Closing the Road Infrastructure Gap: Analysis of Expenditure Dynamics and Public-Private Partnership Shaping Challenges

Jose Guevara

Dissertation Submitted to
the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Civil Engineering

Michael J. Garvin, Chair
John E. Taylor
Navid Ghaffarzadegan
Paul Chinowsky

June 1, 2017
Blacksburg, Virginia

Keywords: infrastructure gap; maintenance expenditures; public-private partnerships; governance; system dynamics; management flight simulator

Closing the Road Infrastructure Gap: Analysis of Expenditure Dynamics and Public-Private Partnership Shaping Challenges

Jose Guevara

ABSTRACT

The global infrastructure gap has continually widened over the last few decades. Industry reports and academic publications suggest that, in terms of road infrastructure, both advanced and developing economies have not paid sufficient attention to modernize their infrastructure assets. A wider road infrastructure gap signifies that highway conditions have declined because governments have not had enough resources for maintenance and rehabilitation. In the same way, it also indicates that congestion levels have grown and the level of service in most road networks has dropped because public agencies have not had sufficient funds to generate new highways and expand existing corridors. This dissertation, therefore, provided insights into the difficulties associated with improving the existing highway assets and the barriers related to expanding the current roadway capacity through public-private partnerships (PPPs). The research involved three interdependent studies. In the first study, I examined the continuous deterioration of the US highway system through a system dynamics model, which focused on the dynamics of capital investments and maintenance expenditures in the US road infrastructure. The results confirmed that the American highway system is currently stuck in a capability trap. This makes it difficult for the system to improve at the rates required by the country's economic growth. In my second investigation, my attention shifted toward the governance challenges related to building new roads and expanding highway capacity through PPPs. I developed a systems map of governance variables informed by past-published evidence from actual projects. By specifically examining the

shaping phase of public-private initiatives, the work uncovered the effects of feedback relationships and interdependencies on PPP feasibility. This offered insights about the relationship between governance mechanisms and successful PPP development. In the third study, I utilized variables and relationships identified in my second investigation to develop a management flight simulator in order to better explain governance difficulties in the procurement phase of PPP projects. The simulator was implemented during an educational exercise with graduate students of civil engineering. By doing so, I confirmed that the simulator has the potential to increase our understanding of PPP procurement processes. Results indicated that the simulation tool was a suitable instrument to explain how government capacity, project uncertainty, and technical complexity influence PPP tendering. Overall, my findings across the three studies illustrate different means to understand why closing the global road infrastructure gap is challenging. Together, the three inquiries indicate that examining the road infrastructure sector as a socio-technical system contributes to improve our understanding of the expenditure dynamics related to existing assets and to enhance our comprehension of the governance challenges associated with developing new roads.

Closing the Road Infrastructure Gap: Analysis of Expenditure Dynamics and Public-Private Partnership Shaping Challenges

Jose Guevara

GENERAL AUDIENCE ABSTRACT

Over the last decades, the global infrastructure gap has continually expanded. In the road infrastructure sector, governments around the world have failed to meet the growing societal and economic demands for additional infrastructure investments. This suggests that highway conditions have declined because there are not enough resources to improve the existing roads and develop new highways. As a result, the size and quality of global road network keep deteriorating annually.

This dissertation provided insights into the difficulties related to enhancing the quality conditions of the existing road network and the problems associated with increasing roadway capacity through public-private partnerships (PPPs). The research was conducted through three interdependent studies. In the first study, I developed a simulation model in order to understand the continuous deterioration of the US highway system. I concluded that the US government has been unable to achieve sustained improvements in the system because of prioritizing rehabilitation over preventive maintenance. In my second investigation, I conducted a literature review focused on analyzing governance-related concepts in PPP projects. I created a systems map that helps to understand how governance variables influence failure and success in the shaping phase of public-private agreements. In the third study, I developed an educational tool focused on explaining some of the challenges of conducting procurement processes in PPPs. This tool proved to be effective

in terms of illustrating how government capacity, project uncertainty, and technical complexity influence PPP tendering.

Overall, the three studies offer a socio-technical perspective of why closing the global road infrastructure gap is challenging. Together, they contribute to improve our understanding of the difficulties associated with enhancing the conditions of the current road network and developing new roads through PPPs.

Dedicated to my wife Luz Mery

ACKNOWLEDGEMENT

I would like to thank Michael J. Garvin for being my advisor and guiding me through the multiple intricacies of this adventure. He always motivated me to become a better researcher and challenged me to develop my research in a better way. I would also like to thank Navid Ghaffarzadegan for providing me the opportunity to explore the field of System Dynamics. Thanks to him, I was able to learn how to study and analyze socio-technical systems. A special thanks to my other committee members John E. Taylor and Paul Chinowsky for their insightful recommendations and remarkable support. I am really grateful to be surrounded by such special group of scholars along my PhD journey. I strongly believe that, thanks to them, I was able to expand my knowledge and capabilities.

This dissertation would not have been possible without the support of my friends and colleagues. I cannot express my appreciation to Armin Rahimi, Behshad Ghadimi, Duc Nguyen, and Edwin Gonzalez for their advice, insightful comments, and friendship in challenging times. I also would like to thank Alireza Ebrahimvandi, Arash Baghaei, Maryam Andalib, and Nasibeh Azadehfard for their ideas and suggestions on my research.

I would like to acknowledge several funding sources. This study was supported by the US National Science Foundation under Grant No. 1333264. I also received funding support from Colciencias-Fulbright (Convocatoria 568) and the Professors Development Program of Universidad de los Andes, Bogota, Colombia. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the financial sponsors.

Finally, I would also like to thank my wife for her unconditional and genuine support. Thanks to her love and patience, I was able to successfully complete this PhD journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. CHAPTER 1: INTRODUCTION

The global infrastructure gap has continually widened over the last few decades. Governments have been unable to cope with the rising demands imposed by increasing economic development, population growth, and higher urbanization levels (Gil and Beckman 2009; World Economic Forum 2014). Recent reports from the World Bank, World Economic Forum, and McKinsey Global Institute show that economies around the world have not invested what is required to cover their societies' needs (Andres et al. 2014; Biller et al. 2014; McKinsey Global Institute 2016; World Economic Forum 2014). They have estimated that while current infrastructure-related expenditure levels are about \$2.5 to \$2.7 trillion per year, maintaining the current economic growth rate would require annual investments of around \$3.3 to \$3.7 trillion – creating a gap of around \$1 trillion per year (i.e. 3.8% of global GDP) (McKinsey Global Institute 2016; World Economic Forum 2014). Regardless of its exact magnitude, there is clearly a sizeable infrastructure gap that needs closing to improve quality of life worldwide.

Within the infrastructure domain, the road infrastructure sector plays an important role. Industry reports and academic publications suggest that both advanced and developing economies have not paid sufficient attention to modernize their road infrastructure assets (Gil and Beckman 2009; World Economic Forum 2014). The gap in the road infrastructure sector, therefore, has increased because the size and quality of the global road network have failed to meet growing economic and societal demands (World Economic Forum 2014). A wider road infrastructure gap indicates that highway conditions have declined because governments have not had adequate resources for maintenance and rehabilitation. In the same way, it also reveals that congestion levels have grown and the level of service in most road networks has dropped because public agencies have not had sufficient funds to generate new highways and expand existing corridors.

Governments around the world have been aware of the continuous widening of the road infrastructure gap. Since the 1990s, they have implemented multiple policies focused on improving maintenance and rehabilitation efforts. However, the actions directed to upgrade the existing highway assets have proven unsuccessful in terms of closing the gap. In the US, for example, around 40% of the roads were still in poor or acceptable condition (as opposed to good) in 2013 (FHWA 1999; 2002; 2008; 2013). Similarly, in the UK, industry reports produced during the last two years estimated that the road maintenance backlog is 15 years in London and 12 years in the rest of the country (Asphalt Industry Alliance 2016; Bayliss 2015). Analogous situations can be found in other countries in Europe, Asia, Africa, and Latin America.

As a means to expanding existing corridors, building new roads and securing maintenance and operations obligations, governments have implemented greater private sector participation strategies. Consequently, over the last two decades, public agencies have used public-private partnerships (PPPs) as a way to deliver infrastructure solutions in the transportation sector (Garvin 2010; Yescombe 2011).Through PPPs, public agencies have incorporated private resources and expertise in order to develop and operate new highway assets. Unfortunately, despite successful experiences in some jurisdictions, PPP development worldwide has been marred by multiple controversies (Jooste and Scott 2012; Jooste et al. 2011). These difficulties have prompted scholars and practitioners to highlight the need for improving public sector skills and capabilities.

In this dissertation, I examine why it has been so difficult to close the road infrastructure gap from two perspectives. First, I explored the difficulties of maintaining and rehabilitating road networks by studying it as a dynamic system. I focused on the US highway system to gain insight into the expenditure dynamics associated with maintenance and rehabilitation policies and discovered that the system suffers from the capability trap phenomenon. Subsequently, I examined some of the challenges related to PPP implementation in the road infrastructure sector by analyzing PPP shaping and procurement through the concept of governance. I reviewed the body of literature during the shaping phase of PPPs and developed a systems map showing interdependencies and feedback relationships amongst governance variables. Based on that, I also explored PPP procurement processes and created a management flight simulator to better explain governance issues in PPP tendering. Both perspectives have followed a socio-technical approach and are further explained below.

1.1 Perspective 1: Maintenance and Rehabilitation in US Highway System

The US highway system comprises more than eight million lane-miles and has been recently valued around $3 trillion by the Bureau of Economic Analysis (Geddes and Wagner 2013). It includes urban and rural roads under the jurisdiction of federal, state, and local government agencies. The system has traditionally been funded on a pay-as-you-go basis, and most of its revenues have come from fuel- and vehicle-related taxes. Over the last several decades, however, government agencies have failed to make consistent inflation adjustments to taxes while fuel consumption has steadily decreased due to technological improvements (Gomez and Vassallo 2014; National Surface Transportation Infrastructure Financing Commission 2008). Since 2008, as a result, the Highway Trust Fund (the main federal funding account for transportation infrastructure) has received appropriations from the General Fund in order to remain solvent.

Government agencies at all levels (federal, state and local) have faced this recurrent insolvency problem for decades. Since they have not obtained sufficient revenues, roads have not been maintained on time, multiple maintenance actions have been postponed, quality levels have dropped, and deferred maintenance has accelerated deterioration and led to higher repair costs (ASCE 2009). Scholars and policy makers have suggested multiple measures to increase highway receipts (Garvin 2010; Geddes and Wagner 2013; Gomez and Vassallo 2014; Strong and Chhun 2014). However, there is little research directed to understand why maintenance and rehabilitation costs keep increasing and how the lack of capital improvements and deferred maintenance efforts have affected the overall system performance. Understanding such issues can shed light on whether or not the highway system is stuck in a capability trap (i.e. failure to achieve long-term quality improvements).

1.2 Perspective 2: Governance Challenges in PPP Development

Despite their potential advantages, the global PPP implementation experience has been far from perfect (van Buiten and Hartmann 2015). In the US, for example, some public-private agreements have made it evident that this project delivery approach has important governance challenges (Garvin 2010; Ho et al. 2015). In some states, PPPs are not legally authorized as an alternative to solve the increasing infrastructure problems affecting the highway system. This has led scholars to argue that it is necessary to understand the governance challenges affecting PPPs in order to improve their development processes (Henisz 2006; Ho et al. 2015; Levitt et al. 2010).

Stoker (1998) defines governance as the series of mechanisms related to "…the action, manner, or system of governing in which the boundary between organizations and public and private sectors has become permeable" (Stoker 1998 p. 38). His arguments emphasize that the essence of governance is the interrelationship among power structures in which authority has not been clearly defined. The rulers and the ruled interact in a continuum that comprises policies and shared values. Unlike domains in which official authoritative structures define decision-making processes, governance is about the study of formal and informal interactions between those officially in power and those that are not (Rakodi 2003).

In many ways, the development of public-private partnerships resembles an environment without clear hierarchy and authority. In PPPs, for example, the uncertainty, complexity, uniqueness, and variety of stakeholders contribute to promote an inter-firm organizational environment in which opportunism and adversarial relationships may easily prosper (Guo et al. 2014; van Buiten and Hartmann 2015). In this context, many authors claim that it is necessary to have mechanisms focused on coping with challenges related to opportunism, socio-political legitimacy, displaced agency, and uncertainty (Caniëls et al. 2012; Lin and Ho 2013; Too and Weaver 2014).

Although the concept of governance is very important to understand PPP failures and successes, PPP literature is fragmented and does not examine the governance challenges of public-private agreements in an integrative way. Researchers do not often study how such challenges emerge and how they influence each other in real PPP projects (Ke et al. 2009; Osei-Kyei and Chan 2015; Tang et al. 2010; Zhang et al. 2016). More importantly, policymakers, practitioners, and the general public seem not to recognize why governance plays an important role in PPP development (Henisz 2006; Henisz et al. 2012; Levitt et al. 2010). In order to gain insight into the challenges, I mapped the ways PPP governance-related variables interact among each other and influence project feasibilities. Similarly, I created a management flight simulator directed towards illustrating the importance of governance concepts in PPPs to stakeholders. Overall, by doing so, my research increases our understanding of governance, PPPs, and the infrastructure gap.

1.3 Research Approach

My investigation of the difficulties associated with closing the infrastructure gap is organized around two main perspectives and three distinct studies. As shown in Figure 1-1, I have developed one research paper under Perspective 1 and two manuscripts for Perspective 2. The three investigations follow a socio-technical approach in which I have utilized system dynamics as my main methodological tool. I have selected this technique because it allows me to examine the causal relationships, nonlinearities, and feedback mechanisms underlying the efforts towards improving the existing highway assets and generating more capacity through PPPs. As a result, across the dissertation, I have been able to explore budgetary and governance-related variables through the use of quantitative and qualitative data.

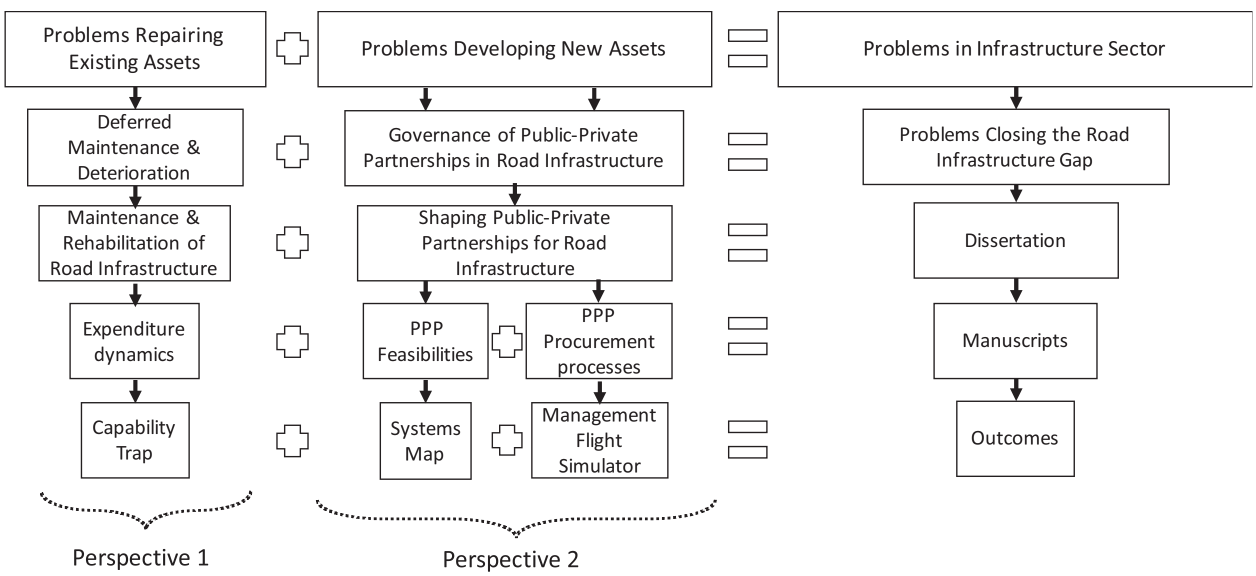


Figure 1-1. Research Framework

In the first manuscript, I explored Perspective 1 and examined the role of maintenance and rehabilitation efforts in closing the infrastructure gap. I focused on the US highway system because, although it is the biggest economy in the world and the country with the largest roadway network, it has not been able to provide sustained solutions to the increasing deteriorated conditions of its highways. As a result, the US offered a very good opportunity to analyze the barriers for generating a better road infrastructure sector. Based on that, in this manuscript I answered the following questions:

- What are the dynamics of capital investment and maintenance expenditures in the US highway system?
- How do these dynamics interact amongst each other and influence road conditions?

In the second manuscript, I gained insights into Perspective 2. I studied the failures and successes of implementing PPP projects, focusing on real-world PPP cases described in academic publications and paying particular attention to the shaping phase of public-private agreements. By doing so, I attempted to integrate the current fragmented PPP literature through examining the stage in which the majority of the most important decisions in PPPP development are made. Specifically, in this manuscript I responded to these questions:

- What are the interactions and emergent challenges that hinder the implementation of governance mechanisms in PPP developments?
- How do governance challenges affect PPP development?

In the third manuscript, I kept examining Perspective 2 as I explored one important segment of the PPP shaping phase, the PPP procurement process. Here, I analyzed the impact of government capacity, project uncertainty, and technical complexity on the overall success of public-private procurement activities. Based on the idea that PPP tendering needs to be better explained and communicated to stakeholders and general public, I developed and educational tool that has been tested in a simulation exercise (approved under IRB #17-306). In this study, I responded to the following inquiries:

- How do governance variables facilitate or hinder procurement processes in PPP projects?
- Why are these variables difficult to control in PPP development?

1.4 Dissertation Structure

This dissertation follows the manuscript-style format and includes three distinct research papers. Chapters 2, 3, and 4 are independent articles that have been submitted or are in preparation for submission to peer-reviewed journals. Chapter 2 reports the first manuscript of this dissertation and examines the dynamics of maintenance expenditures in the US highway system. This has been published on the Journal of Management in Engineering. Chapter 3 presents the second manuscript and provides a systems map of the governance challenges associated with PPP development. This study is in preparation for submission to the journal Construction Management and Economics. Chapter 4 presents the third manuscript and focuses on exploring decision-making dynamics in PPP procurement. It is in preparation for submission to the Journal of Construction Engineering and Management. Since the papers are written for different journals and each journal has different writing policies, Chapters 2 and 4 do not use first-person pronouns. All of the papers have been (or will be) co-authored with professors Michael J. Garvin and Navid Ghaffarzadegan. I am the first author in each one of the three articles. Beyond these core chapters, I conclude this dissertation by presenting my conclusions, summarizing findings, discussing implications, and highlighting future research avenues in Chapter 5.

2. CHAPTER 2: THE CAPABILITY TRAP OF THE US HIGHWAY SYSTEM: POLICY AND MANAGEMENT IMPLICATIONS[1]

2.1 Abstract

The deterioration of the US highway system has received significant attention from scholars, industry practitioners, and policy makers over the last several decades. This growing interest has encouraged the production of multiple reports highlighting the challenges of enhancing system conditions in the long-term. Since government agencies do not have sufficient resources to take care of roads in a timely manner, deterioration worsens and available funds are primarily used for previously deferred maintenance and rehabilitation activities. The current work seeks to gain insight into the dynamics of capital investments and maintenance expenditures in US road infrastructure. Based on a system dynamics model, we argue that the highway system is stuck in a capability trap (failure to achieve sustained improvements) because authorities tend to promote short-term reactive efforts over long-term proactive actions. The study contributes to the existing literature by highlighting the feedback mechanisms that connect maintenance and rehabilitation expenditures with aging and deterioration processes. Building on a counterfactual analysis between 1994 and 2010, the research reveals that incentivizing preventive practices not only enhances system conditions, but also reduces major rehabilitation expenses and in the long term frees up resources for capacity expansion. Conclusions point to the difficulties associated with

[1] This paper was co-authored with professors Michael J. Garvin and Navid Ghaffarzadegan and was published in the Journal of Management in Engineering.
Guevara, J., Garvin, M. J., & Ghaffarzadegan, N. (2017). Capability Trap of the US Highway System: Policy and Management Implications. *Journal of Management in Engineering*, 10.1061/(ASCE)ME.1943-5479.0000512. Available at: http://ascelibrary.org/doi/abs/10.1061/%28ASCE%29ME.1943-5479.0000512
.

escaping the trap, and the impacts of implementing reactive and proactive policies throughout the highway system.

Keywords: US highway system, system dynamics, road maintenance, simulation.

2.2 Introduction

Over the last few decades, many reports have highlighted the decline in the quality of US transportation infrastructure. In the 1980s, Barker (1984) and the Congressional Budget Office (1988) pointed out that the current state of roads and bridges across the country made them barely sufficient to meet future economic challenges and traffic demands. In the 1990s, the National Research Council (NRC) and Transportation Research Board (TRB) recommended the implementation of more advanced pavement management systems across the state Departments of Transportation (DOTs) (National Research Council 1993). After 2000, reports by the American Society of Civil Engineers and several US Congressional hearings asserted the necessity of improving maintenance activities and increasing highway capacity (ASCE 2011; U.S. Senate 2008; 2012).

Improving the US transportation infrastructure is a difficult challenge because the existing highway assets steadily demand increasing maintenance and rehabilitation requirements year after year (Geddes and Wagner 2013; Strong and Chhun 2014). Responding to such demands has not been easy due to budgetary limitations experienced by governments at the federal, state, and local levels (National Surface Transportation Infrastructure Financing Commission 2008; 2009). These limitations have hindered improvement processes and postponed multiple annual maintenance and rehabilitation activities across the road network (Jenn et al. 2015; Little 2010; Watts et al. 2012). Deferred maintenance, in turn, has accelerated aging processes and future repair costs (Arif et al. 2016; Fallah-Fini et al. 2010; la Garza et al. 2011; 1998). As a result, deterioration worsens daily and available funds are primarily used for maintenance and rehabilitation tasks, postponing capacity expansion and quality improvement efforts.

The combination of limited budgets and deferred maintenance with insufficient capacity and low-quality facilities is not exclusive to the transportation infrastructure sector. Referred to as the *Capability Trap* (CT) in the literature of operations management, managers – in response to pressures to provide timely throughput – often tend to fix existing major problems that inhibit continuous operation while decreasing attention and resources for long-term actions. In the automotive industry, for example, managers often fail to implement proactive maintenance endeavors due to issues related to day-to-day pressures and short-term preferences (Repenning and Henderson 2010; Repenning and Sterman 2002). In the building construction sector, researchers have analyzed how deferred maintenance of mechanical, electrical, and plumbing (MEP) systems increases costs and reduces funding for innovative improvements (Lyneis and Sterman 2015). Similar studies have been explored in the power sector pointing to the problems arising from managerial focus on short term fixes (Lyneis 2012). Although the benefits of preventive maintenance and proactive investments are easy to understand in theory, organizations keep deferring preemptive actions and seem to accept future expensive failures and breakdowns.

Building on experiences from multiple industrial sectors and taking a system dynamics (SD) approach, this paper seeks to understand the dynamics of capital investments and maintenance expenditures in the US highway system. A simulation model is developed in order to examine the factors behind this system's growing costs and deteriorating conditions. The scope of the model encompasses a counterfactual analysis of the highway system's conditions and the expenses needed to improve such conditions. The paper begins with a brief discussion of the US highway system, its current condition, and its funding model. Subsequently, SD is introduced and the CT concept is described. Given this background, the research methodology is presented, and the proposed simulation model is explained and validated. Next, model results are examined and policies to enhance road conditions and reduce future rehabilitation expenditures are formulated and assessed. Finally, conclusions point to the difficulties associated with getting the highway system out of the trap.

2.3 Problem Definition: the US highway system

Consistent with reports from the Federal Highway Administration (FHWA), the terms highways, roadways, and roads are considered to have equivalent meanings and are used interchangeably (FHWA 2015). The US highway system includes more than eight million lane-miles and has been recently valued around $3 trillion by the Bureau of Economic Analysis (Geddes and Wagner 2013). It includes urban and rural roads under the jurisdiction of federal, state, and local government agencies. Although locally classified roads account for more than 70% of the national mileage, most of the traffic is carried by interstate highways (221,056 lane-miles), arterial roads (1,043,597 lane-miles), and expressway corridors (73,254 lane-miles) (FHWA 2013).

Despite the importance of the highway system, government agencies have traditionally struggled to allocate funds for maintenance, rehabilitation, and capacity expansion. Scholars point out that until the mid-1990s, most governmental efforts had been focused on infrastructure development and new construction, while largely postponing long-term preservation actions (Dornan 2002; Hicks et al. 1997). This generated a backlog of lane miles in need of maintenance and rehabilitation that have proven increasingly expensive to repair. Although transportation agencies have recognized the relevance of maintenance and asset management programs over the last 20 years, public resources have not been sufficient to cope with such rising highway expenditures (Arif et al. 2016; la Garza et al. 2011). As a result, US governments at all levels continue to strive to solve their maintenance, rehabilitation, and new construction requirements (ASCE 2013; Brown et al. 2009; National Surface Transportation Infrastructure Financing Commission 2008; U.S. Senate 2012).

Clearly, the funding problems of the US highway system can be partially explained by the increasing lack of road revenues. Between 2000 and 2010, for example, while the percentage of total highway receipts coming from vehicle- and fuel-related taxes decreased from 67% to 47%, the proportion of government appropriations and bond issue proceeds increased from 15% to 27% and 9% to 15%, respectively (FHWA 2013). Consequently, scholars and policy makers have suggested multiple measures to increase highway receipts and reduce expenditures (Geddes and Wagner 2013; Gomez and Vassallo 2014; Strong and Chhun 2014). However, little research has targeted understanding why maintenance and rehabilitation costs keep increasing and how the lack of capital improvements and deferred maintenance efforts have affected overall system performance. Understanding such issues can shed light on the need to implement sustained highway investment initiatives in order to improve road conditions and reduce expenditures in the long-term. This study, therefore, does not focus on analyzing revenue-related policies. Instead, it seeks to understand how decisions related to maintenance and rehabilitation interact with new construction and overall system condition within a financially constrained environment.

2.4 System Dynamics Modeling and the Capability Trap in the US Highway System

System dynamics (SD) is a methodology for analyzing and managing complex systems (Forrester 1961; Sterman 2000). The approach focuses on understanding how system conditions evolve over time as a result of causal interdependencies and feedback relationships between system components. The methodology employs simulation models as a means to examine dynamic problems. Models entail a series of differential equations capable of capturing causal interactions through feedback loops (Sterman 2000). Simulation results allow highlighting counterintuitive behaviors and offer novel insights into the underlying structures of social systems (Ghaffarzadegan et al. 2011).

Building on experiences from the manufacturing, building, and power sectors, SD scholars have examined how managers seek to alleviate financial constraints by making decisions concerning proactive investments and reactive expenditures (Lyneis and Sterman 2015). Researchers have analyzed how some organizations seem to fear the uncertainty of implementing long-term improvements, reacting on a day-to-day basis to short-term issues. They seem to embrace the certainty of future failures and breakdowns (Repenning and Henderson 2010). This phenomenon is known as the Capability Trap and has generated insights into why it is difficult for poor-performing organizations to invest in the capabilities needed to achieve future improvements (Repenning and Sterman 2001; 2002). Such organizations are trapped and are not able to break the vicious cycle of corner cutting, deferred maintenance, and high costs (Lyneis and Sterman 2015).

Trapped organizations are analogous to a leaky ship; in such a situation, some crew members need to bail and some others need to sail (Lyneis 2012; Lyneis and Sterman 2015). Regardless of the number of people sailing, those who bail need not only to avoid sinking (short-term solution), but to stop water leaks (long-term solution). Otherwise, the ship will not be able to move forward. Similarly, managers in poor performing organizations need to allocate resources to cope with long-term improvements and short-term issues. Although solving immediate problems is important, the organization needs sustained efforts to make progress. If managers focus on reactive expenditures without seeking long-term enhancements, poor performance issues will not disappear in the future. Such organizations have fallen into the capability trap.

Based on the leaky ship metaphor, the US highway system appears to have fallen into the trap. According to the FHWA, road quality levels have not significantly increased over the last several years. Additionally, the total number of lane-miles across the country has remained stable for more than three decades (FHWA 2015). However, at the same time, highway expenditures keep escalating at an exponential rate due to increasing maintenance and rehabilitation requirements (FHWA 2013). Moreover, government agencies at all levels keep asking for more resources while trying to cope with the difficult financial situation (ASCE 2013). Clearly, although the ship is not sinking, governmental efforts have not been enough to move it forward.

2.5 Research Methodology

The main objective of this research is to analyze the investment dynamics associated with the construction and maintenance of the US highway system. The CT concept is employed in order to examine the factors that enable and hinder such processes. The methodological approach involves a system dynamics model that captures several causal relationships between variables associated with highway deterioration, road funding mechanisms, highway aging, and maintenance expenditures. Parameters are estimated by using partial-calibration procedures (Homer 2012) and data from publicly available datasets. Based on multiple simulation runs, the model is validated through comparing simulated and actual data. The model is suited to test effects of different policies and formulate recommendations.

2.6 Data Sources

The investigation focused on six functional highway categories: urban interstate, urban freeways/expressways, urban principal arterial, rural interstate, rural principal arterial, and rural minor arterial. This data set was selected because it was generated by following the same reporting procedures, conceptual definitions, and measurement mechanisms. The selected highway categories comprise more than 1 million lane-miles and include the corridors with the highest annual average daily traffic across the US (Levitt et al. 2010).

In order to measure deterioration, national road condition data were collected from the annual US Highway Statistics reports published by FHWA between 1994 and 2010 (Chi et al. 2013; Levitt et al. 2010). Based on these reports, road condition is found by relying on the International Roughness Index (IRI). Although multiple measures exist for establishing pavement condition (i.e., rutting, cracking, and faulting), this is the only metric that has consistently been employed by government agencies at a national level since 1994 (Federal Highway Administration 2013a). Additionally, despite not providing information regarding other factors affecting the system (e.g. congestion levels, the state of signage, the condition of guardrails, and others), the IRI offers a reliable and consistent measure for comparing different roads across the US. Hence, despite its limitations, the IRI is deemed a suitable metric to start exploring the impacts of the CT phenomenon within the highway system.

Publicly available data was also employed for determining maintenance, rehabilitation and new construction expenditures. These expenses were calculated from information published by the Federal Highway Administration and the US Department of Transportation in a series of biennial reports entitled *The Status of the Nation's Highways and Bridges: Conditions and Performance* (FHWA 1999; 2002; 2008; 2013). In order to establish proper comparisons, current maintenance expenditures were converted to constant dollars by using the annual national consumer price indices for the period under study. Similarly, rehabilitation and new construction costs were converted by utilizing the FHWA's bid-price index and the National Highway Construction Cost Index (NHCCI).

Apart from this data, information was also gathered related to the average costs per lane-mile for different road improvements throughout the US. Since various pavements exist across the country, such costs were acquired from the Highway Economic Requirements System (HERS) developed by FHWA, including the unit costs for rehabilitation, reconstruction, and new construction activities in multiple road categories throughout rural and urban areas (FHWA 2013). This allowed utilizing unit costs that were consistent with the information provided in the *US Highway Statistics* and the *Status of the Nation's Highways and Bridges: Conditions and Performance* reports.

2.7 Causal Loop Diagram

The causal structure underlying the capability trap issues of the US highway system is shown in Figure 2.1 and Figure 2.2. The causal map focuses on maintenance, rehabilitation, and new construction dynamics. Its variables are connected through arrows representing cause and effect relationships. The polarity marks on the arrows indicate the direction of the relationship. Positive signs denote that variables move in the same direction while negative marks imply the opposite. Once a series of concatenated links form a closed loop, a feedback structure is created. These feedback loops are responsible for controlling system behavior and are labeled as either “B” for balancing loops (self-correcting) or “R” for reinforcing loops.

When highways are in good condition, they have an IRI of less than 95 in/mi. If this value is higher than 95 in/mi, the system has a condition shortfall and roads are in either an acceptable state (IRI between 95 in/mi and 170 in/mi) or a deteriorated state (IRI of more than 170 in/mi) (Federal Highway Administration 2013a).

As shown in the causal loop diagram (CLD), if the highway system falls short of its desired condition target due to aging and deterioration processes, governments can respond in two different ways: implement reactive efforts or apply proactive measures (Ahmed et al. 2013; Irfan et al. 2009; Khurshid et al. 2010), which as Figure 2.1 shows form two balancing loops (B1 and B2).

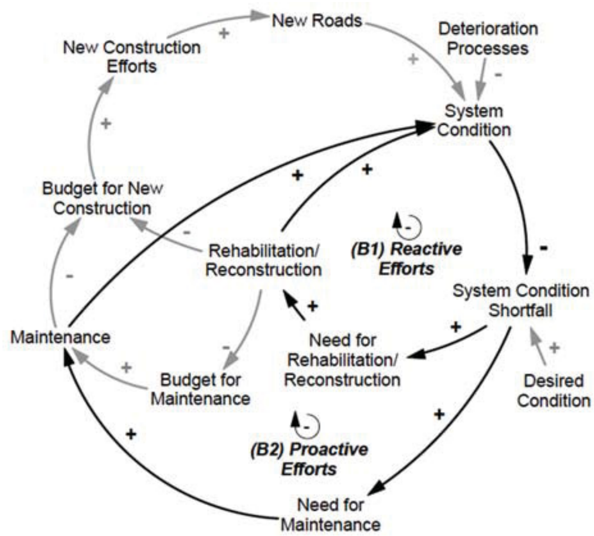


Figure 2-1. Causal map: first-order responses

2.7.1 B1: Reactive Efforts

Governments are responsible for road quality and react to quality shortfalls when IRIs of more than 170 in/mi occur. This condition shortfall leads to an increase in the number of lane-miles in need of rehabilitation and pushes for more rehabilitation/reconstruction activities. These developments include but are not limited to actions such as resurfacing, restoration, changing malfunctioning joints, replacing deteriorated materials, strengthening the pavement structure, or reconstruction. As shown in loop B1, all else constant, once such activities are completed, the roads that were in poor condition are restored to a good form and the whole network improves its overall condition. This mode of maintenance is a reactive one, an immediate response to the quality shortfall.

2.7.2 B2: Proactive Efforts

Obviously, governments do not have to wait until roads have roughness indices that are more than 170 in/mi. A proactive response is generated when highways have IRIs of more than 95 in/mi. In loop B2, a shortfall leads to an increment in the amount of lane-miles in need of maintenance. These roads necessitate maintenance activities such as routine surface operations, crack sealing, spot patching, or any other actions taken to improve roughness levels. These actions allow the maintained roads to regain their good roughness levels and, at the same time, contribute to enhance the overall system condition.

The described balancing loops of B1 (reactive [focus on rehabilitation]) and B2 (proactive [focus on maintenance],) are first order reactions in response to condition shortfall. However, these reactions need resources, and thus they are interconnected. More simply, there is a tradeoff between reactive and proactive responses. The feedback loops presented in Figure 2.2 describe how the focus on one (e.g., reactive) can influence the other (e.g., proactive).

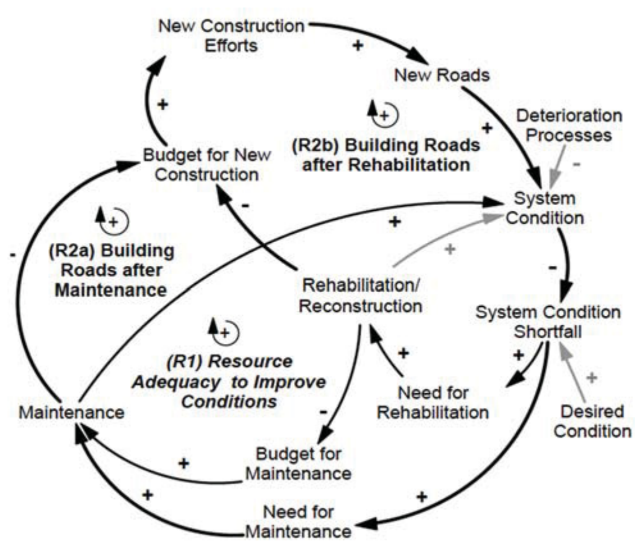


Figure 2-2 Causal map: reactions to first-order responses

2.7.3 R1: Resource Adequacy to Improve Conditions

As stated previously, governments implement both reactive and proactive efforts simultaneously. The problem is that funds are limited and if too many lane-miles are in need of rehabilitation, most of the budget will be directed to cover the increasingly urgent rehabilitation/reconstruction challenges. As reactive efforts are implemented, fewer resources for maintenance are available. This creates a reinforcing loop (R1): less budget available for maintenance → less maintenance → lower system condition → higher system condition shortfall → more rehabilitation/reconstruction → even less budget for maintenance.

This reinforcing loop is based on studies showing that agencies without adequate maintenance management programs are not able to slow the rate of pavement deterioration and have to rely on more expensive rehabilitation works (Ahmed et al. 2013; Fallah-Fini et al. 2015; de la Garza et al. 2011). This is because neither the rehabilitation costs can be reduced nor the frequency of reconstruction can be diminished without good maintenance policies (Dornan 2002; Galehouse et al. 2006; Hicks et al. 1997). In other words, this loop represents how reactive maintenance can use resources, which otherwise could have been allocated to proactive maintenance. This is analogous to the effort to focus on avoiding sinking rather than fixing water leaks in the leaky ship metaphor.

2.7.4 R2: Building Roads after Maintenance and Rehabilitation

Budget availability has an impact on the construction of new lane-miles. Although new roads contribute to improve conditions, highway construction is expensive and governments need to cover their maintenance and rehabilitation liabilities. As the highway system keeps falling short of its condition targets, governments increase their proactive and reactive efforts to cope with an increasing number of roads in line to be repaired. This creates two supplementary reinforcing loops: R2a and R2b. In loop R2a, more maintenance → less budget available for new construction → less new construction efforts→ fewer roads → lower system condition → higher system condition shortfall → even more maintenance. In loop R2b, more rehabilitation/reconstruction → less budget available for new construction → less new construction efforts→ fewer roads → lower system condition → higher system condition shortfall → even more rehabilitation/reconstruction. More simply, a focus on reactive maintenance shifts resources from new construction, decreasing new construction (loop R2a). Similarly, more maintenance will deplete resources that are needed for constructing new roads (loop R2b).

These two reinforcing loops underpinned by studies showing that maintenance, rehabilitation, and new construction are three processes that compete against each other within the same pool of resources. According to some scholars, since the 1990s, transportation agencies have started to prioritize rehabilitation and maintenance works over new construction initiatives due to increasing system deterioration (Arif et al. 2016; Dornan 2002; Hicks et al. 1997; de la Garza et al. 2011). The FHWA also indicates that, between 1998 and 2010, most of the budgetary allocations have been directed towards maintenance and rehabilitation activities, while the number of new lane-miles has remained fairly stable year after year (FHWA 2008; 2013). As a result, the loops represent what academic and technical papers reveal: increasing maintenance and rehabilitation requirements constrain the available budget for new roads and increase the system condition shortfall by limiting the number of lane-miles in good condition.

2.8 Model Description

The system dynamics model simulates the maintenance and deterioration dynamics of the US highway system. It employs lane-miles of roads as its main unit and calculates system conditions over time. Figure 2.3 presents a simplified version of the model. A complete description of the system dynamics equations used in the model can be found in Appendix A (Equations S1-S68).

The main logic of the model is the same as the causal loop diagram. The model represents the deterioration and aging processes of the highway system. In order to quantify system condition and evaluate condition shortfalls, it classifies highways in three categories: good, acceptable, and deteriorated. It also indicates the maintenance and rehabilitation rates through which acceptable and deteriorated roads are restored into a good condition. The model comprises a series of interconnected variables that contribute to calculate the rates and expenditures related to rehabilitation, reconstruction, maintenance, and new construction, following the logic explained in the causal loop diagram. The model has two main policy parameters: "Budget Fraction for Maintenance" and "Rehabilitation Fraction" (see the bold and underlined variables in Figure 2.3). These are useful to understand the mechanisms associated with promoting proactive and reactive practices within the system. More information about the structure of the model follows.

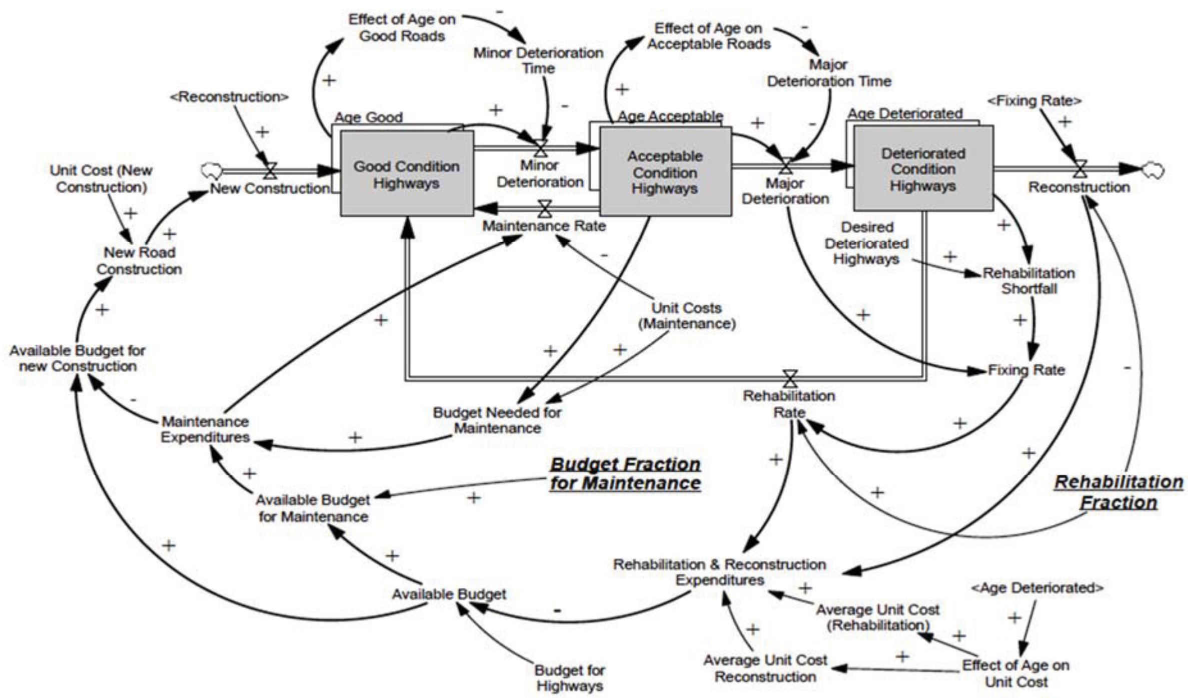


Figure 2-3 System Dynamics Model

2.8.1 Road Categories

This is represented by an aging chain, a dynamic structure that represents aging and deterioration processes (Osei-Kyei and Chan 2015; Tang et al. 2010). It has three stock variables (i.e., boxes), representing accumulation of roads in good (IRI of less than 95 in/mi), acceptable (IRI between 85 and 170 in/mi), and deteriorated conditions (IRI of more than 170 in/mi). The double-line arrows connecting the stocks indicate flows or rates of change in the number of roads within each one of the accumulation variables. As shown in Figure 2.3, new lane-miles start as good condition highways and successively move into the acceptable and deteriorated condition stocks through the minor and major deterioration flows, respectively. Both deterioration rates depend on the amount of lane-miles and the average age of the highways within each stock.

