business although the consortium states that its business is feasible. Specifically, the public sector plans to survey launch demand in the international launch market. It will also investigate whether the price and performance of GX are competitive in the market. However, in the public sector, there are some opinions that the public sector should not intervene in the company's business decision because the company is responsible for its own decision.

Second, the public sector is required to develop new technologies from the long-term perspective while the private sector is interested in short-term profits. From this aspect, in the GX project, the public sector aims to develop LNG propulsion technologies, which might be useful for inter-orbit transportation systems. It also aims to learn U.S. Atlas V technologies. Currently, cost to benefit on these issues is under discussion.

The market and R&D issues discussed above have also influenced on the project even before the consortium proposed the new plan. In 2006, when the project faced the irregular combustion pressure of the LNG engine, two different proposals about design changes were discussed to solve the problem. One proposal adopted a minor design change which kept the method to burn liquid propellant. This option included low schedule risk while it was unclear whether the change would fix the technical problem. The other proposal adopted a more radical change which used a new method to burn gas propellant. This option included high schedule risk although the technical problem would be completely fixed. The second option was also expected to reduce cost in the long-term scale. The consortium preferred the first option while the public sector supported the second option. After a negotiation, the second option was chosen as the primary solution although the first option was also adopted as a backup.

Third, the public sector gives a high priority on assured access to space. In the proposal of the consortium, it plans to launch GX at the Vandenberg Air Force Base as an option. This option may not only achieve the $500 million cost reduction at most, but also enhance the launch capability of GX. However, when GX is launched in the United States, it may be affected by U.S. regulation and political constraints. Therefore, the public sector is investigating the influence of this option on assured access to space.

Because these issues cannot be solved immediately, they are likely to cause additional cost increase and schedule delays.

This section analyzed the case of the GX project in terms of dynamic structures by which challenges emerge. As discussed above, the GX program includes the same dynamic structures described in the PPP model. Therefore, this section concludes that the PPP model explains challenges that emerged in the GX case.

4.4.4 EELV: U.S. Evolved Expendable Launch Vehicle

PPP Background

The EELV program consists of three phases: the low cost concept validation (LCCV) phase, pre-engineering and manufacturing development (Pre-EMD) phase, and development phase. In the final phase, contractors were responsible for developing reliable and efficient launch vehicles based on their technologies developed in previous phases. This analysis focuses on the final phase because this phase clearly describes the dynamic structures of PPPs.

In the final phase, DoD initially planned to choose one single contractors from Boeing and Lockeed Martin and to fully finance the development cost [RAND, 2006]. The ultimate goal of EELV was to reduce government's unit launch cost by 25-50%. DoD viewed that choosing one single contractor would be suitable to the commercial demand at that time.

However, a higher commercial launch demand forecast than previously envisioned changed DoD's strategy [RAND, 2006]. The 1997 forecast projected by the U.S. Commercial Space Transportation Advisory Committee (COMSTAC) nearly tripled the 1994 forecast projected by DoD [Saxer, 2002]. Therefore, DoD was inclined to the new strategy of retaining the two contractors and procuring better service of them. DoD expected this strategy to provide not only two proven launch services, but also lower unit launch cost because the competition among the contractors would facilitate their cost reduction efforts [RAND, 2006]. Finally, DoD decided in 1997 to retain both Boeing and Lockheed Martin as final contractors.

Under the two-contractor strategy, DoD transferred part of its financial responsibility to the private partners with the anticipation that robust commercial demands would provide sufficient funding to them. If a contractor provides better service than the other partner's, the wining contractor would handle the majority of the DoD's launch needs as well as commercial launch needs [Space News, 1998].

Public and Private Funding

In the final phase, DoD evenly split the originally planned $1 billion between Boeing and Lockeed Martin. Boeing and Lockheed Martin reportedly invested $2.3 billion and $1.6 billion, respectively, in their development activity. DoD also started the "buy" strategy, which awarded launch services contracts totaling some billion dollars to the two contractors based on competitive bidding [RAND, 2006].

Unexpected Problems

As the program progressed, an unexpected problem emerged. By 2002-2003, the failure of commercial customer market materialized [RAND, 2006]. The significant decrease of demand was partly because demand was deteriorated in the broadband market. During 2001, Astrolink and Wildblue suspended 4 satellites and 2 satellites, respectively. Several other companies that had been expected to procure broadband satellites also signaled their intention to defer such programs. These decisions indicated satellite service providers' intentions to reduce risk exposures and focus on near-term financial results. [U.S. FAA and COMSTAC, 2002]. In addition, satellites have become more capable. Therefore, fewer and more expensive satellites with longer lifetime are major occupation of the market. As a result, the world's launch capability resulted in oversupply [RAND, 2006].

Cost Schedule Inefficiencies

The collapse of the expected commercial launch market caused significant cost increase to all of DoD, Boeing, and Lockheed Martin. The two competitors had to work in low production rate and then the unit cost increased. DoD had to spend additional funding to retain the two EELV rocket lines [Space News, 2003 and 2004b]. Estimated costs for the launch service procurement also increased along with the total cost of the program. DoD's 2003 cost estimate for the program showed an average procurement unit cost for EELV launch services that was 77 percent higher than its 2002 cost estimate [U.S. GAO, 2004].

User Satisfaction

The EELV failed in maintaining the user satisfaction of commercial launch customers because the increase in production costs led to high launch prices. Although there were no significant schedule delays or launch failures, the impact of higher prices was critical. On the other hand, the U.S. government was a more patient customer than commercial customers because it had invested a lot of funding in the program. The RAND report says that the U.S. government is the only likely customer [RAND, 2006].

The Private Partner's Revenue Risk

The low satisfaction of commercial users increased revenue risk to the two contractors. In 2004, Delta IV of Boeing withdrew the commercial launch market. Although Atlas V remained in the launch market, there were no sales in 2003 [Space News, 2004a]. Foreign launch vehicles such as Ariane 5 had more commercial competitiveness than EELV. In addition, the world's launch capability was oversupply.

To help the private partners reduce revenue risk, DoD decided in 2004 to finance annual fixed infrastructure costs for the private partners, including costs for production facilities and supplier readiness [U.S. GAO, 2004]. Regarding to infrastructures, DoD shifted contracts from fixed price contracts to cost plus contracts [RAND, 2006]. While fixed price contracts require the private partners to be responsible for cost increase, cost-plus contracts require the public sector to pay for cost increase.

