

ABSTRACT

Title of Dissertation: AGENT-BASED MODELS OF HIGHWAY
INVESTMENT PROCESSES: FORECASTING
FUTURE NETWORKS UNDER PUBLIC AND
PRIVATE OWNERSHIP REGIMES

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The present highway funding system, especially fuel taxes, may become a less reliable revenue source in the future, while the transportation public agencies do not have sufficient financial resources needed to meet the increasing traffic demand. In the last two decades there has been increasing interest in utilizing private sector to develop, finance and operate new and existing roadways in the United States. While transportation privatization projects have shown signs of success, it is not always clear how to measure the true benefits associated with these projects for all stakeholders, including the public sector, the private sector and the public. “Win-win” privatization agreements are tricky to make due to conflicting nature of the various stakeholders involved. Therefore, there is a huge need to study the welfare impacts of various road privatization arrangements for the society as a whole, and the financial implications for private investors and public road authorities.

In order to address these needs, first, an empirical analysis is performed to study the investment decision processes of public transportation agencies. Second, the agent-based decision-making model is developed to consider transportation investment processes at different levels of government which forecasts future transportation networks and their performance under both existing and alternative transportation planning processes. Third, various highway privatization schemes currently practiced in the U.S. are identified and an agent-based model for analyzing regulatory policies on private-sector transportation investments is developed. Fourth, the above mentioned models are demonstrated on the networks with grid and beltway topologies to study the impacts of topology configuration on the privatization arrangements. Based on the simulation results of developed models, a number of insights are provided about impacts of ownership structures on the socio-economic performance in transportation systems and transportation network changes over time. The proposed models and the approach can be used in long-run prediction of economic performance intended for describing a general methodology for transportation planning on large networks. Therefore, this research is expected to contribute significantly to the understanding and selecting proper road privatization programs on public networks.

AGENT-BASED MODELS OF HIGHWAY INVESTMENT PROCESSES:
FORECASTING FUTURE NETWORKS UNDER PUBLIC AND PRIVATE
OWNERSHIP REGIMES

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List of Abbreviations

BDI – Belief, Desire and Intention

BRTB – Baltimore Regional Transportation Board

CLRP – Constrained Long-Range Plan

CIP – Capital Improvement Program

CNI – Capital Needs Inventory

CTP – Consolidated Transportation Program

DDOT – District Department of Transportation

DOT – Department of Transportation

EIS - Environmental Impact Statement

HNI – Highway Needs Inventory

ISTEA – Intermodal Surface Transportation Efficiency Act

JCC – Jurisdictional Coordinating Committee

KDOT – Kansas Department of Transportation

MAA – Maryland Airport Administration

MARC – Maryland Rail Commuter Service

MDOT – Maryland Department of Transportation

MdTA – Maryland Transportation Authority

MnDOT – Minnesota Department of Transportation

MoDOT – Missouri Department of Transportation

MPA – Maryland Port Authority

MPO – Metropolitan Planning Organization

MTA – Maryland Transit Administration

MVA- Maryland Motovehicle Administration

MWAA – Metropolitan Washington Airport Authority

MWCOG – Metropolitan Washington Council of Governments

NEPA – National Environmental Policy Act

ODOT – Ohio Department of Transportation

PPP – Public-Private Partnership

RAC – Rider’s Advisory Committee

SHA – State Highway Administration

SIB – State Infrastructure Bank

SLA – Stochastic Learning Automata

STIP – Statewide Transportation Improvement Program

STP – Surface Transportation Program

TAB – Transportation Advisory Board

TAC – Technical Advisory Committee

TIP – Transportation Improvement Program

TTF – Transportation Trust Fund

TPB – Transportation Planning Board

TSO – Transportation Secretary Office

U.S. DOT – United States Department of Transportation

VDOT – Virginia Department of Transportation

Chapter 1: Introduction

1.1 Background

Traditionally, in the United States it has been assumed that roads should be constructed and maintained by the public sector and be free of charge. However, the present highway funding system, especially fuel taxes, may become less reliable revenue sources in the future, while the public transportation agencies do not have financial resources to meet the needs of maturing infrastructure and increasing traffic demand. Facing budgetary constraints and recognizing their inability to provide infrastructure services timely and efficiently, state and local governments are now willing to cooperate with private sector agencies in order to bring additional investments into transportation infrastructure. As a result, a growing number of roads in the United States are being operated privately or by various forms of public-private partnerships (PPPs) (Roth 1996).

Although private investment in infrastructure is not quite new for this country, conversion of government owned infrastructure into privately owned or operated is a fairly new movement. A wide range of approaches and models have been proposed to study socio-economic effects of private ownership, but just few studies have been devoted to the detailed analysis of the ownership structure and its resulting socio-economic outcome. This research is focused on toll road financing and optimal regulation and tries to identify equitable combination of revenue policies for

achieving welfare maximizing goals at the federal and state levels and profit maximizing interests of private entities. It is believed that a better understanding of various private financing options can assist transportation policy makers with the selection of investment policies that achieve a greater balance between revenue and equity objectives. Therefore, the goal of this research is to provide an insight about institutional strategies that may best align the private sector's profit-maximizing and resource efficiency objectives with the government's social welfare maximizing objectives.

1.2 Problem Statement

As the traffic demand increases at a faster rate than the upgrade and maintenance of transportation facilities funded by the traditional public financing methods, there is currently significant deficiency in transportation infrastructure. At present 33 percent of America's major roads are in poor condition and 36 percent of America's major urban highways are congested. Each year Americans lose 4.2 billion hours and 2.9 billion gallons of fuel stuck in traffic, creating a 78.2-billion-dollar annual drain on the U.S. economy (TTI 2007). The nation's population grew by 20 percent from 1990 to 2006 and vehicle travel on highways increased by 41 percent during the same time period, while new road mileage increased by only 4 percent (TRIP 2010). Moreover, much of the existing roadway system is beyond its designed service life and needs major improvements or replacements (Samuel 2000). Unfortunately, the traditional road financing method, with motor fuel taxes as the

main revenue source, can no longer meet the required transportation system maintenance and expansion needs. Over the last two decades, the buying power of motor fuel taxes has been significantly weakened by the combined effects of inflation, improved vehicle fuel efficiency, increased construction costs and diversion of road funding to other transportation programs. In contrast, there is a lack of political will at both the federal and state levels to increase fuel tax rates. The federal fuel tax has remained at 19.3 cents per gallon since 1993. All these factors have jointly led to an unprecedented challenge and funding gap for public-sector roadway transportation financing in the U.S. Under these conditions, it is not surprising that private investment resources have already found several ways to enter the U.S. roadway systems. Although most roads in the U.S. are still owned and operated by government agencies, an emerging trend is characterized by the development of new private toll roads (e.g. Denver E-470, Texas State Highway 130, The Dulles Greenway, San Diego SR125) and the private takeover/leasing of existing state-owned roads (e.g. Chicago Skyway, Indiana Turnpike). U.S. Department of Transportation 2006 statistics show that more than 50% of the current highway mega-projects (> \$500 million investment) involve some form of public-private partnerships (PPP). Various PPP schemes have been adopted for these projects in their finance, leasing, design, build, operate, maintenance, and ownership transfer stages. The most popular regulatory tools include concession period agreement, price ceiling (i.e. maximum toll rates), revenue sharing and shadow tolling.