Within the aging chain, the model incorporates the age of highways as a special attribute in each stock and assumes that older pavements deteriorate faster (AASHTO 1993). For each road condition, the average age is calculated by considering the amount of lane-miles in the stock (collected from actual databases), the initial age of the roads (assumed from literature and calculated through parameter calibration), and the annual age increment. A higher average age in the good and acceptable condition stocks leads to higher deterioration rates. For deteriorated condition highways, on the other hand, a higher average age increases the rehabilitation and reconstruction costs, thus hindering improvement efforts.

2.8.2 Resources available

Building on the aging chain, the second model section focuses on calculating the rates and costs associated with rehabilitation, reconstruction, maintenance, and new construction processes. First, the model determines the "Rehabilitation & Reconstruction" expenditures based on the rehabilitation and reconstruction rates. The parameter "Rehabilitation Fraction" determines the number of lane-miles that are either rehabilitated or reconstructed. This means that the model assumes that governments prioritize the upgrade of deteriorated roads over acceptable highways. This is consistent with the acceptable ride quality goals established by FHWA (FHWA 1999; 2013).

Second, rehabilitation and reconstruction expenditures are compared with the budget available for the highway system (i.e., the six highway functional categories under study). If money is available, the parameter "Budget Fraction for Maintenance" allocates the resources between maintenance and new construction. For maintenance activities, the maintenance rate is determined based on the available and needed budgets. If the needed maintenance budget is less than the available funds, the remaining resources are used for building more lane-miles. On the other hand, in terms of new road construction, the "New Construction" rate is calculated by taking into account the funds available after maintenance, rehabilitation, and reconstruction.

2.8.3 Limitations

The scope of this study involves the following limitations: (1) the proposed model relies exclusively on the IRI and does not take into account other measures of pavement condition (e.g., rutting, caulking, and faulting); (2) the model neither considers how the condition of other multiple assets (e.g. signage, striping, guardrails, bridges) affects the whole system nor incorporates all the functional road categories across the US highway system; this is due to the fragmented nature of the available data and because the IRI is the main indicator employed by the FHWA across the country and is currently the most reliable road condition metric (FHWA 2013); and (3) the analysis is a counterfactual examination of data related to highway expenditures and road conditions; it does not take into account data from sources depicting traffic, economic, or urban growth; hence, the model has not been designed to make forecasts and assumes that the causal relationships represented within the simulation tool follow the principle of ceteris paribus (i.e. all other things being equal) (Sterman 2000).

2.9 Model Testing and Validation

The model was tested through employing standard methods for system dynamics (2009). Parameters, for instance, were estimated through partial model calibration (2010). In order to ensure structural validity, the model was built from formulations that had been employed in the past in order to examine similar infrastructure-related issues (Chasey 1995; Egilmez and Tatari 2012; Fallah-Fini et al. 2010; Kim 1996; de la Garza et al. 1998; Wang and Yuan 2016). These structures include standard dynamic formulations such as aging chains and goal-seeking configurations.

To further strengthen reliability, dimensional consistency and parameter assessment tests were performed (Forrester 1961). Each one of the equations employed within the model was inspected to ensure consistency. All their parameters have a real world meaning and are used in a logical and coherent way. Both equations and parameters have responded satisfactorily to extreme changes in model inputs. For instance, model stocks have always remained positive, even when parameters assume extreme values. As a result, the model responds plausibly and consistently to potential fluctuations of its variables.

To test the fidelity of the model to replicate the historical patterns, simulation results were compared to the actual data. We focus on three major state variables as well as a major cost measure as depicted in Figure 2.4. The first three variables, “Good Condition Highways”, “Acceptable Condition Highways”, “Deteriorated Condition Highways” are our major state variables and represent the highway system condition. For example, a drop in the number of good condition highways represents a system condition shortfall, an increase in the amount of acceptable highways indicates the need for maintenance, and a higher number of deteriorated lane-miles denotes that more rehabilitation/reconstruction is required. Furthermore, these variables are often measured in practice and their data are available. The fourth variable, “Rehabilitation and Reconstruction Expenditures” was chosen because rehabilitation/reconstruction activities are often the first reaction to quality deterioration with significant implications on highway expenditures. We believe that a useful model of the US highway quality and expenditure dynamics should be able to reproduce this variable.

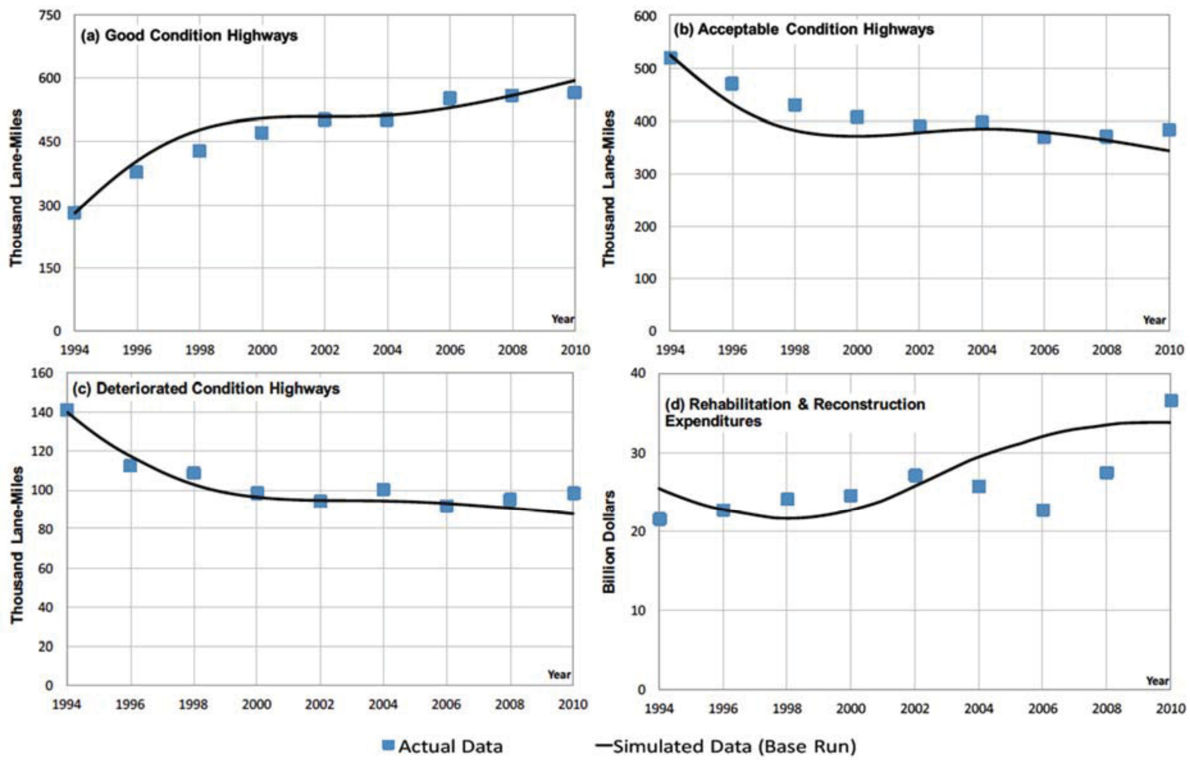


Figure 2-4 Actual vs Simulated Data

As shown on Figure 2.4, initial visual validation indicates that the model fairly captures the dynamic trends throughout the different highway conditions and expenditures. However, a statistical test is required to mathematically assess the model's ability to reproduce historical behavior. In system dynamics, model results are compared to actual data through the implementation of metrics, such as the coefficient of determination (R^2), the root mean square error (RMSE), and Theil's inequality statistics (Sterman 2000). The coefficient of determination allows measuring the variance in the data related to the model. The RMSE is an indicator of the average error between the simulated and actual data. The Theil's metrics represent a way to disaggregate MSE into three different errors: bias (U^M), unequal variation (U^S), and unequal covariation (U^C). This helps examine what portion of MSE is due to bias vs. unequal variation vs. unequal covariation (Sterman 2000).

Table 2.1 shows the measures to assess model fit to data. As observed, the coefficient of determination is relatively high in three of the four variables. This means that there is a good point-by-point correspondence between the model and the data for the system condition variables. For the fourth variable, however, the coefficient is around 0.5, which is not unexpected since there are several factors outside of the scope of our model which can influence costs. The rapid rise in construction material prices between 2004 and 2006 (FHWA 2008; 2013), the 2008 economic recession, and the increase of rehabilitation expenditures after 2008 due to the implementation of the American Recovery and Reinvestment Act (Dupor and Mehkari 2016; Honek et al. 2012) are three potential exogenous factors. Overall, considering the model's scope, we believe the fit between the simulation results and the data are reasonable.

Table 2-1. Statistics for assessing model fit to data

Indicator	Highway Condition			Rehabilitation Expenditures
	Good	Acceptable	Deteriorated	
R^2	0.947	0.86	0.945	0.484
RMSE	2.4E+04	2.5E+04	4.1E+03	4.2E+09
Bias, U^M	0.25	0.44	0.21	0.13
U. Variation, U^S	0.03	0.0007	0.06	0.0001
U. Covariation, U^C	0.72	0.56	0.73	0.87

We also analyze systematic and unsystematic errors in our model using Theil's metrics (2005). Theil's metrics breaks MSE down into three major factors. Table 2.1 shows that most of the MSE accumulates around the covariation component for each one of the four variables (i.e. $U^C > U^M > U^S$). This suggests that errors are unsystematic and do not originate from the simulation process, but from natural randomness in actual data (Sterman 2000). It also confirms that the model's aging chain is endogenously driven and is able to properly capture system behavior. Similar results have been obtained in other studies (i.e. simulation models) in which aging chains have been incorporated (Fallah-Fini et al. 2010; Ghaffarzadegan and Tajrishi 2010; Taylor et al. 2012).

Consequently, the model and the historical data differ point by point, but exhibit a good fit in terms of their means and trends.

2.10 Policy Analysis

For policy testing, the model is used to conduct a simulation-based counterfactual analysis. This means that base-run parameters are modified in order to examine what would happen if particular changes had been implemented. For example, a counterfactual experiment may involve incremental increases of the maintenance budget since year 2000 in order to compare the results from these simulations with base-run outputs. The results of the counter-factual test are compared with the base run simulation.

Three policies are defined assuming that the total budget follows the historical trend and no additional revenues are added to the system: (a) Policy 1 is focused on promoting maintenance practices through changing the budget allocated for such activities; (b) Policy 2 evaluates system reactions to variations in the rehabilitation rate; and (c) Policy 3 tests the impacts of combining Policies 1 and 2.

For all the policy tests, interventions are implemented from 2000 for a period of 10 years. This allows evaluating short term and long term response of the system. Results of the policy tests are summarized in Table 2.2 and further discussed in the subsequent sections.

Table 2-2. Studied Policies

Policy actions	Policy Adjustments		
	Parameter	Base-run value	Test values
P1: Promoting Maintenance	Budget Fraction for Maintenance	45%	0%, 35%, 55%, 65%, 85%, and 100%
P2: Promoting Rehabilitation/Reconstruction	Rehabilitation Fraction	93%	90%, 91%, 92%, 97%, and 100%
P3: Combining Maintenance and Rehabilitation	P1 and P2 parameters	P1: 45% P2: 93%	P1: 0% to 100% P2: 80% to 100%

2.10.1 Policy 1: promoting maintenance

Policy 1 (P1) was formulated through increasing the percentage of funds allocated for maintenance. The parameter "Budget Fraction to Maintenance" was changed from 45% (base run value) to 55%, 65%, 85%, and 100%. The analysis also included percentage reductions from 45% to 35% and 0%.

Figure 2.5 compares base-run results with P1 outputs for the four major outcome variables: Good Condition Highways, Acceptable Condition Highways, Deteriorated Condition Highways, and Rehabilitation Expenditures. In each graph, the numbered thicker line represents the original, base-run simulated behavior and the other numbered curves indicate the six different simulations associated with P1 (where Curve 5 is the base-run). Changes take place after year 2000 and are based on multiple budget allocations. With respect to Good Condition Highways, for example, the amount of lane-miles increases with maintenance budget allocation percentages higher than 45% and decreases with lower ratios. Figure 2.5 illustrates that although various fractions produce very similar end results in 2010 (around a 33% increase for ratios higher than 45%), initial system reactions are significantly different. For example, while a 100% budget allocation generates a 40% increase in the first two years, a 55% ratio only achieves a 10% increment in the same period. This means that when maintenance is fully prioritized, system conditions are able to improve at a much higher rate. In other words, governments wanting to enhance system conditions in the short-term, should prioritize maintenance over rehabilitation.

System responses seem to follow similar trends for the other variables. In this case, Acceptable Condition Highways, Deteriorated Condition Highways, and Rehabilitation Expenditures decrease for ratios higher than 45% and increase for lower allocation percentages.

Also, as with Good Condition Highways, each variable shows similar final outputs and distinct initial system responses after 2000.

Overall, Figure 2.5 reveals that although the system achieves similar outcomes for different budget allocation percentages by 2010, system behavior between 2000 and 2010 varies according to the percentage of funds allocated to maintenance. If governments had wanted a rapid increase in the number of lane-miles in good condition and a significant short-term reduction in rehabilitation expenditures, they should have raised the maintenance budget allocation from 45% to 85% or more. If, on the other hand, public agencies were looking for more gradual changes, they could have opted for percentage levels around 55% or 65%. In any case, the long-term results for the variables shown in Figure 2.5 would have been approximately the same by 2010.

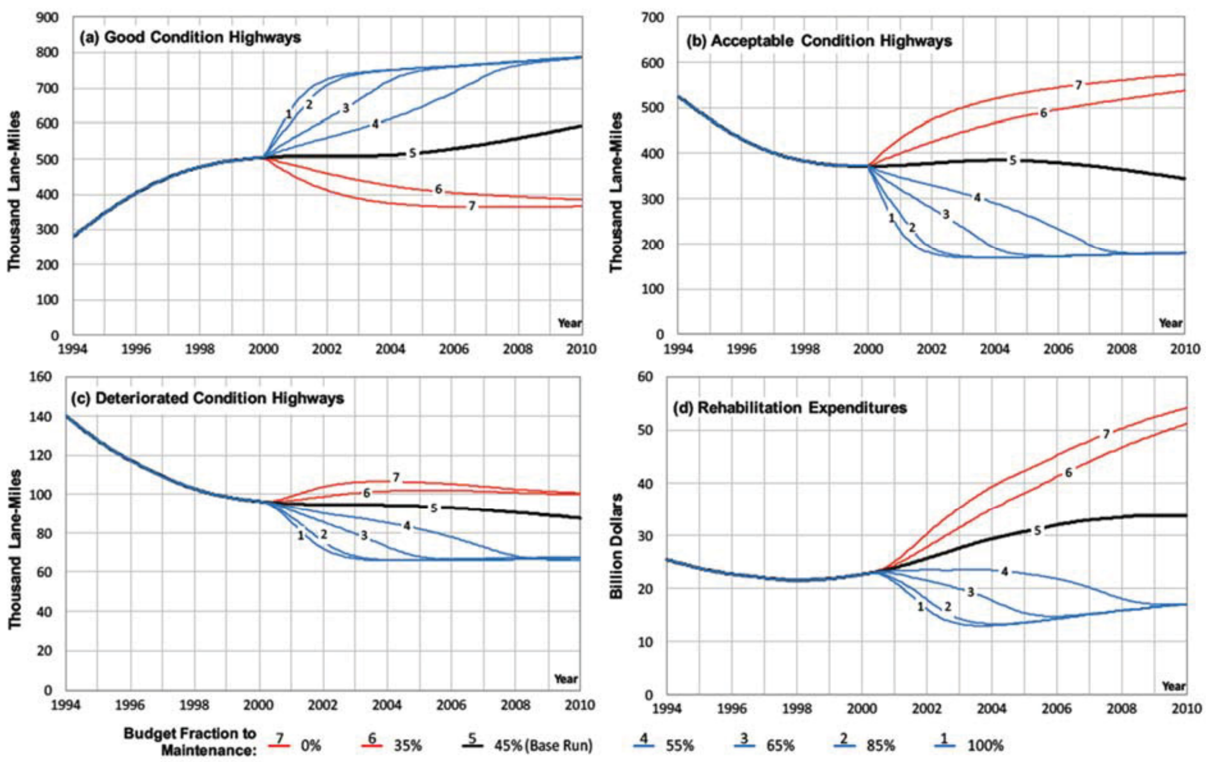


Figure 2-5 Effect of Policy 1 on System's Conditions and Expenditures

2.10.2 Policy 2: promoting rehabilitation

After conducting the first policy test, P2 was formulated to analyze the effects of incentivizing rehabilitation and reconstruction. To simulate the impact of having more rehabilitation and less reconstruction, the parameter Rehabilitation Fraction was raised from 93% (base run value) to 97% and 100%. In the same way, to evaluate the effects of having more reconstruction at the expense of rehabilitation, the same parameter was reduced from 93% to 92%, 91%, and 90%.

Figure 2.6 depicts how the same four major outcome variables are impacted by changes in the rehabilitation fraction. By 2010, for instance, a 97% ratio approximately accounts for a 15% increment in good condition roads, a 30% reduction in acceptable lane-miles, a 10% decline in deteriorated highways, and a 50% drop in rehabilitation expenditures. Alternatively, by 2010 a 90% rate generates a 20% decrease in good lane-miles, a 25% increment of acceptable roads, a 5% increase in deteriorated highways, and a 35% rise in rehabilitation expenditures.

Figure 2.6 shows that any increment in the rehabilitation fraction generates more good condition roads, fewer expenditures, and lower values in the acceptable and deteriorated highway stocks because rehabilitation is cheaper than demolishing and reconstructing deteriorated lane-miles. Therefore, if more resources are directed to rehabilitation instead of reconstruction, expenditures decrease and overall system conditions improve. If government agencies had wanted to incentivize rehabilitation without modifying the budget allocated to maintenance, they could have increased the rehabilitation rate beyond 93%.

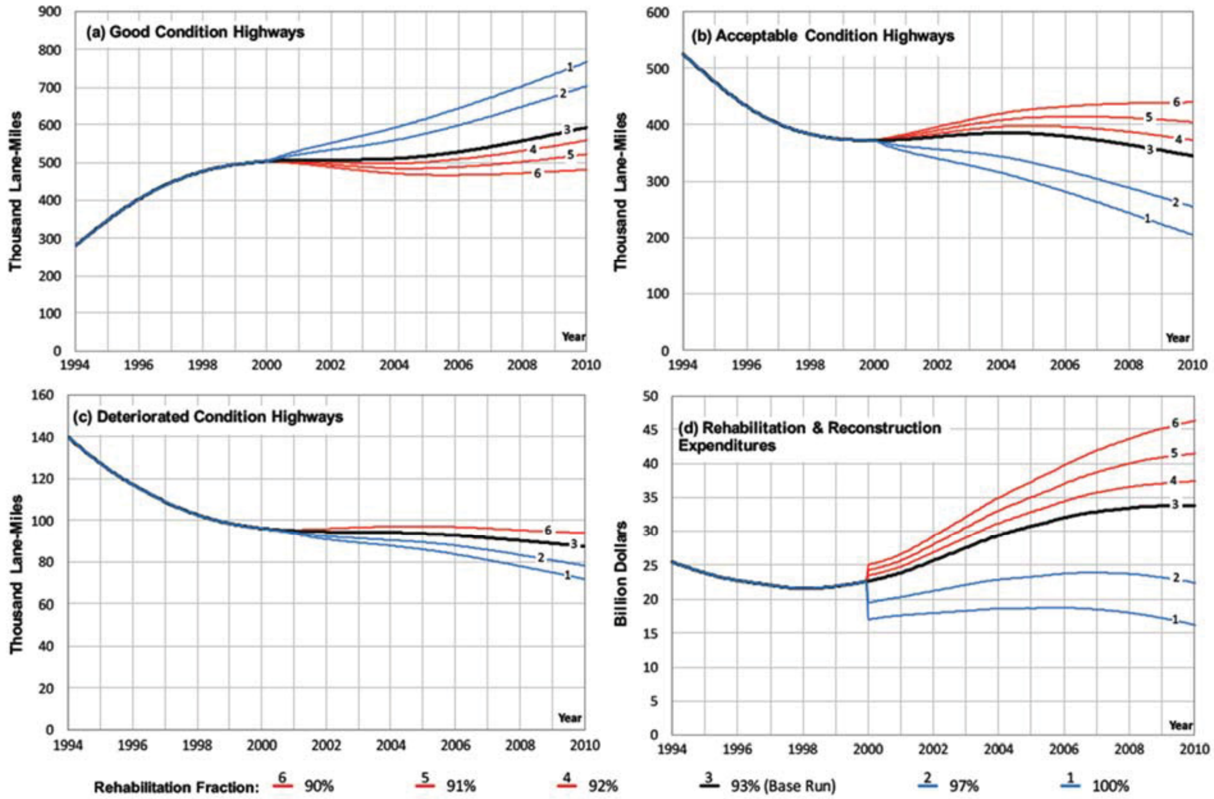


Figure 2-6 Effect of Policy 2 on System's Conditions and Expenditures

2.10.3 Policy 3: combining maintenance and rehabilitation

So far, Policies 1 and 2 show that road conditions can be significantly improved by incentivizing either maintenance or rehabilitation. P3, as a result, was formulated with the intention of integrating both maintenance and rehabilitation efforts. P3 seeks to examine how the system responds to simultaneous changes in two parameters: Budget Fraction to Maintenance and Rehabilitation Fraction. In this test, the maintenance-related variable varied from 0% to 100% and the rehabilitation-related parameter adopted values between 80% and 100%.

Figure 2.7 reports the 2010 values resulting from combining different maintenance and rehabilitation allocations. In the four graphs, the vertical axis indicates the 2010 outcomes, the horizontal axis depicts maintenance budget fractions, and rehabilitation fractions are presented as different data series. As shown for the four variables in the figure, all the simulation curves can be divided into three main parts: two stable condition regions (horizontal sections) and one rapid change area (inclined section). The three sections are present in each data series and its emergence depends on the maintenance budget allocation ratio. While low- and high-value maintenance budget fractions generate the stable sections, middle-value ratios produce the rapid change portions.

For all the data series, the curves representing higher rehabilitation fractions tend to have longer high-value regions and shorter middle- and low-value sections than the curves denoting lower rehabilitation ratios. For example, if the rehabilitation ratio is 100%, the short- and high-value sections include maintenance allocation fractions from 0% to 25% and 50% to 100%, respectively. However, if the rehabilitation fraction is 80%, then the same sections range between 0% to 65% and 75% to 100%.

The high-value regions in Figure 2.7 suggest that the system has achieved a stable improved condition. For a constant rehabilitation fraction, once the system has achieved such a state, any variation in the maintenance budget allocation ratio does not trigger significant changes. For instance, if the rehabilitation fraction is 100% and the maintenance budget allocation changes from 25% to 50%, the number of roads in good condition is doubled, the amount of lane-miles in acceptable condition is reduced by two thirds, the number of deteriorated highways declines 30%, and rehabilitation expenditures decrease more than 70%. For this case, however, maintenance allocations higher than 50% do not significantly affect model outcomes because the system is already in a steady, improved state.

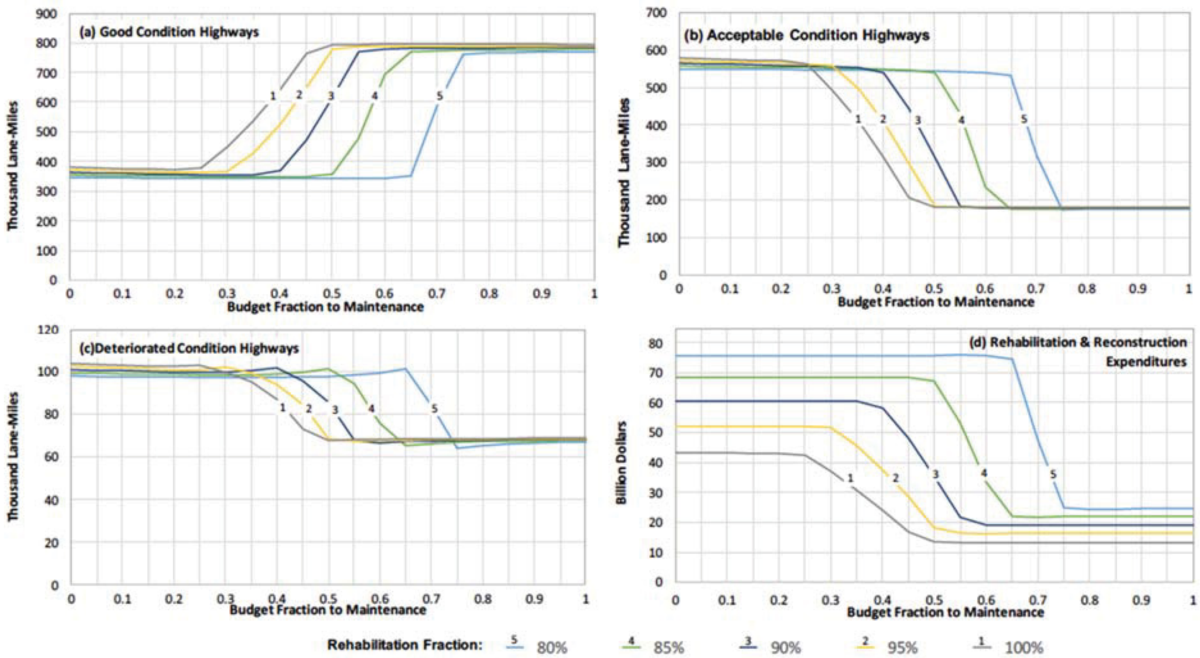


Figure 2-7 Effect of Policy 3 on System's Conditions and Expenditures

Although Figure 2.7 shows that different combinations of maintenance and rehabilitation fractions affect model results in several ways, it does not indicate the effects of such combinations on new road construction. Consequently, Figure 2.8 illustrates how the total number of new lane-miles (new roads built between 1994 and 2000) changes according to multiple maintenance budget allocations and rehabilitation ratios. For each rehabilitation fraction, ceteris paribus, the amount of new lane-miles varies in line with the maintenance ratios. For instance, if the model assumes a 100% rehabilitation fraction, new road construction is maximized when no budget is allocated to maintenance, it constantly decreases when the maintenance ratio changes from 0% to 25%, and it remains relatively stable for values higher than 25%. However, if the rehabilitation fraction is 80%, results are slightly different. Total new construction steadily decreases between 0% and 40%, remains constant between 40% and 65%, and gradually increases for budget maintenance ratios higher than 65%.

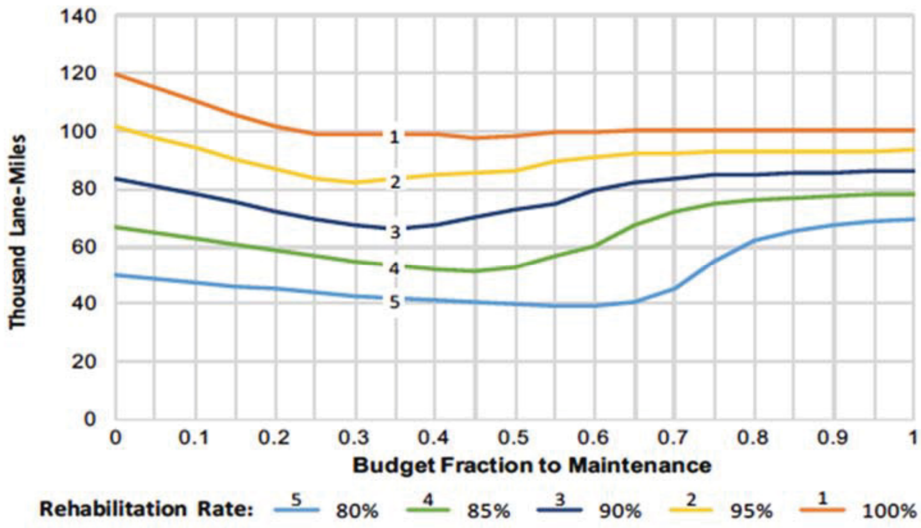


Figure 2-8 Effect of Policy 3 on Total New Lane-Miles

Given the simulation results and taking into account the model's limitations, multiple combinations of maintenance and rehabilitation ratios are present that would have allowed the highway system to be in a better condition by 2010. For example, if governments had implemented more aggressive rehabilitation programs since 2000, the number of good condition roads would be higher, there would be fewer acceptable and deteriorated lane-miles, and rehabilitation expenses would be lower. Also, more rehabilitation would have allowed a reduction in the budget allocated to maintenance and provided more resources for building new roads. On the other hand, if more resources had been allocated to maintenance activities, governments could have demolished and reconstructed more lane-miles and achieved very similar outputs in terms of road conditions. Additionally, higher maintenance budget allocations would also have meant more rapid improvements across the entire highway system.

2.11 Discussion

Based on the studied policies, P1 and P2 offer different paths toward system improvement. Under P1, the system improves more rapidly when budget allocation ratios move closer to 100%.

However, any ratio higher than 45% (base run value) generates approximately the same result in 2010. Under P2, for rehabilitation fractions higher than 93%, any incremental change produces gradual system improvements and results in different final outcomes by 2010. In general, P1 achieves better final system conditions than P2, except when the rehabilitation fraction (P2 parameter) assumes a value of 100%. In this case, results in 2010 are very similar for both policies. For the two policies, the system deteriorates when parameters are lower than base run values.

These results suggest that P1 and P2 illustrate some of the feedback mechanisms associated with the capability trap phenomenon. P1 focuses on increasing maintenance activities, so its application reveals the effects of implementing proactive efforts on the highway system. This policy shows that promoting maintenance decreases rehabilitation expenditures because high maintenance budget allocation percentages prevent roads from suffering significant deterioration (i.e. moving from an acceptable condition to a deteriorated state). With lower rehabilitation costs, more resources are available to improve minor deterioration issues and more funds are free to increase the number of lane-miles in good condition.

The focus of P2, on the other hand, is on rehabilitation activities. Its results indicate that although improving the highway system by incentivizing rehabilitation is possible, P2 implementation generates outcomes that are mostly inferior to those of P1 every year. Hence, when rehabilitation practices are incentivized without promoting maintenance activities, the system relies more on reactive actions than on proactive measures. As a result, despite showing some improvements, P2 is not as effective as P1.

The application of P3 sheds light on how different combinations of maintenance *and* rehabilitation affect system behavior. According to Figure 2.8, for all cases, model results improve when maintenance budget allocations move toward 100%. Simulation curves show that before achieving a stable improvement state, the system experiences a rapid change where outcomes significantly improve for any variation in maintenance allocations. Such rapid change in simulation results signals the existence of a shifting feedback loop dominance within the system.

P3 implementation reveals the interaction of the feedback mechanisms underlying the application of P1 (proactive efforts) and P2 (reactive efforts). When the system experiences low-value maintenance budget allocation ratios, proactive efforts are not strong because there are not enough resources to promote maintenance. Consequently, reactive efforts dominate, and the system relies on rehabilitation practices. However, when allocation fractions start increasing, reactive efforts decline and proactive actions begin to dominate. Model results generated from middle-value ratios reflect a transition in feedback loop dominance. Once high-value maintenance allocations start, more funds are available to incentivize preventive maintenance and proactive efforts begin to control system behavior.

P3 implementation also reveals how the interaction of reactive and proactive efforts affect the construction of new roads. As shown in Figure 2.7, the highest total number of lane-miles built between 1994 and 2010 is achieved with a rehabilitation fraction of 100% and a maintenance budget allocation ratio of 0%. Although this combination of ratios produces the highest number of new lane-miles, this policy is not pragmatic because, as shown in Figure 2.5, deterioration increases when maintenance efforts are diminished. Therefore, the most realistic outcomes emerge with rehabilitation fractions higher than 90% and maintenance budget ratios greater than 55%. This suggests that the amount of new roads built between 1994 and 2010 is higher when proactive efforts dominate reactive measures.

2.12 Conclusions

The current work explores the challenges associated with generating road capacity and funding maintenance and rehabilitation activities in the US highway system. The simulation model shows how maintenance and rehabilitation expenditures are endogenously linked with the system's aging and deterioration processes. The results indicate that such expenditures are continuously growing because every year it is more expensive to repair old and deteriorated pavements. In other words, reactive efforts seemingly dominate proactive actions. Since funding has been mostly directed to cover previously postponed maintenance and rehabilitation activities, capital available to invest in building new roads is significantly depleted. Although other factors may also contribute to cost increments, this research shows that the road infrastructure in the US needs a significant upgrade so as to reduce the expenses associated with its aging condition.

Improving the US road infrastructure is not an easy task because the system seems to be experiencing the capability trap phenomenon. Model results show that, although the amount of lane-miles in good condition has improved over time, rehabilitation/reconstruction expenditures have steadily increased and the number of deteriorated roads has not been significantly reduced. This suggests that governments have been focused on implementing rehabilitation improvements in order to cope with major deterioration conditions (i.e. short-term issues). However, they have not been able to curtail long-term degradation and have not properly promoted maintenance activities. As a result, (using the leaky ship metaphor described), the US highway system is not sinking because of governments' bailing efforts, but it is not moving forward either because authorities have not been able to prevent long-term water leaks.

The studied policies shed light on the feedback mechanisms associated with the CT phenomenon and propose steps for escaping the trap. The implementation of P1 and P2, for example, suggests that although both policies achieve similar final results in 2010, P1 accomplishes better outcomes in the short-term. When proactive efforts (loop B2) dominate reactive actions (loop B1), more resources for future maintenance are available (loop R1), the amount of deteriorated roads declines more rapidly, and more new lane-miles are built (loops B4 and R2). Ceteris Paribus, the application of P3, on the other hand, highlights that capacity expansion is possible through properly combining maintenance and rehabilitation efforts. Based on these policies, simulation results imply that governments should incentivize maintenance over rehabilitation/reconstruction in order to reduce long-term deterioration and free up funds for building new roads.

The current work contributes to the literature in various ways. First, this study provides a SD model that describes the investment dynamics associated with the maintenance, rehabilitation, and construction of road infrastructure in the US. While some previous studies have developed SD models to examine deterioration and maintenance processes in road infrastructure, this paper introduces the concept of CT in order to explain the difficulties related to improving road conditions and expanding current system capacity. Second, the policies under analysis aim to illustrate the relationship between the implementation of reactive short-term efforts (i.e. rehabilitation/reconstruction activities) and the application of proactive long-term actions (i.e. maintenance activities). This highlights the feedback mechanisms underlying the links between road conditions and resources available. Third, the simulation model can analyze the difficulties related to improving the condition and performance of the US highway system in a graphical and interactive way.

Similarly, this study has several engineering management and policy implications. Since simulation results suggest that the US highway system has not improved rapidly enough because rehabilitation works have been prioritized over maintenance activities, the model can become a supporting tool for policy makers. Future studies can be focused on generating a more graphic and interactive interface in order to enhance user experience. Additionally, the results also indicate that increasing rehabilitation expenditures limits new road construction in the long-term, so the model helps to generate awareness about how deferred maintenance contributes to restrain capacity expansion budgets. However, further research is necessary to incorporate the impact of highway revenues into the model.

The model developed also provides opportunities to analyze similar issues in different contexts. Since road infrastructure is a public-asset, further investigations can be focused on examining the differences between improving trapped systems in public and private domains. This is particularly important during maintenance and rehabilitation budget allocation because public entities typically have more annual budget constraints than private firms. On the other hand, within the transportation sector, similar CT-based models can be built to analyze transit systems or infrastructure sectors in jurisdictions at all levels. This is feasible in the near future because the system dynamics structures employed in this model are neither specific to the US nor exclusive to the infrastructure field. Further studies can also explore the differences in maintenance cost dynamics between publicly procured projects and public-private initiatives.

While the study has several implications for decision making and practice, we are also aware of its limitations. Like all modeling studies, this study has limitations imposed by its scope and assumptions, as stated previously. For example, the focus of this work is on dynamics of rehabilitation/reconstruction and maintenance activities. We did not model dynamics of demand for highway usage as influenced by exogenous factors such as fuel prices, macroeconomic factors, etc. This circumstance creates an opportunity for future research and model expansion.

Overall, the findings challenge the common mode of response and type of practice that focuses on fixing major problems/failures before anything else. All economic, social, and organizational pressures push decision makers to focus on the so-called “high priority” tasks and fixing major immediate problems (such as rehabilitating deteriorated highways). Our results show how this pattern of response leads to long term deterioration of the highway system. In addition, our findings show that new road construction (which might be a very long term investment) is not necessarily the solution. Finally, this study contributes to the capability trap literature since past capability trap studies have not been applied to a highway system.

2.13 Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1333264. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

2.14 Supplemental Data

The system dynamics equations (S1-S68) of the model described in this paper are available in Appendix A.

3. CHAPTER 3: A SYSTEMS MAP OF GOVERNANCE INTERDEPENDENCIES IMPACTING THE SHAPING PHASE OF PUBLIC-PRIVATE PARTNERSHIPS[2]

3.1 Abstract

The global experience of public-private partnerships (PPPs) has attracted significant scholarly attention because they have faced multiple questions about their real benefits and costs. However, despite the growing interest, the collection of reasons behind PPP successes and failures remains unclear. To address this lack of clarity, we seek to gain insight into the shaping phase of public-private agreements by examining the existing literature in a systematic way. Adopting the concept of socio-technical governance, our objective is to analyze how governance-related variables influence the shaping of PPP projects in the road infrastructure sector. Our methodology involves a multi-stage systematic literature review and uses elements from system dynamics. The outcome of this endeavor is a systems map, informed by past-published cases, depicting how project socio-political, operational, and financial feasibilities are affected by governance challenges associated with PPPs. Conclusions point to the key drivers and causal relationships underlying the main sources of complexity in PPP governance.

Keywords: public-private partnerships, PPP governance, causal mapping, systems thinking

[2] This paper was co-authored with professors Michael J. Garvin and Navid Ghaffarzadegan and will be submitted to a peer-reviewed journal.

3.2 Introduction

Since the 1990s, governments around the globe have used public-private partnerships (PPPs) extensively as a way to improve infrastructure, particularly the roadway sector (Liu et al. 2016; Tang et al. 2010). However, the implementation of public-private agreements has encountered various challenges, and questions about their benefits and costs have emerged in both developed and developing countries. Despite their potential benefits and efficiencies, many national and regional governments have not had successful experiences with PPPs (van Buiten and Hartmann 2015). As a result, an increasing number of researchers have investigated PPP-related topics in order to gain insight into the challenges of developing PPP projects.

The extensive variety of PPP-related publications has encouraged scholars to conduct studies focused on developing comprehensive literature reviews (Ke et al. 2009; Osei-Kyei and Chan 2015; Tang et al. 2010; Zhang et al. 2016). These have been useful to critically analyze past and current research trends, explore future research avenues, and highlight knowledge gaps. However, these studies provide limited insights about PPP implementation challenges because most of these efforts only categorize research papers by thematic fields or methodological approaches. Therefore, the PPP body of knowledge needs examination from a different perspective in order to fully understand the reasons behind failed or successful experiences in public-private agreements.

Using the concept of socio-technical governance as its principal basis, this study completes a systematic literature review focused on *analyzing how governance-related variables influence the shaping of PPP projects in the road infrastructure sector*. The concept of governance is selected because it allows examining how different PPP challenges arise and propagate across the project life cycle. Consequently, the literature review approach explores PPP-related publications in order to highlight governance challenges, identify the governance-related variables behind the challenges, and establish causal relationships between such variables. The outcome of this investigation is a systems map depicting the governance dynamics associated with the shaping phase of PPP projects.

Moreover, the review focuses on finding actual evidence of PPP governance challenges in real public-private projects. Our unit of analysis is the shaping phase of PPP projects themselves, rather than general implementation policies or national public-private initiatives. Hence, we limit our efforts to search for data related to the project phase where a project's political, financial, and operational feasibility is established. Our methodology uses elements from system dynamics to reveal the main sources of complexity in PPP governance. We intend to answer the following questions: what type of causal relationships between governance challenges and PPP development processes can be deduced from project data in the existing literature? Based on these relationships, what are the main drivers behind implementing contractual and relational mechanisms within the PPP shaping phase?

To address these questions, we begin with an overview of the most important governance mechanisms associated with PPP implementation. Second, we discuss the importance of the shaping phase in PPPs and describe the main governance challenges emerging in this stage. Third, we introduce the methodology for our systematic literature review and describe the process of developing our systems map. Fourth, we analyze the relationships found in the data of the reviewed articles, the PPP governance challenges, and the proposed causal diagram. Finally, we present our conclusions and discuss future research avenues.

3.3 Theoretical Background

3.3.1 Contractual and Relational Mechanisms

Over the past few decades, researchers have examined the development of public-private partnerships through the lens of contractual and relational mechanisms (Ahola et al. 2014; Guo et al. 2014; Lu et al. 2015). Building on the theory of institutional economics (Coase 1937) and transaction cost economics (TCE) (Williamson 1979), scholars have explored how PPP contracts contribute to reduce uncertainty, diminish opportunistic behaviors, and minimize risk exposure in long-term infrastructure projects (Roehrich and Lewis 2010; Van Den Hurk and Verhoest 2015; Zheng et al. 2008). Alternatively, based on social and normative principles (Gulati 1995; Poppo and Zenger 2002), researchers have also studied how to enhance construction performance and PPP project outcomes through incentivizing relational processes, shared values, and trust-based transactions (Caniëls et al. 2012; Lu et al. 2015; Meng 2012; Roehrich and Lewis 2010; Zou et al. 2014).