Conflicts of Interest among Parties

DoD and Congress had conflicts over two interests: assured access to space and cost reduction. Since 2002, the Air Force has stated that it is important for the United States to keep two sources of launch vehicles available for assured access to space because a single launch failure usually results in the loss of six to eight months of launch services [Saxer, 2002]. DoD officials also stated that the case for keeping two rocket families outweighed any economic argument for going down to one [Space News, 2003].

However in 2004, the U.S. House Appropriations Committee questioned the two-contractor strategy in a report accompanying the House version of the 2005 Defense Appropriations bill, stating that fully funding one contractor may be a wiser approach to assured access than the current approach of underfunding two contractors [Space News, 2004d]. The committee indicated in the report that it understood the concept of a backup launcher, but questioned whether this approach is practical given the two-year lead time required to buy launch vehicles from the second vender. The committee stated that a more effective approach might be to invest more money in a single contractor to improve reliability of its rocket to avoid accidents.

In 2005, the U.S. president, George W. Bush signed a new U.S. space transportation policy, which directed DoD to keep Delta IV and Atlas V for the foreseeable future as follows: “The Secretary of Defense shall maintain overall management responsibilities for the Evolved Expendable Launch Vehicle program and shall fund the annual fixed costs for both launch services providers” [U.S. White House, 2005]. Thus, the U.S. government supported DoD’s stance which gave a higher priority on assured access to space over cost saving.

However, because of the continuing revenue risk, Boeing and Lockheed Martin decided in 2005 to establish the United Launch Alliance (ULA), a joint venture that offers launch services to government missions [SpaceRef, 2005]. They intended to consolidate business, engineering, and manufacturing activities while maintaining Delta IV and Atlas V families. The Federal Trade Commission (FTC) approved the merger under the condition that ULA was nondiscriminatory to other companies seeking launch services [U.S. GAO, 2008].

This section demonstrated that the PPP model was consistent with the case of the EELV program in terms of dynamic structures by which challenges occurred in PPPs. Therefore, this section concludes that the PPP model consistently explains challenges in the EELV case.

4.5 Results of the Analysis

Analysis in Section 4.4 has verified that the proposed PPP model in Figure 4-4 successfully passes the tests of all the four cases. These four tests showed that they included the common reinforcing loop, named stakeholder interaction, in their PPP dynamic structures. The reinforcing loop includes conflicts of interest among parties. Such conflicts include multiple issues such as work distribution, legal framework, R&D interest, and assured access to space. Once the conflicts of interest occur, they incur cost schedule inefficiencies such as cost increase and schedule delays. Then, cost schedule inefficiencies lead to decrease user satisfaction due to higher price and delayed service delivery. Degradation in user satisfaction results in increasing the private sector’s revenue risk. Thus, users choose other available services offered by competitors. Finally, the private sector's high revenue risk causes additional conflicts of interest among parties.

In the dynamic structures, unexpected problems also play important role. They include demand decrease and technical problems. The unexpected problems accelerate the feedback of the reinforcing loop through the private partner's revenue risk and cost schedule inefficiencies. From technological aspect, unexpected problems such as design changes are more likely to emerge in the early stage of the project. However, from market aspect, unexpected problems such as demand decrease can occur in any phases of the project.

To better understand the influence of the reinforcing loop, this research runs a simple simulation. The purpose of this simulation is to visualize an example of behaviors of the PPP model. Therefore, the outcome does not include quantitative implications. To implement the simulation, this research allocates to each causal link an equation which defines relationship between two variables connected by the causal link. Because no precise data about the relationships are available, this simulation uses a set of purely hypothetical equations. The equations are listed in Table 4-4.

Figure 4-6 and Figure 4-7 show an example of behaviors of the PPP models. Some variables are compared with those in the traditional-approach model. Other variables are unique to the PPP model. As the graphs show, conflicts of interest among parties and the public sector's revenue risk increase while user satisfaction decreases. Consequently, the project is completed later in the PPP model than in the traditional-approach model as shown in the graph of the accumulated completed work.

Moreover, it should be noticed that the accumulated cost schedule inefficiencies are higher in the PPP model than in the traditional-approach model. However, one problem in these behaviors is that the cost schedule inefficiencies in both models behave similarly in the early stage of the project. Therefore, it would be difficult to predict in the early stage whether the PPP project will be completed efficiently or will result in facing multiple challenges. The reason for the similar behaviors in the early stage is that the reinforcing loop in the PPP model work more intensively in the later stage. Therefore, it might be important to carefully analyze the dynamic structures of the project before starting a PPP project. The next chapter analyzes how to improve the dynamic structures to avoid challenges in PPP projects.

Table 4-4: Equations Used in the Simulation (Source: Author)

Variables	Equations
Work Rate	= (Annual Public Funding + Annual Private Funding)*2 /(1+140*Cost Schedule Inefficiencies)
Accumulated Completed Work	= INTEG (Work Rate, 0)
Unexpected Problems	=0.8/(Accumulated Completed Work+1)+0.2
Accumulated Unexpected Problems	= INTEG (Unexpected Problems, 0)
Cost Schedule Inefficiencies	= Conflicts of Interest among Parties/60+Unexpected Problems/60
Accumulated Cost Schedule Inefficiencies	= INTEG (Cost Schedule Inefficiencies, 0)
User Satisfaction	=1/(1/3*Accumulated Cost Schedule Inefficiencies+1)
Private Partner's Revenue Risk	=3*(1/User Satisfaction-1)+Accumulated Unexpected Problems
Annual Public Funding	=0.5+Private Partner's Revenue Risk/50
Annual Private Funding	= 0.5+Private Partner's Revenue Risk/50
Conflicts of Interest among Parties	=(Annual Private Funding + Annual Public Funding + Private Partner's Revenue Risk)*0.04