Private financing is believed to be a suitable approach to provide financing for infrastructure projects while transferring the burden of capital, operating, and

maintenance costs from government to private companies. Private toll roads can provide a new revenue stream for highway systems, provide extra road capacity, better quality road services and be effective tool for congestion management. However, various considerations need to be addressed regarding the proper scope of private sector involvement in roadway financing. Roads have monopoly power because they uniquely occupy space. There also exist barriers to market entry including the significant sunk cost of building new roads and the uncertain return on road investment especially when competitors already exists. Also, equity and safety concerns are not necessarily consistent with the profit-maximizing objective of private investors.

To reliably estimate the impacts of the privatization of roadways, this dissertation addresses these problems in the following steps. First, the literature review is provided to study the history of transportation financing in the United States. Here it is described in detail how the US highway system was financed, constructed and operated; how traditionally FHWA, State DOTs, small and big MPOs, as well as state counties were generating revenues for highway and transit systems in their jurisdictions and how that money was allocated to different activities. In addition it is discussed how private investment resources have found ways to enter the U.S. roadway systems, how private toll roads are regulated and what are the benefits and drawbacks of private-sector roadway ownership. Also, the previous research on roadway privatization and methods of studying network changes is presented. Second, a qualitative analysis of the multimodal transportation investment decision rules and processes adopted by various jurisdictions in the Washington DC-

Baltimore area is provided. Interviews have been conducted for this research with staff members at the county-, metropolitan-, state- and regional-level agencies. Findings from these interviews reveal the details of the investment process in the DC region, and the advantages and disadvantages of the existing processes and procedures. Third, a quantitative model with agent-based techniques is developed that forecasts future networks and their performance under existing and alternative transportation planning processes based on information obtained from qualitative analysis of the multimodal transportation investment decision processes in the Washington DC region. This model predicts the long-term impacts of transportation planning and policy decisions on the network evolution and configuration. In the fourth step such a quantitative agent-based model is developed that simulates the evolutionary process of roadway privatization and captures its impacts on roadway users, private investors, and the society at large. Privatization of roadways is considered in this research with a primarily U.S. focus. However, the methodology developed herein for analyzing the impact of private roads on users, private investors, and social welfare is general, and can be applied for roadway privatization studies elsewhere. In the final step, the developed models of future networks under existing and alternative transportation planning processes and of roadway privatization are demonstrated on the networks with grid and beltway topologies to demonstrate the effects of topology configuration on the privatization arrangements.

The remainder of this introductory chapter is organized as follows. The following section discusses the objectives and methodology of the research. The next

section summarizes expected research contributions. The organization of this dissertation is then discussed in some depth to offer an overview of the research plan.

1.3 Research Objectives and Methodology

A practical motivation of this research arises from a growing interest of deploying private sector investments into transportation infrastructure. As a result, an increasing number of private toll road projects are constructed or proposed in the U.S. through various forms of privatization agreements, and more states are removing legal constraints on the entry of private roads into the existing public road system. Therefore, it is very important to analyze the welfare and financial implications of utilizing private sector capitals in road financing for both public policy decisions and private investment decisions for improving forecasting, planning, policy-making, and evaluation, as well as to understand how public and private transportation investment decisions and policies translate into transportation facilities on the ground in the long-run. Therefore the objective of this dissertation is twofold: (1) to understand how jurisdictional planning and investment decision-making processes translate into transportation facilities on the ground, and develop the quantitative model with agent-based techniques, which can forecast future transportation networks and their performance under both existing and alternative transportation planning processes; and (2) to identify the various highway privatization schemes currently practiced in the U.S. and to develop agent-based model for analyzing regulatory policies on

private-sector transportation investments, as well as to demonstrate its applicability on real-world Maryland statewide network.

In order to achieve the specified objectives, the following methodology is developed to achieve the desired research outcomes:

1. Interview the key agencies responsible for transportation planning and funding allocation in the Washington DC region. In particular, learn what are:

- Agencies' main priorities and criteria that guide investment processes;
- Procedures for identifying needs and generating candidate projects;
- Procedure for selecting/prioritizing candidate projects;
- Methods for quantitative technical project evaluation, and the role of non-technical political influences;
- Procedures for agency interactions concerning needs identification and funding allocation;
- Summarize the data collected from interviews and draw conclusions.

2. Develop a quantitative model with agent-based techniques that forecasts future networks and their performance under existing and alternative multi-modal and multi-jurisdictional transportation investment decision-making processes based on information obtained from interview qualitative analysis;

3. Develop a quantitative agent-based model that simulates the evolutionary process of roadway privatization under public and private ownership regimes and captures its impacts on roadway users, private investors, and the society at large, and test the model on a hypothetical network;

4. Study the impact of regulation and network topology on the effectiveness of roadway privatization.

The described objectives and methodology of this research lead to the research contributions specified below.

1.4 Research Overview

The remaining chapters of this dissertation are arranged in the following way. Chapter 2 presents literature review on transportation financing in the United States, on how private sector made its way into the transportation investment system, what types of roadway privatization there exist nowadays and what theoretical studies have been done with regard to toll road projects and network growth.

Chapter 3 describes and analyzes the decision rules and processes currently adopted by various agencies in the Washington DC and Baltimore region. Interviews have been conducted with staff members at the county, metropolitan, state and regional transportation and planning agencies. The key research questions to address were how multimodal highway and transit investment decisions are made in this region, how transportation funds are allocated to different modes, different jurisdictions, and different projects, and how agencies at different levels of government interact with each other. Findings suggest that agencies have developed qualitative and quantitative methods to handle competing objectives and various considerations. This section also discusses how decision powers can be potentially allocated at different government levels for greater resources allocation efficiency.

Chapter 4 provides a background on how the agent-based models are developed in this research, and describes the major components of those models, such as demand and supply modules, cost and performance measures necessary for modeling investment prioritization processes of public and private sectors.

Chapter 5 develops a quantitative model of public investment processes with agent-based techniques, and forecasts future transportation networks and their performance under both existing and alternative transportation planning processes. The existing planning process is modeled based on in-depth interviews with state, metropolitan, and local transportation agencies in the Washington DC-Baltimore Region that have influence on transportation investment decisions (these is described in detail in Chapter 3).

Chapter 6 develops an agent-based model of mixed ownership structures, and forecasts future transportation networks and their performance under alternative transportation planning processes and ownership regimes, as well as regulation scenarios. This chapter details four policy scenarios for the analysis, including the two roadway privatization scenarios and two benchmark scenarios: status quo and social optimum.

Chapter 7 presents, interprets, and compares model results under each of the four policy scenarios, and discusses the findings and their policy implications. Conclusions are offered at the end of the chapter.

Chapter 8 applies the proposed modeling framework to the networks with grid and beltway topologies to study the influence of topology configuration on the privatization decisions.

Chapter 9 concludes the research. It provides a summary of research efforts and findings, followed by an outlook on the advance of agent-based privatization models. The dissertation ends by proposing several future research topics.

Chapter 2: Literature Review

In this Chapter the literature review is provided on the history of transportation financing in the United States. It discusses how private investment resources have found ways to enter the U.S. roadway systems, how private toll roads are regulated and what are the benefits and drawbacks of private-sector roadway ownership, what private road categories there exist nowadays. Also, previous research on roadway privatization is reviewed and summarized on how the researchers have been modeling network growth patterns, since part of my research is focused on understanding how investment decisions and privatization arrangements affect network changes and their evolution in the long-run.