The literature on contractual governance mechanisms suggests that these instruments follow a TCE rationale (Williamson 1979). According to this logic, contracts are the main instruments for organizing the transactions through which project actors are able to cooperate and compete (Ruuska et al. 2011; Williamson 1999). The objective of contractual arrangements, therefore, is to create legally binding relationships so as to tackle opportunism and bounded rationality. Through the contract, project participants seek to mitigate project risks and minimize transaction costs.

In PPPs, contractual governance and TCE contribute to control issues related to asset-specificity and uncertainty (Ho et al. 2015; Lu et al. 2015; Sanderson 2012). It is assumed that well-designed contracts are capable of mitigating renegotiation risks through ensuring complete contractual compliance (Hartmann et al. 2014). Thus, an optimal contract would be an agreement focused on achieving its objectives with the lowest transaction costs. However, PPP contracts are often characterized as incomplete because they do not contain all the necessary provisions and safeguards against opportunism (Cruz and Marques 2013a). Similarly, PPP contracts are also portrayed as expensive because they involve considerable procurement costs (Zheng et al. 2008). As a result, many authors argue that contractual mechanisms need to be complemented with relational instruments (Caldwell et al. 2009; Caniëls et al. 2012; Roehrich and Lewis 2010; Zou et al. 2014).

Relational mechanisms seek to improve project performance through promoting trust, flexibility, solidarity, and shared-values among project participants (Caniëls et al., 2012; Guo et al., 2014; Maurer, 2010). In PPPs, scholars report that implementing relational practices has the potential to streamline procurement processes, decrease opportunism conflicts, and minimize transaction costs (Cao and Lumineau, 2015; Clifton and Duffield, 2006; Roehrich and Lewis, 2010). However, despite the claimed benefits, little evidence of the adoption of relational mechanisms in PPP projects worldwide exists (Guo et al., 2014). In many public-private agreements, project participants remain hesitant about complementing their traditional contractual arrangements with relational practices (Lenferink et al., 2013; Smyth and Edkins, 2007). It seems that integrating contractual and relational mechanisms remains a work in progress (Caniëls et al., 2012; Roehrich and Lewis, 2010). Many governance challenges still need to be overcome in order to facilitate such integration.

3.3.2 Governance challenges in shaping PPPs

Project shaping entails all the organizational efforts focusing on the creation of a project vision and all the processes around securing resources and attracting support to develop this vision

(Winch and Leiringer, 2016). In complex civil engineering projects, this stage is very important since during this period project participants make many choices that move a project towards either success or failure (Lessard and Miller, 2013). Since the shaping phase comprises a high degree of flexibility and involves multiple stakeholders with heterogeneous mindsets, it provides a very good opportunity to carefully and recurrently evaluate project viability (Miller and Olleros, 2000). However, due to the variety of efforts involved in shaping a project, this stage is not easy to manage and demands leadership and resiliency from project actors (Winch and Leiringer, 2016).

Similar to large and complex civil engineering projects, scholars characterize the shaping phase of PPPs as a complex endeavor in which a changing network of dissimilar project participants make decisions concerning the project's political, financial, and technical feasibility (Henisz 2006; Liu et al. 2016; Tang and Shen 2013). Researchers emphasize that the dynamic nature of interests and relationships among project actors makes it difficult to understand how to optimize project viability in PPPs (El-Gohary et al. 2006). Also, the literature suggests that shaping PPPs is challenging because it involves decision-making processes distributed across multiple life-cycle phases including activities such as, conceptualization, feasibility, pre-tendering, procurement, negotiation, commercial close, and financial close (Henisz et al., 2012; Levitt et al., 2010; Miller and Olleros, 2000). As a result, shaping PPPs entails multiple interactions that need to be properly managed through contractual and relational governance mechanisms.

Considering the asset-specific and long-lasting nature of public-private agreements, many scholars concur that multiple governance difficulties are related to implementing contractual and relational governance mechanisms in the shaping phase of PPPs (Jooste et al. 2011; Jooste and Scott 2012; Koppenjan 2005). The socio-political legitimacy of the agreement, for example, is an important governance challenge that may affect the way contracts are designed. Since developing a PPP involves the utilization of private capital in projects that have traditionally relied on public resources, scholars report that if projects are not perceived as legitimate initiatives, the general public might call for ex-post interventions (Levitt et al. 2010; Zhang et al. 2015). Similarly, private firms may find it difficult to build trust with government agencies that are not committed to successful delivery of these arrangements (Kivleniece and Quelin 2012).

Apart from the socio-political concerns, the hazard of displaced agency is also an important issue within the shaping phase of PPPs. Multiple project participants may make several decisions without fully considering their long-term consequences, so decision-making processes are sub-optimal (Henisz et al., 2012; Henisz, 2006). In other words, the project actors who make most of the front-end decisions (i.e. the most important decisions) are not fully accountable for the long-term effects of such actions (Levitt et al. 2010). By the time such effects materialize in the construction and operation phases, those decision-makers are often no longer a part of the project. This circumstance helps explain over-optimistic traffic projections and inaccurate cost and schedule estimates in PPPs (Chi et al. 2013; Levitt et al. 2010).

Additional governance challenges within the project shaping phase involve the uncertain nature of the agreement and potential opportunistic behaviors among project participants. In terms of uncertainty hazards, it is mostly in the shaping phase where project participants must make decisions with insufficient information (Chan et al. 2010; Garvin 2010; Guo et al. 2014; Wang 2015). Thus, public and private sectors seek to control uncertainty through different instruments such as, contractual provisions, government guarantees, transparent procurement processes, and trust-based strategies (DeCorla-Souza et al. 2013; Mayer 2007). With respect to opportunism problems, these are often the result of: project leaders trying to maximize their own returns without implementing proper safeguards for other stakeholders (Cruz et al. 2015; Ho et al. 2015); private participants trying to design advantageous contractual arrangements (Carpintero et al. 2014; Cruz and Marques 2013b); or governments using PPP projects as instruments to achieve political and electoral goals, i.e. government hold-up (Cruz et al. 2015; Guasch et al. 2008).

In short, project participants seek to attain political, financial, and technical feasibility during the shaping phase of PPP projects. To achieve project viability, project actors rely on the implementation of multiple relational and contractual governance mechanisms. However, the application of such instruments is not easy because it is usually hindered by a series of challenges. Despite some research efforts, scholars only provide fragmented evidence regarding how to successfully deal with the emergence of such challenges. As a result, ample room remains to improve our understanding about how to develop better PPPs through successfully implementing governance mechanisms. We intend to gain insight into these issues by examining the shaping phase of public-private agreements through a systematic literature review.

3.4 Research Methodology

Our research approach is informed by methodological processes originating in the management field (Locke and Golden-Biddle 1997; Tranfield et al. 2003), the infrastructure and project management domains (Al-Sharif and Kaka 2004), and system dynamics (Sterman, 2000; Richardson, 1991). In general terms, following the example of similar literature analyses (Osei-Kyei and Chan 2015; Tang et al. 2010), our review has been conducted in a systematic multi-stage way with the intention of ensuring a reliable, transparent, and replicable methodology (Kokkonen and Alin 2015; Rashman et al. 2009). We have adopted a systems perspective in order to comprehend the complexities of the shaping phase in PPPs. We focus on developing a causal map to better visualize and analyze the interactions and emergent challenges associated with the implementation of governance mechanisms (Ackermann and Alexander 2016; Kim and Andersen 2012). Specifically, we have divided our methodology into four main stages as discussed below.

3.4.1. Paper selection strategy

In this stage, our intent was to yield a sample of articles describing real situations in actual PPP projects. Regardless of the paper type (i.e. qualitative, quantitative, theoretical, or case study), we looked for analyses published between 1997 and 2015. Our goal was to identify papers providing actual evidence about the effects and influence of governance challenges throughout the shaping phase of PPP projects for road infrastructure. To do so, we conducted database searches that included not only journals from the construction and project management domain, but also academic publications from fields related to finance, law, public policy, and many other disciplines. These processes were consistent with methodologies implemented in other reviews (Garvin and Gross 2012; Ke et al. 2009; Kokkonen and Alin 2015; Rashman et al. 2009; Tang et al. 2010).

The database search in the construction and project management domain followed the paper selection procedures established by Al-Sharif and Kaka (2004), Ke et al. (2009), and Tang et al.-(2010). Based on these authors, we reviewed titles/abstracts/keywords in articles from the following leading journals: Construction Management and Economics (CME), Engineering, Construction and Architectural Management (ECAM), International Journal of Project Management (IJPM), Journal of Construction Engineering and Management (JCEM), Journal of Management in Engineering (JME), Proceedings of Institution of Civil Engineers-Civil Engineering (PICE), Public Money and Managemet (PMM), and Building Research and Innovation (BRI). Our search terms comprised all of the keyword combinations employed by the aforementioned authors, such as ‘public private partnership’, ‘build operate transfer’, and ‘private finance initiative’, among others. Overall this search resulted in 362 articles.

To generate a sample of PPP-related articles from journals outside the construction and project management domain, we implemented the methodology established by Garvin and Gross (2012). We used their search parameters and employed Google Scholar to identify articles in 142 peer-reviewed journals from multiple disciplines. After confirming that the targeted journals were listed in ISI Web of Science or Scopus, we selected 368 additional papers. In total, the whole search process identified 730 articles from journals within and outside the construction and project management domain.

3.4.2 Paper filtering and categorization

After identifying the 730 PPP-related articles, our goal was to choose only those papers depicting governance issues in the shaping phase of real road PPP projects (Figure 3-1). We implemented a multi-step review protocol in order to filter and select this final group of papers. Initially, we excluded 45 articles because they were editorials, book reviews, or any other document not qualifying as a research paper. We then examined the titles/abstracts/keywords of the remaining 685 articles. From these, we excluded studies that were exclusively focused on simulations, statistical procedures, real options, or any other mathematical models (196 articles found). We also discarded papers based on surveys of industry practitioners (54 articles found) and investigations about non-transportation PPPs (88 articles found). We were eventually left with 347 articles.

To select only those articles complying with our research goal, we reread the abstracts of the remaining 347 papers in conjunction with their introduction and conclusion sections. This helped us to exclude studies not focused on the PPP project itself, but on examining construction firms and stakeholders within the PPP market (37 articles found). Likewise, we also excluded investigations exploring national and/or international PPP markets as a whole (53 articles found), papers discussing PPP concepts and definitions from a theoretical standpoint (64 articles found), and analyses of PPP-related policies and regulations within local, regional, and national jurisdictions (59 articles found). After these procedures, 134 papers were left.

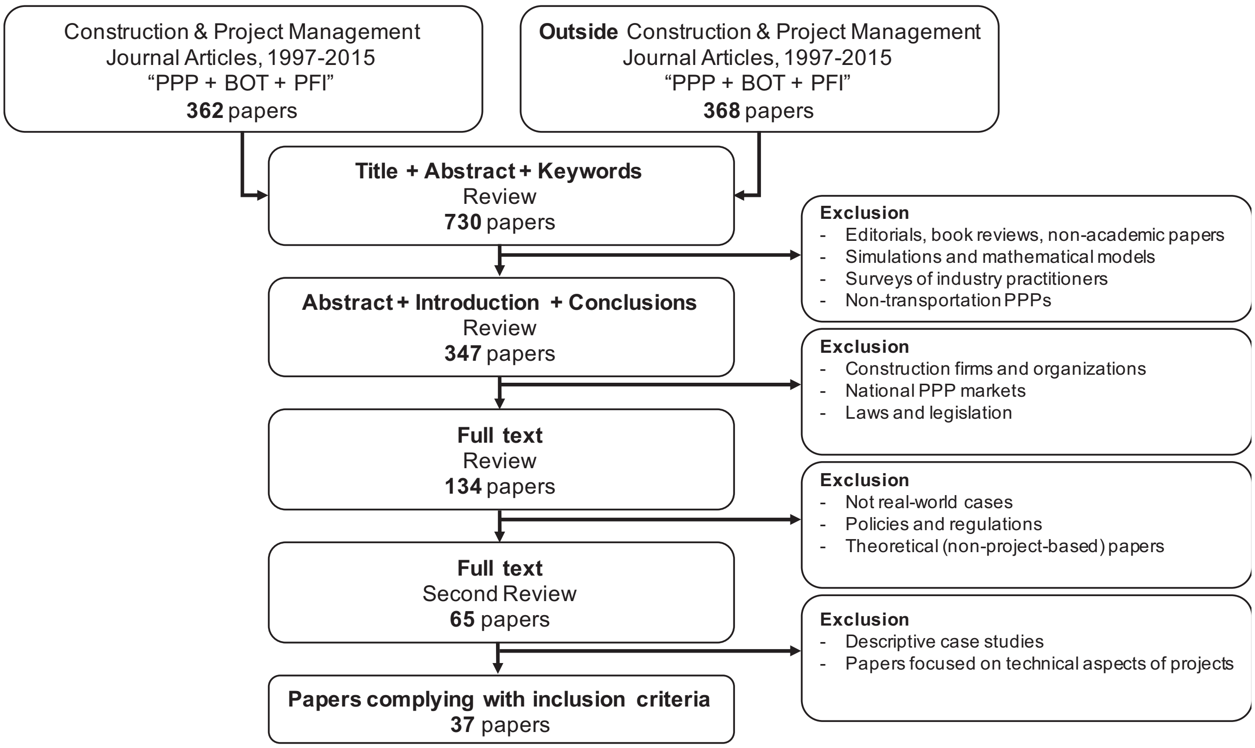


Figure 3-1. Literature Review Process

Subsequently, we conducted a full text review in order to determine our final group of papers. Of the 134 full-text reviewed documents, we excluded 90 additional studies because: they did not analyze PPP-issues in actual projects (36 articles excluded); they focused on examining PPP policies and regulations (42 articles excluded); or they provided descriptive accounts of real projects without further analysis (19 articles excluded). So, our overall inclusion/exclusion process resulted in 37 articles (shown in Table 3-1) for coding analysis. All of them are peer-reviewed archival articles published on journals indexed by Scopus or ISI (see Appendix B for a full list of journals). This is comparable to the amount of papers examined in other similar literature reviews (Kokkonen and Alin 2015; Müller et al. 2014; Svejvig and Andersen 2015).

Table 3-1. Reviewed Articles

Reference ID	Journal	Authors (Year)	PPP evidence
1	Canadian Journal of Civil Engineering	Abdel-Aziz and Russell (2001)	Channel Tunnel (UK-France).Confederation bridge (Canada). SR 91 (US).
2	JCEM	Schaufelberger and Wipadapisut (2003)	Highway 407(Canada). Dulles Greenway and SR 125 (US).
3	JME	Vassallo et al. (2012)	Toll highways in Spain
4	JCEM	Zhang (2005)	Multiple projects in the UK and the US.
5	Transportation Research Record	Vassallo et al. (2013)	Toll highways in Spain
6	Transport Reviews	Shaoul (2006)	Multiple projects in the UK
7	CME	Abdel Aziz (2007)	Multiple road projects in Canada
8	IJPM	Verweij (2015)	A15 highway project in the Netherlands
9	JCEM	Abdel Aziz (2007)	Multiple projects in the UK
10	Public Performance & Management Review	Ni (2012)	SR 91 (US)
11	Journal of Transport Economics and Policy	Debande (2002)	The Skye Bridge project (UK)
12	Public Works Management Policy	Ortiz and Buxbaum (2008)	Chicago Skyway, Indiana Toll road, Texas State Highway 130 (US).
13	Journal of Financial Management of Property and Construction	Zou et al. (2008)	Sydney Cross City Tunnel (Australia)
14	JME	Lee and Schaufelberger(2014)	North-South Highway (Malaysia) and the Second Express Highway (Thailand)
15	Research in Transportation Economics	Chung et al. (2010)	Projects in Sydney and Melbourne (Australia)
16	JCEM	Garvin (2010a)	Multiple road projects in the US and Canada
17	JCEM	Regan et al. (2011)	Multiple projects in Australia
18	Public Budgeting & Finance	Bunch (2012)	Road PPP projects in Texas
19	Research in Transportation Economics	Iseki and Houtman (2012)	Golden Ears Bridge (Canada). Texas State Highway 130 (US)
20	Case Studies on Transport Policy	Daito et al. (Daito et al. 2013)	495 Express Lanes in Virginia (US)
21	IJPM	Lenferink et al. (2013)	Road PPP projects in the Netherlands
22	CME	Park and Chang (2013)	Channel Tunnel Project
23	JME	Soomro and Zhang (2013)	Multiple road PPPs worldwide
24	Australian Accounting Review	Chung and Hensher (2015)	The M4 motorway (Australia)
25	JME	Ho et al. (2015)	Channel Tunnel Project
26	IJPM	Wang (2015)	Dulles Greenway, SR 91, Pocahontas Parkway, and LBJ lanes (US)
27	JME	Soomro and Zhang (2016)	Multiple road PPPs worldwide

28	Journal of Professional Issues in Engineering Education and Practice	Edkins and Smyth (2005)	Road PFI projects in the UK
29	International Review of Administrative Sciences	Johnston and Gudergan (2007)	Cross-City Tunnel (Australia)
30	Public Works Management Policy	Garvin and Bosso (2008)	SR 91,Dulles Greenway, Pocahontas Parkway (US)
31	JME	Carpintero et al. (2014)	PPP projects in Latin America
32	Public Administration	Koppenjan (2005)	PPP projects in the Netherlands
33	Journal of Comparative Policy Analysis	Vining et al. (2005)	Dulles Greenway, SR 91 (US). 407 Highway and Confederation Bridge (Canada).
34	JCEM	Zhang and Kumaraswamy (2001a)	Tunnel projects in Hong Kong
35	JCEM	Zhang and Kumaraswamy (2001b)	Tunnel project in Hong Kong and toll roads in the US
36	Australian Journal of Public Administration	Johnston (2010)	Cross-City Tunnel (Australia)
37	Public Administration Review	Gilmour (2012)	Indiana Toll Road and Chicago Skyway

3.4.3 Coding Strategy

We coded the selected papers by following a methodology developed by Kim (2009) within the field of system dynamics. Kim's technique uses a grounded theory approach and seeks to elicit causal maps from written texts (Kim and Andersen 2012). Building on Kim's approach, we coded the 37 papers with the intention of developing a systems map of the governance issues underlying real public-private agreements. We paid particular attention to the governance challenges previously discussed and developed the systems map presented in the Results section. First, we conducted an open coding procedure, read every article on a line-by-line basis, and extracted a total of 813 data segments. Second, we inspected each text excerpt and elicited 5,000 variables and 2,439 causal relationships. Third, we graphed a word-and-arrow diagram for each one of the causal relationships previously identified. Fourth, we combined the individual word-and-arrow diagrams into a single causal map (i.e. systems map) by merging the similar-meaning variables into a series of macro-variables. Finally, we iteratively compared the causal structures with the original text segments in order to avoid disconnections between the final map and the original dataset.

3.4.4 Feedback Analysis

Feedback loops comprise a series of variables concatenated in a closed circular chain. These structures control system performance and their identification helps to recognize reinforcing and balancing (self-correcting) behaviors (Richardson, 2011). After checking that all the causal relationships represented in the systems map had a clear connection with the literature dataset, we proceeded to highlight the main feedback loops within the proposed causal diagram. These are presented and analyzed in the Results and Discussion sections.

3.4.5 Validity of Selection and Coding

As described above, paper selection and filtering strategies were conducted through a step-by-step procedure in which the reasons for inclusion or exclusion were established in a transparent and clear way. Both processes were performed by the first author and reviewed by the second author. In order to evaluate the replicability and reliability of the process, the second author applied the inclusion/exclusion criteria into a randomized sample of 70 articles that were extracted from the initial group of 730 papers. This procedure resulted in a percentage of agreement of 90%.

The coding process was also performed by the first author and was evaluated by the other two authors. In line with the paper selection procedure, the second author examined a randomized sample of 5 text segments (selected and non-selected excerpts) in each one of the 37 articles included in the final group. This helped to strengthen the open coding technique and ultimately led to an agreement of 85%. Subsequently, both the second and third authors iteratively reviewed the causal diagrams in terms of structural generalization and conceptual consistency. Any disagreements were discussed until reaching consensus.

3.4.6 Limitations: dealing with mapping issues

Although the systems map was developed through a systematic paper selection strategy and a methodical coding process, its causal relationships and feedback loops are inevitably affected by the coder's own interpretations and mental models (Kim 2009). This is because the map is produced through a process in which the coder uses his knowledge about PPP governance in order to select and interpret the multiple extracted texts (Doyle and Ford 1998). In this sense, we sought to reduce bias by implementing systematic and organized procedures. However, despite these efforts, it is difficult to completely eliminate bias and remove our perceptions and judgements from the map development process (Doyle and Ford 2008; Kim 2009; Lane 2008).

Taking into account the difficulties associated with reducing bias in paper selection and coding processes, the systems map is limited in the following ways: (1) although the map has been built through utilizing literature focused on actual PPP projects, the mapping process did not involve any direct consultation of industry practitioners; (2) the macro-variables represented in the final map were created through an iterative process that developed an organized and succinct map; initial governance variables were grouped by considering similar and compatible text segments and word-and-arrow diagrams; our understanding of PPP governance concepts helped us in this process; consequently, the final map does not fully portray all the extracted variables and relationships because we sought to produce a visually organized instrument and avoid unruly representations (macro-variables and their associated references are shown in Appendix B); and (3) our interpretation of the causal relationships played a crucial role in resolving apparent conflicting interpretations on causal structures. For instance, if similar causal relationships with opposite link polarity were found in the selected text segments, then we incorporated both perspectives by generating new variables and providing new causal paths that were later merged into different macro-variables (this procedure is explained in Appendix C).

3.5 Results

After reviewing and coding the selected papers, we organized our results by considering the multiple governance challenges emerging within the shaping phase of PPP projects. We categorized the relationships found as socio-political, operational, and financial, as shown in Figure 3-2. The *socio-political* element refers to the degree of project acceptability within the impacted communities. It includes variables concerning government capacity and societal understanding. Analyzing how a project is perceived by the general public and how government agencies either improve or worsen such perceptions is quite important. The *operational* element comprises the dynamics associated with the efficiency of contractual and procurement processes. It involves the technical and legal procedures necessary to deal with project complexity and to confirm high standards of quality. In addition, this element is critical to insights about issues related to opportunism and transaction costs. The *financial* element entails the variables and relationships associated with acquiring the private and public resources required for successful PPP implementation. It illustrates how public-private agreements need to be financed through a mixture of public funding, debt capital, and equity investments. Jointly, the three elements not only mutually interact with each other, but also contribute to generate a successful PPP shaping phase.

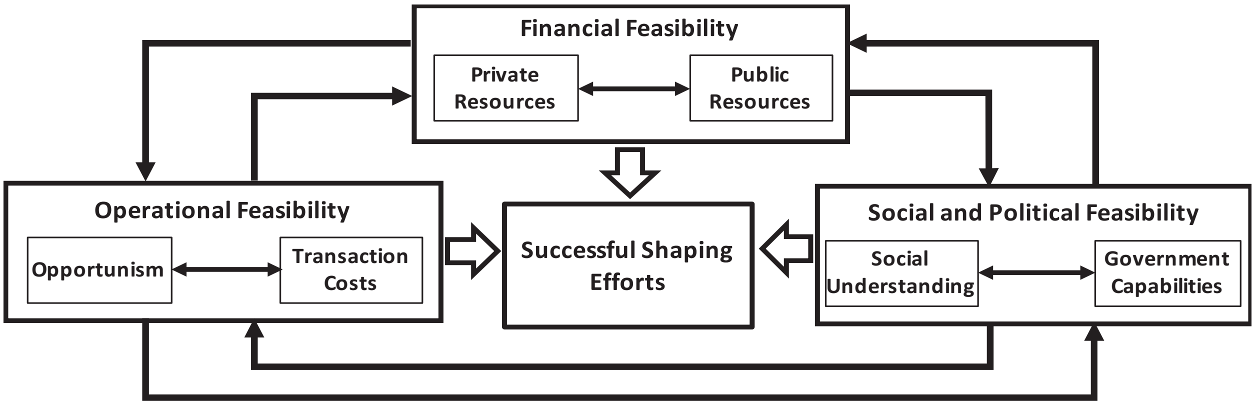


Figure 3-2. Simplified Causal Map

In the following subsections, we provide a more detailed synthesis of the causal relationships between PPP-related variables and examine the feedback mechanisms that are useful to understand the dynamics associated with the governance challenges of the shaping phase. Figures 3-3 through 3-7 show how the three overarching elements are expanded and how each one of them incorporates a series of variables that are highly interconnected. In the figures, arrows symbolize cause-effect relationships and the polarity marks denote that variables move either in the same (positive sign) or in opposite directions (negative sign). We have labeled each loop as reinforcing (R) or balancing (B). Since both the variables and the links were created from the aggregation of multiple relationships obtained from the reviewed articles, the thickness of the arrows represents the number of publications used to elicit each causal relationship (Hu et al., 2011). In total, the systems map involves 27 governance variables and 48 causal links. In Figures 3-3 – 3-7, the map is presented incrementally for clarity.

3.5.1 Socio-Political and Operational interactions

3.5.1.1 Loop R1: Government capacity and social complexity

As depicted in Figure 3-3, public understanding plays a crucial role in achieving socio-political feasibility (SPF) within the shaping phase of a public-private agreement. The reviewed studies made it clear that when governments have enough capacity, they are capable of clearly explaining why a PPP solution is required and how it will be implemented (Bunch 2012; Ortiz and Buxbaum 2008). This leads to better socio-political understanding because the affected communities see that the project is not an imposition and is truly necessary (Aziz 2007). By doing so, governments not only strengthen a project's socio-political feasibility, but they also reinforce (loop R1) their own capacity to develop PPP agreements.

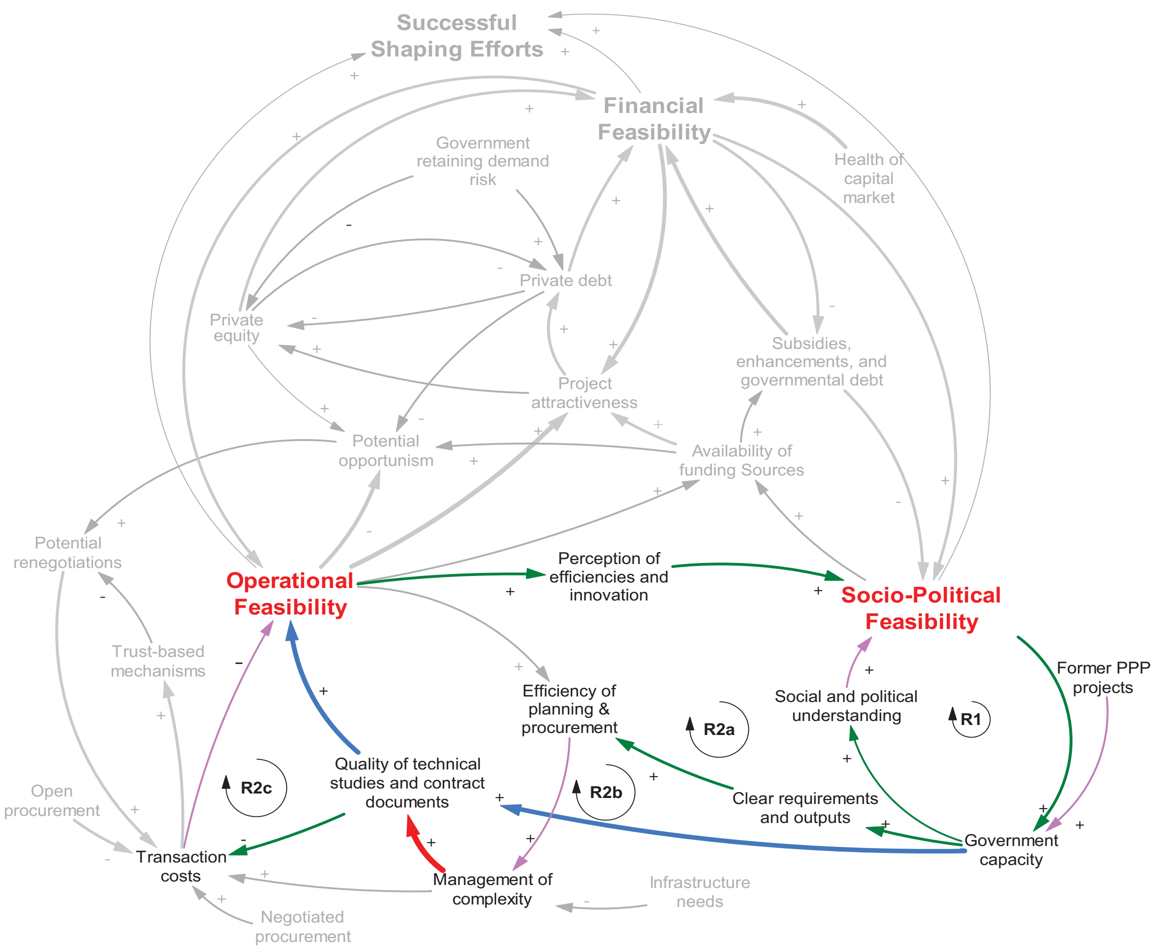


Figure 3-3. Socio-Political and Operational Dynamics

Scholars have cited multiples cases in which strong and competent government units have been able to achieve satisfactory levels of SPF in their projects. These include experiences in Canada

(Aziz 2007), the UK (Chung et al. 2010) and Spain (Vassallo et al. 2012). Researchers have also highlighted the effects of incapable public agencies. The lack of experience and enabling capabilities are identified as an important inhibitor of SPF. Inexperienced governments, for example, have struggled to improve public acceptance in projects such as the Melbourne CityLink (Bunch 2012; Chung and Hensher 2015) and in projects implemented under AB 680 in California (Aziz 2007; Garvin 2010; Ortiz and Buxbaum 2008; Zhang 2005).

3.5.1.2 R2: Government commitment to streamline procurement, produce high-quality project documents, and reduce transaction costs

Apart from shaping public understanding, Figure 3-3 also shows that government capacity also influences SPF through streamlining procurement processes (loop R2a). The literature shows that as government capacity increases with stronger regulatory frameworks and greater commitment from public officials, public agencies are able to generate better objectives and clearer outputs for any given project (Debande 2002; Iseki and Houtman 2012; Lenferink et al. 2013; Soomro and Zhang 2016). This results in more efficient procurement processes (Aziz 2007; Ortiz and Buxbaum 2008; Zhang 2005), thus enhancing the management of a project's technical complexity and facilitating the development of high-quality technical studies and specifications (Garvin 2010; Koppenjan 2005). Further, this boosts the operational prospects of projects and contributes towards generating positive perceptions from the general public (Asenova and Hood 2006; Aziz 2007; Johnston 2010; Vining et al. 2005). Ultimately, if citizens perceive public-private agreements as efficient and well-organized, socio-political prospects and government capacity improve (Abdel-Aziz and Russell 2001; Asenova and Hood 2006; Debande 2002).

Another aspect to consider in the relationship between government capacity and SPF is the role of two variables*: Quality of technical studies* and *Transaction costs*. Loop R2b reflects research indicating that highly capable governments are increasingly likely to produce high-quality technical studies that increase the accuracy of traffic forecasts (Garvin 2010; Iseki and Houtman 2012; Ni 2012; Zhang and Kumaraswamy 2001b), the reliability of engineering designs, and the cost-effectiveness of construction schedules (Lee and Schaufelberger 2014; Vassallo et al. 2012; Verweij 2015). Also, as shown in loop R2c, scholars contend that strong and organized public agencies have the ability to reduce transaction costs by generating more transparent and standardized contractual arrangements (Debande 2002; Johnston 2010; Johnston and Gudergan 2007; Wang 2015). Accordingly, as the technical quality increases and the transaction costs diminish, projects become more operationally viable through increasing value for money. Similar to loop R1 , this contributes to increase positive perceptions and leads to enhancement of SPF and reinforcement of government capacity (Iseki and Houtman 2012; Park and Chang 2013; Schaufelberger and Wipadapisut 2003; Zhang 2005).

Examples of loops R2a, R2b, and R2c are found in numerous studies. The literature reports multiple cases where, whether successfully or not, governments have sought to improve the socio-political viability of PPP agreements through developing operationally feasible projects. Arguably, scholars indicate that most projects in the UK (Aziz 2007; Debande 2002; Park and Chang 2013), Canada (Abdel-Aziz and Russell 2001; Iseki and Houtman 2012), and Chile (Carpintero et al. 2014) have been successful in this respect. In these cases, thanks to the development of strong PPP units, governments have been able to limit their transaction costs, generate well-organized and transparent procedures, and produce quality engineering studies. This has not only enabled the development of public-private agreements that have been accepted by most of the public, but it also has strengthened government capacity to implement PPP projects.

Alternatively, researchers also highlight that negative experiences have occurred in many countries. In these cases, governments have unable to produce sufficient operational viability to generate positive public perceptions. In Australia, for instance, a poorly designed procurement process generated confrontations between government agencies and communities during the shaping of the Eastern Distributor and Cross-City Tunnel in Sydney (Chung et al. 2010; Johnston 2010). In the Netherlands, the A4 Midden Delfland Motorway was not considered operationally feasible enough due to disorder and division among multiple government units (Koppenjan, 2005a). In the US, the public in California became increasingly skeptical of PPP agreements because of failures in implementing the projects sponsored by the AB 680 program throughout the 1990s (Garvin and Bosso 2008; Wang 2015).

3.5.1.3. Loops R3 and B1: Opportunism and renegotiations

Opportunism is cited as one of the main hazards for PPP development (Gilmour 2012; Ho et al. 2015). Public-private agreements without sufficient operational feasibility are prone to opportunistic behaviors (Asenova and Hood 2006; Park and Chang 2013; Shaoul et al. 2006). Such issues may entail but are not limited to misuse of public and private resources invested in a project or a change of project specifications to obtain financial/political gains (Chung et al. 2010; Chung and Hensher 2015; van Marrewijk et al. 2008). As loop R3 in Figure 3-4 illustrates, as operational feasibility decreases, potential opportunistic behaviors are more likely because project participants may take advantage of deficient due diligence practices or inadequate technical studies (Debande 2002; Johnston 2010; Regan et al. 2011). Consequently, the possibility of renegotiations intensifies because both parties anticipate that changes will occur, resulting in additional ex-ante contingencies and more expensive transactions (Edkins and Smyth 2005; Iseki and Houtman 2012). However, anticipating renegotiations hinders the project's operational feasibility, further exacerbating opportunism (Ho et al. 2015; Soomro and Zhang 2016).

Figure 3-4 shows that transaction costs are also likely to increase due to the implementation of negotiated procurement processes or when public agencies are not able to properly manage project complexity (Ho et al. 2015; Soomro and Zhang 2013; Zhang 2005). In order to reduce expenditures, some governments have opted for open procurement procedures in which there are no contract negotiations. However, this approach may trigger more opportunistic behaviors because, in these processes, getting a low-price bid is crucial to obtain the contract (Carpintero et al. 2014; Vassallo et al. 2013). Therefore, since mitigating opportunism through basic contractual methods increases transaction costs, government entities have started to implement trust-based mechanisms in PPPs (Aziz 2007; Edkins and Smyth 2005). These involve the creation of collaborative environments in which relations become a significant complement to the contractual framework. Thus, building trust among project participants likely reduces potential renegotiations and contributes to decrease transaction expenditures (loop B1).

Data illustrates several instances of these two feedback loops. Examples of loop R3 are the Golden Ears Bridge (Canada) and the Texas SH 130 Segments 5&6, which show that government agencies, aware of potential future renegotiations, drafted well-designed contractual safeguards (i.e. increased operational feasibility) in order to prevent ex post opportunism (i.e. decreased potential opportunism) (Iseki and Houtman 2012; Ortiz and Buxbaum 2008). In contrast, the Channel Tunnel (UK-France) illustrates that insufficient operational feasibility levels (i.e. lack of due diligence and technical deficiencies) contributed to opportunism problems between controlling (i.e. equity providers directly responsible for project development) and passive shareholders (i.e.

equity providers not directly responsible for project development) (Ho et al. 2015; Park and Chang 2013). With respect to loop B1, the literature indicates that elements of relational contracting have been implemented in some British and Australian PPP agreements (Aziz 2007; Edkins and Smyth 2005). The application of such contracting practices has not only diminished the potential of having future renegotiations, but has also reduced the expenditures associated with the transactions.

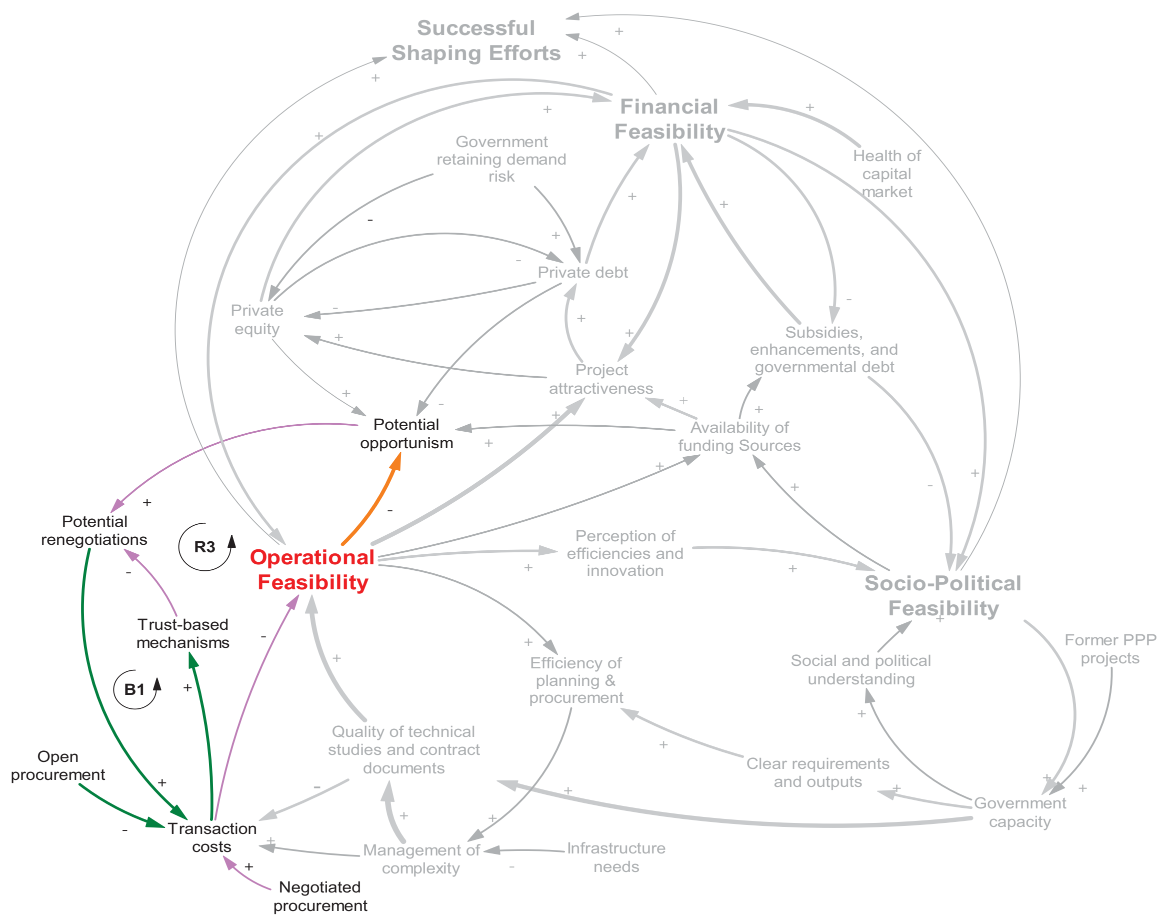


Figure 3-4. Opportunism and Renegotiations

3.5.2 Financial Interactions

This area comprises four different loops associated with achieving financial feasibility in the shaping phase of PPPs. Loops R4, R5, B2, and B3 are depicted in Figure 3-5 and described below.

3.5.2.1 R4: Debt and Equity

During the shaping phase, acquiring debt and equity resources is essential for successful PPP development. However, debt and equity have an inverse relationship where if one increases the other decreases (Chung et al. 2010; Lee and Schaufelberger 2014; Schaufelberger and Wipadapisut 2003). As depicted, increments or reductions in debt and equity values are influenced by the public sector's willingness to assume demand risks (Abdel Aziz 2007; Carpintero et al. 2014; Debande 2002; Garvin 2010; Iseki and Houtman 2012). This is one of the main differences between availability payment projects (i.e. most agreements in Canada and the UK) and revenue risk projects (i.e. most agreements in Australia, the US, and the developing world).

3.5.2.2 R5: Project Attractiveness: debt and equity resources

PPPs need to attract both debt and equity providers because they involve resources from the private sector. Although project attractiveness depends on *Operational feasibility and Availability of funding, Financial feasibility* also plays a crucial role in securing the required private funds (Asenova and Hood 2006; Bunch 2012; Regan et al. 2011). As financial feasibility increases, the project becomes more attractive to private investors, which leads to increased access to debt (loop R5a) and equity (loop R5b) (Abdel-Aziz and Russell 2001; Ni 2012; Zhang and Kumaraswamy 2001a). This, in turn, contributes to strengthen the project's financial viability and reinforces the behavior of the whole loop. Examples include projects in Canada (i.e. Highway 104, Highway 407, and the Confederation Bridge) (Abdel Aziz 2007; Vining et al. 2005), the US (i.e. SR 91) (Abdel-Aziz and Russell 2001), and the UK (i.e. Channel Tunnel and other PFI initiatives) (Aziz 2007; Debande 2002; Schaufelberger and Wipadapisut 2003).

3.5.2.3 B2: Funding and financial feasibility

Loop B2 depicts the connection of public funding with financial feasibility. This relationship has been particularly important to achieve financial close in some projects. The procurement processes of the 495 express lanes (Daito et al. 2013) and SH 130 toll road (Iseki and Houtman 2012; Ortiz and Buxbaum 2008) in the US exemplify the importance of this loop. If projects are able to obtain a sufficient amount of subsidies, enhancements, or government loans, then this improves overall financial feasibility. Once financial feasibility levels are high enough, financial close is secured and the need for more public funding decreases.