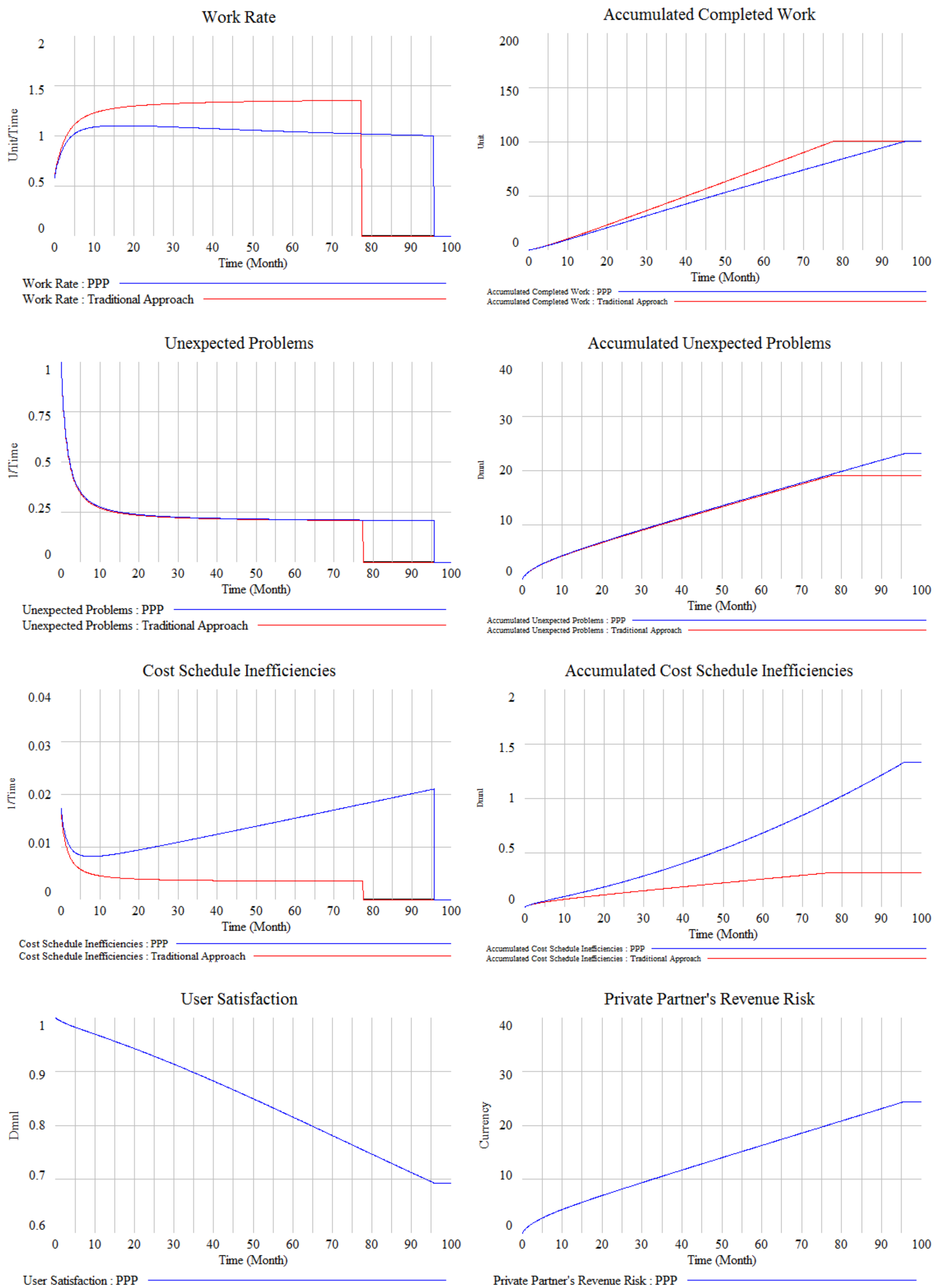

Figure 4-6: An Example of Behaviors of the PPP Model (1) (Source: Author)

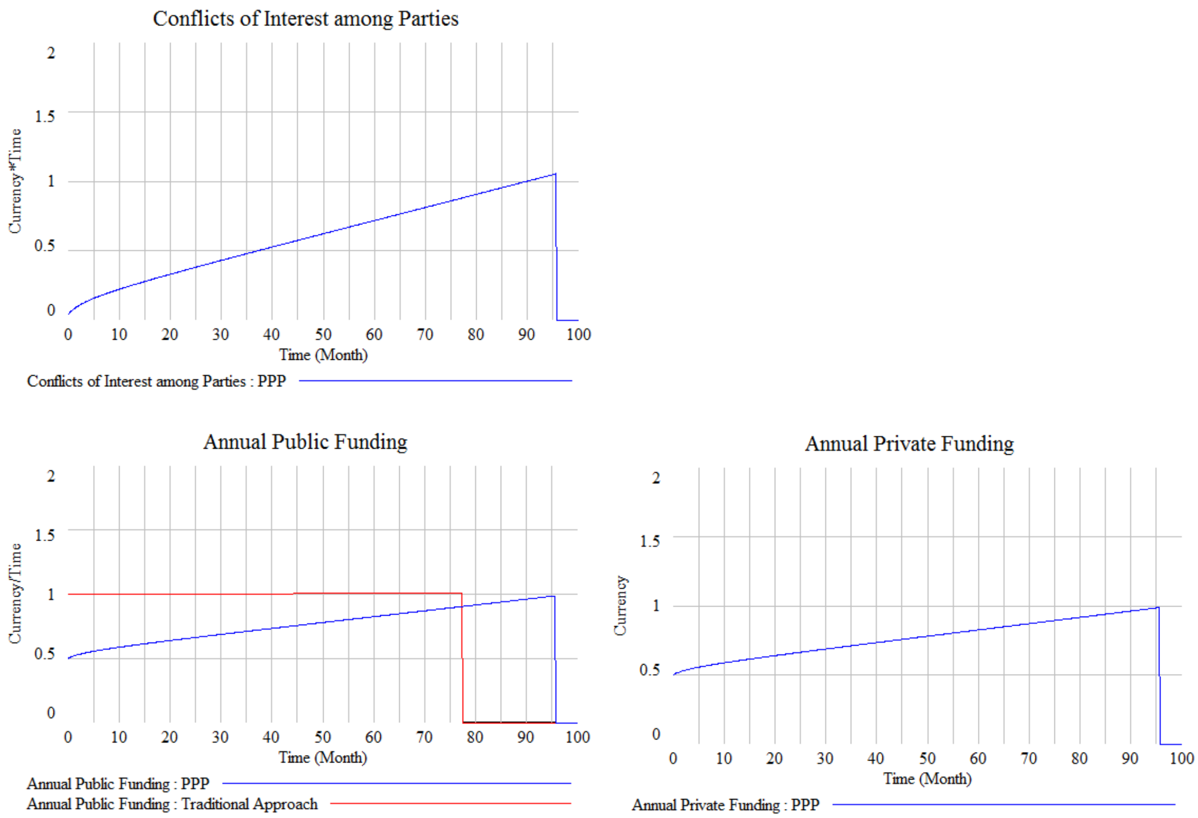

Figure 4-7: An Example of Behaviors of the PPP Model (2) (Source: Author)

5. Improving the Dynamics Model of Space-related Public-Private Partnerships

This chapter addresses the second research questions. Thus, the purpose of this chapter is to investigate ways to improve the dynamic structures of PPPs discussed in Chapter 4. According to the results of Chapter 4, sources of multiple challenges in PPPs are the reinforcing loop of the PPP model and unexpected problems. Therefore, improving these factors makes PPPs a more effective approach for space projects.