2.1 Introduction to Transportation Financing Mechanism in the U.S

The National Highway System of the U.S. is the longest highway system in the world, comprising approximately 162,000 miles of roadway, 97 percent of which is free to public traffic since government provided most of the funding through the years. The system is a product of a delicately balanced partnership of federal, state, regional and local governments, consisting of several subsystems of roadways (FHWA 2006 I). The majority of the Interstate System was built between the 1950s and 1980s. Since then small construction and improvements continue through the present. Two funding mechanisms have made the world's largest highway system

possible. The first is the creation of the Highway Trust Fund (HTF) and the dedication of federal fuel taxes to the fund. Without the HTF funding mechanism the Interstate Highway System would probably never have been possible. A financial report issued in 1991 estimated that the construction of the Interstate Highway System cost approximately \$128.9 billion (in 1991 dollars); the federal government paid about 90 percent of the total costs from the HTF and state governments provided the remaining 10 percent with state matching funds (FHWA 2006 II).

Motor fuel taxes, the major revenue source of transportation finance, were first set up as user fees under the rationale that people should pay in proportion to their use of the roadway system. Since first introduced, fuel taxes have played a crucial role in funding American highways. Besides motor fuel taxes, different levels of governments have a variety of additional sources for highway funding. State governments receive a significant portion of their highway funding from public bonds, tolls and other taxes and fees. Local governments' main highway funding sources consist of general fund appropriation, property taxes and assessments and public bonds.

However, during the past twenty years, investment in highway capacity has not been matched by capacity expansion needs in the highway infrastructure. Also, by 1980, the nation's highway facilities have shown signs of aging due to heavy use. Currently the government does not have sufficient resources needed to meet increasing demand due to decreasing revenues from fuel taxes. On the contrary, private financing is believed to be a suitable approach to provide financing for infrastructure projects while transferring the burden of capital, operating, and

maintenance costs from government to private companies. Private toll roads can provide a new revenue stream for highway system, provide extra road capacity, better quality road services and be effective tool for congestion management.

Private roads are not a new concept to the United States. Between the 1920s and 1960s many states issued tax-exempt public bonds to fund turnpikes to provide fast and convenient transportation. Around the mid 1980s, the U.S. interstate system has been completed, which was build with support of federal grants and gas tax revenues. In the late 1980s the nation's highway system started to deteriorate. Since then the U.S. government has endeavored to once again utilize toll financing as a supplementary source for transportation finance.

2.2 Reasons for Private Financing

Attracting private capital to transportation infrastructure provision offers efficiency gains and shifts project risks from government. When investing in a toll road project, a private entity often becomes the project's sponsor and is responsible for all the phases of the project's development, such as design, construction, operation, and maintenance. In addition to responsibilities, private agency is also interested in cutting costs of construction and operation by being more efficient, resulting from superior private sector's economy of scale and technical efficiency (Frantz 1992).

To summarize, the following reasons have attracted attention to private sector:

(1) Declining purchasing power of fuel tax revenues due to the lack of political will

for raising taxes at all levels; (2) Increasing roadway construction and maintenance costs resulting from material, equipment, and labor price inflation; (3) Underpriced roadway travel and the willingness to charge higher user fees by the private sector; (4) Travel demand increase and worsening congestion; and (5) Immediate payments to the public sector based on concession agreement that can bring much-needed revenue to state and local governments. Consequently, a growing number of roadways in the U.S. are constructed and/or operated by the private sector through various forms of public-private partnerships (PPP).

Under these conditions, it is not surprising that private investment resources have already found several ways to enter the U.S. roadway systems. The idea of private roadway financing is not a new concept in the U.S. and dates back to the beginning of roadway construction. In general, privatization arises from the beliefs of private sector being fundamentally more efficient than the public sector; the possibility of new sources of funding to supplement the constrained resources of the public sector and the potential for financing without increasing taxes. Roadway privatization can take many different forms, but four are the most common: the sale of existing state-owned highways, use of private financing and management instead of public for new infrastructure, contracting to private companies the facilities previously provided by government for a limited period of time, i.e. concession, and simply contracting to the private sector roadway maintenance and operations tasks.

In the U.S., more and more states have enacted or revised legislation allowing public-private partnerships in transportation facility projects and removing institutional obstacles for roadway privatization. According to a 2006 study

(Nossaman 2006), there were already 18 states that had relevant laws, which allowed proposals for PPP projects. Opening in 1995, the SR91 Express Lanes was the first privately funded toll road built in the United States since the 1940s. Since 2001, private leasing projects have been implemented in at least seven states: Alabama, California, Illinois, Indiana, Michigan, Texas, and Virginia. New privatization initiatives have been officially proposed or are moving forward in the following states: Alaska, Colorado, Florida, Georgia, Illinois, Indiana, Missouri, New Jersey, Nevada, New York, Ohio, Oregon, Pennsylvania, Texas, Utah, and Virginia.

In the last few years, two multi-billion-dollar PPP toll road projects have attracted many interests and led to heated policy debates: the Chicago Skyway and the Indiana Toll Roads. In 2005, the Chicago government signed a 99-year concession to lease its 7.8 mile-Skyway toll road to a private sector for \$1.8 billion. The Chicago Skyway is a landmark in the PPP toll road field, because it is the first long-term leasing toll road in the U.S. Indiana soon followed by leasing its 157-mile Indiana Toll Road out to the private sector for 75 years for \$3.8 billion. Additional examples of the contracting out of existing public roads to the private sector include the Virginia Route 895 (Pocahontas Parkway), Dulles Greenway, South Bay Expressway (SR 125), Foley Beach Express, and the E-470 Toll way.

New privately-owned toll roads represent another popular roadway privatization scheme in the U.S. In this case, a private investor builds toll roads on owned or leased land and assumes full ownership-like responsibilities including design, finance, construction, operation and maintenance, while the public sector plays a minimized role in the process. This strategy has been used in several cases,

including four small toll roads in Alabama (Emerald Mountain Parkway, Alabama River Parkway, Black Warrior Parkway Bridge and Foley Beach Express) and Poinciana Parkway in Florida. Recent High Occupancy Toll lane projects in several states can also be categorized as new private toll roads.

A list of the major private toll roads projects in the U.S. is provided in Table 2-1. It can be observed that various PPP schemes have been adopted for these projects in their finance, leasing, design, build, operate, maintenance, and ownership transfer stages. The most popular regulatory tools include concession period agreement, price ceiling (i.e. maximum toll rates), and revenue sharing.

2.3 Benefits of Private Financing

Private financing is believed to be a promising approach to mitigating the current transportation financial shortfall by providing a new revenue stream for highway system.

After a private toll road is built, drivers pay for their direct use of the road and toll revenue go to retire the debt used to finance the construction and set aside funds for operation and maintenance of the road, to subsidize other relevant transport programs, or to be collected as project's investment return. Hence private financing can support road maintenance and provide extra road capacity without further straining government's budget.