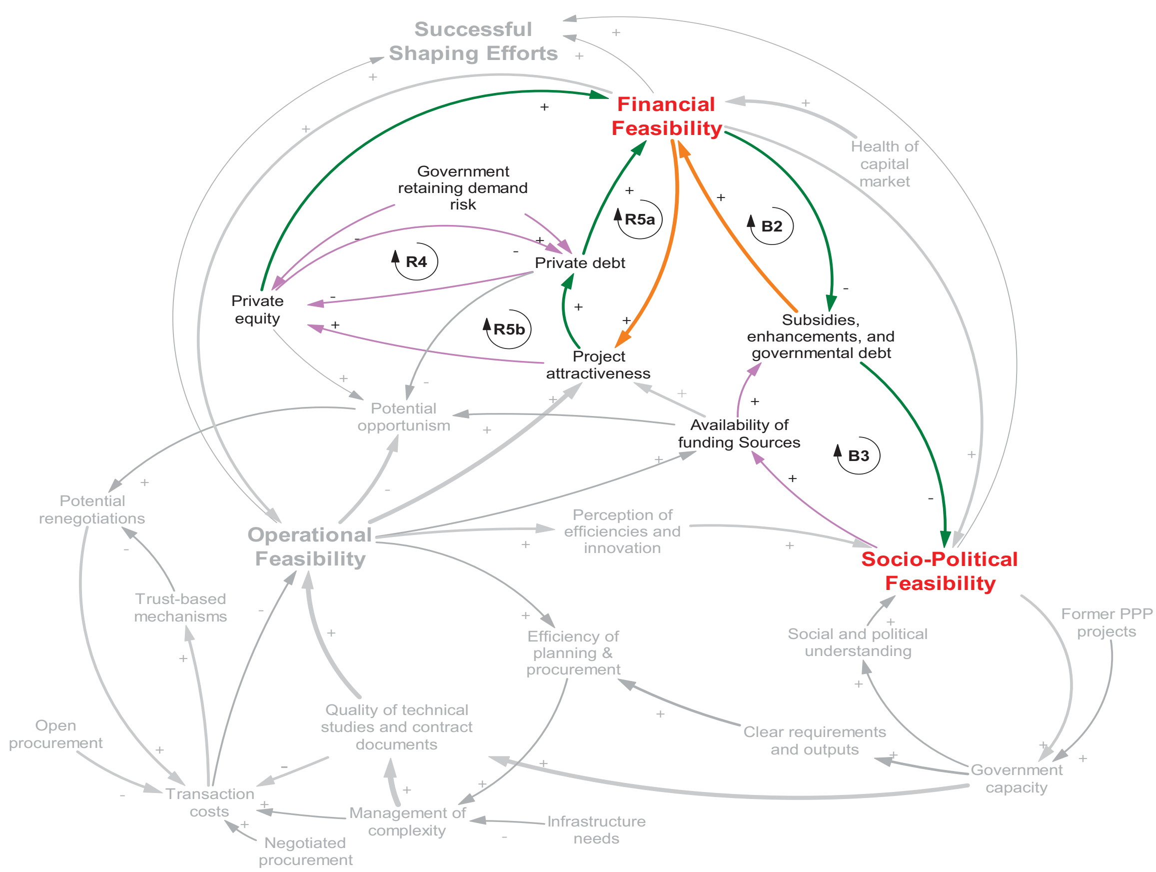


Figure 3-5. Financial Feasibility

3.5.2.4 B3: funding and socio-political feasibility

Access to sufficient levels of funding is not certain because they may affect the project's socio-political feasibility. As more funding options are available, more opportunities arise to take advantage of subsidies, guarantees, or any other type of government fiscal support (Lenferink et al. 2013; Soomro and Zhang 2013; Vining et al. 2005). The literature indicates that securing the proper amount of public funding was crucial for the development of the Confederation bridge in Canada (Abdel-Aziz and Russell 2001), the Skye Bridge in the UK (Debande 2002), and other projects in the developing world (Carpintero et al. 2014; Lee and Schaufelberger 2014). The problem is that funding that helps to generate benefits and enhancements to the private sector can be viewed as opposite to the general public welfare. For instance, unfavorable public perceptions affected the implementation of the Trans-Texas Corridor (Bunch 2012; Iseki and Houtman 2012) and contributed to hinder the development of the AB 680 program of projects in California (Aziz 2007; Ortiz and Buxbaum 2008; Zhang 2005). Thus, as shown in loop B3, excessive increments in government assistance may end up decreasing the project's socio-political feasibility and ultimately limit the availability of fiscal support.

3.5.3. Cross-sectional interactions

A series of causal mechanisms are also depicted that highlight the relationship between the three feasibilities presented. In total there are 128 loops involving all three feasibility elements. Due to space limitations, we describe only one (Figure 3-6). However, the description is illustrative of the other loops.

3.5.3.1 R6: Pushing for attractiveness

This loop represents the relation between government capacity and project attractiveness. As government units increase their capacity, they become more capable of producing higher-quality technical studies and contract documents (Asenova and Hood 2006; Chung et al. 2010; Ortiz and Buxbaum 2008; Wang 2015). With better designs and well-organized due diligence processes, public-private agreements become more operationally feasible (Debande 2002; Ni 2012; Schaufelberger and Wipadapisut 2003; Soomro and Zhang 2016; Vassallo et al. 2012). If a PPP project achieves sufficient operational viability, project attractiveness increases because the agreement likely has high chances of generating long-term financial returns (Ho et al. 2015; Park and Chang 2013; Soomro and Zhang 2013; Wang 2015; Zhang and Kumaraswamy 2001a). This intensifies the interest from private investors, contributing to raise the amount of debt (loop R6a) and equity capital (loop R6b) available, which ultimately improves a project's financial prospects (Carpintero et al. 2014; Iseki and Houtman 2012; Zou et al. 2008). With increasing monetary support, the socio-political prospects improve because the general public is more receptive to a financially successful project (Aziz 2007; Ho et al. 2015; Koppenjan 2005; Schaufelberger and Wipadapisut 2003). This strengthens government capacity and reinforces the whole cycle positively.

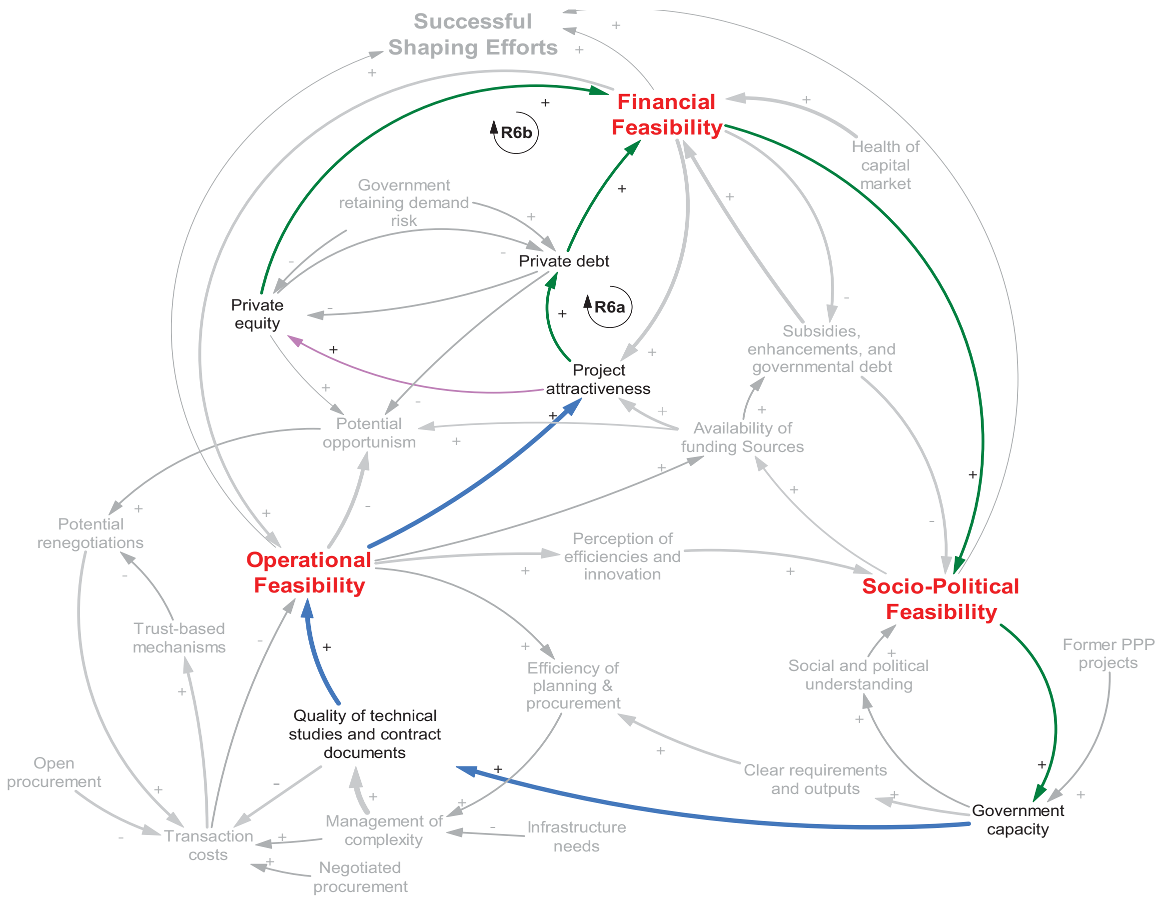


Figure 3-6. Cross-sectional loop

Clearly the relationship between government experience and project attractiveness plays a key role in loop R6. Examples in Canada (e.g. Confederation Bridge and Sea-to-Sky highway) and the UK (e.g. M1-A1 and M40) show that capable governments have developed financially and socio-politically feasible projects because they have attracted sufficient debt and equity resources from the private sector (Abdel Aziz 2007; Asenova and Hood 2006; Vining et al. 2005). In the US, on the other hand, the lack of government capacity has generated difficulties associated with deficient traffic forecasts and revenue studies in some PPP agreements. In the Dulles Greenway and SR 125, this impacted the ability to service debt and caused financial distress in both projects (Garvin and Bosso 2008; Vining et al. 2005; Wang 2015).

3.6. Discussion

Although we have described each loop in isolation, we know that the shaping phase of PPPs involves multiple stakeholders across different processes and it typically takes several years to complete (i.e. reach financial close). Hence, we present the complete map in Figure 3-7 while depicting loops that interact frequently within the system so feedback behaviors evolve over time. We focus on examining the changing interactions among such mechanisms in light of the collected evidence. Now, we explore how to achieve high levels of socio-political, financial, and operational feasibility within a system constrained by emerging governance challenges.

3.6.1 Improving socio-political feasibility and increasing political legitimacy

The literature suggests that achieving high levels of socio-political feasibility within projects depends on how well they address the challenge of political legitimacy. This issue emerges from the interaction of mechanisms related to socio-political (loop R1) and socio-operational dynamics (loop R2). Based on the reviewed studies, socio-political feasibility is higher in those public-private agreements where the variables within loops R1 and R2 always behave positively. If this is not the case, the reinforcing mechanisms start to produce negative outcomes, thus decreasing socio-political feasibility.

Canada and the UK offer the best examples of how to address these interactions. In these two countries, the reviewed projects have generally sustained positive dynamics since early in their shaping phases. This is because strong PPP units have been able to generate clear specifications (loop R2a) and good technical studies (loop R2b and R2c) in order to encourage positive operational perceptions and optimistic social reactions (loop R1) (Abdel Aziz 2007; Aziz 2007; Debande 2002; Zhang 2005). Although evidence suggests that some road users might not agree with giving public guarantees to the private sector (loop B3) (Shaoul et al. 2006; Vining et al.

2005), the reviewed articles do not report significant social controversies at the project-level in either country.

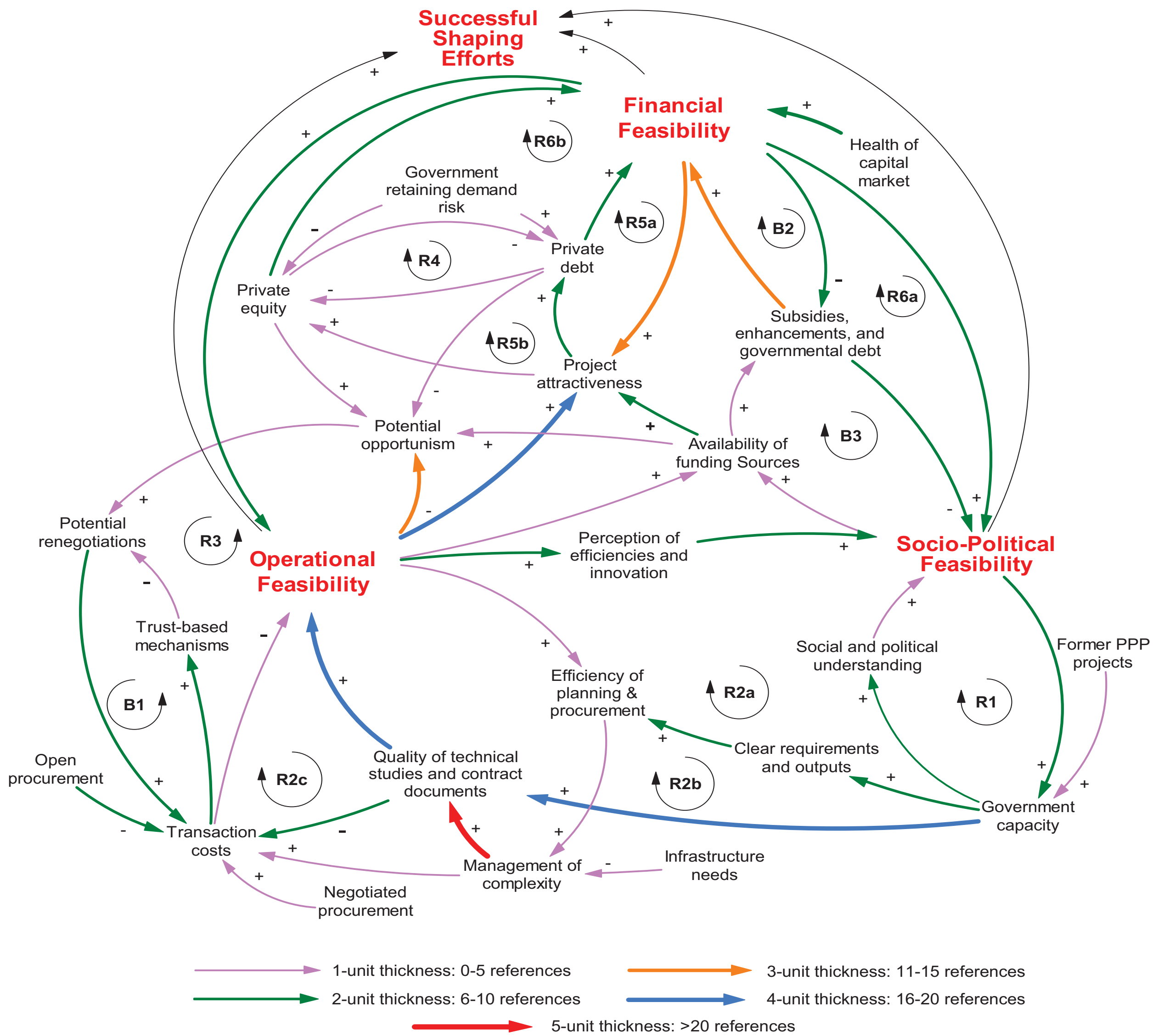


Figure 3-7. Systems Map

In contrast to the British and Canadian experiences, projects in other jurisdictions have not preserved positive reinforcing behaviors in their feedback loops. In the US, for example, the Trans-Texas Corridor (TTC) was not understood by the general public because inexperienced government agencies could not cope with its complexity (loop R2b) (Bunch 2012). Also, in

California, the adoption of ineffective enabling legislation contributed to generate mistrust (loop R1), hindering the development of two out of four projects approved in the Assembly Bill 680 (Garvin and Bosso 2008; Vining et al. 2005; Wang 2015). Additionally, in Australia, the New South Wales government did not establish clear specifications for the Cross-City Tunnel (loop R2a) and ended up accepting a non-compliant proposal; thus reducing the operational feasibility of the project and decreasing public trust (loop R1) (Chung and Hensher 2015; Johnston 2010; Johnston and Gudergan 2007).

3.6.2 Enhancing operational feasibility and tackling uncertainty and opportunism

The literature indicates that operational feasibility is affected by multiple hazards related to the uncertain nature of PPPs. In the shaping phase, these concerns should be tackled through minimizing opportunism (loop R3), reducing transaction costs (loop B1) and improving the management of technical complexity (loop R2). However, the reviewed projects indicate that implementing these actions in an integrative way is not an easy task.

First, opportunistic behaviors (loop R3) can occur if government agencies do not ensure the implementation of clear planning procedures (loop R2a). For example, in the Cross-City Tunnel in Sydney, the public sector manipulated the procurement process in order to select a non-conforming bidder as the winner. This had considerable impacts for both the concessionaire and the users, such as low traffic counts, road closures, and high toll levels (Johnston 2010; Regan et al. 2011; Zou et al. 2008). Second, although relational approaches (loop B1) reduce opportunism, their implementation may not significantly reduce transaction costs and may require a substantial period of time. This is the case in Australia and the UK, where governments have promoted trust-based mechanisms (Debande 2002; Shaoul et al. 2006; Vining et al. 2005). Third, public and private parties may opt to conduct suboptimal studies in order to avoid delays and expedite project development (loop R2b). For instance, in the Dulles Greenway and the Pocahontas Parkway, both government agencies and their private partners seemed more interested in accelerating project execution rather than ensuring due diligence and good quality technical studies (Bunch 2012; Garvin and Bosso 2008; Ni 2012; Wang 2015). Although the appropriate interaction of these loops typically generates very positive results, coordinating their behavior to properly address all of the operational uncertainties at the same time is very difficult. As a result, maximizing operational feasibility depends on an intricate balance between loops R3, B1, and R2.

3.6.3 Increasing financial feasibility and reducing uncertainty

The data show that financial feasibility is highly dependent on multiple feedback loops. *Project Attractiveness* is seemingly the most important variable driving the behavior of such mechanisms. However, to generate an attractive project, both public and private parties need to overcome challenges associated with the uncertain and long-term nature of these projects. In other words, they need to convince equity and debt providers of the benefits of investing in the public-private agreement.

The literature shows that the Canadian provinces of British Columbia and Ontario have accomplished high levels of project attractiveness by offering not only sufficient guarantees and enhancements (loop B2), but also strong government support (loops R6a and R6b detailed in Figure 3.6). This has allowed them to boost their projects' financial prospects by improving both socio-political and operational feasibilities (Abdel Aziz 2007; Abdel-Aziz and Russell 2001; Iseki and Houtman 2012). Additionally, in Spain, the national government has attracted private participants through a combination of low-cost procurement procedures (loop R2a) and subordinated debt schemes (loop B2) in many of the toll roads providing access to Madrid (Vassallo et al. 2012; 2013). Consequently, many Spanish projects accomplish good operational feasibility and, at the same time, ensure financial stability. Through a well-directed interaction of loops B2, R6a, R6b, and R2a, public-private agreements are able to increase their attractiveness and reduce their financial uncertainties.

3.6.4 Controlling the displaced agency challenge

In terms of the proposed map, the challenge of displaced agency may directly affect each one of the three elements of project feasibility. This hazard emerges when a strong dominance of one or more loops generates unintended consequences across the whole system. For example, during the shaping phase of the Dulles Greenway project in Virginia, US, government agencies were focused on attracting private resources (Garvin and Bosso 2008). In this case, loops R5a and R5b were dominant at the beginning of the project because the state government wanted to attract debt and private capital. Such dominance was so strong that it was not affected by the lack of guarantees and enhancements from the public sector (loop B2) (Wang 2015). However, once private resources were secured, it became clear that the public sector was not sufficiently committed to the project (Schaufelberger and Wipadapisut 2003). As a result, loop R2 and R6 began to dominate in a negative reinforcing way, decreasing the project's financial and socio-political feasibilities.

Aside from the Dulles Greenway, similar dynamics can be found in the Channel Tunnel in Europe (Ho et al. 2015; Park and Chang 2013), the SR 91 Express Lanes in California (Garvin and Bosso 2008; Ni 2012; Wang 2015), and many other projects in Latin America and Asia (Lee and Schaufelberger 2014; Soomro and Zhang 2013; 2016; Zhang and Kumaraswamy 2001b). In all of them, it is clear that financial interactions were clearly dominant at the beginning of the shaping phase because governments wanted to incentivize the use of private resources. However, over time, such dominance eroded and contributed to produce unintended effects in operational and socio-political loops. Such effects represent the emergence of displaced agency challenges and constitute a serious hazard for public-private agreements.

3.7 Conclusions

In order to improve our understanding about the governance challenges of public-private agreements, multiple scholars have recognized the need to complete meta-analyses of the increasing number of PPP-related publications. However, most of the studies examining the PPP body of knowledge do not go beyond providing bibliographic metrics and thematic classifications. To deepen our understanding of PPP literature, this paper has offered a systems map depicting the major interdependencies and interactions between governance variables found in the shaping phase of road PPP projects. This has allowed us to gain insight into the main sources of complexity behind the implementation challenges of public-private agreements. The review is limited to road PPP projects from academic peer-reviewed journals. Further, it is focused on the shaping phase and has not considered the construction, operation, and transfer stages.

In the map, we have provided a clear and succinct summary of the causal relationships underlying the governance challenges of shaping PPP projects. The map illustrates that academic efforts have focused on explaining PPP issues related to five variables: *Government Capacity, Management Complexity, Quality of technical studies and contract documents, Operational feasibility, and Project attractiveness*. It also reveals that there is scarce evidence of observations related to financial and funding issues, procurement processes, and opportunism (i.e. variables connected through the pink and thin arrows on Figure 3.7).

Based on Figure 3.7, the main difference between the groups of causal relationships with the highest and lowest number of references can be explained by examining the issues represented in each set. The links with more than 16 references (i.e. red and blue arrows) portray issues that can be explored through publicly available data (e.g. environmental impact statements, stakeholder consultation documents, newspaper articles, or some contract documents of past projects). In contrast, the relationships with less than five references describe governance concerns that are difficult to observe through examining public information sources. For instance, it is difficult to find evidence regarding the dynamics associated with *Private Debt, Private Equity, and Potential Opportunism.* This is because financial details in PPP agreements are not readily available largely due to proprietary concerns.

Our analysis also indicates that successfully developing a public-private initiative depends on the combination of numerous variables and involves overcoming difficulties related to political legitimacy, uncertainty, opportunism, and displaced agency. Since the shaping phase is not a simple process, the map illustrates that a "silver bullet" solution is non-existent for the governance problems of PPP implementation. Our study shows that it is extremely important for public-private agreements to establish the conditions necessary to heighten all the project's feasibilities as early as possible. If this is the case, the reinforcing feedback loops are more likely to generate better outcomes throughout the project life cycle. If not, the opportunity to rebalance the system and avoid failure becomes increasingly elusive because of the multiplicity of variables and interactions.

By analyzing the feedback mechanisms within the proposed map, we identified that *Government Capacity* and *Project Attractiveness* play key roles in overall project governance. The former exerts a major influence in terms of overcoming the challenges of project legitimacy. Having high capacity levels contributes to generate positive results within the feedback loops associated with socio-political and operational concerns. Governments with high capacity are more effective in terms of achieving project support from the general public and project users. They also have the skills to produce good-quality technical studies and contract documents so that their PPP initiatives accomplish higher degrees of operational feasibility. The latter drives the behaviors related to mitigating uncertainty and helps to achieve better financial prospects by attracting more private and public resources. High levels of project attractiveness imply that equity providers, lenders, and developers feel that their return expectations can be achieved by building and operating the PPP project. In addition, having an attractive project suggests that governments, if necessary, have provided adequate funding mechanisms in support of the projects' financial needs. Overall, both *Government Capacity* and *Project Attractiveness* are key determinants of project socio-political, operational, and financial feasibilities.

The proposed systems map advances comprehension of the underlying sources of complexity within PPPs, but it does not allow simulating different patterns of behavior among the variables. As a result, further research is required in order to complement our map with information from non-academic sources such as periodicals and interviews with industry experts. Similarly, future maps can incorporate other lifecycle phases and include mathematical formulations so that it could become a useful simulation tool.

3.8 Acknowledgements

This material is based upon work supported by the US National Science Foundation under Grant No. 1333264. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the US National Science Foundation.

4. CHAPTER 4: A MANAGEMENT FLIGHT SIMULATOR FOR UNDERSTANDING PROCUREMENT PROCESSES IN PUBLIC-PRIVATE PARTNERSHIPS (PPPs) [3]

4.1 Abstract

PPP development in the road infrastructure sector worldwide has been far from perfect. Several projects have faced controversies, and others have been implemented with mixed outcomes. One of the reasons why PPPs have not been more successful is because of shortcomings in their procurement processes. Such problems occur due to a lack of understanding about the underlying complexities of PPP tendering. Hence, this study seeks to gain insight into the mechanisms either facilitating or hindering procurement procedures. Relying on a system dynamics model, this paper presents the background, methods, and results of a management flight simulator designed to better explain how variables related to government capacity, technical complexity, and project uncertainty affect PPP tendering. The simulator was implemented through a simulation game conducted with graduate civil engineering students. Results show that the simulator is useful educational tool to improve the way PPP procurement challenges are identified and explained. Conclusions point to the importance of recognizing the feedback mechanisms related to PPP tendering. Overall, the study contributes to the existing literature by providing a simulation instrument that is a starting point towards enhancing the way public-private agreements are understood by stakeholders from both public and private domains.

Keywords: public-private partnerships, PPP procurement, management flight simulator

[3] This paper was co-authored with professors Michael J. Garvin and Navid Ghaffarzadegan and will be submitted to a peer-reviewed journal.

4.2 Introduction

Public-private partnerships have emerged over the last two decades as an attractive alternative for road infrastructure project delivery worldwide (Gomez-Ibañez et al. 2009; Siemiatycki 2012). Private provision of public infrastructure has encouraged a change in the traditional roles played by private and public actors in the development of transportation projects (Gomez-Ibañez et al. 2009; Orr and Kennedy 2008). Since the mid-1990s, there has been a substantial increase in the use of DBFOM initiatives across developed and developing countries (Garvin and Bosso 2008; Vining and Boardman 2008a). Governments have designed policies and implemented programs in order to facilitate PPP delivery in the road infrastructure sector. However, despite some successful implementations, most of the global experience in the use of PPPs has been mixed.

One of the main reasons why PPPs have not been more successful worldwide is because of issues in procurement processes (Aziz 2007; Liu et al. 2016). The literature shows that PPP procurement is the period in which public authorities, bidders (i.e. equity providers and developers), lenders, and other stakeholders have high levels of interaction (Ahadzi and Bowles 2004; Kwak et al. 2009). This is a crucial stage in PPP delivery because the preferred proponent is chosen, due-diligence procedures are conducted, contract documents are drafted, and financial close is reached (Yescombe 2011). If governments are unable to conduct procurements in a structured and well-organized way, the process is likely to result in deficient decision-making, lengthy tendering periods, high transaction costs, lack of standardization, and poor transparency (Aziz 2007; Liu et al. 2016; Reeves et al. 2016; Tang et al. 2014).

Although many scholars have recognized the importance of PPP procurement processes and have conducted several studies focused on improving such procedures, questions about the benefits and costs of public-private agreements are still frequent in many jurisdictions worldwide (Garvin 2010; Liu et al. 2016; Vining et al. 2005). This suggests that there is a lack of understanding about the underlying complexities of PPP tendering (Ahadzi and Bowles 2004; Reeves et al. 2016; Tang et al. 2014; Zhang and Kumaraswamy 2001a). Managing these processes continues to challenge governments. In particular, handling the uncertainty and complexity of public-private agreements remains an issue, so governments need to improve their understanding about how procurement-related decisions impact PPP projects in the long-term (Jooste et al. 2011; Jooste and Scott 2012; Levitt et al. 2014).

To improve procurement, both public and private players need to be aware that PPP tendering is a complex socio-technical process. Recognizing socio-technical complexity, however, is not easy. Researchers have shown that people fail to understand this concept not because of ignorance or lack of training, but because of difficulties in understanding phenomena such as accumulations, feedback, time delays, and nonlinearities (Isaacs and Senge 1992; Lane 1992; Sterman 2000). Overcoming the learning barriers obstructing procurement enhancement, therefore, constitutes an educational challenge that requires a change in traditional ways of thinking.

In the field of system dynamics, scholars have shown that system thinking helps to overcome the common mental models that hinder the development of strong comprehension abilities (Forrester 1992; Sterman 1994). One of the best ways to improve people's mental models and decision-making skills is through the use of interactive management flight simulators (Bakken et al. 1992; Lane 1995; Sterman 2000). Building on Forrester's ideas, system dynamicists have been able to develop multiple simulators across several knowledge domains. Consequently, this research seeks to apply these ideas in order to develop a management flight simulator for the PPP procurement process.

Building on experiences from PPP and system dynamics domains, this paper first examines the literature to gain insights into the underlying complexity of decision-making processes in PPP procurement. An interactive management flight simulator is then developed to examine some of the factors behind successful PPP tendering. It is designed toward overcoming the educational challenges in the PPP field. The simulator is based on a system dynamics model that is located in an online platform, and its structure is based on archival and institutional sources. The scope of the model includes an analysis of the relationship between government capacity, technical complexity, and project uncertainty. It also examines the use of resources related to: a) procurement execution, b) clarification and review of tender documentation, and c) usage of external advisory services. Both the simulator and the model have been evaluated through an educational game with graduate engineering students.

The paper is organized as follows. The article begins with an examination of literature on the PPP procurement phase and a discussion about the role of system dynamics in enhancing PPP tendering. Subsequently, the research methodology is introduced and the management flight simulator is presented through explaining the model and the user interface. Next, the educational game is described and results are discussed through the lens of the simulations developed by the students. Finally, conclusions explore the importance of recognizing feedback relationships in procurement processes and the difficulties related to improving PPP tendering.

4.3 The PPP procurement process

The PPP procurement process involves the activities directed towards selecting the consortium that will be in charge of designing, building, financing, operating, and maintaining an infrastructure project (Liu et al. 2016; Yescombe 2011). The process typically starts when potential bidders are invited to participate and finishes when financial close is reached. PPP procurement is the period in which bids are requested, proposals are evaluated, and a preferred bidder is chosen. Procedures also involve post-bid negotiations through which the Public Authority (i.e. the government agency responsible for developing the agreement) and the selected proponent finalize the contract documents and funding sources as well as assemble the financing package for the project (Kwak et al. 2009; Yescombe 2011).

Based on a growing body of PPP literature, it is clear that different procurement procedures have been implemented across multiple jurisdictions worldwide. In Spain, Italy, and Latin America, toll road concessions have been mostly procured through open competitive methods. These approaches allow public authorities to select a preferred bidder with minimal post-bid negotiations (Carpintero et al. 2014; Garvin 2010; Vassallo and Soliño 2006). In the US, Canada, and Australia, procurement procedures for toll roads have been characterized as multi-stage competitive processes in which negotiations occur on a limited basis. After bids are received, there are discussions around technical, financial, and funding issues (Aziz 2007; Gomez-Ibañez et al. 2009; Vining et al. 2005). In the UK, the PFI program promotes a more comprehensive negotiated process for highway projects. British authorities have established a process in which multiple rounds of negotiations take place during the bidding stage, after choosing the preferred bidder, and before financial close (National Audit Office 2007; Reeves et al. 2016; Yescombe 2011). Similar experiences can be found in other countries, such as South Africa, India, or China (Mahalingam and Palukuri 2012; Rintala et al. 2008; Tang et al. 2014).

Despite the differences among tendering processes worldwide, transaction cost economics (TCE) literature indicates that all of the them face similar hazards (Williamson 1979). Regardless of the extent of negotiations, these procedures are conducted in environments characterized by high degrees of bounded rationality and opportunism (Soliño and Gago de Santos 2010; Vining et al. 2005). Also, since public-private arrangements in the road infrastructure sector are highly asset-specific and uncertain transactions, most tendering procedures face challenges associated with significant levels of complexity, interdependency, and uncertainty (Levitt et al. 2014; Reeves et al. 2016). All of these hazards have a substantial impact on the efficiency and effectiveness of PPP procurement procedures. If they are not properly managed, the whole tendering process is likely to involve lengthy negotiations and high transaction costs (Soliño and Gago de Santos 2010; 2016).

In the same way, failing to properly mitigate TCE-related hazards during the procurement process may substantially hinder the execution of the construction and operation stages (Soliño and Gago de Santos 2016). If tendering processes are not properly conducted, most projects may have to cope with issues resulting from insufficient socio-political legitimacy, selection of unqualified bidders, deficient due-diligence processes, formation of low-quality contracts, and defective construction activities (Kwak et al. 2009; Liu et al. 2016; Tang et al. 2014). As a result, mitigating TCE-related hazards requires suitable management strategies focused on minimizing the hazards' impacts.

Researchers have examined PPP tendering issues by highlighting critical factors and best practices. Although these studies have not particularly targeted highway projects, they are relevant for analyzing the road infrastructure sector. Findings can be grouped into three main conceptual areas. First, scholars emphasize that pre-procurement phases play a crucial role in successfully developing the tendering process (Liu and Wilkinson 2014; Ng et al. 2012; Tang et al. 2014). Evidence suggests that a well-founded business case contributes to clarify how value for money can be achieved and why the project financing approach is the preferred delivery option (Ahadzi and Bowles 2004; Tang and Shen 2013). This is useful for increasing socio-political legitimacy and reducing project uncertainty. Also, the literature indicates that establishing clear outputs and metrics helps to diminish procurement duration, facilitate consensus building, and enhance the identification of project objectives (Aziz 2007).

Second, scholars highlight that the governance capacity of the public sector is one of the main critical factors behind successful PPP procurement processes. This refers to the skills and capabilities available in the public sector, the expertise of external advisors, and the governance arrangements needed to execute a project (Jooste et al. 2011; Jooste and Scott 2012). Highly skilled government personnel are more likely to better manage the complexity and interdependencies associated with PPP tendering. In the same way, competent advisors can support government decision-makers and also contribute towards a more efficient due-diligence process by providing financial, legal, and technical guidance (Garvin 2010; Reeves et al. 2016; Yescombe 2011). Overall, a capable and knowledgeable procurement team allows specification of clear goals, responsibilities, and roles among the different actors participating in the process. This helps to generate a more supportive and committed political environment, ultimately leading to a successful procurement process.

The third conceptual area recognized by PPP scholars refers to the creation of a competitive and transparent procurement phase (Aziz 2007; Garvin 2010; Jefferies 2006; Kwak et al. 2009). Establishing a competitive environment implies that government authorities need to be able to generate interactive tendering mechanisms in order to promote a constant but fair dialogue between participants (Yescombe 2011). This helps the public sector to examine the PPP market and confirm the project's value for money. It also allows bidders to adjust their proposals and be more innovative. However, incentivizing interactions and generating competition require high levels of transparency and accountability (Abdel-Aziz and Russell 2001; Liu et al. 2016). That is why multiple researchers acknowledge the relevance of conducting audits on a regular basis and establishing clear bidding protocols (Vining et al. 2005; Vining and Boardman 2008b; Yescombe 2011; Zhang 2004).

Clearly, the literature has examined PPP procurement processes from many different perspectives. Scholars have characterized tendering procedures by highlighting important differences among several jurisdictions worldwide. Despite such differences, researchers have also argued that procurement activities in the global PPP market are affected by TCE-related hazards in many similar ways. This has prompted them to explore how to make PPP tendering more efficient, effective, and reliable. As a result, a growing body of literature has started to suggest how the application of critical factors and best practices contribute to mitigate the impact of such hazards.

4.4 The Educational Challenge of PPP Procurement

Despite the substantial amount of research work conducted over the last few decades, developing highway PPP projects and implementing successful PPP tendering procedures are still endeavors surrounded by multiple questions about their real benefits and costs (Garvin and Bosso 2008; Gomez-Ibañez et al. 2009; Wang 2015). Although there have been successful initiatives, failures are not uncommon worldwide (Jooste and Scott 2012). Scholars report that advocates remain unable to improve misunderstandings about how PPPs can bring benefits such as effective risk-sharing, innovation, and cost efficiencies (Levitt et al. 2010; 2014). This gives opponents the opportunity to argue that public-private initiatives do not generate value for money and do not benefit the general public (Boardman and Vining 2012; Vining et al. 2005). In the middle, the general public remains confused, the global infrastructure gap keeps widening, and policymakers remain hesitant to use a potentially controversial project delivery system.

The lack of understanding of how public-private agreements work means that PPP-related education is a major challenge in procuring these projects (Aziz 2007; Garvin 2010). PPP tendering, in particular, comprises a series of activities in which multiple actors need to address TCE-related hazards and be fully informed on how their decisions impact the project in the long-term (Soliño and Gago de Santos 2016). However, the literature suggests that, in many projects, policymakers seem to be not fully aware of such hazards and fail to recognize that PPPs can be characterized as uncertain, asset-specific, and multiphase initiatives (Jooste et al. 2011). In multiple jurisdictions worldwide, as a result, government agencies do not have the required capacity to perform key procurement functions and public sector officials do not have sufficient knowledge about PPP tendering (Garvin 2010; Liu et al. 2016; Reeves et al. 2016). This leads governments to make deficient decisions during the procurement stage, failing to properly tackle highly uncertain issues that are likely to materialize within the construction and operation phases (Aziz 2007; Gomez-Ibañez et al. 2009; Levitt et al. 2014; Tang et al. 2014).

Recognizing the importance of PPP-related education, scholars and practitioners have suggested the creation of working groups, the development of guidelines, the generation of educational reports, and many other similar knowledge products (Aziz 2007; Garvin 2010). Although these efforts have been useful, PPP failures are not uncommon and multiple jurisdictions remain reticent to implement enabling legislation for public-private agreements (Geddes and Wagner 2013; Papajohn et al. 2011). Seemingly, such efforts have not been able to fundamentally change the mental models of those actors and organizations dubious about the benefits of public-private initiatives. Mental models are particularly important in complex dynamic environments such as PPP projects. As a result, much more effective tools are required in order to strengthen the pedagogical efforts directed toward improving how to develop better public-private agreements.

One way of reinforcing the educational efforts related to PPP initiatives is through the use of microworlds (Sterman 2000). Microworlds are learning spaces in which users improve their decision-making and strategic thinking processes within specific organizational settings (Langley and Morecroft 1996; Morecroft 1988; Stouten et al. 2012). They are built upon dynamic simulation models and supported by accessible interfaces. Thanks to their focus on developing problem solving skills and system thinking abilities, they serve as catalysts in overcoming learning barriers and traditional conceptual errors (Graham et al. 1992; Isaacs and Senge 1992). Additionally, since they offer the chance to analyze realistic situations within computerized environments, educators can employ them as tools for evaluating the short- and long-term impacts of users' decisions and the system-wide consequences of users' policies (Morecroft 1988). Consequently, microworlds seem to be very good tools to gain insight into the complexities associated with PPPs and PPP procurement procedures.

Certainly, understanding how to improve the development of PPP projects and PPP procurement processes is a path towards diminishing public questions about the real benefits and costs around public-private initiatives. In this sense, microworlds are a suitable way to enhance people's perceptions about failures and successes in PPPs since they can facilitate learning processes associated with complex issues in multiple academic, public policy, and industry domains.

4.5 Management Flight Simulators

In the field of system dynamics, scholars have examined multiple complex systems by exploiting not only the capabilities of their simulations, but also the usefulness of microworlds. Since system dynamics models focus on gaining insight into the interdependencies and feedback relationships affecting system components over time (Forrester 1961; Sterman 2000), researchers have used them to analyze complex problems through the use of "powerful small models" (Ghaffarzadegan et al. 2011). Although not all of the models have been designed or adapted to be educational tools, those employed for learning purposes have clearly shown their applicability for addressing issues related to project management, economic planning, organizational strategy, public health, climate change, and many others (Graham et al. 1992; Morecroft 1992; Sterman 2011; 2014).

In system dynamics, microworlds are called management flight simulators and have been generated as a way to improve traditional instructional methodologies, such as lectures and discussions (Morecroft 1988; Sterman 1988). Management flight simulators are based on the idea that the most effective way for learners to better understand complex phenomena is by improving their mental models (Langley and Morecroft 1996; Sterman 1994). By building a virtual world in which learners can interact with the system, they seek not only to improve system thinking, but also to change users' mental models (Sterman 2000). This is particularly important for the PPP domain, a field that requires educational efforts directed towards changing some of the traditional paradigms of public procurement.

Since PPP tendering exhibits some of the characteristics of the complex dynamic systems studied in the system dynamics field, it is possible to apply such knowledge to improve public-private procurement processes. As discussed above, the literature suggests that, in many projects, policymakers are not fully aware of the TCE-related hazards and fail to recognize that PPPs can be characterized as complex dynamic systems affected by feedback misperceptions, ambiguous information, and bounded rationality (Henisz et al. 2012; Levitt et al. 2014). For example, during the procurement stage of several projects, participants have made overly optimistic traffic forecasts and deficient technical decisions that have resulted in higher-than-expected toll fees and construction cost overruns (Cantarelli et al. 2010; Flyvbjerg et al. 2007; Priemus and Flyvbjerg 2007). Additionally, there have been cases in which non-compete clauses in project agreements (drafted during the tender phase) or changes in tolling regimes have become one of the major catalysts of public and legal opposition within the operation stage. (Behshad 2017; Garvin and Bosso 2008; Vining et al. 2005)

A system dynamics model of PPP procurement can be built by examining the tendering phase as an interactive decision-making process. Since decisions made in this phase are surrounded by uncertainty and affected by bounded rationality (Henisz et al. 2012; Jooste and Scott 2012; Levitt et al. 2010), it is not simple to analyze how they are able to impact either positively or negatively the construction and operation stages. In this context, a simulation model is useful because it provides the opportunity to explore the feedback responses associated with such impacts in a secure and timely way (Graham et al. 1992; Sterman 2000). In line with this, a management flight simulator can transform a simulation model into an educational tool (Sterman 2014). This can facilitate learning and contribute toward improving the current mental models and paradigms related to PPP tendering.

4.6 Research Methodology

The main objective of this research is to examine the decision-making dynamics associated with procurement processes in public-private partnership projects. The study seeks to contribute towards overcoming the educational challenge of PPP procurement by developing a didactic tool. The methodological approach involved two stages. First, a system dynamics model was created in order to simulate feedback relationships among variables related to government capacity, project uncertainty, and technical complexity. Second, a simulation exercise was generated as a pedagogical tool focused on testing and communicating the insights represented by the model. This exercise involved an educational game that was introduced to graduate students knowledgeable of public-private partnerships (i.e. master's students in civil engineering). Both the model and the game rely on bibliographic data and have been tested in order to verify the realism of their assumptions and behaviors.