To accomplish this purpose, first, this research analyzes the reinforcing loop of the PPP model. It focuses on three PPP characteristics included in the reinforcing loop: conflicts of interest among parties, user satisfaction, and the private partner’s revenue risk. Second, it also analyzes unexpected problems because it plays an important role as a source of multiple challenges in the PPP model.

The analysis results in three new lessons for improving the dynamic structures of space-related PPPs. These lessons are (1) to set cost saving as the primary goal, (2) to choose the government customer market, and (3) to adopt conservative technical and demand forecasts. In identifying these lessons, this research examines whether the reinforcing loop is improved by existing lessons that have developed in prior work. By doing so, this research can strengthen the validity of these existing lessons. The examination of existing lessons also helps to find new lessons.

5.1 Conflicts of Interest among Parties

Four space-related PPP cases in Chapter 4 identified various conflicts of interest among parties. Table 5-1 summarizes these interests that worked as sources of conflicts.

A common source of conflicts across all the four cases is the allocation of funding. As shown in Table 5-1, in all cases, the public sector aims to save public funding by involving the private partners. Thus, for the public sector, the expected benefit of adopting PPP approaches is primarily cost saving. This trend is consistent with the discussion in Section 2.3, which argues that in terms of the public sector, the rationale of PPPs is to address budgetary constraints. On the other hand, private partners desire more public funding for projects. Because the goal of private partners is profit maximization, this kind of conflicts would be inevitable in PPP projects.

Table 5-1: Interests of the Public Sector and Private Partners (Source: Author)

Cases	Interests of the Public Sector	Interests of Private Partners
Galileo	• Saving public funding • Work distribution	• Additional public funding • Work distribution
QZSS	• Saving public funding • Legal framework	• Additional public funding
GX	• Saving public funding • Technology development • Assured access to space	• Additional public funding
EELV	• Saving public funding • Assured access to space	• Additional public funding

Table 5-1 also indicates two other sources of conflicts. One source of conflicts is that the public sector has no experience even in traditional approaches. Galileo is the first case of collaboration between the EU and ESA. Therefore, conflicts emerged over work distribution schemes: ESA has the geographical return rule while the EU does not. In the case of QZSS, QZSS is the first Japanese satellite navigation system. Therefore, there is no framework of legal responsibility in the operational phase of the system. High uncertainties on the legal framework made it difficult to allocate legal responsibility among ministries. In both cases, conflicts are closely connected with the lack of experience.

Another source of conflicts is that the project pursues multiple goals. In the GX project, the public sector aims at developing new technologies and fostering the competitive space industry as well as saving cost. In the EELV program, DoD originally gave a high priority on cost saving. However, DoD subsequently emphasized the priority of assured access to space over cost saving. In both cases, conflicts are tightly connected with multiple goals.

To reduce these sources of conflicts, Bochinger (2008) suggests that visible policy/regulatory environment is prerequisite. He also argues that clients must clearly qualify and quantify their requirements. His first point about policy/regulatory environment would effectively reduce conflicts which emerge from the lack of experience. In fact, as analyzed in

Chapter 3, the UK Ministry of Defense (MOD) succeeded in the PPP of Skynet 5 because visible policy/regulatory environment was built on experiences on its precedent, Skynet 4, developed by traditional approach. Bochinger's second point would also address conflicts which emerge from multiple goals. Again in Skynet 5, the UK MOD focused on procuring secure communication services at low cost.

In addition to Bochinger's lessons, this research proposes a new lesson: the primary goal of space-related PPP projects should be cost saving. Taking into consideration that the rationale of PPPs is to address budgetary constraints, the public sector should give a high priority on cost saving as the goal of the PPP project. As shown in Table 5-1, cost saving often causes conflicts of interest between the public sector and private partners. If the project gives higher priorities on other goals than cost saving, additional conflicts of interest occur in the connection with the multiple goals. Therefore, the public sector should choose cost saving as the primary goal of the project. Unless it is feasible, the project would not be suitable to PPP approaches.

Lesson 1: *The primary goal of space-related PPP projects should be cost saving.*

5.2 User Satisfaction

In the PPP model, more cost schedule inefficiencies result in less user satisfaction. Cost increase leads to higher pricing risk to users. In addition, schedule delays reduce benefits for users. However, prior work has never discussed lessons about this issue.

Low user satisfaction with PPP projects causes two types of problems. First, when the market is competitive, users do not want to choose the service of the PPP project. Users pursue lower cost, higher quality, and earlier timing services offered by competitors. Therefore, as the PPP model shows, the private partner's revenue risk increases. Second, when the market is not competitive, thus monopolistic, users have no options but to choose the service of the PPP project. Therefore, users face higher pricing risk. In this light, lessons to avoid both problems are necessary.

One lesson proposed by this research is that space-related PPP projects should choose the government customer market rather than the commercial customer market. This lesson can solve both problems discussed above. First, because the government customer market is usually less competitive than the commercial customer market, government customers are more likely to bear cost increase and schedule delays than commercial customers. In addition, government customers are often the sponsor of the PPP project. In such cases, they would be more patient. Therefore, the government customer market is helpful to reduce the impact of user satisfaction on revenue risk. Second, the government customer market prevents private partners from setting monopolistic prices to commercial customers. Although private partners might set monopolistic prices to government customers, the public sector can easily oversee the service price as customers. In the commercial customer market, it would be difficult for the public sector to carefully oversee the price. Therefore, the government customer market is more suitable to PPP approaches than the commercial customer market.

Lesson 2: *The government customer market is more suitable for space-related PPP projects than the commercial customer market.*

5.3 The Private Partner's Revenue Risk

Revenue risk is one of the most influential factors for private partners. Additionally, as the PPP model shows, it is a source of conflicts of interest among parties. To reduce revenue risk, Bochinger (2008) points out the importance of a secured market. He argues that long-term cash flow is required for private sectors to commit the project. Similarly, Spude and Grimard (2008) contend that the market for PPPs should be large and profitable enough to justify the investment. Spude and Grimard specifically mention that the clear candidate for PPPs is the downstream value-added services. These lessons would be useful to reduce revenue risk of private partners.