Project Name	State	Type of PPP Arrangement	Regulation
Chicago Skyway	IL	Lease - Operate	99-year concession, maximum toll rate setting
Indiana Toll Road	IN	Lease - Operate	75-year concession, maximum toll rate setting
Pokahontas Parkway	VA	Lease – Develop - Operate	99-year concession, revenue sharing agreement
183A - Turnpike	TX	Design – Build	
I-15 Corridor Reconstruction	UT	Design – Build	
SH 130 (Segments 5 – 6)	TX	Design – Build – Finance – Operate - Maintain	50-year concession, revenue sharing agreement
Route 3 North	MA	Design – Build - Maintain	30-year lease
Dulles Greenway	VA	Design – Build – Finance - Operate	Maximum toll setting
Foley Beach Express	AL	Design – Build – Finance - Operate	
I – 495 Capital Beltway	VA	Design – Build – Finance - Operate	80-year revenue sharing agreement
I – 595	FL	Design – Build – Finance – Operate – Maintain	35-year concession
IH 635 Managed lanes	TX	Design – Build – Finance – Operate – Maintain	52-year concession
North Tarrant Express	TX	Design – Build – Finance – Operate – Maintain	52-year concession
South Bay Expressway	CA	Build-Transfer-Operate	35-year concession, market tolls
DC Streets	DC	Operate and Maintain	5-year concession
King Coal Highway	WV	Design - Build	
Palmetto Expressway	FL	Design – Build - Finance	
I-635 Managed Lanes	TX	Design – Build – Finance – Operate – Maintain	52-year concession, revenue sharing agreement
91 Express Lanes	CA	Design – Build – Finance – Operate	35-year lease, “non-compete” clause
Northwest Parkway	CO	Lease – Operate	99-year lease, revenue sharing agreement

Source: FHWA <http://www.fhwa.dot.gov/ipd/p3/>

Table 2-1: Major Roadway Projects in U.S Involving the Private Sector

Besides providing extra road funding, private financing has been proved to be an effective tool for congestion management (Samuel 2000; Nash 2007). Also, private roads are expected to provide better quality road services because of the self-financing nature of the roads. Unlike general transportation agencies that rely on legislators for funding and tend to be responsive to key politicians, private agencies are inclined to be more customer oriented because they live on toll revenues from hundreds of thousands of motorists and hence are under more pressure to provide good value for money. Last but not least, fairness is another strong argument in support of private finance. The sense of fairness lies in the fact that private roads usually charge variable tolls based on the number of vehicle axles, meaning heavier vehicles like trucks pay higher tolls than regular passenger automobiles. The rationale behind the policy is that heavy vehicles tend to impose more costs on roads than lighter vehicles and that it is fair for those impose more road costs to pay proportionately (Samuel 2000). In fact, the current highway charge system centering on motor fuel taxes is doing a poor job of reflecting road costs imposed by heavy vehicles. Most toll roads generally charge variable tolls based on the number of vehicle axles, a way corresponding more closely than motor fuel taxes with the degree of pavement wear imposed by vehicles. Hence private roads have greater potential than public highways in reflecting road costs imposed by vehicles.

2.4 Concerns Regarding Private Financing

Double taxation is the greatest concern many people have about private roads. Motorists argue they already pay for roads through user fees, mostly in the form of motor fuel taxes, and charging tolls on facilities, especially the ones built and operated with taxes, constitutes double taxation (Samuel 2000). This is hardly a valid argument which can be rebutted from two perspectives. The buying power of motor fuel taxes has been significantly weakened, user fees paid in this manner are simply not enough to pay for current road services and hence charging extra fees is necessary. Also heavy vehicles are paying much less than the costs they impose on roads in the current user charge system and tolling is an effective way to correct the unfairness by charging user fees in proportion to the costs vehicles impose on roads.

Another way to explain why tolling does not constitute double taxation is to define transportation costs as consisting of direct costs of building and maintaining a roadway and indirect costs of traffic emission, noise and delays imposed by users on the road system. Motor fuel taxes only pay for direct costs of roadway system and don't cover the indirect costs. However, when drivers squeeze their vehicles onto already crowded freeways, they impose surprisingly large levels of additional delay on the vehicles already on the network. Therefore, the indirect costs associated with traffic delays, noise and emissions are in fact very significant and should not be ignored (Wachs et al. 2003). By imposing tolls on private roadway, drivers are motivated to pay for the indirect costs by either paying tolls or reducing unimportant trips.

2.5 Private Road Categories

There are several most common private road arrangements in the U.S:

- **Design-Bid-Build (DBB):** Design-Bid-Build is a traditional contracting method for a construction project. Under this mode, the design and construction phases are bid and performed by separate independent contractors.
- **Shadow Toll and Private Contract Fee Services:** Shadow tolls are payments made by government to the private sector operator of a road based, at least in part, on the number of vehicles using the road. First proposed in the UK by the Conservative government in 1993, they are currently in operation on some roads in the UK, and then have also been adopted in other countries. Private contract fee service is a kind of shadow toll. Public operating agencies utilize fee service contracts to transfer responsibility for asset operation and management to the private sector. These comprehensive agreements involve both service and management aspects and are often useful in encouraging enhanced efficiencies and technological sophistication. Contractors can be paid either on a fixed fee basis or on an incentive basis, where they receive premiums for meeting specified service levels or performance targets.
- **Design-Build (DB):** Design-Build is an innovative contracting method for a construction project, comparing to the Design-Bid-Build method. Under this mode, the agency or owner holds a single contract with a single private entity for both the design and construction of a project. However, the private sector

will transfer the road to the government and state when construction is completed.

- **Build-Operate-Transfer (BOT)/Design-Build-Operate-Maintain (DBOM):** Under this mode, private firms will receive a franchise from the public sector to build a road and operate it, get the investment back through the revenue of the toll road. The government and state generally sets out regulatory provisions in the franchise agreement to regulate the toll of the road. After a specify period, which was negotiated before, the toll road will be taken over by the state usually without charge and debt.
- **Lease-Develop-Operate (LDO)/ Lease Agreements:** Under this mode, the private firms and government will negotiate a lease that the government holds the ownership of the road and the private firms will lease the toll road for a period of time to get the investment back from the revenue. The government and state generally sets out regulatory provisions in the franchise agreement to regulate the toll of the road. After a specified period, which is previously negotiated, the toll road will be transferred back to the public sector.
- **Design-Build-Finance-Operate (DBFO):** Under this mode, the private sector may agree to provide some or all of the financing for the toll road project by raising independent capital. Then the private sector will operate it to recover the investment and earn a reasonable return from the toll revenue during a set period. After that, the road will be reverted to public ownership.
- **Build-Own-Operate (BOO):** Under this mode, a private sector is granted the right to develop, finance, design, build, own, operate, and maintain a toll road

project. The private sector partner owns the project outright, retains the operating revenue risk and all of the surplus operating revenue in perpetuity.

Through the definition of the categories, we can find that from the Category Design-Bid-Build (DBB) to Category Build-Own-Operate (BOO), the public responsibilities decrease, while the private responsibilities increase.

2.6 Risks Associated with Private Financing

Transportation economists studying the interaction of economics and the law have long recognized that contracts play a key role in allocating the risk of any economic activity among the contracting parties. Public-private partnerships are no exception. One role of a public-private agreement is to determine how the risks inherent in a given transportation project will be distributed between the government and the private partner. Importantly, without some form of private participation, state and local governments by default bear almost all the risks associated with financing, designing, constructing, operating and maintaining a transportation asset.