4.7 Bibliographic Sources

As Table 4-1 shows, this research has been built upon a comprehensive group of bibliographic sources from multiple origins: scholarly articles focused on system dynamics formulations, archival publications aimed to analyze PPP procurement processes, and institutional documents directed towards offering PPP procurement guidelines and highlighting best practices. This approach was selected because of the educational orientation adopted in this research and due to the lack of publicly available procurement-related data from real projects.

In respect to system dynamics formulations, the literature has provided ample information about the two core structures employed in the model: rework cycle and capability development dynamics. Both formulations have been employed to study schedule delays in design and construction activities, quality control in product development processes, and concurrent development methodologies in the software industry. Thanks to these structures, the model has been able to simulate the execution of procurement activities and the effects of public sector capacity on the tendering process.

In terms of archival and institutional literature related to PPP tendering, this investigation has employed different sources. In order to be informed about the importance of the procurement stage and the factors associated with its successful execution, this research relied on publications about risk allocation, general PPP delivery, and PPP contract management. Additionally, the authors have consulted publications focused on identifying best practices in procurement processes and exploring the effects of government capacity in PPP development. This investigation has also incorporated case studies of real PPP experiences worldwide to understand reasons for failures. Institutional sources, on the other hand, have contributed to identify the main guidelines to implement procurement procedures and the current practices.

Table 4-1 Bibliographic sources

Area	Topic	Reference
System dynamics	Rework cycle	Richardson and Pugh (1981), Ford and Sterman (1998), Sterman (2000), Lyneis and Ford (2007), Taylor and Ford (2006), Rahmandad and Hu (2010).
	Capability dynamics	Rahmandad and Repenning (2015), Rahmandad and Weiss (2009), Rahmandad (2015), Lyneis and Sterman (2015), Repenning (2002)
PPP	Project delivery	Grimsey and Lewis (2004), Grimsey and Lewis (2002), Garvin (2010), Abdel-Aziz (2007), Gomez-Ibanez et al. (2009), Vining et al. (2005), Vining et al. (2008a)
	Procurement processes	Kwak et al. (2009), Ahadzi and Bowles (2004), Reeves et al. (2016), Liu et al. (2016), Tang et al. (2014), Tang et al. (2013), Tang et al. (2013).
	Governance and capacity	Jooste et al. (2011), Jooste et al. (2012), Henisz et al. (2012)
	Cases	Garvin and Bosso (2008), Vining et al. (2005), Regan et al. (2011), Carpintero et al. (2014), Wang et al. (2015), Iseki and Houtman (2012), Abdel-Aziz and Russell (2001), Chung et al. (2010), Koppenjan (2005), Ortiz and Buxbaum (2008)
	Institutional information	Eno Center for Transportation (2014), KPMG (2010), Virginia PPP Office (2016), National Audit Office (2007)

4.8 The PPP Procurement Model

The model simulates a generic procurement process by considering that PPP tendering is a collection of tasks that can be completed in a maximum of 36 months. These tasks involve decisions related to all procedures that need to be conducted from issuing the request for qualifications until reaching financial close. It is based on system dynamics structures that have been employed to examine similar behaviors in domains related to project management, product development, design management, systems engineering, and software development. As shown in Figure 4-1, in general terms, the model comprises components related to resources, procurement work and government capacity. These are interconnected through variables associated with productivity and latent issues.

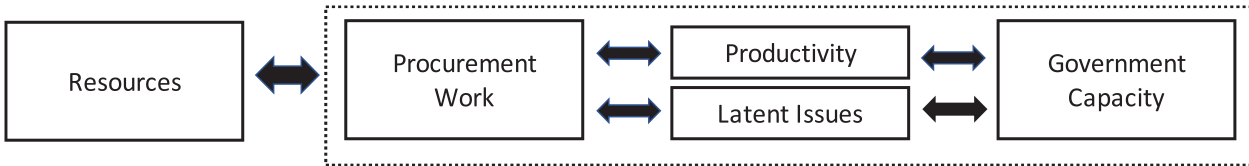


Figure 4-1. General Overview of Simulation Model

The model is based on a series of simplifying assumptions that are helpful to capture the basic feedback dynamics and nonlinearities associated with PPP tendering. First, the simulation does not differentiate between tasks. It assumes that each one of them has the same level of difficulty and is carried out on a continual basis (i.e. there are not multiple stages within the process). Second, there are only three types of resources. They correspond to external advisors responsible for providing legal, financial, and technical assistance; public agency personnel in charge of executing procurement tasks; and public agency personnel focused on providing clarification to potential bidders and conducting reviews of procurement documents. Third, resource allocation depends on user's inputs. From a total of resources, the user decides the proportions allocated to each one of the three categories. Fourth, the model does not differentiate between the different public agencies supporting the process and aggregates them as a single government agency. Similarly, it aggregates the proponents bidding for the project and does not differentiate between bidders' interests. Fifth, it does not incorporate cost-related variables because it considers that the unit costs associated with each one of the three resources are the same.

The causal structure underlying the model comprises three main components: stocks, rates, and auxiliary variables. Stocks are represented by rectangles and symbolize accumulation of tasks. The rates are denoted by double-line arrows with a valve in the middle. They are the means through which stocks accumulate or deplete. Auxiliary variables are all the other variables connected through arrows representing cause-and-effect relationships. A positive mark on the arrows indicates that both components move in the same direction, whereas a negative mark suggests the opposite. The interconnection between components creates feedback loops, groups of concatenated variables forming closed cycles. These are responsible for controlling system behavior and can be characterized as R for reinforcing or B for balancing (self-correcting). The model structure is furtherly examined below. A complete description of the system dynamics equations used in the model can be found in Appendix D (Equations S69-S195).

4.8.1 Procurement Work Cycle

In the system dynamics literature, the most important structure to model project management dynamics is the rework cycle. This structure recognizes that project tasks can be executed either correctly or incorrectly (Ford and Sterman 1998; Lyneis and Ford 2007). Work developed incorrectly needs to be recognized in order to be fixed. Once flawed tasks are recognized, they need to be reworked in order to be executed in the right way. While task execution and rework depend on resource availability and productivity levels, the amount of defective tasks is influenced by a quality rate. In this way, project completion is a function of the number of tasks, resource availability, productivity rates, and quality levels.

Figure 4-2 shows the rework cycle adopted for this research (i.e. the procurement work cycle). At the start of the procurement stage, no work has been performed and all tasks are contained in *Work to Do*. These tasks symbolize all the procurement procedures that need to be carried out from when bidders are requested to participate until financial close is reached. These include but are not limited to drafting bidding documents, evaluating proposals, drafting comprehensive agreements, negotiating the final contract, and achieving financial close. In order to perform these activities, the government agency in charge of the tendering process needs to fully address all the TCE-related hazards surrounding the PPP project. If they address the hazards adequately, tasks flow into *Work Correctly Done.* If not, procurement procedures are completed and approved without being fully capable of coping with the hazards and tasks move into *Work Done with Undiscovered Latent Issues*.

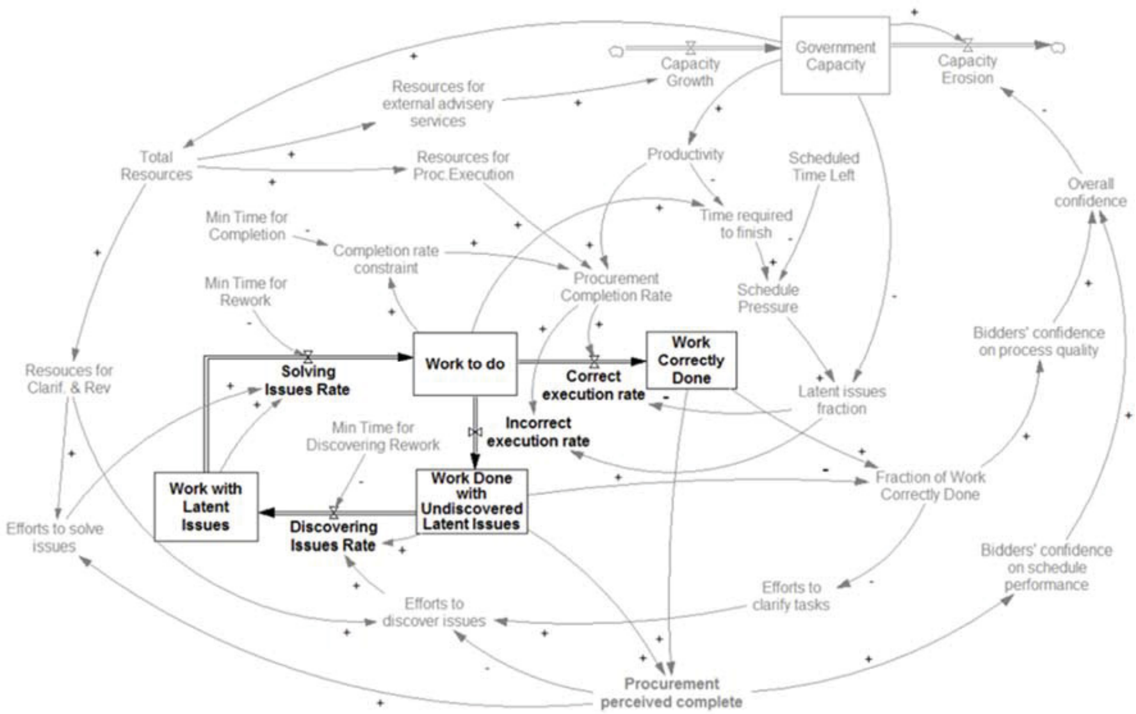


Figure 4-2. Rework Cycle

Latent issues comprise all of the hazards that have the potential to impact the project in the long-term and that have not been fully addressed at the moment of designing contractual provisions, conducting due-diligence procedures, and developing technical studies. Since they depend on the relationship between complex procurement processes and the uncertainty around the PPP project, highly complex and uncertain initiatives are likely to have more latent issues. However, due to the incomplete nature of public-private agreements, even the least uncertain and simple projects are likely to be impacted by latent issues in the long-term.

Since government agencies know that there could be approved tasks with latent issues, they seek to discover them through clarification and review procedures. Thanks to these efforts, discovered tasks flow into *Work with Latent Issues.* Once there, government officials are responsible for solving such issues and move the tasks into *Work to Do*. From this stock, tasks need to be formally completed and approved again (e.g. contract provisions need to be drafted again or technical documents need revision). If this is completed without any issues, tasks are considered as *Work Correctly Done.* If not, further rework is required and the whole cycle starts one more time.

In general, the relationships described in the rework cycle for PPP procurement processes can be found in multiple initiatives. Examples of procurement work conducted with minimal latent issues can be found in Canadian and British projects (Aziz 2007; Li et al. 2005). Experiences where latent issues have not been discovered during the procurement phase include the SR 91 in California (i.e. a non-compete clause in the original contract triggered legal disputes between private and public partners) (Garvin and Bosso 2008; Gomez-Ibañez et al. 2009; Vining et al. 2005), the Elizabeth River Tunnels in Virginia (i.e. the original tolling structure was modified due to local opposition and legal challenges) (Guthkelch 2017; Reinhardt 2012), and the Cross City Tunnel in Sydney (i.e. the original technical design was modified and traffic volume was not properly forecasted) (Johnston 2010; Johnston and Gudergan 2007) among others.

4.8.2 Schedule Pressure and The Procurement Work Cycle

As stated previously, completing procurement activities is a function of (among other factors) the amount of *Work to Do*. When government agencies do not execute procurement activities on time, the time required to finish all work increases and procurement gets delayed if available resources and productivity rates remain fixed. However, since the deadline to complete procurement has already been set and is difficult to change, increasing the time required to finish elevates the pressure to complete tasks on time. This, in turn, includes the generation of latent issues because government personnel are likely to make more errors when working under pressure. As a result, two loops are created (Figure 4-3): R1 and B1. In Loop R1, more *work to do* → more *time required to finish* → higher *schedule pressure* → higher *latent issues fraction* → lower *correct execution rate* → even more work to do. In Loop B1, more *work to do* → more *time required to finish* → higher *schedule pressure* → higher *latent issues fraction* → more *incorrect execution rate* → less work to do.

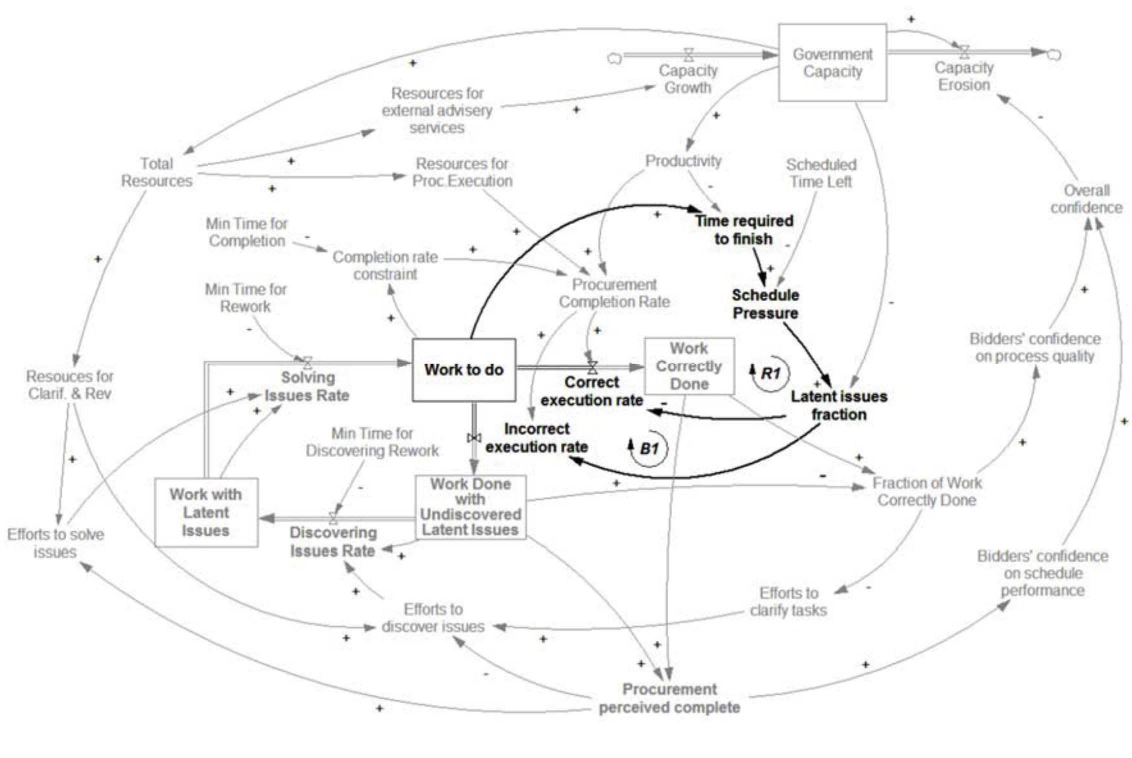


Figure 4-3. Loops R1 and B1

These two loops show that once the PPP tendering process gets delayed, procurement tasks are likely to be completed with more latent issues (Loop B1) or not completed on time at all (Loop R1). These behaviors are underpinned by investigations focused on producing simulations of project dynamics as shown by Lyneis and Ford (2007). These feedback structures are also supported by studies showing that PPP tendering processes with no clear timelines and organized schedules tend to be completed either carelessly or at a slow pace. This certainly has been the case for some procurement processes in Australia (i.e. Cross City Tunnel) (Johnston 2010), Latin America (i.e. first generation programs in Mexico and Colombia) (Carpintero et al. 2014; Vassallo 2007) (Papajohn et al. 2011; Wang 2015), and US (i.e. projects in Virginia and California) during the 1990s and early 2000s.

4.8.3 Capacity and Task Completion

Completing procurement tasks is also a function of the productivity rate at which such procedures are conducted. If resources remain constant, productivity depends on the capacity of the public agency in charge of the project. Higher capacity levels lead to better productivity rates, which contributes to more work completion (with or without latent issues). As more work is perceived to be done, bidders start feeling that the procurement process is complying with its timeline and improving its schedule performance. This enhances the overall confidence of the tendering process and reduces capacity erosion by freeing up resources that otherwise would have been utilized on attracting/sustaining bidder participation. The whole process is summarized in Loops R2a and R2b (Figure 4-4). In Loop R2a, higher *productivity* → higher *procurement completion rate* → more *correct execution rate* → more *work correctly done* → more *procurement perceived complete* → higher *bidders' confidence on schedule performance* → greater *overall confidence* → less capacity erosion → more *capacity* → even *higher productivity*. In Loop R2b, higher *productivity* → higher *procurement completion rate* → more *incorrect execution rate* → more *work done with undiscovered latent issues* → more *procurement perceived complete* → higher *bidders' confidence on schedule performance* → greater *overall confidence* → less capacity erosion → more *capacity* → even *higher productivity*.

Loops R2a and R2b rely on the idea that successful PPP procurement needs to be conducted by capable public agencies. The model follows a body of PPP literature in which public sector capacity refers to all the competences and skills necessary to manage the contract drafting procedures, oversee the due-diligence activities, evaluate the technical documents, and promote an efficient tendering process between public and private sides (Jooste et al. 2011; Jooste and Scott 2012; Yescombe 2011). In this way, public agencies with high capacity levels are likely to be more productive at the moment of conducting procurement procedures and more resilient to bidding-related conflicts and negotiation problems. Examples of strong public agencies have been highlighted in the UK (Carrillo et al. 2008; Henjewele et al. 2014; Li et al. 2005), Canada (Abdel Aziz 2007; Abdel-Aziz and Russell 2001; Vining and Boardman 2008a) and Australia (Chung et al. 2010; Chung and Hensher 2015; Jefferies and McGeorge 2009). Less successful cases have also been documented in Eastern Europe, East Asia, and some US states (Soomro and Zhang 2016; Zhang and Ali Soomro 2016).

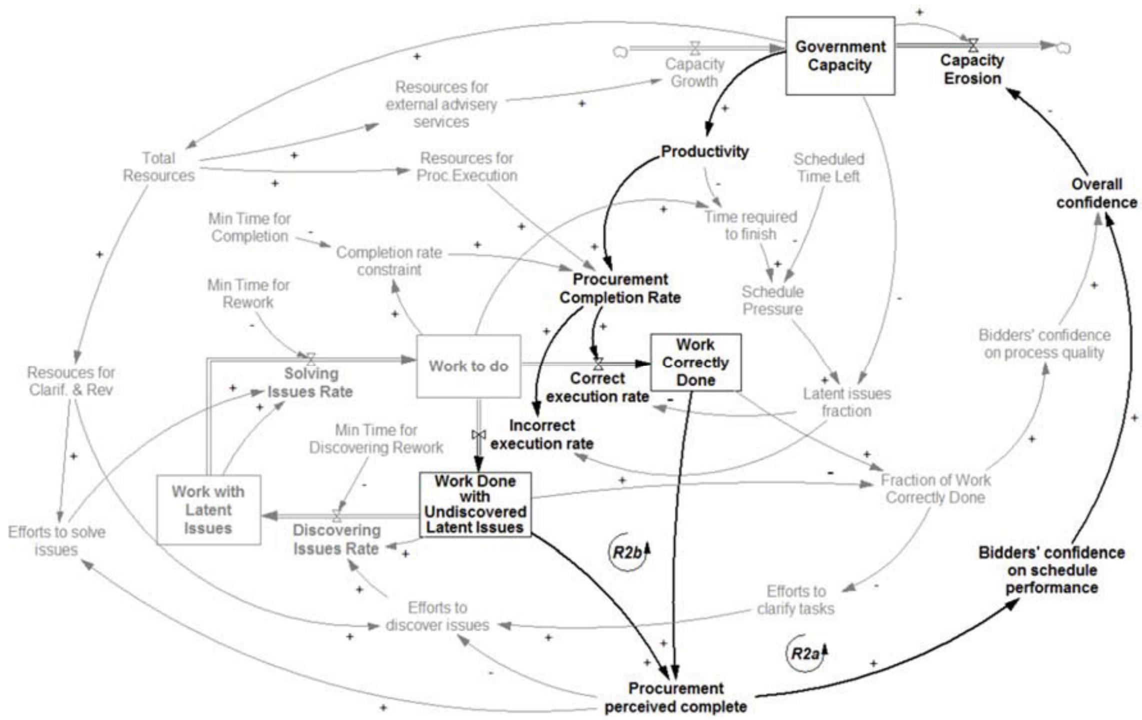


Figure 4-4. Loops R2a and R2b

4.8.4 Capacity and Latent Issues

High capacity levels are also helpful to decrease the amount of latent issues that are approved within the procurement process. This is because capable government agencies have the required resources and expertise to properly address undiscovered latent issues. By doing so, such agencies enhance the quality of the completed tasks, improve the bidder's confidence in the process, and do not waste resources in resolving lengthy conflicts. This creates two supplementary loops (Figure 4-5): R3a and R3b (differences between the loops are indicated in parenthesis). In Loop R3a (or Loop R3b), more *work correctly done (*less *work done with undiscovered latent issues)* → higher *fraction of work correctly done* → higher *bidders' confidence on process quality* → greater *overall confidence* → less capacity erosion → more *capacity* → *less latent issues fraction* → more *correct execution (*less in*correct execution)* → even *more work correctly done (*even *less work done with undiscovered latent issues)*.

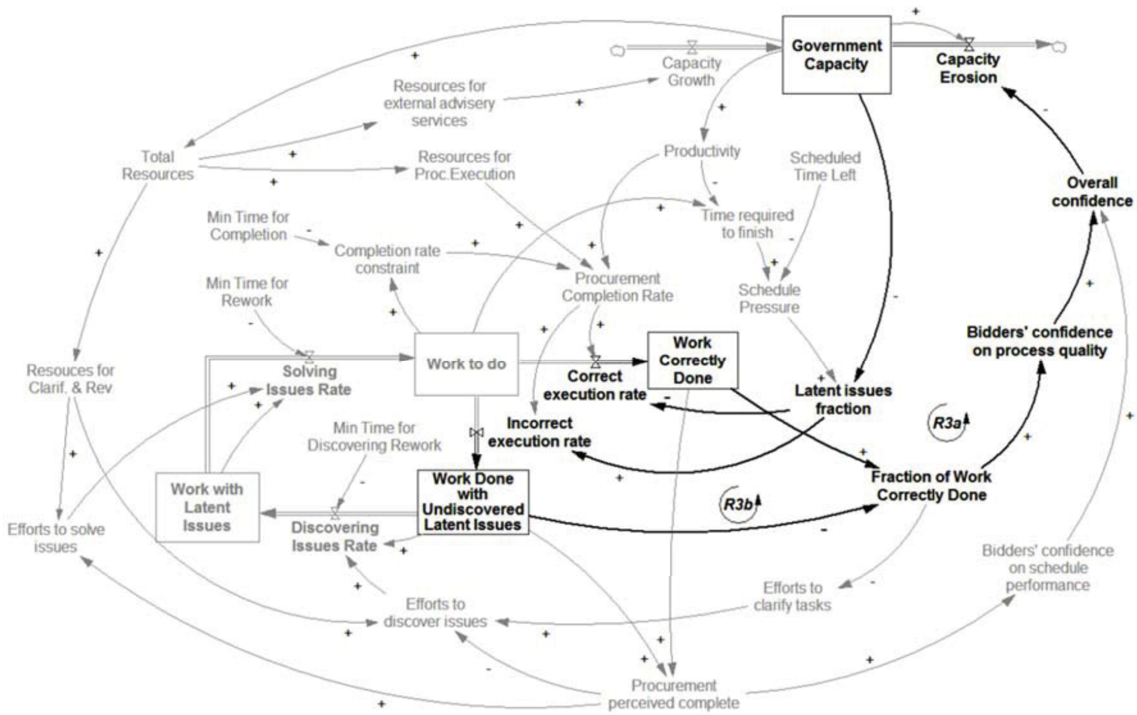


Figure 4-5. Loops R3a and R3b

This set of loops highlights the relationship between the amount of latent issues and the capacity of the government agency. A more capable public sector is less likely to complete procurement tasks with latent issues because it is able to conduct better value for money analyses, produce good-quality technical and financial studies, and assemble an adequate package of risks and incentives (Yescombe 2011). This not only improves the general quality of the procurement process, but also makes PPP tendering more attractive to the private sector. In Canada and the UK, for example, strong public agencies have played a key role in developing successful procurement processes and consolidating the PPP market (Aziz 2007; Garvin 2010; Kwak et al. 2009; Liu et al. 2016).

4.8.5 Discovering and Solving Latent Issues

So far, it is clear that the rework cycle plays an important role in terms of completing procurement work with or without latent issues. Also, it is clear that schedule pressure, public sector capacity, bidders' confidence in the process, and procurement productivity are involved in major feedback loops that affect the amount of work done and the fraction of latent issues. However, it is not clear how such latent issues are discovered and subsequently solved.

Discovering latent issues depends on two main variables: procurement perceived complete and fraction of work correctly done. At the beginning of the tendering process, when procurement perceived complete is close to zero, it is assumed that public authorities have time and resources to review the tasks perceived to be correctly completed. This incentivizes the discovery efforts and contributes to reduce the amount of undiscovered latent issues. At the end of the tendering process, when procurement perceived complete is close to one, the assumption is that government agencies are more interested in finishing than in conducting reviews. Thus, discovering efforts are not a priority anymore. In parallel, the discovery rate is also influenced by the fraction of work correctly done. If these ratio decreases, bidders' confidence in the quality of the process declines and the private sector is likely to request clarifications about many of the tasks completed. Since clarification requests force public authorities to review their procedures, it raises the discovery rate and ultimately reduces the number of undiscovered latent issues.

Once tasks with latent issues are discovered, they need to be solved in order to be approved again. In this process, procurement perceived complete plays an important role. Since at the beginning of the process efforts are focused on reviewing and clarifying tasks, it is assumed that public agencies are not strongly interested in solving issues when procurement perceived complete is close to zero. In contrast, at the end of the process, government authorities prioritize solving rather than discovering because they need to re-approve those tasks in which discovered latent issues have been identified. As a result, the more progress is made, the more the solving efforts are emphasized in the procurement process.

The effects of procurement perceived complete and fraction of work correctly done are shown in Figure 4-6. In Loop R4a, more work done with undiscovered latent issues → *more procurement percent complete → less effort to discover issues → lower discovery rate → even more work done with undiscovered latent issues.* In Loop R4b, more *work correctly done* → *more procurement percent complete → more effort to solve issues → higher solving rate* → more *work to do* → more *correct execution rate* → even more *work correctly done*. In Loop B2*, lower fraction of work correctly done → more efforts to clarify procurement tasks → more effort to discover issues → less work done with undiscovered latent issues → higher fraction of work correctly done.*

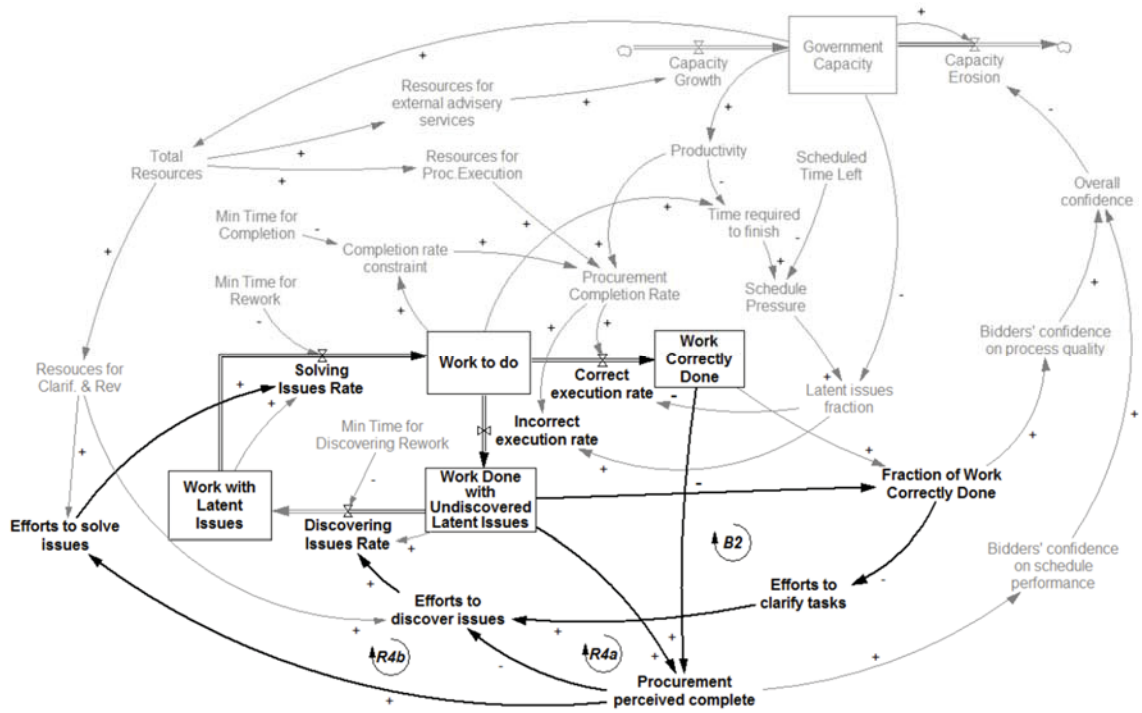


Figure 4-6. Loops R4a, R4b, and B2

Clearly, the three loops associated with discovering and solving latent issues have important effects over developing successful procurement processes. In the PPP literature, clarification and review procedures are highlighted as important tools to allocate risks, address complexity, and mitigate uncertainty. Many scholars, for example, emphasize that adequate due-diligence processes are crucial for avoiding cost overruns and contractual problems during the construction and operation stages (Flyvbjerg 2013; Tang et al. 2014; Yescombe 2011). Researchers also point out that incentivizing bidder participation is critical to align public and private interests towards the project (Garvin 2010; Li et al. 2005). In general, practitioners and academics agree that communication with bidders and review protocols are beneficial as demonstrated by successful experiences in the UK (Li et al. 2005), Canada (Vining and Boardman 2008a), and Chile (Vassallo 2006) . The lack of such procedures may diminish procurement performance as shown in projects developed in the US, Australia, China, and Latin America (Carpintero and Barcham 2012; Gomez-Ibañez et al. 2009; Liu et al. 2016; Papajohn et al. 2011).

4.8.6 Resources for PPP Procurement

In order to simulate the aforementioned feedback loops, the model utilizes three types of resources as shown in Figure 4-7. First, resources for execution represent government personnel directed towards completing procurement activities. These are responsible for moving tasks from w*ork to do* to either w*ork correctly done* or *work done with undiscovered latent issues.* Second, resources for clarification and review symbolize public officials focused on the discovery and resolution of latent issues. They are necessary to reduce the amount of latent issues and improve process quality. Third, resources for external advisory services simulate the use of transaction advisors for financial, legal, and technical issues. They increase the in-house capacity of the government agency, help to liberate more resources, and are helpful to increase productivity and decrease latent issues.

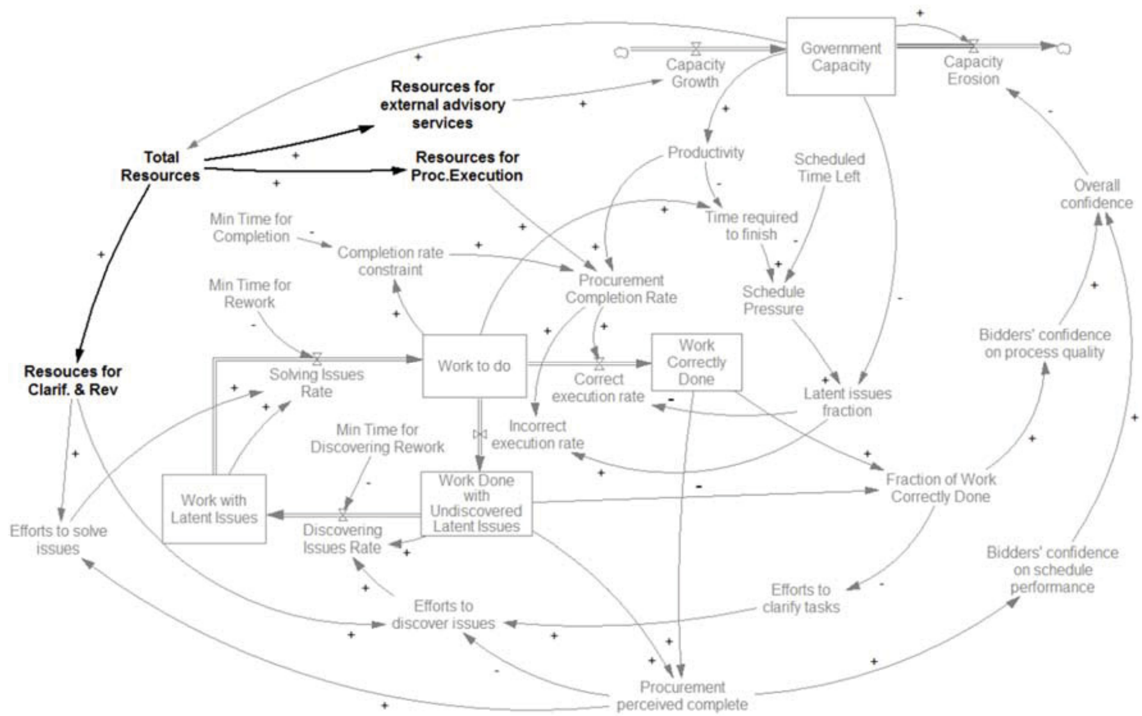


Figure 4-7. Resources and Capacity

As depicted in Figure 4-7., the model uses *total resources* as the single variable behind resources for execution, external advisory services, and clarification and review. Although the model is built in order to allocate resources through users' inputs, *total resources* are endogenously affected by the capacity of the government agency (see link between *capacity* and *total resources)*. As more capacity is built, governments are able to properly offset capacity erosion (i.e. they are better in managing conflicts with bidders and other stakeholders), this allows agencies to liberate more man-hours for conducting procurement procedures. In other words, in high-capacity agencies, the personnel in charge of the procurement process are likely to be less disturbed by issues not directly related to the tendering process (e.g. potential legal conflicts with stakeholders, lack of adequate regulations). This creates the effect of having more man-hours available for execution, advisory, and review.

4.9 User Interface: Web-Based Simulator

The model (Figure 4-8) is located on an online platform (Forio Simulate) to be accessible as an interactive web-based simulator. From there, users can explore the simulator interface and run multiple simulations.

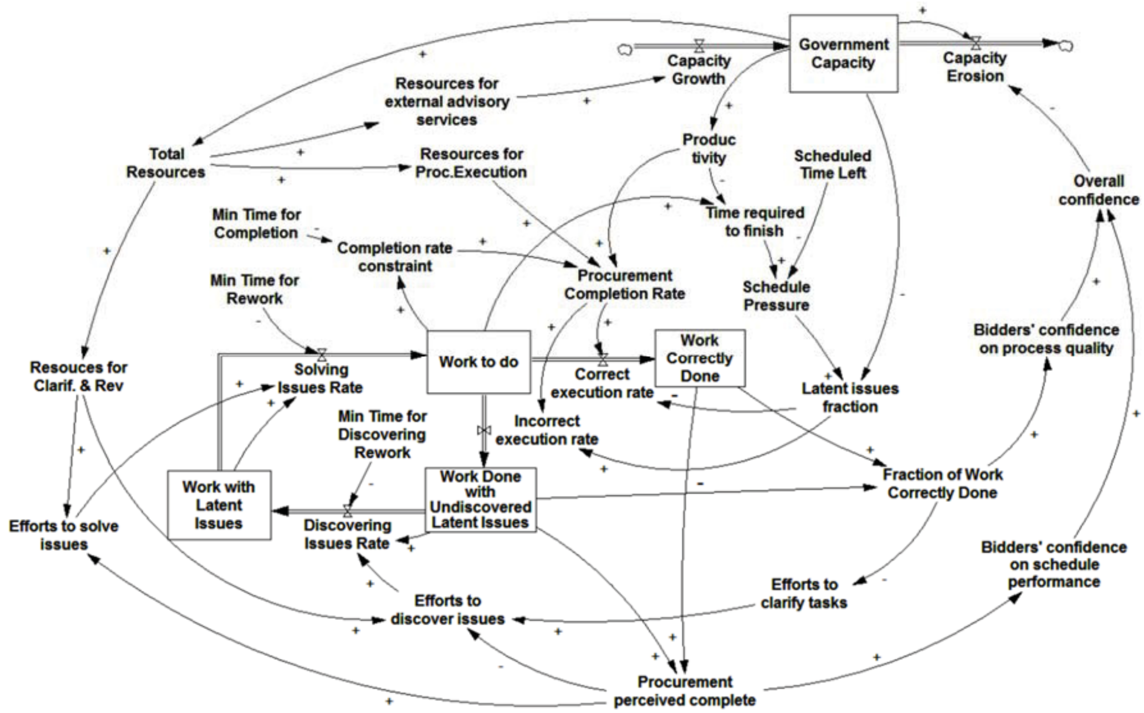


Figure 4-8. Procurement Model

The interface comprises two main screens that are helpful for selecting scenarios and making resource allocation decisions. In the first screen that is shown (Figure 4-9), users have the opportunity to establish the desired duration of the procurement process. They can select periods that vary from 6 to 36 months. Additionally, users also choose between two simulation scenarios. These represent different initial conditions in terms of technical complexity, project uncertainty, and government capacity. This selection is important to establish the background over which resource allocation decisions are going to be made.

Figure 4-9. Scenario page

Once users select the scenario and the desired duration, the model introduces the screen shown in Figure 4-10. This can be divided in four sections. In section 1, users make their resource allocation decisions by proportionally distributing the total amount of resources. They allocate resources into three main areas: procurement execution, clarification and review, and external advisory services. In this way, users do not assign resources directly (i.e. the model works with a pre-determined amount of total resources), but are concern on how to proportionally allocate them. In section 2, there are four graphs that depict the effects of the resource allocation decisions. They offer users the opportunity to analyze if they have made good decisions or not. In section 3, the results of the game are presented. Users are informed about their final score, the duration of the process, and the percentage of latent issues in their projects. Finally, section 4 involves four buttons that allow users to make decisions every 6 months and navigate through the interface.

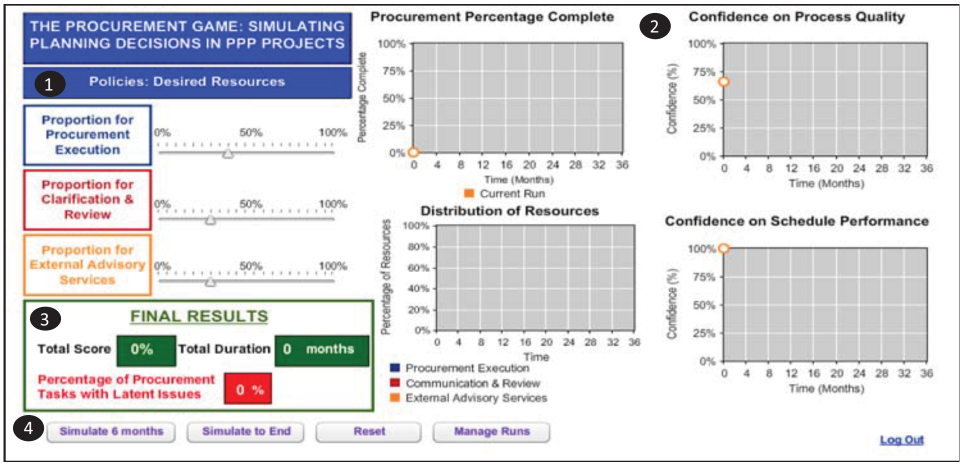


Figure 4-10. Simulator page

4.10 The Procurement Game

The game is a simulation exercise based on the *Procurement Model*. It focuses on developing strategic thinking skills for analyzing the implementation of PPP procurement processes in the road infrastructure sector. It seeks to communicate two main insights of PPP tendering procedures: (1) local conditions exert an important influence over PPP procurement processes; and (2) the interplay among government capacity, technical complexity, and project uncertainty play a crucial role in PPP tendering. The game comprises several implementation stages as described below.

4.10.1 Stage 1: Briefing information

Users receive information about public private partnerships and their procurement processes. Several successful and failed experiences are presented in order to highlight the importance of conducting well-organized tendering procedures. The concepts of government capacity, technical complexity, and project uncertainty are introduced by emphasizing their influence over the decisions made during the procurement phase. Based on that, users are informed that if decisions are not properly made, latent issues will be created and will likely materialize during the construction or operation stages. Overall, this helps users to learn about the TCE-related hazards affecting PPP procurement in a simply way.

4.10.2 Stage 2: Hypothetical case

Users receive a fact pattern in which a hypothetical case is described. In the case, they personify a recently hired program manager in a national government agency. He/she is in charge of providing assistance for the procurement of two DBFOM projects in two different regional jurisdictions. Each jurisdiction represents two different scenarios. In scenario 1, the regional public agency has a mature PPP program and needs to develop high-occupancy toll lanes in the median of an existing highway. For this initiative, a smooth delivery is anticipated because of the agency's experience and the low uncertainty and complexity levels associated with traffic forecast and construction risks. In scenario 2, on the other hand, regional officials do not have experience with PPPs and need to develop an urban toll road that comprises several bridges and underpasses. However, since residents are not used to paying tolls, traffic forecasts are highly uncertain. Consequently, the newly appointed program manager needs to carefully study each scenario before making any recommendation.

4.10.3 Stage 3: Pre-simulation questions

Since users are playing the role of a public official, they need to make policy recommendations for both scenarios. These recommendations involve decisions concerning the distribution of resources during the procurement process. In each scenario, they need to establish how to proportionally distribute three types of resources: personnel for procurement execution, staff for clarification and review, and consultants for external advisory services. Users record the allocation fraction for each resource type in both scenarios.

4.10.4 Stage 4: Simulation

The simulator is introduced and users are asked to conduct their first two simulation runs based on the distribution strategy recorded for each scenario in Stage 3. Subsequently, they are free to try any allocation approach focused on minimizing latent issues, completing procurement procedures on time, and achieving the highest score. This phase finishes when all participants have been able to complete the procurement processes of scenarios 1 and 2 at least once.

4.10.5 Stage 5: Post-simulation questions

After completing stage 4, users are requested to respond some post-simulation questions. They are asked to provide a new resource distribution for each scenario based on the simulation experience. Additionally, they are questioned about their recommendations to public agencies involved in PPP procurement processes.