This research compares the commercial customer market and the government customer market in terms of the private partner's revenue risk, taking the lesson 2 into consideration. First, in the commercial customer market, private partners are usually responsible for most part of revenue risk because the public sector rarely does business in the commercial customer market. Therefore, the private partner's revenue risk is high. Exceptions are shadow toll and availability payment. In the case of London highways, users do not pay highway toll [Howells, 2008]. On behalf of users, the public sector pays fees to private partners by the shadow toll and availability payment. Shadow toll refers to the method in which the public sector pays based on the number of vehicles using the road and the distance of they traveled. Availability payment refers to the method in which the public sector pays based on safety and congestion performance. These payment methods are designed to share the revenue risk of projects between the public sector and private partners.

Second, in the government customer market, private partners are usually responsible for little revenue risk because the demand is determined by the public sector, not by market principles. For example, in the case of Skynet 5, the private partner gains revenue by meeting MOD's nominal requirements. The payment of MOD covers the development and operating costs for the private partner. For additional revenue, the private partner can sell the extra capacity to third party users. As described in this example, in the government customer market, the private partner's revenue risk is lower than in the commercial customer market.

In light of the above discussion, the government customer market is more suitable to space-related PPPs than the commercial customer market. The conclusion of this section is consistent with the lesson 2.

5.4 Unexpected Problems

Unexpected problems occur regardless of PPPs or traditional approaches. As described in Chapter 4, both of the PPP model and the traditional-approach model include unexpected problems. This section discusses how to mitigate the influence of unexpected problems on the reinforcing loop in the PPP model.

In the PPP model, two types of unexpected problems may occur. One type is technical problems. In the cases of GX, unexpected technical problems such as design changes caused cost increase and schedule delays. In space projects, engineers carefully estimate technology risk to avoid such unexpected problems. However, it is impossible to predict every single technical problem that occurs during the project. In particular, space projects require high technology standard under highly uncertain circumstances. Therefore, unexpected problems are the nature of space projects regardless of PPPs or traditional approaches. In other words, technical risk of space projects inherently tends to be underestimated.

The other type of unexpected problems is demand decrease. Galileo, QZSS, and EELV faced demand decrease which had not been foreseen at the beginning of the projects. As shown in the PPP model, unexpected demand decrease results in not only increasing the private partner's revenue risk, but also causing cost schedule inefficiencies. To preventing unexpected demand decrease, it is important to accurately forecast user demand at the beginning of the project. However, it is often unfeasible to gain a reliable demand forecast because demand forecasts inherently include uncertainties.

Bent Flyvbjerg et al. [2003] first systematically investigated differences between demand forecast and actual demand of transport infrastructure projects, regardless of PPPs or traditional approaches. They surveyed forecasting errors of more than 200 large-scale transport projects in 20 developed and developing countries. As shown in Figure 5-1, a lot of large-scale infrastructure projects in the world have experienced unexpected demand decreases. Flyvbjerg et al. concluded that forecasting errors on demand of transport projects were very common and systematically overestimated [Prud'homme, 2004].

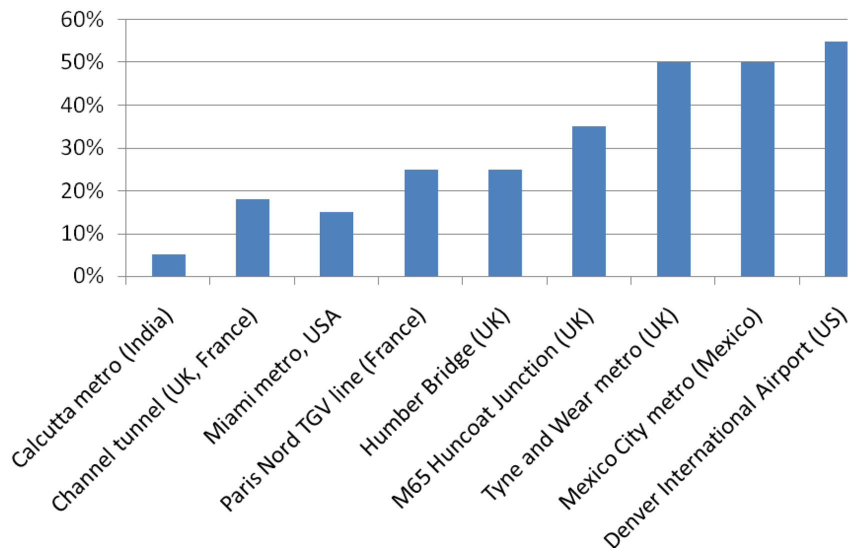

Figure 5-1: Actual Traffic as Percentage of Forecast Traffic for Opening Year in Projects that Have Experienced Serious Revenue Problems (Source: Flyvbjerg et al., 2003)

Prud'homme [2004] analyzed three main types of errors on demand forecast: economic, technical, and institutional errors. First, economic errors arise from the change of the overall economic climate. For example, decisions of potential users are heavily dependent on their income. Such economic changes are beyond the responsibility of the project planner. Second, technical errors occur in relation to technical difficulties of the project. Insufficient data and immature methodology reduce accuracy of demand forecasts. For instance, in many countries, there is no continuous generation of field data. Although demand may be forecasted by asking people what they would do in defined decision situations, actual behavior of people may, and often does, deviate substantially from the stated preferences. Third, institutional errors explain the systematic error toward overestimate of demand. Project promoters want the project to be constructed because they often have interests in the project. In addition, they are unlikely to be affect by the failure of forecasts. Institutional errors explain why differences between forecast and actual number are not statistically random, but overestimated [Flyvbjerg, 2003].

Although it is unclear how much institutional error is included in demand forecasts of space projects, the case studies of space-related PPPs show that their demand forecasts tend to be overestimated. Putting together the analyses of technical risk and demand forecast, this research concludes that both technical and demand forecasts tend to be overestimated. Therefore, this research proposes the following lesson.

Lesson 3: *Space-related PPP projects should adopt conservative technical and demand forecasts.*

5.5 Lessons for Future Space-related PPPs

The analysis in this chapter focused on four key variables of the PPP model: conflicts of interest, user satisfaction, the private partner’s revenue risk, and unexpected problems. Then, it developed three new lessons to improve the dynamic structures that cause challenges in space-related PPP projects.

First, the analysis reviewed existing lessons founded in prior work in relation with the above four variables. The existing lessons learned are listed in Table 5-2. The analysis demonstrated that each of the existing lessons would effectively improve the reinforcing loop of the PPP model. Therefore, these lessons are expected to reduce challenges in space-related PPPs. The PPP model contributed to strengthening the validity of these existing lessons.