Traffic, revenue, or demand risks may be the most important economic risks associated with the design and construction of a new transportation facility, that is, with a private toll road. These are the risks that actual or realized traffic volumes, and thus revenues, will be less than projected at the time the facility was planned and constructed. These risks are important because they could impact the private partner's financial viability, and its ability to repay its debt. In many public-private agreements, the private partner receives its compensation through collection of facility toll

revenue. The private company therefore assumes demand risk. This is consistent with basic principles of efficient risk allocation, since private investors are usually highly diversified, assume demand risk voluntarily, and are compensated for this type of risk assumption. The risk of competing facility construction (normally addressed in the United States through non-compete clauses, as discussed below), is a subset of traffic or revenue risk, since a competing free facility may reduce traffic and thus revenues on the facility. The most common types of risks associated with private sector involvement into construction and operation of transportation facilities are the following:

- **Cost Overrun Risk:** This is the risk that the actual cost of a transportation project will exceed its expected cost. There are a variety of risks associated with completing a transport facility that may cause costs to raise, such as unexpected geological conditions, problems in design, and increases in the cost of materials.
- **Time Overrun Risk:** This is the risk that a project will take longer to design and construct than expected. This risk is sometimes conflated with cost overrun risk. Although it is obviously related to cost overruns, it is a distinct risk, since it is possible for a project to be completed on budget, but later than expected, which carries a unique set of hazards. If a project is delayed, motorists will be denied the use of the facility during the time delay. Those are not necessarily hazards associated with cost overruns.
- **Maintenance and Operation Risk:** These include maintenance costs that are higher than anticipated as well as operational failures. Operational risk is

generally associated with the risk that road capacity might be unavailable. It includes roadway unavailability during winter due to snow and ice, as well as lack of availability due to staff management issues.

- **Financial Risk:** This risk arises because the anticipated financing for the project might not materialize at the expected cost of finance. It includes not only risks associated with raising the necessary capital, but also exchange rate risks, interest rate risks, and insurance costs, among other sources.
- **Environmental Risk:** This is the risk that the necessary environmental permits to construct the facility will not be forthcoming, and that costs associated with environmental mitigation will be higher than expected. It is usually relevant for a major expansion of an existing facility.
- **Regulatory Risk:** This risk includes the possibility that regulations will adversely affect facility profitability. If, for example, a facility is rate-of-return regulated, this includes the possibility that tolls will not be increased adequately to allow the operator to realize a market rate of return on their investment. It can also include changes in planning and environmental requirements. Also there is the possibility that the public sponsor will decide to cancel the project after bidding has been completed or after construction has begun.

The key question that must be addressed in public-private partnerships is: which of these risks are best borne by investors and which by public sector in their capacity as transportation facility owners? There are two basic elements to risk management: who is best able to control the risks and who is best able to bear the

remaining systematic risk via hedging and diversification. Investors may be better able to manage some risks while others are best borne by the public sector. The public agency may be better able to manage risks associated with regulatory and environmental risks, whereas private partners may be better positioned to manage financial risks.

Although patterns are emerging, the contracting parties often determine the best allocation for the particular project at hand and given the prevailing capital market conditions. The optimal risk allocation across parties may vary across projects, jurisdiction, and time. The public sector might assume greater risk (such as assuming demand risk through shadow tolls or availability payments) in some cases in order to attract private investment and to realize the numerous other benefits associated with private participation. Risk sharing does in fact appear to vary widely across projects. As noted, under exclusive government operation public sector assumes almost the entire range of risks associated with facility design, construction, maintenance, expansion and operation.

Risks transferred to the private sector are priced into the cost of the bid. The gains from risk sharing accrue from the fact that the private sector may be better at managing certain risks, so that the overall cost of risk management is reduced. The pricing of risk also helps to make the actual costs of risk more transparent. Some parties exposed to particular risks will be willing to pay a large sum to have those risks transferred to others. Other parties may be able to bear, or take actions to mitigate, those risks at a low cost and are thus willing to take them in return for some lower sum.

2.6.1 Sharing Risks through Non-Compete and Compensation Clauses

A non-compete clause is a provision in a public-private contract that prohibits the public partner from constructing an unplanned government-supported transportation facility that would compete directly with the privately operated facility in question. The clause is intended to protect the private partner's investment from competition from an unplanned competing facility. The issue of non-compete clauses was brought to the forefront of the U.S. PPP debate by the SR 91 Express Lanes in California.

A less restrictive version of a non-compete clause has emerged both in the United States and abroad, called a compensation clause. In a compensation clause, the public partner may construct an unplanned competing facility but is required to compensate the private partner for revenues lost from the added competition. The Indiana Toll Road concession agreement for example requires the state to compensate the concessionaire for lost revenues if the state constructs, within 10 miles of the Indiana Toll Road, a new interstate-quality highway of 20 or more continuous miles.

The economic rationale for such clauses is straightforward: both debt and equity investors will be loath to invest if they fear competition, and thus a loss of revenue, from a nearby government-supported facility. Non-compete clauses originally evolved to assure buyers of toll revenue bonds (both private and government issued) that traffic would not be diverted from the toll road, reducing its ability to repay that debt. The holders of any type of bond who anticipate being paid back via a facility's toll revenue are likely to demand guarantees against unplanned competing non-tolled roads. Although they are not always viewed as such in the

United States, compensation clauses are another example of risk allocation through contracts. They attempt to address one type of event among many (the construction of a competing facility) that can affect the revenues accruing to a particular facility. Compensation clauses in the United States have been adjusted depending on the contractual setting. The Chicago Skyway agreement, for example, offers the concessionaire no protection against the construction of unplanned competing facilities. However, this may not reflect imprudent risk assumption by the concessionaire since dense urbanization near the Skyway makes competing facility construction costly.

2.7 Previous Research on Roadway Privatization

Research on the general topic of congestion pricing and toll road financing dates back to the early 20th century (e.g. Pigou 1920). Mohring and Harwitz (1962) have researched whether the revenue generated by the socially optimal toll charges can cover the optimal road investment and, i.e. the self-financing theorem. Small (1999) examined the conditions under which a congested facility is self-financing with nonlinear pricing. Yang and Meng (2002) showed that the self-financing theorem holds on a network of toll roads when each link is optimally priced and all capacities are optimized. Verhoef and Rouwendal (2004) addressed some implications of the first-best and second-best congestion pricing on the applicability of the self-financing theorem using a numerical experimental approach.

When investing in toll roads, the private sector relies on future profitability of the toll roads to benefit financially. Viton (1995) assessed the economic viability of private roads for the situation where a private toll road competes with a free road. He concluded that private roads can be highly profitable under a range of assumptions about the mix of vehicle types and the costs of travel time, and presented a discussion of regulatory approaches to modify the impacts of simple profit-maximization. Mills (1995) discussed the possibility of divergence between profit and welfare objectives.

Another research subject regarding private toll roads is the market of private toll roads, in particular the competition/complementarities between private roads and between public and private roads on a network. De Palma and Lindsey (2002) investigated whether private toll road operators will implement time-based congestion pricing in a competitive environment using Vickrey's bottleneck model (Vickrey 1969) and three types of routes: private roads, public roads, and free access roads. Several studies have investigated traffic patterns and economic welfare under various types of mixed-ownership schemes in parallel networks where links are substitutes for each other (de Palma 1992, Verhoef et al. 1996, Zhang and Levinson 2004, 2006, Zhang 2008). Previous research on revenue choices on a serial network managed by multiple jurisdictions (Levinson 1999, 2000, Small and Verhoef 2007, Verhoef 2007) have shown that if each link in a serial network is controlled by a different private operator, each private operator internalizes both the congestion externality of its own link and other links in setting the toll. Verhoef and Small (2004) examined the revenue-maximizing, first-best and second-best pricing schemes under user heterogeneity and elastic demand in a simple network with both parallel and serial

links. They showed that product differentiation mitigates the difference between the revenue-maximizing and the first-best results, and that user heterogeneity has more impact on the effectiveness of the second-best policies. Yang and Meng (2000) investigated the profitability and social welfare gain of a single new toll road in a general network through numerical experiments. Yang et al. (2002) further examined the impact of user heterogeneity on the profitability and social welfare gain of new toll roads.