4.10.6 Stage 6: Debriefing

This phase addresses multiple concerns related to the execution of PPP tendering processes and underlying principles of system dynamics. In respect to the tendering procedures, the debriefing highlights the importance of recognizing how the local conditions of each scenario impact the development of procurement tasks. In line with that, the relationship between government capacity and latent issues is furtherly explored by comparing the two scenarios. Also, participant reactions and comments about the model and the educational experience are addressed.

4.10.7 Stage 7: Follow-up interviews

In this stage, semi-structured interviews are conducted with some of the users. The purpose of these interviews is to gain insight into the users' overall experience during the activity. They are asked about their reactions and feelings in respect to the simulator as an educational tool. Questions are also directed towards eliciting participant knowledge of the difficulties associated with PPP procurement processes. These inquiries seek to evaluate participant understanding of concepts such as government capacity, latent issues, and project uncertainty.

4.11 Limitations

The scope of the game activity involves the following limitations: (1) it was designed principally as an instrument to test the simulation model's internal coherence; in other words, the game is a pilot test focused on assessing the simplifying assumptions made at the moment of developing the model; (2) it does not seek to gauge learning about PPP governance; its main goal is to convey to its users how governance variables and feedback relationships affect decision-making in PPP tendering; and (3) the analysis relies on a hypothetical case that only incorporates variables relevant to the simulation model; hence, it is assumed that variables not represented in the model behave according to the principle of ceteris paribus (i.e. all other things being equal) (Sterman 2000).

4.12 Results

The game was implemented during a special session of a master's level course focused on PPPs. Users were students in a master's of civil engineering program. The session followed each one of the stages previously described for the game. A total of 19 students took part in the exercise, 18 of them agreed to share their data. Users had access to the simulator through Forio Simulate and spent around two hours in the activity. Before starting to use the simulator, participants received the case rubric and were asked to proportionally allocate their resources in each scenario. After that, students were directed to conduct their first two simulations based on the pre-test question. In this way, each participant conducted his/her first two runs (i.e. scenarios 1 and 2) according to pre-test decisions. At the end of the game, they were requested to state their final resource distribution strategy based on their best results. They were also asked to provide written recommendations for both scenarios. After the session, invitations for follow-up interviews were sent and seven students agreed. During the game, participants remained anonymous and were informed that their simulation results did not have effects on their grades.

As shown in Table 4-2, participants generated a total of 469 simulation runs and most of the them were performed on scenario 2 (i.e. 319 runs). On average, each student conducted 8 runs on scenario 1 and 17 on scenario 2. These simulations were examined by comparing a series of parameters based on the pre- and post-test questionnaires. Parameters included: proportions for the three resources under consideration, procurement percent complete, percentage of tasks with latent issues, and procurement duration.

Table 4-2. Participants and simulations characteristics

Parameters	Value	Percentage	Average per participant
Participants	18	100%	N/A
Simulation Runs	469	100%	26
Scenario 1	150	32%	8
Scenario 2	319	68%	17

Table 4-3 presents the parameters through which the simulations were examined. As shown, at the beginning of the simulation phase (stage 4), while all participants were able to complete scenario 1 with a duration of about 10 months, none of them was able to achieve 100% completion in scenario 2. At the end of the exercise, users were able to finish scenario 1 and 2 in 7.58 and 26.27 months, respectively. Additionally, the table shows important differences in the way users distributed their resources in both scenarios. In scenario 1, for instance, students seemed to prioritize execution in all their simulations. In scenario 2, on the other hand, users started their simulations by favoring execution but ended up prioritizing external advisory services. In respect to tasks with latent issues, scenario 1 seemed to have been less affected by uncertainty and complexity than scenario 2.

To understand the statistical significance of the allocation decisions made by participants, the Wilcoxon signed-rank test was employed at a 0.05 significance degree. This statistical procedure is a paired difference test that was selected because it has proven to be a good alternative in cases where samples cannot be assumed to be normally distributed. According to the data presented in Table 4-3, scenario 1 shows a significant difference in the resource allocation decisions for execution and clarification and review activities. In scenario 2, a significant difference is observed for resources related to external advisory services and clarification and review. In both scenarios, the Wilcoxon test compares allocation decisions made at the beginning and the end of the simulation exercise.

Table 4-3. Simulation results in scenario 1 and scenario 2

Parameters	N	Mean before simulations	Mean after simulations	p-value
Scenario 1				
Resources for execution (%)	18	45.00%	64.72%	0.0226
Resources for clarification & review (%)	18	29.17%	14.73%	0.0114
Resources for advisory services (%)	18	25.83%	20.56%	0.3196
Procurement percent complete (%)	18	100.00%	100.00%	N/A
Tasks with Latent Issues (%)	18	5.13%	6.79%	N/A
Procurement duration (months)	18	10.08	7.58	N/A
Scenario 2				
Resources for execution (%)	18	34.77%	31.15%	0.879
Resources for clarification & review (%)	18	33.00%	9.74%	0.0001
Resources for advisory services (%)	18	32.00%	59.11%	0.001
Procurement percent complete (%)	18	6.00%	100.00%	N/A
Tasks with Latent Issues (%)	18	N/A	45.27%	N/A
Procurement duration (months)	18	N/A	26.27	N/A

Immediately after the game, participants had the opportunity to write general recommendations to government agencies based on the experiences described in the hypothetical case. Written comments are summarized as follows:

- Procurement of PPP generally depends on the type of project
- External advisors are most useful when agencies are not experienced in P3 delivery
- Clarification and review do not help if uncertainty is not reduced
- Utilize external services for projects where the governing agency is not familiar with
- Resource allocation depends on project complexity and experience of PPP in the area
- For projects which are more complex and involve high risks, external advisory services help to identify and mitigate risks in advance
- For projects which have minimal risks, resource allocation should be done for execution and review.
- Clarification and review is important but do not identify risks in advance

In the days following the simulation exercise, follow-up interviews allowed to closely examine participants' experiences and understanding of the concepts represented in the game. Comments can be grouped in four categories, as follows:

- Overall experience: six students argued that the activity *"was a nice [fun] experience"*. Four of them seemed to concur that "*it was nice to see how everything was related"*. In terms of the learning process, one participant asserted that *"I was surprised my assumptions sometimes can be wrong",* while others agreed that the exercise contributed toward learning about procurement and resource allocation *"through a different medium"*. One of them also complained about the difficulty of scenario 2.

- Strengths and weaknesses: participants highlighted the hypothetical nature of the model as a major weakness. Six users acknowledged that, although the game allowed to examination of basic concepts, it needed to include "*other conditions*" to be *"perfect"* or to be more *"accurate"* in relation to *"real projects"*. These conditions may involve *"political and economic factors"* not included in the current *"algorithm"*. *"More options within the scenarios"* are required so that the model *"could be fully utilized in any type of projects"*. In terms of the strengths of the exercise, five students highlighted the graphic interface as the most *"helpful"* feature in the simulator. Four participants recognized that the activity *"helped to recognize resource allocation difficulties"* in PPP procurement processes. One of them acknowledged that the activity contributed to improve his *"mental preparedness"* to analyze PPP tendering procedures.
- Conclusions about scenarios 1 and 2: all participants recognized that each scenario required a different allocation strategy. While scenario 1 needed *"execution"*, scenario 2 required *"external advisors"*. They agreed that this was because of the high *"confidence levels"* and *"experience"* in scenario 1. Three of them claimed that scenario 2 was different because of the *"uncertainty"*, *"risks"*, and *"complexity"*.
- Latent issues in PPP procurement: four participants recognized the role played by *"government experience"* and *"external advisors"* at the moment of reducing latent issues. They highlighted that *"if you do not have experience"*, *"you need expert advice to analyze risks"*. At the moment of comparing scenarios 1 and 2, they claimed that the first scenario *"was easy"* because *"government had experience"*; in the second one, government needs to rely on *"outside consultants"*.

4.13 Validity and Reliability

The model has been examined through the use of system dynamics methodologies (Forrester 1961; Sterman 2000). It has been generated by considering archival and institutional sources. All of the parameters and equations have a real-world meaning and have responded well when model inputs assume extreme values (Sterman 2000). To ensure structural validity, formulations have been built upon widely accepted structures such as the rework cycle (Lyneis and Ford 2007; Rahmandad and Hu 2010; Richardson and Pugh 1981) and capability dynamics (Rahmandad and Repenning 2015; Rahmandad and Weiss 2009; Repenning and Sterman 2002). Since these have been applied in domains related to project and construction management (Ford and Sterman 1998; Lee et al. 2005; Park and Peña Mora 2003), they were used for establishing endogenous relationships between major variables. Consequently, both the model and its components are able to respond logically and consistently to potential external variations.

Since model outputs reflect a hypothetical PPP tendering process, the web-based simulator was used to test the model's internal coherence. Before implementing the game, the simulator was piloted using graduate students from the fields of civil engineering and industrial engineering. This helped to ensure that model inputs (i.e. resource distribution decisions) were consistent with real allocation strategies. Also, it contributed to confirm that variables were exhibiting plausible values and model outputs were the result of adequate feedback relationships. Thanks to these processes, model reliability was strengthened and there were no complaints about the behavior of the model during the game implementation activity.

To ensure replicability in the simulation exercise, the game was implemented according to the multi-phased protocol described previously. Based on the use of pre- and post-simulation questionnaires, allocation decisions were compared through the Wilcoxon signed-rank test.

Additionally, participants' written comments and follow-up interviews offered the opportunity to examine the accomplishment of the proposed educational objectives. As a result, the authors confirmed that, for both scenarios, students were likely able to acknowledge the role played by local conditions; recognize the influence of government capacity, technical complexity and project uncertainty in PPP tendering; and be aware of the role of feedback processes in procurement decisions.

4.14 Discussion

Results suggest that, based on the scope and objectives of this study, the model does a good job in terms of capturing the basic behaviors of procurement-related variables in PPPs. Although the model is based on institutional and archival data, model outputs were able to show behaviors that were reasonably consistent with actual tendering processes. During the simulation exercise, for example, participants were able to successfully recognize that resource allocation decisions were not only directly associated with executing procurement tasks on time, but also strongly connected to the capacity of the regional agency and the uncertainty of the specific scenario.

Since participants had foundational understanding of PPP delivery mechanisms, results indicate that users recognized model behaviors and outputs as plausible effects of their allocation actions within the hypothetical case. In other words, results suggest that the model, the simulator (i.e. user interface), and the simulation exercise (i.e. multi-phased game activity) are intrinsically connected. The connection between these three elements can be better understood by examining if the objectives proposed for the exercise were accomplished or not, as discussed subsequently.

4.14.1 Effect of local conditions: scenarios 1 and 2

Before starting the simulation, the game instructions clearly indicated that scenario 1 involved a less uncertain project, low-complexity characteristics, and a more mature government agency than scenario 2. At the beginning of the simulation phase, however, some participants were surprised because they were not able to solve scenario 2 in the first run, despite successfully completing scenario 1 during the first run. While all participants were able to achieve 100% completion for scenario 1 during their first run, they could not do the same for scenario 2. This made them realize that a different approach was required. They acknowledged that it was necessary to change their initial assumptions about scenario 2.

Figure 4-11 depicts the number of simulation runs completed for both scenarios across eight periods (i.e. 5 minute intervals) within the simulation stage. As shown, participants were mostly focused on scenario 1 during the first two intervals (i.e. first 10 minutes of the activity). Subsequently, users started to focus on scenario 2 between the third and eighth periods. The percentage of runs for the second case increased from 0% in the first period to around 88% in the last interval. Clearly, students began their simulation experience by executing scenario 1 and were certainly able to complete it for the first time before the fourth period. By this time, most participants were playing with scenario 2.

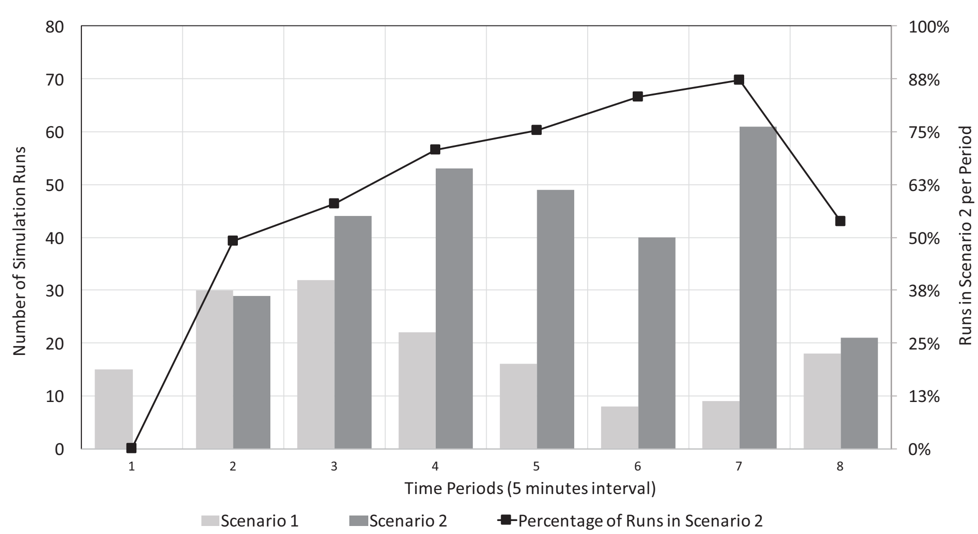


Figure 4-11. Simulations in scenarios 1 and 2

By period four, some of the participants commented about the difficulty of scenario 2. Figure 4-12 shows that, during the first half of the activity, users had conducted more than 100 runs with a success rate of less than 10%. At this point, most of them started to change their resource allocation strategy. This increased their completion success rate to levels of 70% and 65% in the last two periods. These results indicate that students were able to differentiate the two scenarios under study. Interviews and written comments confirm it (i.e. *if you do not have experience"*, *"you need expert advice to analyze risks"). Clearly,* they were able to fully recognize the local conditions described for both projects and decided to implement different approaches to complete them.

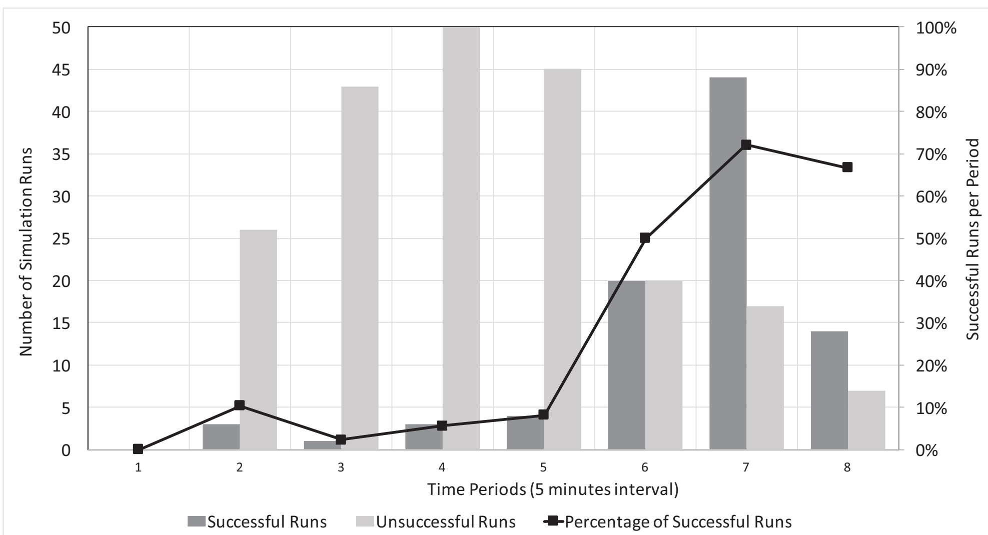


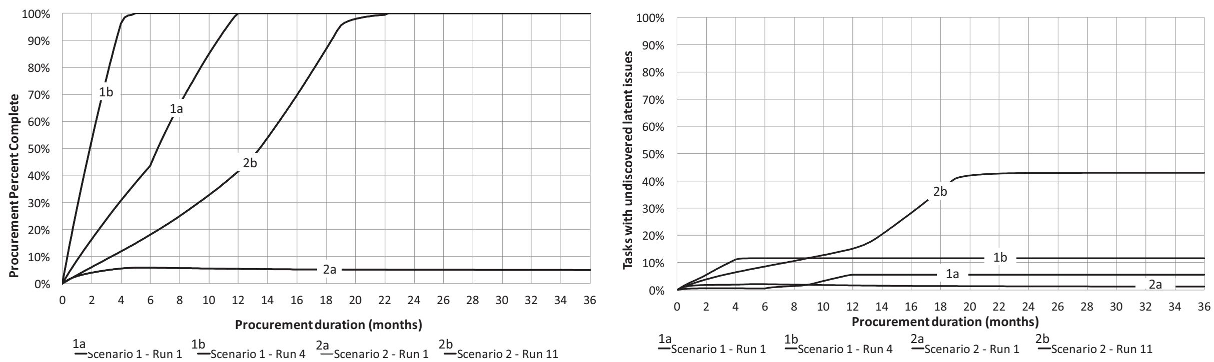
Figure 4-12. Completion rate in scenario 2

4.14.2 Effect of government capacity and project uncertainty

Understanding the relationship between capacity, complexity, and uncertainty was a crucial step towards successfully completing scenarios 1 and 2. Once participants were able to recognize the differences between the proposed PPP projects, they had to figure out how to address project uncertainty and complexity with the available resources. This required finding a balance between the proportions assigned to procurement execution, external advisory services, and clarification and review. Based on the way participants conducted their simulations runs (Figure 4-11 and Figure 4-12), it is clear that finding such a balance proved to be more difficult in scenario 2.

Based on the follow-up interviews, students' written comments, and simulation runs, participants tried to allocate their resources by relying on specific model outputs. The most important outputs for them were *procurement percent complete* and *tasks with undiscovered latent issues*. By observing the behavior of these two variables, students were able to adjust their resource allocation decisions. In scenario 1, students observed that they were able to achieve 100% completion and reduce undiscovered latent issues with multiple combinations of resource proportions. In scenario 2, however, the experience was different because not all combinations were effective and it was difficult to reduce the amount of latent issues.

Figure 4-13 provides a graphical example of how one of the participants attempted to complete the two scenarios. In both graphs, curves 1a and 2a represent the participant's first runs in scenarios 1 and 2, respectively. While able to complete scenario 1 in around 12 months with less than 10% of tasks with latent issues, the student could not even achieve 10% completion in scenario 2. Subsequently, the student improved the procurement duration of scenario 1 to around five months with a small change in level of undiscovered issues (curves 1b in the graphs). However, the student could not do the same in the other scenario. Although the student finished the procurement process in about 22 months (curves 2b in the graphs), the student did so without discovering latent issues in more than 40% of the tasks.

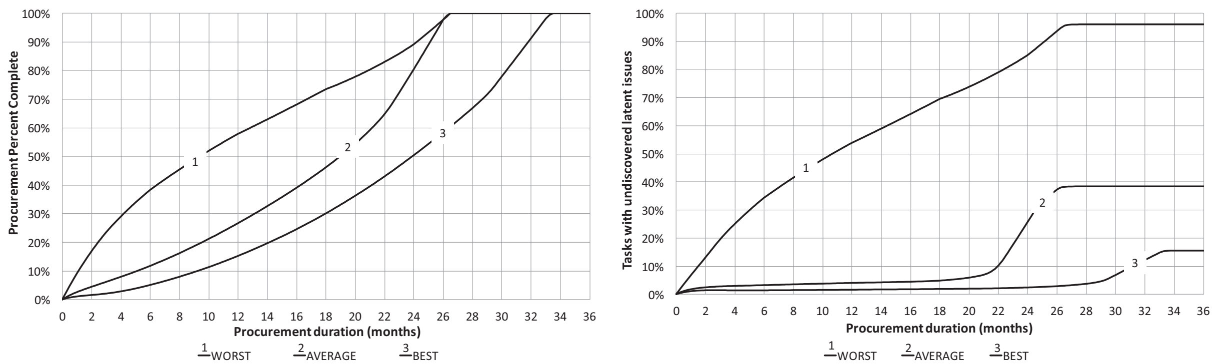


(a) **(b)**

Figure 4-13. Example of simulation runs: (a) procurement percent complete; (b) tasks with undiscovered latent issues

The search for suitable allocation strategies in scenario 2 led participants to try multiple alternatives in their decision-making process. According to their written comments and interviews, the uncertainty of the scenario made them realize that they needed to increase the capacity (i.e. hire "outside consultants") because *"if you do not have experience"*, *"you need expert advice to analyze risks"*. However, they also recognized that although advisory services were important to mitigate uncertainty and deal with complexity, completion could not be achieved without execution and clarification resources.

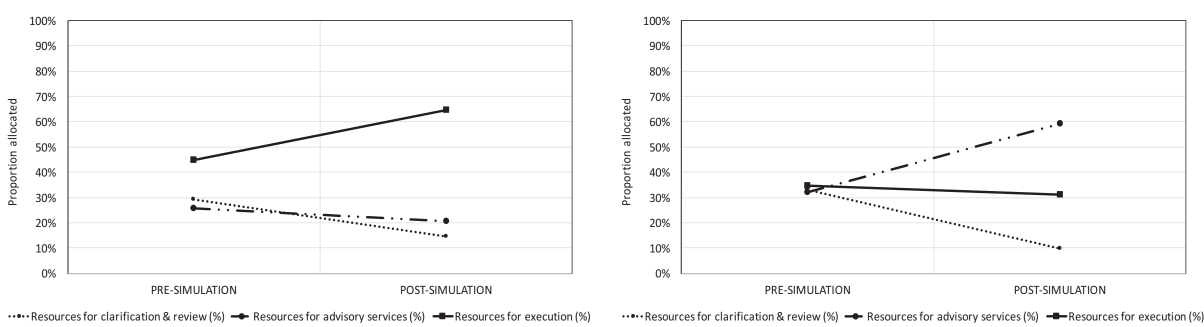
As an example of how participants sought to reach an adequate balance between capacity and uncertainty, Figure 4-14 depicts the best, the worst, and the mean simulations in scenario 2. As observed in curve 1, the tendering process can be completed in about 26.5 months. However, if there are not enough resources allocated for conducting clarification and hiring external advisors, the amount of tasks with latent issues will be high. In this way, curves 2 and 3 show how uncertainty and complexity can be addressed by prioritizing external advisory services over the two other resources (i.e. increasing capacity). The main difference between these two curves, as a result, is that the former prioritizes execution over clarification, while the latter does the opposite.



(a) (b)

Figure 4-14. Selected simulation runs: (a) procurement percent complete; (b) tasks with undiscovered latent issues

On average, as shown in Figure 4-15, it is clear that participants understood the relationship between capacity, complexity, and uncertainty. In scenario 1, they allocated more resources to execution because the government agency had enough capacity to manage the project mostly by itself. Although external advisory services were helpful, they were not the priority at the moment of distributing resources. On the other hand, in scenario 2, students assigned more resources to external consultants because the government agency needed more capacity to deal with a highly complex and uncertain project. In this way, consultants helped to reduce latent issues and improve productivity in execution.



(a) (b)

Figure 4-15. Mean resource allocation percentages: (a) Scenario 1; (b) Scenario 2

4.15 Conclusions

This study examines decision-making dynamics associated with PPP procurement processes. The simulation model shows how standard system dynamics formulations were able to portray causal relationships among variables related to government capacity, technical complexity, and project uncertainty. The management flight simulator has proven to be a useful application of the model because it reasonably reflected how procurement-related variables are affected by different project conditions and government capabilities. Both the model and the simulator have been implemented in a game activity that has been helpful to illustrate the difficulties associated with enhancing PPP tendering. Results show that users conducted a series of simulations that enabled them to recognize how local conditions have a direct effect on the way procurement processes are developed. Also, simulations have contributed to communicate why government capacity is paramount in terms of dealing with complex and uncertain conditions.

Simulation results showed that the game activity helped students to acknowledge that procurement processes are highly affected by project conditions and government capacity. At the beginning of the game, resource allocation strategies between scenario 1 and 2 were not very different despite their dissimilar conditions. At the end of the exercise, it was clear that while scenario 1 could be completed by emphasizing execution activities, scenario 2 required more external advisory services to cope with its complex and uncertain conditions. This suggests that, when capable agencies are in charge of low-complexity projects (i.e. scenario 1), the public authority is able to efficiently increase productivity levels and rapidly complete procurement processes without significantly increasing undiscovered latent issues (i.e. loop 2a). On the other hand, for low-capacity agencies (i.e. scenario 2), the dependence on external consultants indicates a necessity to increase capacity in order to address complexity and mitigate uncertainty. In this way, low-capacity governments are able expedite completion and decrease the amount of undiscovered latent issues (i.e. loop 3a).

Simulation results also indicated that resources for clarification and review were not prioritized in either scenario. Although these activities were recognized as important to discover and solve latent issues, they were also acknowledged to delay procurement completion because clarifying and reviewing tasks demanded more time and increased work to do. This suggests that loops B2, R4a, and R4b did not play a major role in the simulations. In scenario 1, the procurement process was not sufficiently complex and uncertain to spend resources in such loops. In scenario 2, in contrast, clarification and review were helpful to discover latent issues, but did not help to decrease the procurement duration. As a result, it is more efficient to mitigate uncertainty and complexity through increasing capacity.

The current work contributes to the literature in various ways. First, this study provides a system dynamics model and a management flight simulator to better understand decision-making in PPP tendering. Although several scholars have studied similar topics in the past, it is difficult to find investigations focused on simulating socio-technical issues in civil engineering projects. Second, the game activity is a pedagogical exercise that constitutes a start towards overcoming the learning barriers hindering improvement in tendering processes. This proved to be a useful way to recognize feedback effects and nonlinearities in procurement-related variables. The game, therefore, is a first step towards filling the educational gap within the PPP domain. Third, the model and the management flight simulator highlight the importance of analyzing complex socio-technical phenomena through small models in a graphical and interactive way. Consequently, scholars are able to be more focused on the phenomenon than on the intricacies of the simulation model.

This investigation has several implications in fields related to engineering management and public policy. Because the flight simulator is a user-friendly and interactive instrument that produces graphic results for many different allocation strategies, it can become a decision-making tool with additional studies. It can help policymakers and practitioners to design better policies or approaches towards improving PPP procurement and PPP delivery in general. Also, by showing that project complexities and uncertainties can be addressed with adequate procurement strategies, opponents and skeptical stakeholders can be persuaded in a more effective way. On the other hand, with supplementary future research, the model can incorporate more procurement-related variables and provide a more comprehensive reproduction of PPP tendering procedures. Thus, a more inclusive simulator can be designed in order to improve learning about PPP governance.

This study also offers several avenues for future research. Further investigations can focus on expanding the simulation model. This can be enlarged by incorporating variables related to other stakeholders participating in the procurement process (i.e. general public, advocacy agencies, amongst others). A more comprehensive model would help to understand more feedback loops associated with PPP tendering. Additionally, taking into account the similarities between public-private initiatives and megaprojects, future studies can examine how to apply both the model and the simulator into different project delivery methodologies. In this way, comparisons between PPPs and traditional delivery methods could be explored.

Despite the implications and future research avenues, this investigation is limited in many ways. As stated previously, the model represents a generic PPP procurement process and the flight simulator is based on a hypothetical case study. More research is required in order to incorporate real data into the model and analyze specific real-world situations through the simulator. Also, although the model and the simulator have proven to be a good tool for enhancing awareness of the difficulties related to PPP tendering, it is not possible to claim with sufficient confidence that they effectively improve learning about PPPs. In order to do so, additional educational experiments need to be conducted with more participants and in different contexts.

4.16 Acknowledgements

This material is based upon work supported by the US National Science Foundation under Grant No. 1333264. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the US National Science Foundation.

4.17 Supplemental Data

The system dynamics equations (S69-S195) of the model described in this paper are available in Appendix D.

5. CHAPTER 5: CONCLUSIONS

5.1 Summary of Findings

In my first manuscript (Chapter 2), I found that the dynamics of capital investments and maintenance expenditures in the US highway system are associated with proactive and reactive practices. If governments incentivize proactive asset management policies in their roads, system conditions improve and rehabilitation expenditures decrease in the long-term. However, if reactive practices dominate, public agencies have to spend more resources in repairing their roads. This constrains the amount of funds oriented towards proactive measures, increases the deferred maintenance backlog, and raises the cost of preventing future system failures. Consequently, in order to obtain sustained improvements in their highway systems, governments should prioritize proactive measures over reactive actions.

Results show that balancing proactive and reactive maintenance policies is not a simple task. In the US, federal and state governments have been unable to substantially promote preventive practices over rehabilitation measures. By building a system dynamics model and conducting a counterfactual analysis between 1994 and 2010, I showed that this is because the US highway system is stuck in a capability trap. This means that public agencies are not able to prioritize proactive policies because they are focused on implementing rehabilitation improvements to cope with the increasing deterioration in the system.

To further examine the capability trap phenomenon, I studied three different policies (i.e. promote maintenance, promote rehabilitation, and combine maintenance and rehabilitation). My conclusion from this analysis was that the US highway system could have been in a much better state in 2010 if governments had effectively prioritized proactive efforts. Although, based on the simulation results, reactive efforts could have generated some benefits to the system, there is no doubt that promoting maintenance would have allowed policymakers to enhance system condition more rapidly, reduce long-term deterioration, and free up resources for capacity expansion. Since the analysis was counterfactual and proactive policies have not been implemented, the US highway system is currently trapped. Metaphorically, the system is clearly not sinking, but it is not moving forward either.

In my second paper (Chapter 3), I analyzed real-world cases from 37 archival publications, implementing a grounded theory approach. I highlighted interdependencies and interactions of governance variables within the shaping phase of PPPs. Such relationships were categorized in three different groups: socio-political, financial, and operational. Also, I examined how four different governance challenges (i.e. lack of socio-political legitimacy, uncertainty, opportunism, and displaced agency) played a crucial role in the development of such interactions. Subsequently, I generated a systems map in order to analyze both governance variables and their associated challenges.

The systems map helped me to explore the challenges of shaping PPPs in a clear and succinct way. My analysis suggested that there is not a simple recipe for success in public-private agreements. However, what is really important in these initiatives is to obtain positive outcomes as early as possible in the project lifecycle. For example, I showed that if operational feasibility is not high enough at the beginning of a project, it starts to become increasingly difficult to attract private sector partners. If this happens, securing financial and funding resources might be jeopardized. Likewise, I also argued that having adequate levels of socio-political feasibility at the front-end of the shaping phase helps to achieve better operational and financial feasibilities early in the project.

Based on the analyzed project cases, results indicated that feedback mechanisms played an important role in terms of understanding how governance variables were affected by multiple implementation challenges in such experiences. The developed systems map comprised eight main feedback structures, six reinforcing loops and two balancing mechanisms. Among these, the two most important variables (i.e. parameters involved in the highest number of loops and with the highest number of references) were *government capacity* and *project attractiveness.* The former proved pivotal in dealing with socio-political legitimacy and opportunism issues. The latter was fundamental to control uncertainty and displaced agency problems.

In my third paper (Chapter 4), I used the concept of *government capacity* from Chapter 3 and focused on understanding how the capacity of public agencies in charge of procurement processes affects PPP development. I built a system dynamics model, generated a management flight simulator, and developed a game activity to gain insight into decision-making dynamics of PPP procurement processes. I showed that traditional system dynamics formulations were able to characterize PPP tendering procedures. In the same way, the simulator helped me to better communicate and explain the feedback mechanisms associated with procuring public-private agreements. I showed a way to explain how procurement variables are highly affected by project conditions and government capacity. As a result, the game contributed to confirm the internal coherence of the model and the usefulness of the simulator.

The system dynamics model and the management flight simulator helped me to better explain procurement dynamics associated with allocating resources for execution, external advisors, and clarification and review. In the game, participants were able to recognize how allocation strategies were affected by project uncertainty and technical complexity. Students acknowledged that for projects conducted in low-uncertainty and low-complexity environments, capable government agencies can prioritize execution over the other resources because of their experience and maturity. On other hand, participants also confirmed that for procurement processes in uncertain and complex settings, high-capacity agencies are quite necessary to successfully complete tendering procedures. If administrations do not have the required skills, the amount of undiscovered latent issues at procurement completion is likely to be high.

Overall, the model, the simulator, and the game contribute to improve the educational efforts required to increase our understanding of PPP development. They are useful tools because governance and PPPs are two concepts that have been widely discussed in academic publications, but not highly understood by policymakers and the general public. The whole educational exercise, therefore, was designed to show how governance variables affect the development of procurement processes. Results indicate that, although there is still room for improvement, my attempt to better communicate the influence of governance in public-private agreements was fruitful. This is because participants clearly recognized that there is not one-size-fits-all solution and acknowledged the crucial role that governance variables (e.g. government capacity, project uncertainty, and technical complexity) play in achieving successful PPP procurement processes.

5.2 Contributions and Implications

In general, this dissertation contributes to our understanding of the difficulties associated with closing the infrastructure gap in the highway sector. By implementing a socio-technical approach and adopting system dynamics methodologies, I have studied the phenomenon of the capability trap and the implementation of governance concepts in PPPs. The former offers opportunities for improving existing assets and the latter contributes to enhance PPP development and expand road network capacity. Specific contributions and implications for practice are discussed below.

5.2.1 Improving existing highway assets

Manuscript 1 provides contributions to the literature in various ways. It offers a new way of understanding the barriers to improve system conditions in highway networks. By analyzing the US highway network as a dynamic system, the paper introduces the capability trap phenomenon. It argues that feedback mechanisms associated with proactive and reactive maintenance policies need to be adequately controlled in order to enhance road quality. This is an innovative approach in construction management and civil engineering domains. Rather than analyzing how to optimize asset management practices (Brunetto et al. 2014; Fallah-Fini et al. 2010; 2015; la Garza et al. 2011; van Buiten and Hartmann 2015), the paper focuses on explaining the reasons why many of these practices fail (i.e. the capability trap in the highway system). Additionally, instead of studying road deterioration as a sequential process in which maintenance efforts are required at certain periods of time (Ahmed et al. 2013; Jiang et al. 2016; Lai 2010; Ng and Wong 2006; Ozbek et al. 2010), the work examines decreasing road quality conditions through a cyclical approach. By doing so, it incorporates the effects of deferred maintenance and the potential future impacts of current policies.

In this manuscript, I have also developed a model that is helpful to understand capital investment dynamics and highway policies. With the help of further studies, the model can be transformed into a management flight simulator focused on explaining how to analyze expenditures associated with highway systems from a dynamic perspective. In this way, policymakers will have the opportunity to graphically examine how maintenance and rehabilitation policies interact. More importantly, they will be able to explore how deferred maintenance contributes to limit capacity expansion in the long-term. As a result, the model is a simulation tool that can be employed to illustrate the impact of strategic decisions directed towards improving quality conditions in highway systems.

Additionally, both the model and the concept of the capability trap can contribute to other domains and literatures. By developing similar investigations, they can be used to examine other sectors, such as building construction , transit infrastructures, and water services (Li et al. 2012; Lyneis and Sterman 2015; Rehan 2011; Rehan et al. 2013; Yuan et al. 2010). This will require the model to be more flexible, but it will allow improving our understanding about how to close the infrastructure gap beyond the road infrastructure sector. All of this is possible because system dynamics is a methodology that is useful to analyze socio-technical systems. Ultimately, the entire infrastructure sector is a collection of technical, socio-political, and economic variables.

5.2.2 Implementing governance concepts in PPPs

In my second and third manuscripts, I gained insight into the challenges of implementing governance concepts in public-private agreements. The systems map generated in my second paper is a first step towards analyzing PPP governance from an integrated perspective. So far, there is little evidence that scholars have studied PPP governance variables by fully considering their interactions in real-world cases (Henisz 2006; Henisz et al. 2012; Levitt et al. 2010; 2014). Accordingly, the map has contributed not only to establish relationships between multiple governance concepts, but it also shows how governance affects the feasibility of real-world PPPs. By doing so, the map has defined implementation challenges as a collection of variables linked through causal relationships. This has facilitated our understanding of the way governance concepts impact PPP development. For example, the map is able to illustrate how mature and skillful government agencies (i.e. with high levels of government capacity) are able to reduce *opportunism* and increase *operational feasibility* (i.e. how viable the project is, in terms of achieving the desired operational goals).

My third paper has also contributed to the literature in various ways. The system dynamics model provides the opportunity to analyze procurement processes as a group of tasks affected by nonlinearities and feedback complexity. This is an important contribution to the current literature because most of the investigations in the field examine PPP tendering as a collection of sequential activities not affected by feedback mechanisms (Ahadzi and Bowles 2004; Kwak et al. 2009; Liu et al. 2016; Zhang and Kumaraswamy 2001a). Correspondingly, the management flight simulator and the game activity show how an internally coherent simulation model can be used to explain PPP governance concepts to civil engineering students. This is not very common in PPP-related scholarly publications; researchers in this field have not employed simulation models to examine socio-technical concepts (Jooste and Scott 2012; Jooste et al. 2011).

With respect to implications for practice, my second study provides a clear and concise systems map through which the shaping phase of public-private projects can be analyzed. The map highlights that the two most important governance variables within the shaping phase are government capacity and project attractiveness. Public agencies, therefore, should primarily focus on reinforcing these two parameters.

Strengthening government capacity means that, in order to develop viable PPP projects, public agencies should improve their abilities to develop public-private agreements (Garvin 2010). They can do so by implementing educational and training programs for their employees and hiring external advisors to complement their skills (Kwak et al. 2009; Reeves et al. 2016). On the other hand, project attractiveness implies that governments should establish clear fiscal support mechanisms (Grubišić Šeba et al. 2014), promote transparent negotiation processes (Hood et al. 2006), and avoid opportunistic behaviors (Ho et al. 2015).

The map also provides information about how governance variables are connected with other PPP parameters. The map emphasizes that such relationships are governed by multiple feedback mechanisms that affect system behavior through time. As a result, this conceptual instrument can be particularly useful to other scholars and policymakers because it describes how governance challenges impact PPP development during the shaping phase.

In line with the implications related to the second paper, my third manuscript describes the development of a management flight simulator to examine PPP procurement processes. Based on a user-friendly graphic interface and a system dynamics model, the simulator is likely to become a useful tool to examine governance variables in PPP projects. Policymakers, academics, and practitioners are potential users of the simulator because it can help them to better understand how project complexities and uncertainties affect decision-making policies in PPP tendering (Liu et al. 2016; Reeves et al. 2016; Soliño and Gago de Santos 2016). Also, with the help of further investigations, the simulator can be expanded in order to incorporate more procurement variables. This will enable the model, for example, to be more realistic and simulate PPP tendering through different phases (i.e. pre-qualification of bidders, selection of preferred proponent, contract award, negotiation, and financial close). This will contribute towards using the simulator as a pedagogical tool to persuade early and late majority groups within the PPP field.

5.3 Future Research

This dissertation increased our understanding about how to close the road infrastructure gap. It included studies focused on improving the existing highway stock and on enhancing the development of more roads through PPPs. Although this investigation has offered valuable insights, it is, however, only the starting point of additional studies focused on analyzing the road infrastructure sector from a socio-technical perspective. Three avenues for future research are described.

5.3.1 The road infrastructure sector as a socio-technical system

The system dynamics models generated in this dissertation have allowed me to explore maintenance and development practices. However, these models can be further expanded in order to incorporate more variables, be more realistic, and capture other important feedback dynamics. Also, new models can be created in order to explain related phenomena that have not been targeted by the simulations presented in this dissertation.

In terms of expanding the existing models, further studies can complement the model presented in my first manuscript. Since this model did not incorporate data related to economic growth and traffic volume, future investigations can explore how increasing economic levels and high traffic counts affect maintenance and rehabilitation dynamics in the US highway system. In addition, further studies are needed to examine how these variables impact the capability trap phenomenon in which the system is stuck. Also, future investigations can incorporate variables related to highway revenues generated from gas- and vehicle-related taxes. This will help to explore the amount, timing, and duration of the investments required to get the US highway system out of the trap.

The model presented in my first paper can also be expanded to study different contexts and sectors. Further investigations can focus on identifying trapped systems in sectors related to transportation, energy, or water systems worldwide. In the US and other countries, for example, transit systems are usually affected by issues related to deferred maintenance and low capital investments (Lyneis and Sterman 2015; World Economic Forum 2014). This suggests that such systems are likely experiencing the capability trap phenomenon (Lyneis and Sterman 2015; Rahmandad and Repenning 2015; Repenning and Sterman 2002). As a result, studies about these topics are feasible in the short-term because formulations supporting system dynamics models are neither exclusive to the highway sector nor limited to US experience.

In the same way, the procurement model presented in my third paper can be expanded by incorporating variables and feedback loops from my second article. For example, socio-political variables can be incorporated in order to analyze how these parameters strengthen or weaken project legitimacy. This will provide opportunities to further examine how such variables can modify the way PPP tendering procedures are conducted. On the other hand, the current formulations can also be expanded through including variables related to securing funding and assembling financial packages. Since these are two crucial processes for reaching commercial and financial close (Eno Center for Transportation 2014; Yuan et al. 2009), their incorporation is an opportunity to explore how financial issues influence procurement performance .

In the long-term, new models focused on closing the road infrastructure gap can be generated. They can be created by joining some of the formulations utilized in the first and third manuscripts. Investigations can explore ways to incorporate variables across all the lifecycle stages of PPP projects. For example, further studies could be directed towards comparing the benefits of public-private agreements versus conducting traditional public procurement projects. They can recreate the behavior of governance variables in order to explore under what conditions public-private agreements are poised to generate value for money.

5.3.2 Education in the road infrastructure sector

Throughout this dissertation, I have recognized the importance of improving our understanding of issues related to reducing the infrastructure gap. I have proposed that the concepts of dynamic systems and governance can be used by policymakers, practitioners, and academics in order to find suitable ways to enhance the road infrastructure sector. However, I am aware that it is not easy to change the way that socio-technical systems behave. Therefore, I believe that education is a good tool not only to enhance awareness of the concepts examined in this dissertation, but also to improve learning processes and skills of all the different stakeholders involved in or interested in the sector.

Although in my third manuscript I made some specific steps towards enhancing educational efforts in the road infrastructure sector, there is plenty of room for improvement. From an educational perspective, I am interested in analyzing if my management flight simulator is able to markedly improve learning about PPP governance in procurement processes. My goal, therefore, is to generate a pedagogical tool capable of enhancing understanding of governance concepts in PPP tendering. In the short-term, I intend to collect new data by conducting an additional experiment with engineering students who have little to no knowledge of PPP development. I expect to analyze this new dataset by putting more emphasis on how students recognize that project conditions and government capacity affect procurement completion. I plan to generate learning curves by taking into account the number of trials per student, their scores, and their answers to the open-ended questions before and after the exercise. Subsequently, I expect to conduct more educational experiments in order to refine the management flight simulator and produce a simulation tool capable of improving learning about the complexities and uncertainties of PPPs.