Table 5-2: Existing Lessons Founded in Prior Work
(Sources: Bochinger, 2008; Spude and Grimard, 2008)

Visible policy/regulatory environment is prerequisite
Clients must clearly qualify and quantify their requirements
Long-term cash flow is required for the private sector to commit the project
The market for PPPs should be large and profitable enough to justify the investment. The clear candidate for PPPs is the downstream value-added services

Second, this research developed three new lessons to improve the reinforcing loop. Table 5-3 listed them. The first lesson is useful to avoid conflicts of interest among parties. The second lesson reduces influences of user satisfaction and revenue risk on PPPs. The third lesson helps to avoid the underestimate of technology risk and the overestimate of demand forecast. These new lessons complement existing lessons and would work effectively when they are used together.

Table 5-3: New Lessons Developed in this Research (Source: Author)

The primary goal of space-related PPP projects should be cost saving.
The government customer market is more suitable for space-related PPP projects than the commercial customer market.
Space-related PPP projects should adopt conservative technical and demand forecasts.

Part of these lessons result from features unique to space projects. One feature is that many space projects include multiple goals with delicate balance. This is applicable not only to PPPs, but also to traditional approaches. Because of this feature, space projects are likely to face complex trade-offs between goals when the projects do not make progress as planned. The reason for setting multiple goals in one single project would be that space missions are suitable to broad purposes such as national security, industry competitiveness, and technological innovation.

Another feature of space projects is high technology risk. Because any space project may face more or less unexpected technical problems, interests of stakeholders are continuously affected by the unexpected problems. As a result, space projects are more likely to cause conflicts among stakeholders than projects in other fields.

While PPP projects usually include more complex dynamic structures than projects in traditional approaches, these features unique to space projects tend to make the dynamic structures more complex.

6. Policy Implications

This chapter addresses the third research questions. It discusses how policymakers might apply PPP approaches to future space projects. In Chapter 5, this research discussed lessons to improve the dynamic structures. Based on this discussion, this chapter proposes a strategy for the future application of PPP approaches to space projects. To develop the strategy, this analysis first discusses implications of new and existing lessons identified in Chapter 5. These lessons suggest that PPP approaches are more suitable for the government customer market than the commercial customer market. Secondly, the analysis reviews space-related PPP cases discussed in Chapter 3. These cases imply that telecommunication, Earth observation, and meteorological monitoring for governments' use might be suitable to PPP approaches.

6.1 Implications of Lessons

Two of the seven lessons in Chapter 5 suggest the choice of markets for PPP approaches:

- The market for PPPs should be large and profitable enough to justify the investment. The clear candidate for PPPs is the downstream value-added services,
- The government customer market is more suitable for space-related PPP projects than the commercial customer market.

This analysis chooses the government customer market rather than downstream value-added services in the commercial customer market because the government customer market has advantages over the commercial customer market in terms of other lessons. Specifically, the following two lessons are better satisfied by the government customer market than commercial customer market:

- Clients must clearly qualify and quantify their requirements,
- Space-related PPP projects should adopt conservative technical and demand forecasts.

The public sector can more accurately grasp needs of the government customer market than those of the commercial customer market because in the government customer market the public sector is the customer itself. Therefore, the public sector can clearly define their requirements and reduce uncertainties of demand forecasts.

Based on the above discussion, a strategy for the future application of PPP approaches to space projects might be to start in the government customer market. Because the government customer market better satisfies lessons for space-related PPP projects, projects would face fewer potential challenges. However, the strategy also must address the remaining lessons. The next section discusses these three lessons.

6.2 Potential Missions for Future Application of Space-related PPPs

This section discusses potential missions suitable to PPP approaches. The potential missions must satisfy the following lessons in the government customer market:

- Visible policy/regulatory environment is prerequisite,
- Long-term cash flow is required for the private sector to commit the project,
- The primary goal of space-related PPP projects should be cost saving.

The visible policy/regulatory environment might be prepared when the public sector has experience in accomplishing the mission in traditional approaches. Galileo and QZSS caused conflicts over work distribution or legal framework because the navigation mission was the first experience in Europe and Japan regardless of PPPs or traditional approaches. Figure 6-1 shows space-related PPP cases investigated in Chapter 3 with their missions. Of these missions, the United States, the EU, and Japan have a long history in telecommunications, Earth observation, meteorological monitoring, and space transportation. The United States also has enough experience in human spaceflight missions.

The long-term cash flow largely depends on cases. However, the EELV case reveals that space transportation will be oversupplied in the next decade. On the other hand, government demand for telecommunications, Earth observation, and meteorological monitoring seems stable as infrastructures of society. In addition, because these missions are satellite missions that have longer lifetimes than launch vehicles or human spaceflight, long-term cash flow seems achievable. According to Galileo and QZSS cases, government demand for navigation is not clear at this point.

The goal of cost saving requires to exclude other strong interests such as R&D and assured access to space. In this light, human spaceflight and launch services might not be suitable very much for PPP approaches because these missions include safety issues or assured access to space as important goals. On the other hand, telecommunication, Earth observation, and meteorological monitoring are less likely to include other significant purposes as long as these missions do not aim at state-of-art technologies. Therefore, these missions are likely to provide environment to focus on cost saving. Navigation will also have environment to focus on cost saving once the country or region completes the development phase.