Several researchers have investigated transportation system privatization with a broader multimodal focus (i.e. not just roadways). Roth (1996) reviewed various aspects of road commercialization and privatization in the market economy conditions. Gomez-Ibanez and Meyer (1993) have reviewed transportation privatization at an empirical level. Kahn (1988) and Train (1991) studied the pros and cons of various ownership regimes based on the type of regulation. Winston and Shirley (1998) developed a quantitative model of the welfare effects of transportation privatization with emphasis on the transit system.

2.8 Literature Review on Network Growth

As acknowledged in previous research, the primary challenge in understanding the various ramifications of roadway privatization is to model the interdependencies among travel demand, roadway congestion, roadway capacity supply, pricing, and market entry decisions in a dynamic mixed-ownership network with both public- and private-sector decision makers to predict network changes in

the future. Various methods have been adopted in previous research for study and modeling transportation network growth.

Few researchers have considered the process of transportation network growth at microscopic level. Taaffe et al. (1963) studied the economic, political and social forces behind infrastructure expansion in underdeveloped countries. Their study finds that initial roads are developed to connect regions of economic activity and lateral roads are built around these initial roads. A positive feedback between infrastructure supply and population was also observed. Barker and Robbins (1975) investigated the London Underground's growth, Miyao (1981) developed macroscopic models to take transportation improvements as either an endogenous effect of urban economy or as an exogenous effect on the economy. Endogenous growth theory suggests that economic growth is a two-way interaction between the economy and technology; technological research transforms the economy that finances it (Aghion and Howitt 1998). The technology of transportation is unlikely to be an exception, suggesting transportation investment drives the growth that funds it. Macroscopically, the growth of infrastructure follows a logistic curve and that road infrastructure also has reached saturation levels in developed countries (Grübler 1990). Miyagi (1998) proposes a Spatial Computable General Equilibrium (SCGE) model interacting with a transportation model to study the interaction of transportation and the economy. Yamins et al. (2003) develop a road growth model to study co-evolution of urban settlements and road systems from an empty space with highly simplified travel demand and road supply mechanisms meaningful only for theoretical works. Garrison

and Marble (1965) observed that connections to the nearest large neighbor explained the sequence of rail network growth in Ireland.

Carruthers and Ulfarsson (2001) find that various public service expenditures like roadways are influenced by demographic and political characteristics. The New Jersey Office of State Planning (1996) also finds a similar pattern in roadways expenditure. A related line of research examines how transportation investment affects the economy at large, but tends to treat transportation (or highways) as a black box, and makes no distinction between different kinds of highway investment (Aschauer 1989, Button 1998, Gramlich 1994, Nadiri and Mamuneas 1996). Boarnet (1997) is the most detailed of these types of studies, considering county level roads. The input is investment in transportation (or infrastructure), and output is gross domestic product, measured at the state or county level.

In the last two decades the dynamic traffic assignment tools became highly popular for analyzing complex transportation systems. The concepts of preference or self-organization have been introduced to interpret network dynamics as a spontaneous process. In the first strand of research the focus was on describing network growth in stages, in the second - researchers constructed models that would replicate observed developed network patterns. However, these studies, originated by the interest to replicate the observation of network topologies, had to deal with simple networks using heuristic and intuitive rules for network growth and transformation due to the lack of understanding on the inherent mechanisms with regard to why and how transportation networks evolve. In recent years, solution algorithms to user equilibrium have been widely incorporated to solve the network design problems

(NDP). Typically the NDP is formulated as a bi-level framework in which the lower-level represents the demand-performance equilibrium for given investment while the upper level represents the investment decision-making of the transport planner to maximize social welfare based on the unique equilibrium flow pattern obtained from the lower-level problem. If the NDP were how decisions are made, network changes would be due to planners' rational behaviors to maximize the efficiency of a given network, measured according to some quantifiable objective, based on predicted traffic with budget and other constraints. Verhoef et al. (2004) explored the interrelations between pricing, capacity choice, and financing in a small network model; Zhang and Levinson (2005) proposed an analytic model discussing properties of long-run network equilibrium with regard to price and capacity with different small network layouts and ownership regimes. Levinson et al. (2003) focused on understanding the conditions under which new links could be constructed on a highway network as opposed to existing links being improved, and developed a model to predict the location of new highway construction based on the surrounding conditions of the new link, the estimated cost of construction, and a budget constraint. Levinson et al. (2007) incorporated jurisdictional planning processes to forecast network growth. In their attempts to predict the Twin-Cities seven-county road network 30 years from now, they developed network forecasting models with stated decision rules, processes encoded in flowcharts and weights developed from official documents or by discussion with agency staff. Montes de Oca and Levinson (2006) have shown that different levels of jurisdictions including the state (the Minnesota Department of Transportation), region (the Metropolitan Council), and seven counties

developed respective stated decision making processes in which federal or local funding are allocated to road projects prioritized according to their funding needs based on measured pavement quality, level of service, safety, and other conditions.

Agent-based modeling, formalized first by Von Neumann and Morgenstern in their work on self-reproducing automata (1944), provides an effective tool for capturing the various interactions between public/private roads and system users over time and across space. A number of transportation related agent-based applications already exist in the literature. Most of them are still under development or at the experimental stages, but they clearly demonstrate that implementing these methods has a significant potential to improve the performance of traffic and transportation systems. The applications of the agent-based models as well as related studies are reviewed in the following section.

2.9 Agent-Based Modeling Applications in Transportation

Kikuchi et al. (2002), Sanford Bernhardt (2007), and Chen and Cheng (2010) are examples of papers that review literature and examine how agent-based modeling is applied to transportation research. These reviews demonstrate that the most common applications of agent-based models in transportation are traffic or pedestrian simulation and demand modeling efforts.

Traditionally, researchers have been using the four-step travel demand models for travel demand forecasting and network growth. As more and more research efforts move from conventional trip-based models to activity-based models, application of

agent-based models in travel demand modeling attracts increasing research interest. Some researchers focused on the departure time and route choice for a specific trip (most of the time the commute trip), and others investigated the more comprehensive activity patterns and the travel demand these activities generate. Departure time and route choice simulation models are traditionally connected with traffic assignment models with an explicit and detailed representation of the transportation network that is subject to congestion. Therefore travelers' choice adjustment from day to day has been investigated since early days (see, e.g., Horowitz 1984; Cascetta and Cantarella, 1991; Yang and Zhang 2009; Cominetti et al. 2010). Route and departure time choice have largely followed the utility-maximization paradigm in these so-called day-to-day "dis-equilibrium" models with a few exceptions including the "indifference band" theory (Mahmassani and Chang 1987) and the SILK-BUE model (Zhang 2006; Zhang 2007).

Simulation-based dynamic traffic assignment models find it straightforward to apply the learning processes similar to those in Horowitz (1984) to simulated individuals. Examples are Ben-Akiva et al. (1991) (DynaMIT) and Emmerink et al. (1995). Both assume that a traveler updates travel times on experienced routes only. Ben-Akiva et al. (1991) assumes utility maximization, and Emmerink et al. (1995) utilizes the "indifference band" theory, which states that a traveler does not necessarily seek the optimum, and would stay on the current route if the change in travel time from consecutive days is not larger than a threshold. Jha et al. (1998) (DYNASMART) uses Bayesian updating to update travel time perceptions for joint departure time and route choice, and also assume utility maximization. Rossetti et al.