In the long-term, further studies are required in order to adjust the management flight simulator to the specific needs of policymakers and industry practitioners. In the future, investigations should incorporate both qualitative and quantitative data directly from real projects. It will be necessary to conduct interviews with project participants and conduct group model building workshops. In this way, both the model and the simulator will increase their robustness by incorporating the variables and behaviors of interest to public and private stakeholders.

The capability trap model can also be transformed into a management flight simulator. Further studies can complement this model to create an educational tool focused on explaining the dynamics associated with the funding gap (i.e. difference between expenditures and revenues) of infrastructure systems. In many countries around the world, this is a problem that policymakers seem not to fully understand (Carpintero and Barcham 2012; Gomez and Vassallo 2014; World Economic Forum 2014). For such reasons, future investigations can focus on depicting how the capability trap phenomenon is related with the lack of improvements within infrastructure systems. This will help policymakers to better understand the impact of their decisions and, in the long-term, contribute to close the global infrastructure gap.

Overall, future studies have the opportunity to expand the current work by adopting a socio-technical approach in their analyses. Further investigations can exploit the governance interdependencies highlighted in this dissertation and simulate them through system dynamics methodologies. Consequently, our understanding about the road infrastructure sector, public-private agreements, and the entire infrastructure domain can be strengthened. In the long-term, I expect that this will contribute to better living conditions and a higher quality of life worldwide.

REFERENCES

Abdel Aziz, A. M. (2007). "A survey of the payment mechanisms for transportation DBFO projects in British Columbia." *Construction Management and Economics*, 25(5), 529–543.

Abdel-Aziz, A. M., and Russell, A. D. (2001). "A structure for government requirements in public–private partnerships." *Canadian Journal of Civil Engineering*, 28(6), 891–909.

Ackermann, F., and Alexander, J. (2016). "Researching complex projects: Using causal mapping to take a systems perspective." *International Journal of Project Management*, Elsevier Ltd and Association for Project Management and the International Project Management Association, 34(6), 891–901.

Ahadzi, M., and Bowles, G. (2004). "Public–private partnerships and contract negotiations: an empirical study." *Construction Management and Economics*, 22(9), 967–978.

Ahmed, A., Labi, S., Li, Z., and Shields, T. (2013). "Aggregate and disaggregate statistical evaluation of the performance-based effectiveness of long-term pavement performance specific pavement study-5 (LTPP SPS-5) flexible pavement rehabilitation treatments." *Structure and Infrastructure Engineering*, 9(2), 172–187.

Ahola, T., Ruuska, I., Artto, K., and Kujala, J. (2014). "What is project governance and what are its origins?." *International Journal of Project Management*, Elsevier Ltd and International Project Management Association, 32(8), 1321–1332.

Al-Sharif, F., and Kaka, A. (2004). "PFI/PPP topic coverage in construction journals." *Proceedings of the 20th ARCOM Conference*, Edinburgh, Scotland, 711–719.

Andres, L., Biller, D., and Herrera Dappe, M. (2014). "Infrastructure Gap in South Asia: infrastructure needs, prioritization, and financing." *World Bank*, <https://openknowledge.worldbank.org/handle/10986/20327> (Apr. 8, 2017).

Arif, F., Bayraktar, M. E., and Chowdhury, A. G. (2016). "Decision Support Framework for Infrastructure Maintenance Investment Decision Making." *Journal of Management in Engineering*, 32(1), 04015030–15.

ASCE. (2009). "The Future of National Surface Transportation Policy." *Testimony before the U.S. Senate Committee on Commerce, Science and transportation*, Washington, DC, 1–83.

ASCE. (2011). *Failure to Act: The Impact of Current Infrastructure Investment on America's Future Economy*. American Society of Civil Engineers (ASCE), Reston, V.A., U.S., 1–40.

ASCE. (2013). "Report Card for America's Infrastructure." Washington, DC, <http:// www.infrastructurereportcard.org> (Dec. 10, 2015).

Asenova, D., and Hood, J. (2006). "PFI and the implications of introducing new long-term actors into public service delivery." *Public Policy and Administration*, 21(4), 23–41.

Asphalt Industry Alliance. (2016). "Annual Local Authority Road Maintenance Survey." *Asphalt Industry Alliance*, <http://www.asphaltuk.org/alarm-survey-page/> (Apr. 1, 2017).

Aziz, A. A. (2007). "Successful delivery of public-private partnerships for infrastructure development." *Journal of Construction Engineering and …*, 133(12), 918–931.

Bakken, B., Gould, J., and Kim, D. (1992). "Experimentation in learning organizations: A management flight simulator approach." *European Journal of Operational Research*, 59, 167–182.

Barker, M. (1984). *Rebuilding America's Infrastructure" an agenda for the 1980's*. Duke University Press, Durham, NC.

Bayliss, D. (2015). *The Condition of England's Local Roads and how they are Funded*. RAC

Foundation, London, UK, 1–52.
Biller, D., Andres, L., and Herrera Dappe, M. (2014). "Infrastructure Gap in South Asia: inequality of access to infrastructure services." *World Bank*, <https://openknowledge.worldbank.org/handle/10986/20344> (Apr. 8, 2017).
Boardman, A., and Vining, A. (2012). "THE POLITICAL ECONOMY OF PUBLICPRIVATE PARTNERSHIPS AND ANALYSIS OF THEIR SOCIAL VALUE." *Annals of Public and Cooperative Economics*, 1–25.
Brown, J., Pieplow, R., Driskell, R., Gaj, S., Garvin, M., Holcombe, D., Saunders, M., Seiders, J., and Smith, A. (2009). *Public-Private Partnerships for Highway Infrastructure: Capitalizing on International Experience. Office of International Programs, Federal Highway Administration*, Washington, D.C., 1–92.
Brunetto, Y., Xerri, M., and Nelson, S. (2014). "Building a Proactive, Engagement Culture in Asset Management Organizations." *Journal of Management in Engineering*, 30(4), 04014014–9.
Bunch, B. (2012). "Preserving the Public Interest in Highway Public–Private Partnerships: A Case Study of the State of Texas." *Public Budgeting Finance*, 1–22.
Caldwell, N. D., Roehrich, J. K., and Davies, A. C. (2009). "Procuring complex performance in construction: London Heathrow Terminal 5 and a Private Finance Initiative hospital." *Journal of Purchasing and Supply Management*, 15(3), 178–186.
Caniëls, M. C. J., Gelderman, C. J., and Vermeulen, N. P. (2012). "The interplay of governance mechanisms in complex procurement projects." *Journal of Purchasing and Supply Management*, 18(2), 113–121.
Cantarelli, C. C., Flyvbjerg, B., and Molin, E. (2010). "Cost overruns in large-scale transportation infrastructure projects: explanations and their theoretical embeddedness." *European Journal of Transport and Infrastructure Research*, 10(1), 5–18.
Carpintero, S., and Barcham, R. (2012). "Private toll roads: lessons from Latin America." Singapore, 98–102.
Carpintero, S., Vassallo, J. M., and Soliño, A. S. (2014). "Dealing with Traffic Risk in Latin American Toll Roads." *Journal of Management in Engineering*, 31(2), 05014016–05014010.
Carrillo, P., Robinson, H., Foale, P., and Anumba, C. (2008). "Participation, barriers, and opportunities in PFI: the United Kingdom experience." *Journal of Management in Engineering*.
Chan, A., Lam, P., and Chan, D. (2010). "Critical success factors for PPPs in infrastructure developments: Chinese perspective." *Journal of Construction Engineering and Management*, 136(5), 484–494.
Chi, C., Ruuska, I., and Guangbin, W. (2013). "Identifying Governance Challenges of Sustainable Infrastructure." *Proceedings of EPOC 2014 conference*.
Chung, D., and Hensher, D. (2015). "Risk Management in Public-Private Partnerships." *Australian Accounting Review*, 25(1), 13–27.
Chung, D., Hensher, D. A., and Rose, J. M. (2010). "Toward the betterment of risk allocation: Investigating risk perceptions of Australian stakeholder groups to public-private-partnership tollroad projects." *Research in Transportation Economics*, 30(1), 43–58.
Coase, R. H. (1937). "The nature of the firm." *Economica*, 4(16), 386–405.
Congressional Budget Office. (1988). *New Directions for the Nation's Public Works*. Congress of the United States, 1–166.
Cruz, C. O., and Marques, R. C. (2013a). "Flexible contracts to cope with uncertainty in public–

private partnerships." *International Journal of Project Management*, 31(3), 473–483.
Cruz, C. O., and Marques, R. C. (2013b). "Exogenous Determinants for Renegotiating Public Infrastructure Concessions: Evidence from Portugal." *Journal of Construction Engineering and …*, 139(9), 1082–1090.
Cruz, C. O., Marques, R. C., and Cardoso, P. (2015). "Empirical Evidence for Renegotiation of PPP Contracts in the Road Sector." *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 7(2), 05014003–9.
Daito, N., Chen, Z., Gifford, J. L., Porter, T., and Gudgel, J. E. (2013). "Implementing public private partnerships during challenging economic times: Case study of the 495 Express Lanes on the Virginia portion of the Washington Capital Beltway Project (USA)." *Case Studies on Transport Policy*, World Conference on Transport Research Society, 1(1-2), 35–45.
Debande, O. (2002). "Private Financing of Transport Infrastructure: an assessment of the UK experience." *Journal of Transport Economics and Policy*, 1–33.
DeCorla-Souza, P., Mayer, J., Jette, A., and Buxbaum, J. (2013). "Key Considerations for States Seeking to Implement Public-Private Partnerships for New Highway Capacity." *Transportation Research Record: Journal of the Transportation Research Board*, 2346(-1), 23–31.
Dornan, D. L. (2002). "Asset management: remedy for addressing the fiscal challenges facing highway infrastructure." *International Journal of Transport Management*.
Doyle, J. K., and Ford, D. N. (1998). "Mental models concepts for system dynamics research." *System Dynamics Review*, 14(1), 3–29.
Edkins, A., and Smyth, H. (2005). "Contractual Management in PPP Projects: Evaluation of Legal versus Relational Contracting for Service Delivery." *Journal of Professional Issues in Engineering Education and Practice*, 1–12.
El-Gohary, N. M., Osman, H., and El-Diraby, T. E. (2006). "Stakeholder management for public private partnerships." *International Journal of Project Management*, 24(7), 595–604.
Eno Center for Transportation. (2014). "Partnership Financing: improving transportation infrastructure through public private partnerships." Eno Center for Transportation, <https://www.enotrans.org/etl-material/partnership-financing-improving-transportation-infrastructure-through-public-private-partnerships/> (Feb. 3, 2016).
Fallah-Fini, S., Rahmandad, H., Triantis, K., and la Garza, De, J. M. (2010). "Optimizing highway maintenance operations: dynamic considerations." *System Dynamics Review*, 26(3), 216–238.
Fallah-Fini, S., Triantis, K., Rahmandad, H., and la Garza, De, J. M. (2015). "Measuring dynamic efficiency of highway maintenance operations." Elsevier, 50(C), 18–28.
FHWA. (1999). *1999 Status of the Nation's Highways, Bridges, and Transit: conditions and performance*. Washington, DC, USA.
FHWA. (2002). *2002 Status of the Nation's Highways, Bridges, and Transit: conditions and performance*. Washington, DC, USA.
FHWA. (2008). *2008 Status of the Nation's Highways, Bridges, and Transit: conditions and performance*. Washington, DC, USA.
FHWA. (2013). *2013 Status of the Nation's Highways, Bridges, and Transit: conditions and performance*. Washington, DC, USA.
FHWA. (2015). "Highway Statistics Series." *Office of Highway Policy and Information*, Washington, DC, USA, <https://www.fhwa.dot.gov/policyinformation/statistics.cfm> (Dec. 13, 2015).
Flyvbjerg, B. (2013). "Quality control and due diligence in project management: Getting decisions

right by taking the outside view." *International Journal of Project Management*, Elsevier Ltd and IPMA, 31(5), 760–774.
Flyvbjerg, B., Skamris Holm, M. K., and Buhl, S. L. (2007). "Inaccuracy in Traffic Forecasts." *Transport Reviews*, 26(1), 1–24.
Ford, D. N., and Sterman, J. D. (1998). "Dynamic modeling of product development processes." *System Dynamics Review*, 14(1), 1–38.
Forrester, J. W. (1961). *Industrial Dynamics*. MIT Press, Cambirdge, MA.
Forrester, J. W. (1992). "Policies, decisions and information sources for modeling." *European Journal of Operational Research*, 59(1), 42–63.
Forrester, J. W. (1994). "System dynamics, systems thinking, and soft OR." *System Dynamics Review*, 10(2-3), 245–256.
Garvin, M. J. (2010). "Enabling Development of the Transportation Public-Private Partnership Market in the United States." 136(4), 402–411.
Garvin, M. J., and Bosso, D. (2008). "Assessing the effectiveness of infrastructure public—private partnership programs and projects." *Public Works Management & Policy*, 13(2), 162–178.
Garvin, M., and Gross, M. (2012). "Identification, Characterization and Analysis of Selected Research on Transportation Public-Private Partnerships from 1997-2010." *Proceedings of the 2012 Engineering Project Organizations Conference*, 1(1), 1–30.
Geddes, R. R., and Wagner, B. L. (2013). "Why do US states adopt public–private partnership enabling legislation?." *Journal of Urban Economics*, 78, 30–41.
Ghaffarzadegan, N., Lyneis, J., and Richardson, G. (2011). "How small system dynamics models can help the public policy process." *System Dynamics Review*, 27(1), 22–44.
Gil, N., and Beckman, S. (2009). "Infrastructure Meets Business: Building New Bridges, Mending Old Ones." *California Management Review*, 51(2), 6–29.
Gilmour, J. (2012). "The Indiana Toll Road Lease as an Intergenerational Cash Transfer." *Public Administration Review*, 1–9.
Gomez, J., and Vassallo, J. M. (2014). "Comparative analysis of road financing approaches in Europe and the United States." *Journal of Infrastructure Systems*, 20(3), 04014008–04014008.
Gomez-Ibañez, J. A., Ingram, G. K., and Hong, Y. H. (2009). "Prospects for private infrastructure in the United States: the case of toll roads." Lincoln Institute of Land Policy Conf. on the …, Cambridge, 399–427.
Graham, A. K., Morecroft, J., Senge, P. M., and Sterman, J. D. (1992). "Model-supported case studies for management education." *European Journal of Operational Research*, 59(1), 151–166.
Grimsey, D., and Lewis, M. (2004). "The Governance of Contractual Relationships in Public–Private Partnerships." *JCC*, 1–19.
Grimsey, D., and Lewis, M. K. (2002). "Evaluating the risks of public private partnerships for infrastructure projects." *International Journal of Project Management*, 20, 107–118.
Grubišić Šeba, M., Jurlina Alibegović, D., and Slijepčević, S. (2014). "Combating fiscal constraints for PPP development." *Managerial Finance*, (B. Monda and M. Giorgino, eds.), 40(11), 1112–1130.
Guasch, J. L., Laffont, J.-J., and Straub, S. (2008). "Renegotiation of concession contracts in Latin America." *International Journal of Industrial Organization*, 26(2), 421–442.
Gulati, R. (1995). "Does familiarity breed trust? the implications of repeated ties for contractual choice in alliances." *Academy of management journal*, 38(1), 85–112.
Guo, F., Chang-Richards, Y., Wilkinson, S., and Li, T. C. (2014). "Effects of project governance

structures on the management of risks in major infrastructure projects: A comparative analysis." *International Journal of Project Management*, 32(5), 815–826.
Guthkelch, C. (2017). "Virginia—Midtown Tunnel case study." *Public Works Financing Newsletter*, Peterborough, NH, 1–12.
Hartmann, A., Roehrich, J., Frederiksen, L., and Davies, A. (2014). "Procuring complex performance: the transition process in public infrastructure." *International Journal of Operations & Production Management*, (D. Mickey Howard and Dr Nigel Caldwell, ed.), 34(2), 174–194.
Henisz, W. (2006). "Governance issues in public private partnerships." *International Journal of Project Management*, 24(7), 537–538.
Henisz, W. J., Levitt, R. E., and Scott, W. R. (2012). "Toward a unified theory of project governance: economic, sociological and psychological supports for relational contracting." *Engineering Project Organization Journal*, 2(1-2), 37–55.
Henjewele, C., Sun, P. M., and Fewings, P. (2014). "Comparative performance of healthcare and transport PFI projects: Empirical study on the influence of key factors." *International Journal of Project Management*, 32(1), 77–87.
Hicks, R., Dunn, K., and Moulthrop, J. (1997). "Framework for selecting effective preventive maintenance treatments for flexible pavements." *Journal of the Transportation Research Record*.
Ho, S. P., Levitt, R., Tsui, C.-W., and Hsu, Y. (2015). "Opportunism-Focused Transaction Cost Analysis of Public-Private Partnerships." *Journal of Management in Engineering*, 04015007–04015011.
Hood, J., Fraser, I., and Mcgarvey, N. (2006). "Transparency of Risk and Reward in U.K. Public–Private Partnerships." *Public Budgeting Finance*, 1–19.
Isaacs, W., and Senge, P. (1992). "Overcoming limits to learning in computer-based learning environments." *European Journal of Operational Research*, 59, 183–196.
Iseki, H., and Houtman, R. (2012). "Evaluation of progress in contractual terms: Two case studies of recent DBFO PPP projects in North America." *Research in Transportation Economics*, Elsevier, 36(1), 73–84.
Jefferies, M. (2006). "Critical success factors of public private sector partnerships." *Engineering, Construction and Architectural Management*, 13(5), 451–462.
Jefferies, M., and McGeorge, W. D. (2009). "Using public-private partnerships (PPPs) to procure social infrastructure in Australia." *Engineering Construction and Architectural Management*, 16(5), 415–437.
Jenn, A., Azevedo, I. L., and Fischbeck, P. (2015). "How will we fund our roads? A case of decreasing revenue from electric vehicles." *Transportation Research Part A: Policy and Practice*, Elsevier Ltd, 74(C), 136–147.
Jiang, T., An, X., Minchin, R. E., Jr., and Li, S. (2016). "Application of Discrete-Event Simulation in the Quantitative Evaluation of Information Systems in Infrastructure Maintenance Management Processes." *Journal of Management in Engineering*, 32(2), 05015008–13.
Johnston, J. (2010). "Examining 'Tunnel Vision' in Australian PPPs: Rationales, Rhetoric, Risks and "Rogues"." *Australian Journal of Public Administration*, 69, S61–S73.
Johnston, J., and Gudergan, S. P. (2007). "Governance of public--private partnerships: lessons learnt from an Australian case?." *International Review of Administrative Sciences*, 73(4), 569–582.
Jooste, S. F., and Scott, W. R. (2012). "The Public–Private Partnership Enabling Field Evidence

From Three Cases." *Administration & Society*, SAGE Publications, 44(2), 149–182.
Jooste, S. F., Levitt, R., and Scott, D. (2011). "Beyond 'one size fits all': how local conditions shape PPP-enabling field development." *Engineering Project Organization Journal*, 1(1), 11–25.
Ke, Y., Wang, S., Chan, A. P. C., and Cheung, E. (2009). "Research trend of public-private partnership in construction journals." *Journal of Construction Engineering and Management*, 135(10), 1076–1086.
Kim, H. (2009). "Qualitative mapping for understanding the collective judgement building process: a study of the federal open market committee ." State University of New York at Albany.
Kim, H., and Andersen, D. F. (2012). "Building confidence in causal maps generated from purposive text data: mapping transcripts of the Federal Reserve." *System Dynamics Review*, 28(4), 311–328.
Kivleniece, I., and Quelin, B. V. (2012). "Creating and Capturing Value in Public-Private Ties: A Private Actor's Perspective." *Academy of Management Review*, 37(2), 272–299.
Kokkonen, A., and Alin, P. (2015). "Practice-based learning in construction projects: a literature review." *Construction Management and Economics*, 33(7), 513–530.
Koppenjan, J. F. M. (2005). "The Formation of Public-Private Partnerships: Lessons from Nine Transport Infrastructure Projects in The Netherlands." 1–23.
Kwak, Y., Chih, Y., and Ibbs, C. W. (2009). "Towards a Comprehensive Understanding of Public Private Partnerships for Infrastructure Development." 1–28.
la Garza, De, J. M., Akyildiz, S., Bish, D. R., and Krueger, D. A. (2011). "Network-level optimization of pavement maintenance renewal strategies." *Advanced Engineering Informatics*, Elsevier Ltd, 25(4), 699–712.
la Garza, De, J. M., Drew, D. R., and Chasey, A. D. (1998). "Simulating Highway Infrastructure Management Policies." *Journal of Management in Engineering*, 14(5), 64–72.
Lai, J. H. K. (2010). "Operation and maintenance budgeting for commercial buildings in Hong Kong." *Construction Management and Economics*, 28(4), 415–427.
Lane, D. C. (1992). "Modelling as learning: a consultancy methodology for enhancing learning in management teams." *European Journal of Operational Research*, 59, 64–84.
Lane, D. C. (1995). "On a resurgence of management simulations and games." *Journal of the Operational Research Society*, 46(5), 604–625.
Lane, D. C. (2008). "The emergence and use of diagramming in system dynamics: a critical account." *Systems Research and Behavioral Science*, 25(1), 3-23.
Langley, P. A., and Morecroft, J. (1996). "Learning from microworld environments: a summary of the research issues." *System Dynamics Review*, 96, 300–303.
Lee, N., and Schaufelberger, J. E. (2014). "Risk Management Strategies for Privatized Infrastructure Projects: Study of the Build–Operate–Transfer Approach in East Asia and the Pacific." *Journal of Management in Engineering*, 30(3), 05014001–05014009.
Lee, S. H., Peña-Mora, F., and Park, M. (2005). "Quality and change management model for large scale concurrent design and construction projects." *Journal of Construction Engineering and Management*, 131(8), 890–902.
Lenferink, S., Tillema, T., and Arts, J. (2013). "Towards sustainable infrastructure development through integrated contracts: Experiences with inclusiveness in Dutch infrastructure projects." *International Journal of Project Management*, 31(4), 615–627.
Levitt, R. E., Garvin, M. J., Scott, W. R., Dewulf, G., Monk, A., and South, A. (2014). "Toward

an Integrated Lifecycle Governance Framework for Delivering Civil Infrastructure Projects through Public-Private Partnerships (P3s).” *Proceedings of EPOC 2014 conference*.
Levitt, R. E., Henisz, W., Scott, W. R., and Settel, D. (2010). “Governance Challenges of Infrastructure Delivery: The Case for Socio-Economic Governance Approaches.” American Society of Civil Engineers, Reston, VA, 757–767.
Li, B., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005). “Critical success factors for PPP/PFI projects in the UK construction industry.” *Construction Management and Economics*, 23(5), 459–471.
Li, D., Chi Man Hui, E., Xu, X., and Li, Q. (2012). “Methodology for Assessing the Sustainability of Metro Systems Based on Emergy Analysis.” *Journal of Management in Engineering*, 28(1), 59–69.
Lin, Y. H., and Ho, S. P. (2013). “Impacts of Governance Structure Strategies on the Performance of Construction Joint Ventures.” *Journal of Construction Engineering and Management-Asce*, 139(3), 304–311.
Little, R. G. (2010). “Toward a New Federal Role in Infrastructure Investment: Using U.S. Sovereign Wealth to Rebuild America.” *Public Works Management & Policy*, 14(3), 288–306.
Liu, T., and Wilkinson, S. (2014). “Critical Factors Affecting the Viability of Using Public-Private Partnerships for Prison Development.” *Journal of Management in Engineering*, 05014020–05014011.
Liu, T., Wang, Y., and Wilkinson, S. (2016). “Identifying critical factors affecting the effectiveness and efficiency of tendering processes in Public–Private Partnerships (PPPs): A comparative analysis of Australia and China.” *International Journal of Project Management*, Elsevier Ltd and Association for Project Management and the International Project Management Association, 34(4), 701–716.
Locke, K., and Golden-Biddle, K. (1997). “Constructing opportunities for contribution: Structuring intertextual coherence and ‘problematizing’ in organizational studies.” *Academy of management journal*.
Lu, P., Guo, S., Qian, L., He, P., and Xu, X. (2015). “The effectiveness of contractual and relational governances in construction projects in China.” *International Journal of Project Management*, Elsevier B.V., 33(1), 212–222.
Lyneis, J. L. (2012). “Resistance from Top to Bottom: The dynamics of Risk Management in Complex Organizations.” MIT.
Lyneis, J. M., and Ford, D. N. (2007). “System dynamics applied to project management: a survey, assessment, and directions for future research.” *System Dynamics Review*, 23(2-3), 157–189.
Lyneis, J., and Sterman, J. D. (2015). “How to Save a Leaky Ship: Capability Traps and the Failure of Win-Win Investments in Sustainability and Social Responsibility.” *Academy of Management Discoveries*.
Mahalingam, A., and Palukuri, S. (2012). “Governance issues in BOT based PPP infrastructure projects in India.” *Built Environment Project and Asset …*.
Mayer, J. (2007). “Private returns, public concerns: addressing private-sector returns in public-private highway toll concessions.” *Transportation Research Record: Journal of the …*, 9–16.
McKinsey Global Institute. (2016). “Bridging Global Infrastructure Gaps.” *Mckinsey Global Institute*, <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps> (Apr. 1, 2017).
Meng, X. (2012). “The effect of relationship management on project performance in construction.” *International Journal of Project Management*, Elsevier Ltd, 30(2), 188–198.

Morecroft, J. (1992). "Executive knowledge, models and learning." *European Journal of Operational Research*, 59, 9–27.

Morecroft, J. D. W. (1988). "System dynamics and microworlds for policymakers." *European Journal of Operational Research*, 35, 301–320.

Müller, R., Pemsel, S., and Shao, J. (2014). "Organizational enablers for governance and governmentality of projects: A literature review." *International Journal of Project Management*, 32(8), 1309–1320.

National Audit Office. (2007). *Improving the PFI tendering process*. National Audit Office Press Office, 1–37.

National Research Council. (1993). *Pavement Management Systems*. National Academy Press, Washington DC, US.

National Surface Transportation Infrastructure Financing Commission. (2008). *Transportation for Tomorrow: The Final Report of the National Surface Transportation Policy and Revenue Study Commission*. Washington, DC, USA.

National Surface Transportation Infrastructure Financing Commission. (2009). *Paying Our Way: A New Framework for Transportation Finance, February 2009*. Washington, DC, USA.

Ng, S. T., and Wong, Y. M. W. (2006). "Adopting non-privately funded public-private partnerships in maintenance projects." *Engineering, Construction and Architectural Management*, 13(2), 186–200.

Ng, S. T., Wong, Y. M. W., and Wong, J. M. W. (2012). "Factors influencing the success of PPP at feasibility stage - A tripartite comparison study in Hong Kong." *Habitat International*, Elsevier Ltd, 36(4), 423–432.

Ni, A. Y. (2012). "The Risk-Averting Game of Transport Public-Private Partnership: Lessons from the Adventure of California's State Route 91 Express Lanes." *Public Performance & Management Review*, 36(2), 253–274.

Orr, R. J., and Kennedy, J. R. (2008). "Highlights of recent trends in global infrastructure: new players and revised game rules." *Transnational Corporations*, 17(1), 95–15.

Ortiz, I. N., and Buxbaum, J. N. (2008). "Protecting the public interest in long-term concession agreements for transportation infrastructure." *Public Works Management & Policy*, 13(2), 126–137.

Osei-Kyei, R., and Chan, A. P. C. (2015). "Review of studies on the Critical Success Factors for Public–Private Partnership (PPP) projects from 1990 to 2013." *International Journal of Project Management*, Elsevier Ltd and IPMA, 33(6), 1335–1346.

Ozbek, M. E., la Garza, de, J. M., and Triantis, K. (2010). "Data and modeling issues faced during the efficiency measurement of road maintenance using data envelopment analysis." *Journal of Infrastructure …*.

Papajohn, D., Cui, Q., and Bayraktar, M. E. (2011). "Public-private partnerships in US transportation: Research overview and a path forward." *Journal of Management in Engineering*, 27(3), 126–135.

Park, A., and Chang, C.-Y. (2013). "Impacts of construction events on the project equity value of the Channel Tunnel project." *Construction Management and Economics*, 31(3), 223–237.

Park, M., and Peña Mora, F. (2003). "Dynamic change management for construction: introducing the change cycle into model-based project management." *System Dynamics Review*, 19(3), 213–242.

Poppo, L., and Zenger, T. (2002). "Do formal contracts and relational governance function as substitutes or complements?." *Strategic management journal*, 23(8), 707–725.

Priemus, H., and Flyvbjerg, B. (2007). “Planning and design of large infrastructure projects.” *Environment and PLanning B Planning and Design*, 34, 576–577.
Rahmandad, H. (2015). “Connecting strategy and system dynamics: an example and lessons learned.” *System Dynamics Review*, 31(3), 149–172.
Rahmandad, H., and Hu, K. (2010). “Modeling the rework cycle: capturing multiple defects per task.” *System Dynamics Review*, 26(4), 291–315.
Rahmandad, H., and Repenning, N. (2015). “Capability erosion dynamics.” *Strategic management journal*, 37(4), 649–672.
Rahmandad, H., and Weiss, D. M. (2009). “Dynamics of concurrent software development.” *System Dynamics Review*, 25(3), 224–249.
Rakodi, C. (2003). “Politics and performance: the implications of emerging governance arrangements for urban management approaches and information systems.” *Habitat International*.
Rashman, L., Withers, E., and Hartley, J. (2009). “Organizational learning and knowledge in public service organizations: A systematic review of the literature.” *International Journal of Management Reviews*, 11(4), 463–494.
Reeves, E., Palcic, D., Flannery, D., Palcic, D., Flannery, D., and Geddes, R. R. (2016). “The determinants of tendering periods for PPP procurement in the UK: an empirical analysis.” *Applied Economics*, Routledge, 49(11), 1071–1082.
Regan, M., Smith, J., and Love, P. (2011). “Impact of the capital market collapse on public-private partnership infrastructure projects.” *Journal of Construction Engineering and Management*, 137(1), 6–16.
Rehan, R. (2011). “Application of system dynamics for developing financially self-sustaining management policies for water and wastewater systems.” Elsevier Ltd, 45(16), 4737–4750.
Rehan, R., Knight, M. A., Unger, A. J. A., and Haas, C. T. (2013). “Development of a system dynamics model for financially sustainable management of municipal watermain networks.” *Water Research*, Elsevier Ltd, 47(20), 7184–7205.
Reinhardt, W. (2012). “Midtown Tunnel Financial Close Ignites Virginia Politics.” *Public Works Management & Policy*, 1–6.
Repenning, N. P. (2002). “A simulation-based approach to understanding the dynamics of innovation implementation.” *Organization Science*.
Repenning, N. P., and Henderson, R. M. (2010). “Making the Numbers? ‘Short Termism’ & the Puzzle of Only Occasional Disaster.”
Repenning, N. P., and Sterman, J. D. (2002). “Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement.” *Administrative science quarterly*, SAGE Publications, 47(2), 265–295.
Richardson, G. P., and Pugh, A. L., III. (1981). *Introduction to System Dynamics Modeling with Dynamo*. MIT Press, Cambirdge, MA.
Rintala, K., Root, D., Ive, G., and Bowen, P. (2008). “Organizing a bidding competition for a toll road concession in South Africa: The case of Chapman's peak drive.” *Journal of Management in Engineering*, 24(3), 146–155.
Roehrich, J. K., and Lewis, M. A. (2010). “Towards a model of governance in complex (product–service) inter-organizational systems.” *Construction Management and Economics*, 28(11), 1155–1164.
Ruuska, I., Ahola, T., Artto, K., Locatelli, G., and Mancini, M. (2011). “A new governance approach for multi-firm projects: Lessons from Olkiluoto 3 and Flamanville 3 nuclear power

plant projects." *International Journal of Project Management*, Elsevier Ltd and IPMA, 29(6), 647–660.

Sanderson, J. (2012). "Risk, uncertainty and governance in megaprojects: A critical discussion of alternative explanations." *International Journal of Project Management*.

Schaufelberger, J. E., and Wipadapisut, I. (2003). "Alternate financing strategies for build-operate-transfer projects." *Journal of Construction Engineering and Management*, 129(2).

Shaoul, J., Stafford, A., and Stapleton, P. (2006). "Highway Robbery? A Financial Analysis of Design, Build, Finance and Operate (DBFO) in UK Roads." *Transport Reviews*, 26(3), 257–274.

Siemiatycki, M. (2012). "The Global Production of Transportation Public-Private Partnerships." *International Journal of Urban and Regional Research*, 37(4), 1254–1272.

Soliño, A. S., and Gago de Santos, P. (2010). "Transaction Costs in Transport Public–Private Partnerships: Comparing Procurement Procedures." *Transport Reviews*, 30(3), 389–406.

Soliño, A. S., and Gago de Santos, P. (2016). "Influence of the Tendering Mechanism in the Performance of Public-Private Partnerships: A Transaction Cost Approach." *Public Performance & Management Review*, 40(1), 97–118.

Soomro, M. A., and Zhang, X. (2013). "Roles of Private-Sector Partners in Transportation Public-Private Partnership Failures." *Journal of Management in Engineering*, 31(4).

Soomro, M. A., and Zhang, X. (2016). "Evaluation of the Functions of Public Sector Partners in Transportation Public-Private Partnerships Failures." *Journal of Management in Engineering*, 32(1), 04015027–11.

Sterman, J. D. (1988). "People Express: Management Flight Simulator." *Massachusetts Institute of Technology*, Cambridge, MA (Dec. 14, 2015).

Sterman, J. D. (1994). "Learning in and about complex systems." *System Dynamics Review*, 10(2-3), 291–330.

Sterman, J. D. (2000). *Business dynamics*. McGraw-Hill, New York, USA.

Sterman, J. D. (2011). "Communicating climate change risks in a skeptical world." *Climatic Change*, 108(4), 811–826.

Sterman, J. D. (2014). "Interactive web-based simulations for strategy and sustainability: The MIT Sloan LearningEdge management flight simulators, Part I." 30(1), 89–121.

Stoker, G. (1998). "Public-private partnerships and urban governance." *Partnerthips in urban governance European and American experience*, Basingstoke, 34–51.

Stouten, H., Heene, A., Gellynck, X., and Polet, H. (2012). "Learning from playing with microworlds in policy making: An experimental evaluation in fisheries management." *Computers in Human Behavior*, 28(2), 757–770.

Strong, K., and Chhun, S. (2014). "Complex governance system issues for transportation renewal projects." *Urban, Planning and Transport Research*, 2(1), 233–246.

Svejvig, P., and Andersen, P. (2015). "Rethinking project management: A structured literature review with a critical look at the brave new world." *International Journal of Project Management*, Elsevier Ltd and International Project Management Association, 33(2), 278–290.

Tang, L., and Shen, Q. (2013). "Factors affecting effectiveness and efficiency of analyzing stakeholders' needs at the briefing stage of public private partnership projects." *International Journal of Project Management*, 31(4), 513–521.

Tang, L., Shen, G. Q., Skitmore, M., and Wang, H. (2014). "Procurement-Related Critical Factors for Briefing in Public-Private Partnership Projects: Case of Hong Kong." *Journal of*

Management in Engineering, 04014096–04014099.
Tang, L., Shen, Q., and Cheng, E. W. L. (2010). "A review of studies on Public–Private Partnership projects in the construction industry." *International Journal of Project Management*, 28(7), 683–694.
Tang, L., Shen, Q., Skitmore, M., and Cheng, E. W. L. (2013). "Ranked Critical Factors in PPP Briefings." 29(2), 164–171.
Taylor, T. R. B., and Ford, D. N. (2006). "Tipping point failure and robustness in single development projects." *System Dynamics Review*, John Wiley & Sons, Ltd., 22(1), 51–71.
Too, E. G., and Weaver, P. (2014). "The management of project management: A conceptual framework for project governance." 32(8), 1382–1394.
Tranfield, D., Denyer, D., and Smart, P. (2003). "Towards a methodology for developing evidence-informed management knowledge by means of systematic review." *British Journal of Management*, 14, 207–222.
U.S. Senate. (2008). *Transportation Infrastructure: Issues and Options*. Washington D.C., 1–108.
U.S. Senate. (2012). *Financing 21st-Century Infrastructure*. Washington D.C., 1–121.
van Buiten, M., and Hartmann, A. (2015). "Asset Management Perspective on the Duration of Public-Private Partnership Contracts: Cost-Control Trade-off?." *Journal of Construction Engineering and Management-Asce*, 141(3), 04014080–04014089.
Van Den Hurk, M., and Verhoest, K. (2015). "The governance of public-private partnerships in sports infrastructure: Interfering complexities in Belgium." *International Journal of Project Management*, Elsevier Ltd and International Project Management Association, 33(1), 201–211.
van Marrewijk, A., Clegg, S. R., Pitsis, T. S., and Veenswijk, M. (2008). "Managing public–private megaprojects: Paradoxes, complexity, and project design." *International Journal of Project Management*, 26, 591–600.
Vassallo, J. M. (2006). "Traffic Risk Mitigation in Highway Concession Projects: The Experience of Chile on JSTOR." *Journal of Transport Economics and Policy*.
Vassallo, J. M. (2007). "Implementation of quality criteria in tendering and regulating infrastructure management contracts." *Journal of Construction Engineering and Management*, 133(8), 553–561.
Vassallo, J. M., and Soliño, A. S. (2006). "Minimum Income Guarantee in Transportation Infrastructure Concessions in Chile." *Transportation Research Record*, 1–8.
Vassallo, J. M., Ortega, A., and Baeza, M. de L. Á. (2012). "Impact of the Economic Recession on Toll Highway Concessions in Spain." *Journal of Management in Engineering*, 28(4), 398–406.
Vassallo, J. M., Ortega, A., and de los Ángeles Baeza, M. (2013). "Risk Allocation in Toll Highway Concessions in Spain." *Transportation Research Record: Journal of the Transportation Research Board*, 2297(-1), 80–87.
Verweij, S. (2015). "Achieving satisfaction when implementing PPP transportation infrastructure projects: a qualitative comparative analysis of the A15 highway DBFM project." *International Journal of Project Management*, 33(1), 189–200.
Vining, A. R., and Boardman, A. E. (2008a). "Public-private partnerships in Canada: Theory and evidence." *Canadian Public Administration*, 51(1), 9–44.
Vining, A. R., and Boardman, A. E. (2008b). "Public--Private Partnerships: Eight Rules for Governments." *Public Works Management & Policy*, 13(2), 149–161.
Vining, A. R., Boardman, A. E., and Poschmann, F. (2005). "Public–private partnerships in the

US and Canada: ‘There are no free lunches’.” *Journal of Comparative Policy Analysis*, 7(3), 199–220.
Virginia Office of Public-Private Partnerships. (2016). *The Commonwealth of Virginia Implementation Manual and Guidelines*. Commonwealth of Virginia, Richmond, VA, 1–79.
Wang, Y. (2015). “Evolution of public–private partnership models in American toll road development: Learning based on public institutions' risk management.” *International Journal of Project Management*, 33(3), 684–696.
Watts, R. A., Frick, K. T., and Maddison, J. (2012). “Policy Making, Incrementalism, and News Discourse: Gasoline Tax Debates in Eight U.S. States.” *Public Works Management & Policy*, 17(3), 238–255.
Williamson, O. E. (1979). “Transaction-cost economics: the governance of contractual relations.” *Journal of law and economics*, 22(2), 233–261.
Williamson, O. E. (1999). “Public and private bureaucracies: a transaction cost economics perspectives.” *Journal of Law, Economics, and Organization*, Oxford University Press, 15(1), 306–342.
Winch, G., and Leiringer, R. (2016). “Owner project capabilities for infrastructure development: A review and development of the ‘strong owner’ concept.” *International Journal of Project Management*, Elsevier Ltd and Association for Project Management and the International Project Management Association, 34(2), 271–281.
World Economic Forum. (2014). “Strategic Infrastructure Steps to Operate and Maintain Infrastructure Efficiently and Effectively.” *World Economic Forum*, <http://www3.weforum.org/docs/WEF_IU_StrategicInfrastructureSteps_Report_2014.pdf> (Apr. 1, 2017).
Yescombe, E. R. (2011). *Public-Private Partnerships: principles of policy and finance*. Elsevier Ltd., Oxford.
Yuan, J. F., Skibniewski, M. J., Li, Q., and Shan, J. (2010). “The driving factors of china‘s public-private partnership projects in Metropolitian transportation systems: Public sector’s viewpoint.” *Journal of Civil …*, Taylor & Francis Group, 16(1), 5–18.
Yuan, J., Zeng, A. Y., Skibniewski, M. J., and Li, Q. (2009). “Selection of performance objectives and key performance indicators in public–private partnership projects to achieve value for money.” *Construction Management and Economics*, 27(3), 253–270.
Zhang, S., Chan, A. P. C., Feng, Y., Duan, H., and Ke, Y. (2016). “Critical review on PPP Research - A search from the Chinese and International Journals.” *International Journal of Project Management*, Elsevier Ltd and Association for Project Management and the International Project Management Association, 34(4), 597–612.
Zhang, S., Gao, Y., Feng, Z., and Sun, W. (2015). “PPP application in infrastructure development in China: Institutional analysis and implications.” *International Journal of Project Management*, 33(3), 497–509.
Zhang, X. (2004). “Improving concessionaire selection protocols in public/private partnered infrastructure projects.” *Journal of Construction Engineering and Management*, 130(5), 670–679.
Zhang, X. (2005). “Paving the way for public–private partnerships in infrastructure development.” *Journal of Construction Engineering and Management*, 131(1), 71–80.
Zhang, X. Q., and Kumaraswamy, M. M. (2001a). “Procurement protocols for public-private partnered projects.” *Journal of Construction Engineering and Management*, 127(5), 351–358.
Zhang, X., and Ali Soomro, M. (2016). “Failure Path Analysis with Respect to Private Sector

Partners in Transportation Public-Private Partnerships." *Journal of Management in Engineering*, 32(1), 04015031–10.

Zhang, X., and Kumaraswamy, M. M. (2001b). "Hong Kong experience in managing BOT projects." *Journal of construction engineering …*, 127(2), 154–162.