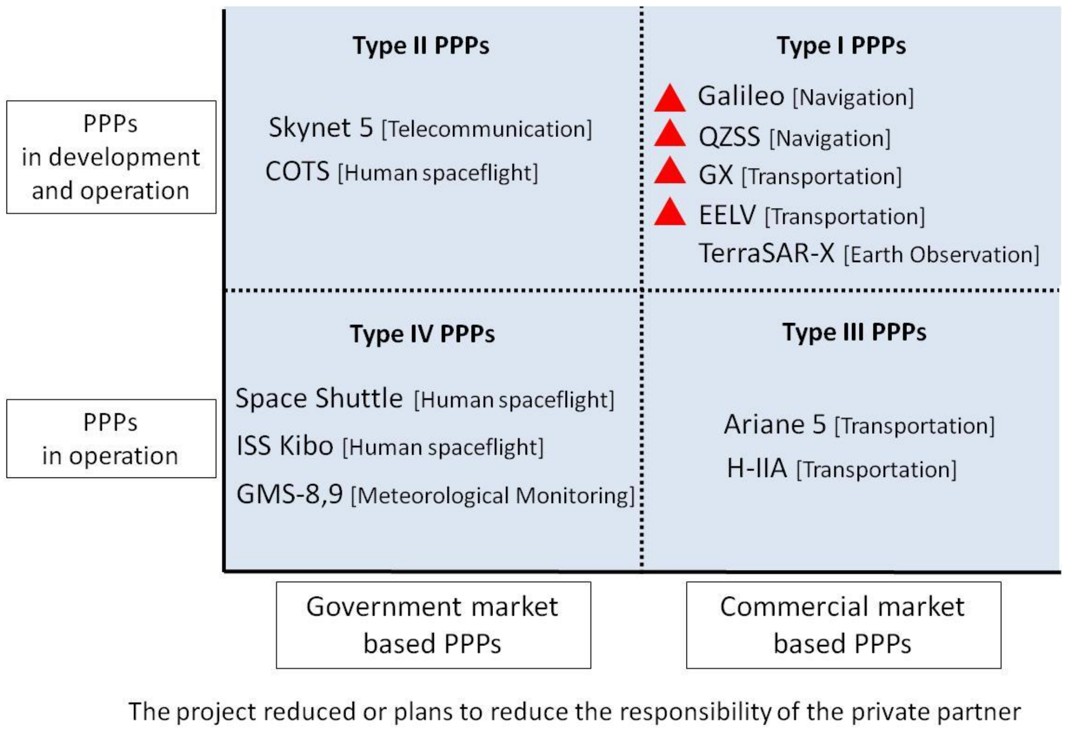

Figure 6-1: Space-related PPP Cases with their Missions (Source: Author)

Table 6-1: Applicability of PPP Approaches in the Government Customer Market (Source: Author)

Missions	Visible policy/ regulatory environment	Long-term cash flow	Goal of cost saving
Navigation			X
Telecommunications	X	X	X
Earth observation	X	X	X
Meteorological monitoring	X	X	X
Human spaceflight	X*		
Space transportation	X		

* Only the United States

Table 6-1 summarized the above evaluation on the future application of PPP approaches to space projects. Based on this evaluation, telecommunication, Earth observation, and meteorological monitoring for governments' use might be potential missions for future space-related PPPs.

6.3 Strategy for the Future Application of Space-related PPPs

Although the boom of space-related PPP projects around 2000 occurred with high expectation to address budgetary constraints, Galileo, QZSS, GX, and EELV resulted in experiencing multiple challenges. One common factor across these projects is to have chosen the commercial customer market. In addition, Galileo and QZSS selected PPP approaches for the navigation mission without sufficient experience in traditional approaches. Furthermore, GX and EELV adopted PPP approaches in spite of the multiple goals such as cost saving and assured access to space. These decisions resulted in made these PPPs difficult. Therefore, the future application of space-related PPPs should reduce project risk from these aspects.

This analysis proposes that policymakers might adopt PPP approaches in the government customer market. In particular, potential missions are telecommunications, Earth observation, and meteorological monitoring. However, each space project has different circumstances. Therefore, when policymakers apply PPP approaches to space projects, they should pay careful attention to the new and existing lessons.

7. Conclusion

PPPs are an attractive approach to build and operate facilities efficiently. In PPPs, private sectors assume more responsibility for public projects than in traditional approaches. Because the private sector has the better ability and stronger incentive for risk management than the public sector, the larger responsibility of private partners allows the public sector to improve efficiencies of the projects. The private partner can also increase profits for itself by managing risk efficiently.

However, PPPs also increase potential challenges. PPP projects sometimes face cost increase, schedule delays, cash-flow shortfalls, and conflicts of interest. In space, major four projects have experienced these challenges in the application of PPP approaches. As a result, they had to reduce the responsibility of the private partners and resulted in shifting in the direction of more traditional approaches.

The purpose of this research was to investigate how challenges arise in the application of PPP approaches to space projects. Identifying the dynamic structures of challenges makes potential challenges in space-related PPPs more predictable. This research also investigated ways to reduce such challenges in space-related PPP projects and a strategy for future space-related PPPs. Specifically, this research set the following three research questions:

- *What dynamic structures cause challenges in the application of PPP approaches to space projects?*
- *Given the dynamic structures, are there any ways to improve the dynamic structures?*
- *Given the ways to improve the dynamics, what is a strategy to apply PPP approaches for future space projects?*

This chapter summarizes results of this research and provides suggestions for future work.

7.1 Results of the Research

To address the above questions, this research analyzed the mechanics of PPPs. The analysis showed that the rationale of PPPs was to allow the public sector to address budgetary constraints. It also identified four characteristics of PPPs: risk transfer, high cost schedule efficiencies, high transaction cost, and higher pricing risk. These four characteristics of PPPs causes trade-offs among interests of stakeholders such as the public sector, private partners, and users. Thus, the public sector expects PPPs to deliver services earlier at lower cost and risk, but subject to higher transaction cost than traditional approaches. The private partner expects PPPs to provide higher incentives and larger right to decide subject to higher risk and transaction cost. Then, users expect PPPs to deliver services earlier subject to higher pricing risk.

Next, this research investigated space-related PPP cases. It categorized twelve ongoing space-related PPPs into four types of PPPs. These space-related PPPs were selected from space projects in the United States, Europe, and Japan and they were best available cases for this research. The categorization showed that space-related PPPs were more likely to face challenges when PPPs chose the commercial customer market and asked private partners to participate in the development phase.

Based on these analyses, this research addressed the three research questions. Answers for the research questions are summarized below.

(1) What dynamic structures cause challenges in the application of PPP approaches to space projects?

This research developed a PPP dynamics model by using system dynamics modeling as shown in Figure 7-1. To develop this model, this research took the following three steps. In the first step, this research developed a traditional-approach model. In the second step, it proposed the PPP model as a modification of the traditional-approach model. In the third step, this research tested the PPP model by applying it to four space-related PPP cases: the European navigation system Galileo, the Japanese navigation system QZSS, the Japanese launch vehicle GX, and the U.S. launch vehicle families EELV. The PPP model passed these four tests.

In the PPP model, three variables play important roles: conflicts of interest among parties, user satisfaction, and the private partner's revenue risk. The three variables represent interests of stakeholders such as the public sector, private partners, and users. Conflicts of interest among parties increase cost schedule inefficiencies. More cost schedule inefficiencies lead to less user satisfaction. Less user satisfaction results in more revenue risk for the private partner. More revenue risk for the private partner leads to more conflicts of interest among parties. Thus, the interaction of stakeholder interests forms a reinforcing loop unique to PPPs. Additionally, unexpected technical and demand problems strengthen the reinforcement. This reinforcing loop and these unexpected problems are the inherent sources of challenges in space-related PPP projects.