(2002) (DRACULA) has a similar link travel time updating mechanism and also assumes shortest path choice. Ettema et al. (2005) use reinforcement learning to update perceptions and assume utility maximization in a day-to-day departure time choice simulation. Nakayama et al. (2001) simulates a learning process in route choice by assuming drivers are choosing from a set of simple decision rules based on experience. Ozbay et al. (2001) use stochastic learning automata (SLA) to analyze drivers' day-to-day route choice behavior. An internet based route choice simulator is developed to calibrate the model. The calibrated SLA model is applied to a simple transportation network to test if global user equilibrium, instantaneous equilibrium, and driver learning have occurred over a period of time. It is shown that the sample network converges to equilibrium, both in terms of global user and instantaneous equilibrium. Arentze and Timmermans (2005a) and the subsequent Han et al. (2008) deal with spatial knowledge learning explicitly. When making a trip, individuals make observations that may increase their knowledge about their environment. Arentze and Timmermans (2005a) develop a measure of expected information gain based on a Bayesian model of mental maps and belief updating. They argue that expected information gain is an element of the utility function of trip choice alternatives under conditions of limited information and learning. The simulations conducted illustrate that expected information gain tends to favor longer trips and variety seeking in terms of both route and destination choice. They argue, therefore, that individuals may perceive a positive utility of travel through environments with which they are less familiar. SILK-BUE is another simulation-based traffic assignment program developed by Zhang (2006) where route choice is modeled

without the perfect rationality assumption (i.e. complete information and utility maximization). Bayesian learning is used to update perceptions of route attributes. Expected search gain is compared to search cost to determine whether a search will be performed at all. A search process is explicitly modeled for the generation of choice set. Search rules are represented by a decision tree generated from survey data, which determine whether an alternative will be considered. If an alternative is indeed going to be considered, another decision tree is applied to decide whether the traveler will switch to the new alternative. The traffic equilibrium under the adopted positive assumptions is defined as the Behavioral User Equilibrium at which the subjective search gain is lower than the perceived search cost for all users. Results suggest that normative assumptions, such as perfect information and unlimited human abilities to maximize utility, can produce significant prediction biases.

With regard to agent-based activity models STARCHILD (Recker et al. 1986a; Recker et al. 1986b) models the activity and travel scheduling decision as a classification and choice process, which is dependent on the basic concepts of utility maximization within a constrained environment, and results in observed travel/activity behavior. The key features are the detailed representation of constraints in the identification of alternatives, and the use of a classification method to generate the choice set. Also, SCHEDULER (Garling et al. 1994; Golledge et al. 1994) is one of the first computational process model (CPM) of activity-travel patterns. A CPM focuses on the process of making a decision, while the econometric approach such as utility maximization focuses on what factors affect the final choice but not how the utility is maximized. AMOS (Kitamura et al. 1993; Kitamura 1996) (Activity-

Mobility Simulator) is a unique system in that it predicts the switch response to a policy change from a “baseline” activity schedule, which is an input to the model. A neural network is used to predict an output signal for each alternative, which is a scalar function of 36 decision-maker characteristics under the policy change. A multinomial logit model converts the output signals to probabilities by using the output signal as the only explanatory variable in the utility function. The parameters of the basic response model are estimated from data supplied by a policy specific stated preference survey. The switch decision is made with a satisfying rule, rather than utility maximization.

Zhang and Levinson (2004) propose an agent-based travel demand model. In this model, three types of agents interact to one another: node, arc, and traveler. The goal of each traveler agent is to find and reach the activity with the lowest travel costs. Travelers move between nodes through the connecting arcs and decide to either accept or reject the opportunities at the nodes. During this search, they learn arc costs. They add this information to the exchangeable knowledge base as well. Similarly, node and arc agents also have specific properties and learning abilities. Along with these properties, some other interaction rules (including learning rules) complete the model. This framework enables the model to perform trip distribution and route assignment. Dia (2002) presents an agent-based approach to model dynamic driver behavior under the influence of real-time traffic information. For each form of the provided information (e.g. quantitative delay, predictive and prescriptive delay) to drivers, a number of multinomial logit models are developed to determine the factors which affect the propensity of the drivers to adjust their travel patterns and to

determine the values of these factors. This evaluation is based on a field behavioral survey in a congested real-world commuting corridor. Based on these driver behavioral models and to evaluate the impacts of providing drivers with travel information, an agent-based framework for a microscopic traffic simulation tool is presented, which applies the Belief, Desire, and Intention (BDI) agent architecture.

Another study which applies the BDI concept is Rossetti et al. (2002). They propose an extension to an existing microscopic simulation model called Dynamic Route Assignment Combining user Learning and micro-simulation (DRACULA). In this extension, the traffic domain is viewed as a multi-agent world and the behavior of agents is represented in terms of mental attitudes, which allow them to make decisions about route choice and departure time. The main part of this paper is concerned with the reasoning mechanism of drivers modeled by means of BDI architecture.

Hao et al. (2010) focus on integration of an activity-based travel demand model, TASHA, with a dynamic agent-based traffic simulation model, MATSim. This research has two main objectives. The first is to develop an agent-based framework that includes both travel demand modeling and traffic assignment by integrating the above mentioned software. The second objective is to employ this newly integrated model in vehicle emission modeling. In this study, an iterative process is applied for the integration and a series of data conversions is proposed to make this process possible. The modeling framework is implemented to the greater Toronto area. Flötteröd et al. (2011) is another study which links the demand models to the agent-based traffic simulation. This study concentrates on the calibration of

demand models in the context of dynamic traffic assignment. Calibration refers to the estimation of the models' parameters (such as the coefficients of a utility function) from time-dependent traffic counts. These parameters represent the simulated travel behavior.

As can be seen, notable efforts have been dedicated to applying agent-based approach in transportation. Transportation systems consist of numerous intelligent agents such as travelers, drivers, and vehicles that interact with one another on various time scales in urban and regional systems, producing important and often complex system-level patterns, such as travel demand and congestion, and agent-based modeling techniques appear to be helpful in handling these interactions.

2.10 Summary

Many issues exist with regard to developing practical methods for evaluating network growth patterns and private toll road projects. While a number of previous studies have addressed these issues theoretically, few quantitative tools are available to decision makers who need reliable information on the impact of roadway privatization. There are large gaps between academic research and the practice of roadway privatization. In the U.S., state and local government officials, when considering individual private road projects, often rely on traffic and revenue estimates provided by consulting firms with their proprietary software and modeling tools. There is also a lack of understanding on the system-wide long-run impact of a series of private toll roads projects enabled by a specific policy regarding roadway

privatization. In practice, it is usually important to determine the type and intensity of regulation on private-sector roadway investment. Proper and effective regulation is the key to compromising and aligning the private sector's profit-maximizing objectives with the public sector's welfare/user benefit maximizing objectives as well as desired network configuration.

Chapter 3: Empirical Analysis of Investment Decision-Making under Public Ownership Regime

3.1 Introduction

Transportation planning in the Washington DC-Baltimore region is a good example of multimodal and multi-jurisdictional transportation planning and investment processes. The region's current transportation network is comprised of highways, arterial and local streets, managed lanes, Metro subway and commuter rail, extensive regional and local bus services, and three major airports (MWCOG 2008). Many agencies are involved in the regional planning process, including transportation departments in the District of Columbia, Maryland, Virginia, two large metropolitan planning organizations, regional and local transit authorities, and county and city planning agencies. The regional transportation system today is the result of previous investment decisions. These decisions are documented in long-range plans, mid-term transportation program reports, and short-term transportation improvement programs. However, often not documented very well is the decision-making process through which investment needs and projects are identified, candidate projects are prioritized, political considerations and technical merits are balanced, and conflicts between the objectives of different agencies are resolved.