Zheng, J., Roehrich, J. K., and Lewis, M. A. (2008). "The dynamics of contractual and relational governance: Evidence from long-term public–private procurement arrangements." *Journal of Purchasing and Supply Management*, 14(1), 43–54.

Zou, P. X. W., Wang, S., and Fang, D. (2008). "A life-cycle risk management framework for PPP infrastructure projects." *Journal of Financial Management of Property and Construction*, 13(2), 123–142.

Zou, W., Kumaraswamy, M., Chung, J., and Wong, J. (2014). "Identifying the critical success factors for relationship management in PPP projects." *International Journal of Project Management*, 32(2), 265–274.

APPENDIX A:SUPPLEMENTAL EQUATIONS TO CHAPTER 2

S1. Acceptable Condition Highways= INTEG (Minor Deterioration-Maintenance Rate-Major Deterioration, 525000)
Units: lanemiles

S2. Age Increment= 1
Units: yr/(year*lanemiles)

S3. Available Budget=Max(Budget-"Rehabilitation & Reconstruction Expenditures",0)
Units: $/year

S4. Available Budget Maintenance= Max(Available Budget*Budget Fraction for Maintenance-"Non-IRI Maintenance Costs"
,0)
Units: $/year

S5. Available Budget New Construction=Available Budget*(1-Budget Fraction for Maintenance)+Max(Available Budget Maintenance-Budget for Maintenance,0)
Units: $/year

S6. Average Age Deteriorated=Total Age Deteriorated/Deteriorated Condition Highways
Units: yr/lanemiles

S7. average time to fix roads=4.125
Units: year

S8. Average Unit Cost=Normal Unit Cost Rehabilitation*Effect of Age on Unit Cost
Units: $/lanemiles

S9. Average Unit Cost Reconstruction=Normal Unit Cost Reconstruction*Effect of Age on Unit Cost
Units: $/lanemiles

S10. Avg Age Acceptable=Total Age Acceptable/Acceptable Condition Highways
Units: yr/lanemiles

S11. Avg Age Good=Total Age Good/Good Condition Highways
Units: yr/lanemiles

S12. Budget:INTERPOLATE::=GET VDF DATA('BUDGET.vdf' , 'Budget for Highways', 0 , 1)
Units: $/year
This budget was generated endogenously during the base run simulation. In order to make proper comparisons between the policies, it has been included as an exogenous variable.

S13. Budget for Maintenance=Max(MIN(Budget Needed for Maintenance, Available Budget Maintenance),0)
Units: $/year

S14. Budget Fraction for Maintenance=0.45+STEP(Parameter Policy 1-0.45, Implementation Year Policy 1)
Units: dmnl

S15. Budget Needed for Maintenance=Acceptable Condition Highways*Unit Cost Maintenance/Time to Maintenance
Units: $/year

S16. Initial Deteriorated Condition Highways=140000
Units: lanemiles

S17. Decrease Age Acceptable=(Maintenance Rate+Major Deterioration)*Avg Age Acceptable
Units: yr/year

S18. Decrease Age Deteriorated=(Rehabilitation Rate+Reconstruction)*Average Age Deteriorated
Units: yr/year

S19. Decrease Age Good=Avg Age Good*Minor Deterioration
Units: yr/year

S20. Delay in Perception=1
Units: year [1,10,1]

S21. Desired Fraction of Deteriorated Highways=0.09
Units: dmnl [0,1,0.01]

S22. Deteriorated Condition Highways= INTEG (Major Deterioration-Reconstruction-Rehabilitation Rate,
dchi)
Units: lanemiles

S23. Effect of Age on Deterioration= WITH LOOKUP (
Avg Age Acceptable*Multiplier Major Deterioration,([(3,0.9)-
(30,2),(3,1),(4.37309,1.023),(5.38226,1.02632),(6.45872,1.04386),(7.93884,1.05263),(9.14985,1.08772),(10.7645,1.11404),(12.3792,1.22807),(13.1193,1.31579),(13.5902,1.42982),(14.4648,1.60526),(15.2049,1.82456),(15.945,1.89474),(16.4832,1.94737),(17.4924,1.98246),(20,2)],(6,1),(7.36697,1.01184),(8.65138,1.02895),(10.6422,1.05263),(11.9908,1.10746),(12.7615,1.17982),(14.3028,1.31974),(14.8807,1.38728),(15.7798,1.50307),(16.9358,1.57061),(18.3486,1.62851),(20.0826,1.67675),(21.6239 ,1.71053),(24,1.75),(25.3761,1.78772),(27.3578,1.81184),(30,1.82632)
))
Units: dmnl

S24. Effect of Age on Minor Deterioration= WITH LOOKUP (
Avg Age Good*Multiplier Minor Deterioration,([(3,1)-
(27,2),(3,1),(4.37309,1.023),(5.38226,1.02632),(6.45872,1.04386),(7.93884,1.05263),(9.14985,1.08772),(10.7645,1.11404),(12.3792,1.22807),(13.1193,1.31579),(13.5902,1.42982),(14.4648,1.60526),(15.2049,1.82456),(15.945,1.89474),(16.4832,1.94737),(17.4924,1.98246),(20,2)],(3,1.2),(5.49541,1.2193),(7.93884,1.25),(10.1927,1.29386),(12.5413,1.42982),(15.0367,1.55263),(17.3853,1.62281),(20.1743,1.67544),(22.0826,1.71053),(25.17,1.73246),(26.9266,1.73684)))
Units: dmnl

S25. Effect of Age on Unit Cost= WITH LOOKUP (
Average Age Deteriorated*Multiplier Unit Costs,([(9,0)-
(31,3)],(9,1.3),(9.908,1.3),(11.43,1.314),(13.31,1.311),(15,1.34),(16.21,1.369),(17.02,1.419),(18.02,1.493),(19.03,1.605),(20.5,1.763),(21.38,1.882),(22.79,2.053),(24.07,2.171),(25.35,2.329),(26.49,2.461),(27.64,2.566),(28.71,2.632)
,(30.31,2.658)))
Units: dmnl

S26. First Age= 12
Units: yr

S27. Fixing Rate= Perceived Deteriorated Highways+Shortfall/average time to fix roads
Units: lanemiles/year

S28. "Goal - Deteriorated Highways"=Desired Fraction of Deteriorated Highways*Total Highways
Units: lanemiles

S29. Good Condition Highways= INTEG (New Construction+Rehabilitation Rate+Maintenance Rate-Minor Deterioration,280000)
Units: lanemiles

S30. Implementation Year Policy 1= 2000
Units: year [1994,2010,1]

S31. Implementation Year Policy 2= 2000
Units: year [1994,2010,1]

S32. Increase Age Acceptable=Minor Deterioration*initial age
Units: yr/year

S33. Increase Age Deteriorated= Initial Age DCH*Major Deterioration
Units: yr/year

S34. Increase Age Good= Maintenance Rate*Avg Age Acceptable+Rehabilitation Rate*Average Age Deteriorated
Units: yr/year

S35. Increase Total Age Acceptable= Acceptable Condition Highways*Age Increment
Units: yr/year

S36. Increase Total Age Deteriorated= Deteriorated Condition Highways*Age Increment
Units: yr/year

S37. Increase Total Age Good= Good Condition Highways*Age Increment
Units: yr/year

initial age= Avg Age Good
Units: yr/lanemiles

S38. Initial Age DCH= Avg Age Acceptable
Units: yr/lanemiles

S39. Initial Age Deteriorated= 17.5
Units: yr/lanemiles

S40. initial age for acceptable= 14
Units: yr/lanemiles

S41. Maintenance Rate= Budget for Maintenance/Unit Cost Maintenance
Units: lanemiles/year

S42. Major Deterioration=(Acceptable Condition Highways*Effect of Age on Deterioration)/Normal Major Deterioration Time
Units: lanemiles/year

S43. Minor Deterioration=Good Condition Highways*Effect of Age on Minor Deterioration/Normal Minor Deterioration Time
Units: lanemiles/year

S44. Multiplier Major Deterioration= 1
Units: lanemiles/yr

S45. Multiplier Minor Deterioration= 1

Units: lanemiles/yr

S46. Multiplier Unit Costs= 1
Units: lanemiles/yr

S47. New Construction= Reconstruction+New Road Construction
Units: lanemiles/year

S48. New Road Construction= Max(Available Budget New Construction/Unit Cost New Construction,0)
Units: lanemiles/year

S49. "Non-IRI Maintenance Costs"= "Unit Costs Non-IRI"*Total Highways
Units: $/year

S50. Normal Major Deterioration Time= 11
Units: year [0,20,0.25]

S51. Normal Minor Deterioration Time= 6.5
Units: year [0,20,0.25]

S52. Normal Unit Cost Reconstruction= 1e+006
Units: $/lanemiles

S53. Normal Unit Cost Rehabilitation= 175000
Units: $/lanemiles

S54. Parameter Policy 1= 0.45
Units: dmnl [0,1,0.05]

S55. Parameter Policy 2= 0.93
Units: dmnl [0.8,1,0.01]

S56. Perceived Deteriorated Highways= SMOOTH3(Major Deterioration,Delay in Perception)
Units: lanemiles/year

S57. Reconstruction=
Fixing Rate*(1-Rehabilitation Fraction)
Units: lanemiles/year

S58. "Rehabilitation & Reconstruction Expenditures"= Rehabilitation Rate*Average Unit Cost+Reconstruction*Average Unit Cost Reconstruction
Units: $/year

S59. Rehabilitation Fraction= 0.93+STEP(Parameter Policy 2-0.93, Implementation Year Policy 2)
Units: dmnl [0,1,0.01]

S60. Rehabilitation Rate= Rehabilitation Fraction*Fixing Rate
Units: lanemiles/year

Shortfall= Max(Deteriorated Condition Highways-"Goal - Deteriorated Highways",0)
Units: lanemiles

S61. Time to Maintenance= 1
Units: year

S62. Total Age Acceptable= INTEG (Increase Total Age Acceptable-Decrease Age Acceptable+Increase Age Acceptable,Acceptable Condition Highways*initial age for acceptable)
Units: yr

S63. Total Age Deteriorated= INTEG (Increase Age Deteriorated+Increase Total Age Deteriorated-Decrease Age Deteriorated,Deteriorated Condition Highways*Initial Age Deteriorated)
Units: yr

S64. Total Age Good= INTEG (Increase Age Good+Increase Total Age Good-Decrease Age Good,300000*First Age)
Units: yr

S65. Total Highways=Acceptable Condition Highways+Deteriorated Condition Highways+Good Condition Highways
Units: lanemiles

S66. Unit Cost Maintenance= 100000
Units: $/lanemiles

S67. Unit Cost New Construction= 3.75e+006
Units: $/lanemiles

S68. "Unit Costs Non-IRI"= 7000+RAMP(200,2000,2010)
Units: $/lanemiles/year [7000,15000]

APPENDIX B: MACRO-VARIABLES AND CAUSAL RELATIONSHIPS

Table B-1. Selected Journals

Journals	Paper I.D.	JCR Impact Factor	JCR Quartile 2014	SJR	SJR Quartile 2014	Subject Area
Australian Accounting Review (AAR)	24	0.38	4	0.36	3	Business Finance
Australian Journal of Public Administration (AJPA)	36	0.42	4	0.26	3	Public Administration
Canadian Journal of Civil Engineering (CJCE)	1	0.56	3	0.38	3	Engineering, Civil
Case Studies on Transport Policy (CSTP)	20	N/A	N/A	0.38	2	Urban Studies
Construction Management and Economics (CME)	7,22	N/A	N/A	1.12	1	Building and Construction
International Journal of Project Management (IJPM)	8,21,26	2.44	1	1.51	1	Management
International Review of Administrative Sciences (IRAC)	29	0.66	3	0.53	2	Public Administration
Journal of Comparative Policy Analysis (JCPA)	33	0.61	3	0.3	3	Public Administration
Journal of Construction Engineering and Management (JCEM)	2,4,9,16,17, 34,35	0.84	3	1.2	1	Construction & Building Technology
Journal of Management in Engineering (JME)	3,14,23,25, 27,31	0.93	3	1.04	1	Engineering, Civil
Journal of Professional Issues in Engineering Education and Practice (JPIEEP)	28	0.27	4	0.45	2	Engineering, Multidisciplinary
Transportation Research Record (TRR)	5	0.54	4	0.52	2	Engineering, Civil
Journal of Transport Economics and Policy (JTEP)	11	1.18	2	0.77	2	Economics
Public Administration (PA)	19,32	1.52	1	1.28	1	Public Administration
Public Budgeting and Finance (PBF)	18	N/A	N/A	0.42	2	Public Administration
Public Performance and Management Review (PPMR)	10	0.909	3	0.91	1	Public Administration
Public Policy and Administration (PPA)	37	N/A	N/A	0.37	2	Public Administration
Public Works Management & Policy (PWMP)	12,30	N/A	N/A	0.35	2	Public Administration
Research in Transportation Economics (RTE)	15,19	N/A	N/A	0.79	2	Transportation
Transport Reviews (TR)	6	N/A	N/A	2.12	1	Transportation

Table B-2. Cause-Effect Relationships: Articles 1 to 19

Cause	Articles	Polarity	Articles																			Total References
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Availability of funding sources	Potential opportunism	+		x										x						x	x	5
Availability of funding sources	Subsidies, enhancements, and government debt	+	x				x				x		x									5
Clear requirements and outputs	Efficiency of planning & procurement	+	x			x		x			x		x				x	x				10
Efficiency of planning & procurement	Management of technical complexity	+							x		x											5
Financial Feasibility	Operational Feasibility	+		x				x			x		x						x		x	10
Financial Feasibility	Socio-Political Feasibility	+		x		x					x						x		x			7
Financial Feasibility	Subsidies, enhancements, and government debt	-	x	x						x									x	x		9
Financial Feasibility	Project Attractiveness	+	x	x		x	x			x	x	x	x	x		x	x	x				15
Former PPP projects	Government capacity	+				x				x											x	5
Government capacity	Clear requirements and outputs	+	x			x		x			x	x	x				x	x				10

Cause	Articles	Polarity	Articles																			Total References
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Government capacity	Social and political understanding	+				x					x	x		x			x			x		9
Government capacity	Quality of technical studies & contract documents	+				x	x			x	x	x		x	x		x	x			x	19
Government retaining demand risk	Private Equity	-							x		x		x								x	5
Government retaining demand risk	Private Debt	+							x		x		x								x	5
Health of capital market	Financial Feasibility	+		x	x					x					x				x		x	10
Infrastructure needs	Management of technical complexity	-					x														x	5
Management of technical complexity	Transaction costs	+													x			x				5
Management of technical complexity	Quality of technical studies & contract documents	+	x	x	x		x				x	x	x		x	x	x			x	x	22
Negotiated Procurement	Transaction Costs	+	x			x												x				5
Open Procurement	Transaction Costs	-	x			x	x											x				8

Cause	Articles	Polarity	Articles																			Total References
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Operational Feasibility	Efficiency of planning & procurement	+	x			x						x										5
Operational Feasibility	Perception of project efficiencies and innovation	+				x				x	x		x				x	x				10
Operational Feasibility	Potential opportunism	-	x	x		x		x		x			x								x	14
Operational Feasibility	Availability of funding sources	+		x				x									x	x				5
Operational Feasibility	Project attractiveness	+					x	x		x	x	x	x			x	x		x		x	20
Perception of Project efficiencies and innovation	Socio-Political Feasibility	+	x			x					x		x	x			x	x				10
Potential opportunism	Potential renegotiations	+					x				x	x	x						x			8
Potential renegotiations	Transaction Costs	+		x			x						x								x	10
Private debt	Financial Feasibility	+	x	x			x	x		x	x								x		x	10
Private debt	Potential opportunism	-		x									x					x				5

Cause	Articles	Polarity	Articles																			Total References
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Private debt	Private equity	-		x			x	x								x	x					5
Private equity	Financial Feasibility	+	x	x			x	x				x	x				x		x			9
Private equity	Potential opportunism	+					x						x					x				4
Private equity	Private debt	-		x			x	x								x	x					5
Project attractiveness	Private equity	+	x	x													x					5
Project attractiveness	Private debt	+	x	x								x	x			x	x		x			9
Quality of technical studies & contract documents	Operational Feasibility	+		x		x	x					x	x			x	x				x	16
Social and political understanding	Socio-Political Feasibility	+				x					x			x						x		5
Socio-Political Feasibility	Government capacity	+	x			x	x				x	x		x			x	x				9
Socio-Political Feasibility	Availability of funding sources	+				x					x							x				5

Cause	Articles	Polarity	Articles																			Total References
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Subsidies, enhancements, and government debt	Socio-Political Feasibility	-	x			x					x			x						x	x	9
Subsidies, enhancements, and government debt	Financial Feasibility	+	x	x		x	x				x	x	x	x					x	x	x	14
Transaction costs	Operational Feasibility	-				x	x								x							5
Transaction costs	Trust-based mechanisms	+				x	x														x	9
Trust-based Mechanisms	Potential renegotiations	-				x	x															5

Table B-3. Cause-Effect Relationships: Articles 20 to 37

Cause	Articles	Polarity	Articles																		Total References
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Availability of funding sources	Potential opportunism	+					x														5
Availability of funding sources	Subsidies, enhancements, and government debt	+												x							5
Clear requirements and outputs	Efficiency of planning & procurement	+		x						x					x						10
Efficiency of planning & procurement	Management of technical complexity	+								x					x					x	5
Financial Feasibility	Operational Feasibility	+			x					x						x				x	10
Financial Feasibility	Socio-Political Feasibility	+						x							x						7
Financial Feasibility	Subsidies, enhancements, and government debt	-				x		x					x			x					9
Financial Feasibility	Project Attractiveness	+		x												x	x				15
Former PPP projects	Government capacity	+						x								x					5
Government capacity	Clear requirements and outputs	+		x						x											10

Cause	Articles	Polarity	Articles																		Total References
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Government capacity	Social and political understanding	+						x	x										x		9
Government capacity	Quality of technical studies & contract documents	+		x		x		x	x			x		x		x		x	x		19
Government retaining demand risk	Private Equity	-												x							5
Government retaining demand risk	Private Debt	+												x							5
Health of capital market	Financial Feasibility	+				x		x	x					x							10
Infrastructure needs	Management of technical complexity	-		x	x															x	5
Management of technical complexity	Transaction costs	+				x						x					x				5
Management of technical complexity	Quality of technical studies & contract documents	+	x	x	x	x		x	x			x				x		x	x		22
Negotiated Procurement	Transaction Costs	+				x						x									5
Open Procurement	Transaction Costs	-				x		x		x		x									8

Cause	Articles	Polarity	Articles																		Total References
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Operational Feasibility	Efficiency of planning & procurement	+	x																	x	5
Operational Feasibility	Perception of project efficiencies and innovation	+		x											x	x			x		10
Operational Feasibility	Potential opportunism	-	x		x			x						x		x			x	x	14
Operational Feasibility	Availability of funding sources	+														x					5
Operational Feasibility	Project attractiveness	+		x	x	x		x	x	x		x		x		x				x	20
Perception of Project efficiencies and innovation	Socio-Political Feasibility	+		x											x	x					10
Potential opportunism	Potential renegotiations	+						x				x							x		8
Potential renegotiations	Transaction Costs	+		x				x			x	x				x			x		10
Private debt	Financial Feasibility	+												x			x				10
Private debt	Potential opportunism	-						x								x					5

Cause	Articles	Polarity	Articles																		Total References
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Private debt	Private equity	-																			5
Private equity	Financial Feasibility	+															x				9
Private equity	Potential opportunism	+			x																4
Private equity	Private debt	-																			5
Project attractiveness	Private equity	+												x			x				5
Project attractiveness	Private debt	+												x			x				9
Quality of technical studies & contract documents	Operational Feasibility	+			x	x						x	x	x				x	x	x	16
Social and political understanding	Socio-Political Feasibility	+							x												5
Socio-Political Feasibility	Government capacity	+														x					9
Socio-Political Feasibility	Availability of funding sources	+					x									x					5

Cause	Articles	Polarity	Articles																		Total References
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
Subsidies, enhancements, and government debt	Socio-Political Feasibility	-											x						x	x	9
Subsidies, enhancements, and government debt	Financial Feasibility	+	x					x								x					14
Transaction costs	Operational Feasibility	-						x				x									5
Transaction costs	Trust-based mechanisms	+		x	x	x		x			x	x									9
Trust-based Mechanisms	Potential renegotiations	-		x				x								x					5

APPENDIX C: PROCEDURE TO RESOLVE DISAGREEMENTS ON CAUSAL STRUCTURES

According to Kim (2009), eliciting causal relationships from written texts involves two types of structural disagreements as depicted in Figure 9.1. Disagreement 1 is related to discrepancies in the polarity of the relationship. Different authors may analyze the same governance issue in a seemingly contradictory way. For example, while one scholar may say that an increase in A leads to an increase in B (positive relationship); another academic may say that increasing A contributes to decreasing B (negative relationship). Disagreement 2, on the other hand, entails multiple causal relationships between two main variables. While one researcher may claim that A and B are mutually connected to C, another scholar may assert that A and B are related through D. In this case, the disagreement is based on the different interpretations of the same relationship.

Figure C-1. Disagreement on Causal Structures

In our coding process, we solved Disagreement 1 by relying on the information provided by the 37 selected papers and our own understanding of PPP governance. If we were unsure of the link polarity in a particular causal relationship, we re-examined the validity of the causal arguments against the text segments related to such relationship (Kim 2009). By doing so, we wanted to avoid errors and highlight other variables capable of resolving the contradiction. If the inconsistency persisted, we sought to explore other text excerpts and, finally, we relied in our own interpretation (Kim 2009).

An example of Disagreement 1 can be found in the relationship between *Management of Complexity* and *Transaction Costs*. While Zou et al. (2008) argue that promoting efforts related to *Management of Complexity* escalate *Transaction Costs*; Park and Chang (2013) claim that improving *Management of Complexity* leads to less *Transaction Costs*. When we found this disagreement, we searched for the authors' causal arguments in both papers. We discovered that both were based on different definitions of transaction costs. Also, we found that Ho et al. (2015) utilized a characterization of *Transaction Costs* that incorporated the two seemingly contradictory definitions.

According to Ho et al. (2015), transaction costs in PPP refer to both expenditures associated with procurement/planning procedures (Zou et al.'s definition) and the amount of unexpected costs that can be materialized due to project uncertainty and complexity (Park's and Chang's definition). Based on that, we identified that a third variable (i.e. *Quality of technical studies and contract documents)* could be associated with *Management of Complexity* and *Transaction Costs.* This helped to solve the disagreement as shown in Figure 9.2.

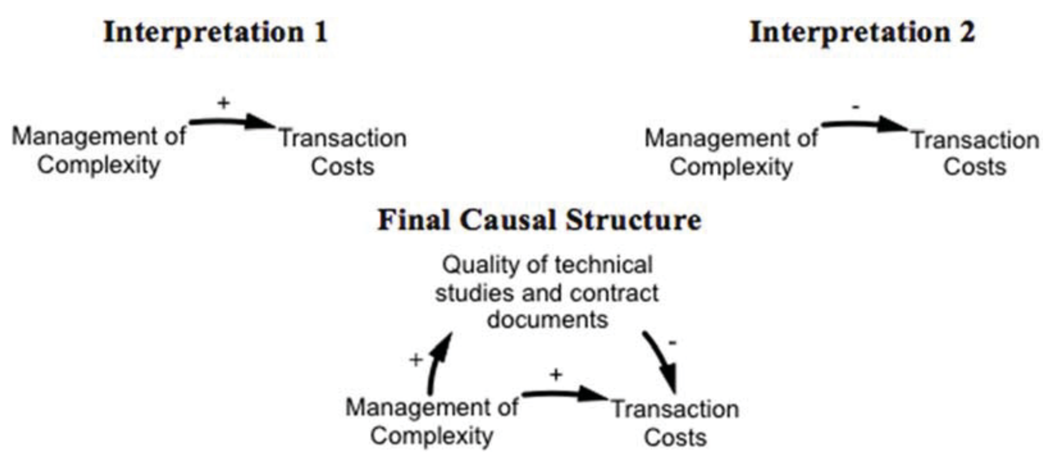


Figure C-2. Disagreement 1 Structures

On the other hand, we solved Disagreement 2 by ensuring that our systems map was able to capture both causal paths as suggested by Kim (2009). First, we carefully analyzed the text segments related to the two different causal interpretations in order to make sure that our understanding was correct. Second, we looked for more text segments confirming the different perspectives around the same relationship. Finally, we established the macro-variables related to the causal maps and included them in the map.

As an example, during our coding process we discovered that *Management of Complexity* could be either beneficial or adverse to *Operational Feasibility*. Multiple sources confirmed that such relationship was based on two different causal paths. While one of them was related to the quality of the procurement process, the other focused on transaction costs. We incorporated both perspectives as depicted in Figure 9.3.

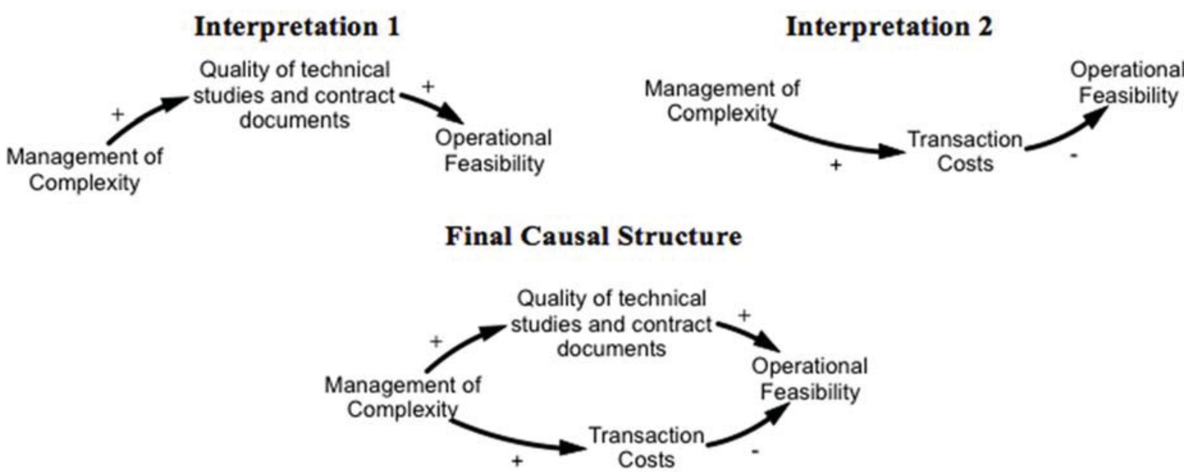


Figure C-3. Disagreement 2 Structures

APPENDIX D: SUPPLEMENTAL EQUATIONS TO CHAPTER 4

S69. ACTIVITY RATE=
Initial Work to Do/Initial Scheduled Time

S71. add to duration=
IF THEN ELSE(Procurement Percent Complete<definition of done, 1 , 0)

S72. AdjTime for Quality=
6

S73. AdjTime for SchPerformance=
3

S74. Adjustment Time for confidence change on work incorrectly done=
(12*IF THEN ELSE((1-Level of Interest)<1/12, 1/12 , (1-Level of Interest)))*0+AdjTime for Quality

S75. Adjustment Time for confidence on performance=
(12*IF THEN ELSE((1-Level of Interest)<1/12, 1/12 , (1-Level of Interest)))*0+AdjTime for SchPerformance

S76. Capability Productivity=
0.0065

S76. Capacity Erosion=
IF THEN ELSE(Procurement Percent Complete<1,Effect of Confidence on Capacity Erosion*Capacity Index/Eros
ion Time,0)

S78. Capacity Growth=
IF THEN ELSE(Procurement Percent Complete<1,Resources for Capability9*Capability Productivity,0)

S79. Capacity Index= INTEG (
Capacity Growth-Capacity Erosion,
Initial Governance Capability)

S81. Change 1=
(Fraction of Work Incorrectly Done-
S1 Output)/(Adjustment Time for confidence change on work incorrectly done/3)

S82. Change 2=
(S1 Output-S2 Output)/(Adjustment Time for confidence change on work incorrectly done/3)

S83. Change 3=
IF THEN ELSE(Procurement Percent Complete<1, (S2 Output-
S3 output)/(Adjustment Time for confidence change on work incorrectly done/3),0)

S84. Change S2 Per=
(S1 Per-S2 Per)/(Adjustment Time for confidence on performance/3)

S85. Change S3 Per=
IF THEN ELSE(Procurement Percent Complete<1,(S2 Per-
S3 Per)/(Adjustment Time for confidence on performance/3),0)

S86. ChangeS1 Per=

(var-S1 Per)/(Adjustment Time for confidence on performance/3)

S87.definition of done=
1

S88. Desired Time to Completion=
24

S89. Discovering Issues Rate=
(Work Done with Undiscovered Latent Issues/Min Time for Discovering Rework)*Effect of Resources on Discove
ring Issues

S90. Doing Planning Right=
(Potential Planning Completion Rate*(1-Fraction of Undiscovered Issues))

S91. Doing Planning Wrong=
(Potential Planning Completion Rate*Fraction of Undiscovered Issues)

S92. Earned Schedule=
IF THEN ELSE(Time<Initial Scheduled Time,Time+(Procurement Percent Complete*100-
Planned Schedule)/ACTIVITY RATE,Initial Scheduled Time
+(Procurement Percent Complete*100-Planned Schedule)/ACTIVITY RATE)

S93. Effect of Capacity on Total Resources=
Function Eff of Capacity on Total Resources(Capacity Index)

S94. Effect of Confidence on Capacity Erosion=
Function for the Eff of Confidence on Capacity Erosion(Private Sector Confidence)

S95. Effect of Experience on Initial Governance Capability=
Function for Eff Experience on Governance Capability(Level of PPP Market Development)

S96. Effect of GovCap on Productivity=
Function for the Eff of GovCap on Productivity(Capacity Index)

S97. Effect of GovCap on Undiscovered Issues=
Function for Eff of GovCap on Undiscovered Issues(Capacity Index)

S98. Effect of Opposition on Capacity Erosion Time=
Function of Eff of Capacity on Legitimacy(Level of Opposition)

S90. Effect of Resources on Discovering Issues=
Multiplier Discovering*Function for Solving Issues(Resources for Discovering Issues/Normal Resources for Disco
vering Issues)

S99. Effect of Resources on Solving Issues=
Function for Solving Issues(Resources for Solving issues/Normal Resources Doing rework)

S101. Effect of Schedule Pressure on Undiscovered Issues=
Function for Eff SchePre on Undiscovered Issues(Schedule Pressure)

S102. Erosion Time=
Normal Erosion Time*Effect of Opposition on Capacity Erosion Time

S103. Expected Time Left=
IF THEN ELSE(Initial Scheduled Time>36, 500 , IF THEN ELSE(Resources for Execution>0, max(Work to Do/P

roductivity/Resources for Execution,1) , 500))

S104.FINAL TIME = 36

S105. Fraction of Undiscovered Issues=
MIN (Normal Undiscovered Issues*Effect of Schedule Pressure on Undiscovered Issues*Effect of GovCap on Undiscovered Issues,1)

S106. Fraction of Work Incorrectly Done=
xidz((Tasks with Latent Issues+Work Done with Undiscovered Latent Issues),(Tasks with Latent Issues+Work Done with Undiscovered Latent Issues+Work Correctly Done
),Fraction of Undiscovered Issues)

S107. Function Eff of Capacity on Total Resources(
[(0,0)-(5,2)],(0,1),(1,1),(1.5,1.5),(5,1.5))

S108. Function for Eff Experience on Governance Capability(
[(0,0.75)-
(1,1.5)],(0,0.75),(0.100917,0.762719),(0.214067,0.779825),(0.318043,0.814035),(0.400612,0.853947),(0.455657,0.922368),(0.5,1),(0.544343,1.09342),(0.587156,1.14803),(0.651376,1.19408),(0.721713,1.21711),(0.801223,1.23684),(0.899083,1.24013),(1,1.25))

S109. Function for Eff of Confidence on Discovering Rate(
[(0,1)-
(1,2)],(0,2),(0.134557,1.96491),(0.253823,1.92544),(0.357798,1.88158),(0.455657,1.80702),(0.559633,1.73684),(0.639144,1.64912),(0.721713,1.55702),(0.816514,1.44737),(0.877676,1.32895),(0.944954,1.16228),(1,1))

S110. Function for Eff of GovCap on Undiscovered Issues(
[(0,0)-
(3,2)],(0,2),(0.284404,1.9386),(0.458716,1.81579),(0.59633,1.59649),(0.688073,1.32456),(0.733945,1.01754),(0.825688,0.798246),(1.05505,0.640351),(1.3578,0.561404),(1.69725,0.517544),(2,0.464912),(2.31193,0.429825),(2.56881,0.404),(2.79817,0.4023),(3,0.4))

S111. Function for Eff of Perceived Performance on PS Confidence(
[(0,0)-
(5,2)],(0,0),(0.281346,0.0438596),(0.48318,0.184211),(0.685015,0.350877),(0.831804,0.54386),(0.93578,0.745614),(1,1),(5,1))

S112. Function for Eff of Work Incorrectly Done on Process Quality(
[(0,0)-
(1,1)],(0,1),(0.0917431,0.719298),(0.189602,0.517544),(0.281346,0.368421),(0.382263,0.219298),(0.486239,0.131579),(0.593272,0.0701754),(0.691131,0.0350877),(0.798165,0.0219298),(1,0))

S113. Function for Eff SchePre on Undiscovered Issues(
[(0,0.9)-
(100,2)],(0,1),(1,1),(1.11315,1.02061),(1.24771,1.09781),(1.36391,1.27149),(1.5,1.5),(1.65138,1.74912),(1.71254,1.86009),(1.78593,1.94693),(1.86544,1.98553),(2,2),(100,2))

S114. Function for Effect of PPC on Resources for Solving issues(
[(0,0)-
(1,0.9)],(0,0.8),(0.1161,0.792857),(0.224033,0.771429),(0.307536,0.737143),(0.405295,0.677143),(0.509165,0.552857),(0.604888,0.39),(0.704684,0.227143),(0.8,0),(1,0))

S115. Function for Solving Issues(
[(0,0)-
(5,1)],(0,0),(0.3,0),(0.443425,0.179825),(0.688073,0.364035),(1,0.5),(1.5,0.66),(2.11,0.78),(2.75,0.88),(3.5,0.95),(4,

0.987),(5,1))

S116. Function for the Eff of Confidence on Capacity Erosion(
[(0,0)-(1,2)],(0,1.25),(0.5,1),(1,0.75))

S117. Function for the Eff of GovCap on Productivity(
[(0,0)-
(3,2)],(0,0),(0.293578,0.0350877),(0.495413,0.149123),(0.66055,0.289474),(0.752294,0.464912),(0.899083,0.736842),(1,1),(1.15596,1.21053),(1.33028,1.35088),(1.57798,1.44737),(1.84404,1.5),(3,1.5))

S118. Function of Eff of Capacity on Legitimacy(
[(0,0.7)-(1,2)],(0,1.25),(0.5,1),(1,0.75))

S119. Initial Governance Capability=
Normal Governance Capability*Effect of Experience on Initial Governance Capability

S120. Initial Productivity=
1

S121. Initial Resources for Capability0=
Initial Total Resources*Percentage Resources Allocated for EAS

S122. Initial Resources for Execution=
Initial Total Resources*Resources Policyt for Procurement Execution

S123.INitial Resources for Rework0=
Initial Total Resources*Resource Policy for Solving Issues

S124. Initial Scheduled Time=
Desired Time to Completion+0*(MIN(IF THEN ELSE(Initial Resources for Execution>0,Initial Work to Do/Initial Productivity/Initial Resources for Execution
,500
),36))

S125.INITIAL TIME = 0

S126. Initial Total Resources=
20

S127. Initial Work to Do=
100

S128. Level of Interest=
0.75

S129. Level of Opposition=
0

S130. Level of PPP Market Development=
IF THEN ELSE(Scenarios=1, 0.75 , IF THEN ELSE(Scenarios=2,0.75,0.25))

S131. Min Time for Completion=
0.25

S132. Min Time for Discovering Rework=
1

S133. Min Time for Rework=
0.5

S134. Min Time Left=
1

S135. Multiplier Discovering=
Function for Eff of Confidence on Discovering Rate(Private Sector Confidence on Process Quality)

S136. Normal Erosion Time=
15

S137. Normal Governance Capability=
1

S138. Normal Resources Doing rework=
2

S139. Normal Resources for Discovering Issues=
2

S140. Normal Undiscovered Issues=
IF THEN ELSE(Project Complexity<0.2, 0.16 ,0.8*Project Complexity)

S141. Perceived Progress on Overall Procurement=
(Work Correctly Done+Work Done with Undiscovered Latent Issues-Tasks with Latent Issues)/Initial Work to Do

S142."Percentage Resources Allocated for C&R"=
"Resources for Communication & Review"/Resources for Procurement

S143. Percentage Resources Allocated for EAS=
Resources for External Advisory Services/Resources for Procurement

S144. Percentage Resources Allocated for PE=
Resources for Procurement Execution/Resources for Procurement

S145. Percentage Resources Execution=
Resources for Execution/Total Resources

S146. Percentage Resources for Capability=
Resources for Capability9/Total Resources

S147. Percentage Resources Rework=
Resouces for Rework0/Total Resources

S148. Planned Schedule=
IF THEN ELSE(Time<Initial Scheduled Time,(Initial Work to Do/Initial Scheduled Time)*Time,100)

S148. Potential Planning Completion Rate=
MIN(Productivity*Resources for Execution,Work to Do/Min Time for Completion)

S150. Private Sector Confidence=
Private Sector Confidence on Process Quality*Private Sector Confidence on Schedule Performance

S151. Private Sector Confidence on Process Quality=

Function for Eff of Work Incorrectly Done on Process Quality(Private Sector Perception of Work Incorrectly Done)

S152. Private Sector Confidence on Schedule Performance=
Function for Eff of Perceived Performance on PS Confidence(Schedule Performance Index)

S153. Private Sector Perception of Work Incorrectly Done=
IF THEN ELSE(Procurement Percent Complete<1,SMOOTH3(Fraction of Work Incorrectly Done, Adjustment Time for confidence change on work incorrectly done
),S3 output)

S154. Process Duration= INTEG (
add to duration,
0)

S155. Procurement Percent Complete=
IF THEN ELSE(Tasks Perceived Complete/Initial Work to Do<0.995,Tasks Perceived Complete/Initial Work to Do,1)

S156. Productivity=
Effect of GovCap on Productivity*Initial Productivity

S157. Project Complexity=
IF THEN ELSE(Scenarios=1, 0.25 , IF THEN ELSE(Scenarios=2,1,IF THEN ELSE(Scenarios=3,0.25,1)))

S158. Resouces for Rework0=
Total Resources*Resource Policy for Solving Issues

S159. Resource Policy for Solving Issues=
"Percentage Resources Allocated for C&R"

S160. Resources for Capability9=
Percentage Resources Allocated for EAS*Total Resources

S161."Resources for Communication & Review"= GAME (
0.25)

S162. Resources for Discovering Issues=
Resouces for Rework0*Review Policy Solving Issues

S163. Resources for Execution=
Resources Policyt for Procurement Execution*Total Resources

S164. Resources for External Advisory Services= GAME (
0.5)

S165. Resources for Procurement=
"Resources for Communication & Review"+Resources for External Advisory Services+Resources for Procurement Execution

S166. Resources for Procurement Execution= GAME (
0.25)

S167. Resources for Solving issues=
Resouces for Rework0*(1-Review Policy Solving Issues)

S168. Resources Policyt for Procurement Execution=
Percentage Resources Allocated for PE

S169. Review Policy Solving Issues=
Function for Effect of PPC on Resources for Solving issues(Procurement Percent Complete)

S170.S1 Output= INTEG (
Change 1,
Fraction of Work Incorrectly Done)

S171.S1 Per= INTEG (
ChangeS1 Per,
var)

S172.S2 Output= INTEG (
Change 2,
Fraction of Work Incorrectly Done)

S173.S2 Per= INTEG (
Change S2 Per,
var)

S174.S3 output= INTEG (
Change 3,
Fraction of Work Incorrectly Done)

S175.S3 Per= INTEG (
Change S3 Per,
var)

S176.SAVEPER =
TIME STEP

S177. Scenarios=
1

S178. Schedule Performance Index=
IF THEN ELSE(Procurement Percent Complete<1,SMOOTH3(IF THEN ELSE(Procurement Percent Complete<1,
xidz(Earned Schedule,Time
,1),xidz(Earned Schedule,Process Duration
,1)),Adjustment Time for confidence on performance
),S3 Per)

S179. Schedule Pressure=
Expected Time Left/Scheduled Time Left

S180. Scheduled Time Left=
max(Min Time Left,Initial Scheduled Time-Time)

S181. Score Confidence on Process Quality=
Private Sector Confidence on Process Quality*0.35

S182. Score Confidence on Schedule Performance=
Private Sector Confidence on Schedule Performance*0.15

S183. Score Process Duration=

IF THEN ELSE(Process Duration>Desired Time to Completion, 0 , 0.15)

S184. Score Quality=
(0.35)*(1-Fraction of Work Incorrectly Done)

S185. Solving Issues Rate=
Tasks with Latent Issues/Min Time for Rework*Effect of Resources on Solving Issues

S186. Tasks Perceived Complete=
Work Done with Undiscovered Latent Issues+Work Correctly Done

S187. Tasks with Latent Issues= INTEG (
Discovering Issues Rate-Solving Issues Rate,
0)

S188.TIME STEP = 0.0625

S189. Total Planning Work=
Tasks with Latent Issues+Work Done with Undiscovered Latent Issues+Work Correctly Done+Work to Do

S190. Total Resources=
Initial Total Resources*Effect of Capacity on Total Resources

S191. Total Score=
IF THEN ELSE(Procurement Percent Complete<1, 0, Score Confidence on Process Quality+Score Confidence on Schedule Performance+Score Process Duration+Score Quality)

S192.var=
IF THEN ELSE(Procurement Percent Complete<1, xidz(Earned Schedule,Time,1),xidz(Earned Schedule,Process Duration,1))

S193. Work Correctly Done= INTEG (
Doing Planning Right,
0)

S194. Work Done with Undiscovered Latent Issues= INTEG (
Doing Planning Wrong-Discovering Issues Rate,
0)

S195. Work to Do= INTEG (
Solving Issues Rate-Doing Planning Right-Doing Planning Wrong,
Initial Work to Do)