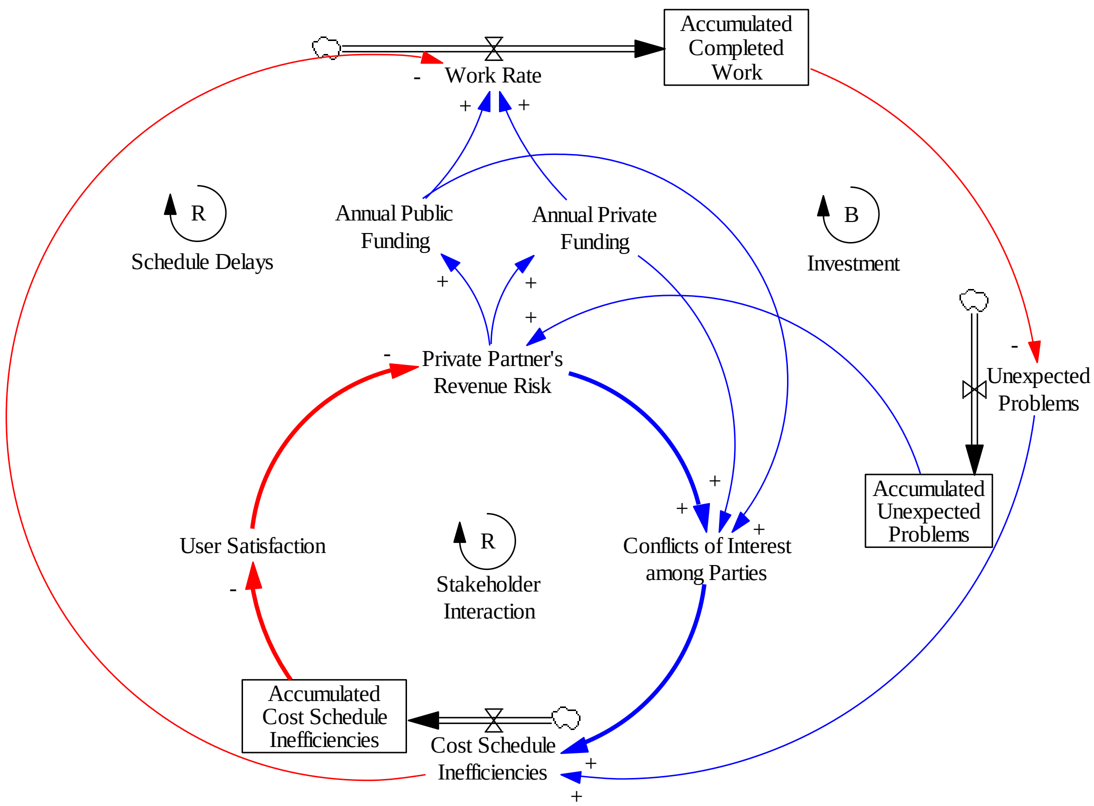

Figure 7-1: The Dynamics Model of Space-related PPP Projects (Source: Author)

(2) Given the dynamic structures, are there any ways to improve the dynamic structures?

This research developed three new lessons for improving the dynamic structures. The lessons are shown in Table 7-1. These lessons aim at reducing the influence of the reinforcing loop and unexpected problems. To set cost saving as the primary goal of PPPs is useful to avoid conflicts of interest among parties. To choose the government customer market reduces influences of user satisfaction and revenue risk on PPPs. To adopt conservative technical and demand forecast helps to avoid the underestimate of technology risk and the overestimate of demand forecast.

In developing the lessons, the analysis reviewed existing lessons founded in prior work. It then showed that each of them would effectively improve the reinforcing loop of the PPP model. Therefore, the PPP model contributed to strengthening the validity of these existing lessons. The new lessons are developed to complement the existing lesson and work more effectively when they are used together.

Table 7-1: Lessons for Improving the Dynamic Structures (Source: Author)

The primary goal of space-related PPP projects should be cost saving.
The government customer market is more suitable for space-related PPP projects than the commercial customer market.
Space-related PPP projects should adopt conservative technical and demand forecasts.

(3) Given the ways to improve the dynamics, what is a strategy to apply PPP approaches for future space projects?

Finally, this research proposed a strategy for the future application of PPP approaches to space projects. The strategy is to adopt PPP approaches in the government customer market. In particular, potential missions are telecommunications, Earth observation, and meteorological monitoring. However, each space project has different circumstances. Therefore, when policymakers apply PPP approaches to space projects, they should pay careful attention to the new and existing lessons.

This research revealed that the space-related PPP projects might be more successful if the PPP approaches were carefully applied with better understanding of the dynamic structures by which challenges arose in the projects. PPP approaches are unquestionably attractive unless they cause challenges investigated in this research. The analyses in this research contributed to reducing the influence of these challenges and to making space-related PPPs more successful.

Based on the results of this research, one expected advantage of PPPs might be to connect manufacturers and users closely through service provision because in many space-related PPPs space system manufactures rather than system operators are the private partners. Bringing more manufacturers' attention to users might improve communication between them. Close communications will enhance the sustainability of space community. In terms of this, space-related PPPs may be an effective approach to induce innovative service.

7.2 Future Work

Modeling incentives of private partners would be a good candidate for future work. Although this research focused on modeling the dynamic structure that causes challenges in space-related PPPs, it would be useful to better understand the positive aspect of space-related PPPs. With both positive and negative aspects modeled, one can effectively compare PPPs and traditional approaches to choose the better approach for a space project.

In addition, future work on specific missions, such as telecommunications, Earth observation, and launch vehicles, would be useful. Requirements of space projects greatly vary, depending on their missions. Telecommunication missions may require stable operation with long lifetime in the geostationary orbit. Earth observation missions may require more active operation with short lifetime in low Earth orbit. Launch vehicles may require short lead time and accumulated high success rate. User demand also varies, depending on missions. Therefore, PPP framework needs to be arranged to meet the mission environments. In addition, although this research did not implement deep numerical analysis using System Dynamics, such numerical simulation will be feasible in specific mission analyses.

Furthermore, it would be necessary to review the results of this research several years later because some case investigated in this research were too early to evaluate their success in PPPs. For example, it has been only two years since Skynet 5 and TerraSAR-X started their operations in orbit. In addition, GMS-8 and 9 are still in the planning phase. These PPP projects may provide new findings in the later stage.

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