This chapter presents a qualitative analysis of the multimodal transportation investment decision rules and processes adopted by various jurisdictions in the Washington DC-Baltimore area. Interviews have been conducted with staff members

at the county-, metropolitan-, state- and regional-level agencies. Findings from these interviews reveal the details of the investment process in this region, and the advantages and disadvantages of the existing processes and procedures.

This chapter is organized as follows. Background information about transportation and planning agencies in the DC-Baltimore region and the overall decision-making structure is presented in Section 3.2. Section 3.3 summarizes the interview methodology and general questions discussed during the agency interviews. Section 3.4 documents the interview findings, and analyzes the investment decision-making processes within and between individual agencies. Section 3.5 discusses the pros and cons of the existing transportation investment process based on the interview findings, as well as possible alternative investment processes. Section 3.6 present examples of investment processes in other states, and Section 3.7 concludes the chapter.

3.2 Background

The growth and decline of transportation networks result from a series of interdependent systems investment decisions (e.g. maintenance, capacity expansion) in response to changing travel demand and technology. Authorities making these investment decisions include federal, state and local government and planning agencies, which often share mobility, accessibility, and welfare objectives. However, agencies are most interested in the achievement of these objectives in their own jurisdictions, or for the transportation modes under their direct supervision. This

multimodal and multijurisdictional reality sometimes fosters collaboration, but can also create funding competition between agencies as the total amount of transportation funds for a region is often fixed. Transportation revenues in the DC-Baltimore area traditionally come from different sources including federal grants, user fees, fuel taxes, local revenues, bond sales, and are held in state transportation trust funds. Like many other regions in the US, rising costs, stagnating revenue, and greater needs in the DC-Baltimore area have created a transportation investment environment where priorities are given to system preservation, maintenance, and safety needs, and major new initiatives and capital programs have to be scaled back. Cities, counties, states, and modal agencies are all concerned with funding operational and capital needs in the transportation system in times of limited budgets. In such a situation, to achieve the greatest investment returns, it could be beneficial to implement new investment frameworks in order to meet the target levels of system performance, as suggested by Oh and Kumares (2009). Different organizational structures, such as independent Metropolitan Planning Organizations (MPO) in Florida (2007) or more powerful regional MPOs, or DOT-oriented schemes may have different implications on the efficiency and equity of transportation investments. While changing the existing organizational structure is difficult and a long-term issue, a critical routine task for transportation planning agencies is to coordinate transportation investment and maximize overall system effectiveness under the existing organization structure.

One may argue that the goal of maximizing transportation investment returns (in terms of improved mobility, accessibility, and support for economic development)

would be more or less achievable if the transportation system in a region is completely controlled by a powerful centralized agency. In reality, there are often many jurisdictions and agencies involved. This is particularly true for the DC-Baltimore region. The key players in the region are DC, Maryland, and Virginia Departments of Transportation (DOTs), state transportation modal agencies (e.g. State Highway Administration, and Transit Administration in Maryland), Metropolitan Washington Council of Governments (MWCOC) that includes the MPO for the DC metropolitan area – DC Transportation Planning Board (TPB), Baltimore Metropolitan Council (BMC) that includes the MPO for the Baltimore metropolitan area – Baltimore Regional Transportation Board (BRTB), several smaller MPOs in Maryland and Virginia, Washington Metropolitan Transit Authority (WMATA) – the regional transit authority, as well as county and city planning agencies. Figure 3-1 illustrates the relationship among these agencies and how in general transportation needs are identified (dashed arrows) and funds allocated (solid arrows) by these agencies. DOTs are largely responsible for expanding and maintaining the major highway systems and supporting public transit in the region (MWCOC 2008). DOTs are the main recipients of Federal Highway Trust Fund dollars and state transportation funds, which are then distributed to all modes of transportation. In the DC-Baltimore region, three state DOTs participate in the planning and investment processes: Virginia DOT (VDOT), Maryland DOT (MDOT) and the District DOT (DDOT).

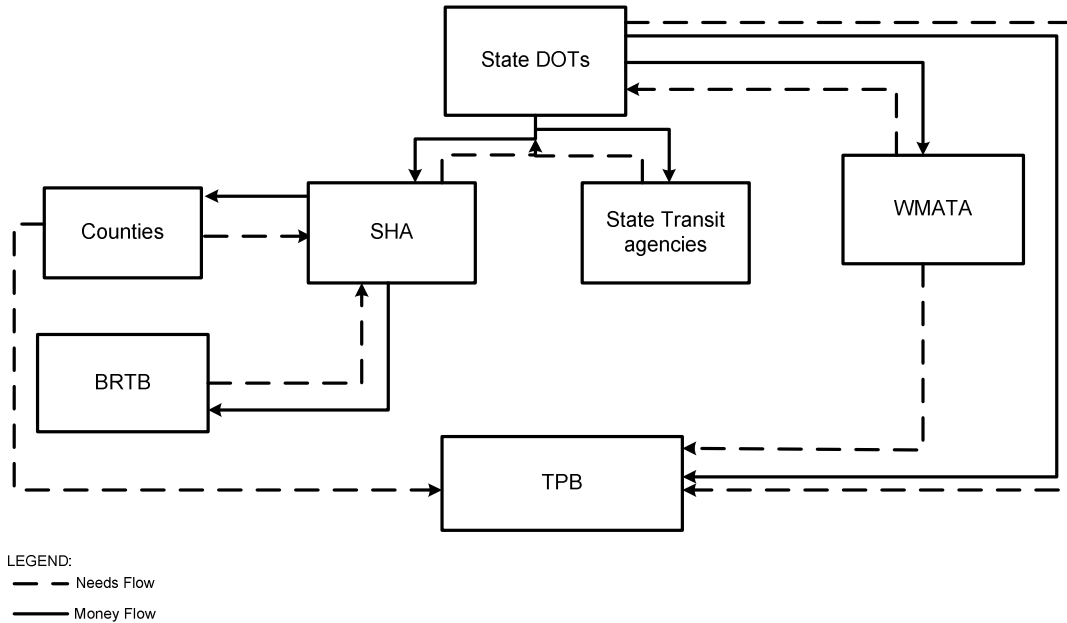


Figure 3-1: Washington DC - Baltimore Region Key Transportation Agencies Interactions

Although the District of Columbia is not a state, DDOT is officially recognized by the federal government as a state DOT. DDOT has responsibility for the federal interstate highways within the District’s boundaries as well as local streets and roads. MDOT manages all state highways through its State Highway Administration (SHA), and state transit facilities through Maryland Transit Administration (MTA). WMATA operates the Metrorail subway system, Metrobus regional bus transit system, and MetroAccess on-demand bus service. Many jurisdictions of Virginia and Maryland support their local bus services in addition to WMATA systems.

The majority of funding for the region comes from federal and state sources. These funds are allocated through the state budgeting process in the state legislatures. Every year the governors of Maryland and Virginia submit proposed capital

improvement budgets for transportation to their state legislatures. These budgets include state and local tax revenues, bond sales and federal funds that have been apportioned to the states on a formula basis. Using the governor's budget as a starting point, each state legislature enacts a spending bill for transportation. In general, some transportation funding is allocated according to predetermined formulas and in other cases projects are funded individually due to strong promotion by interest groups. In the District of Columbia the mayor submits a budget to the D.C. Council that includes transportation funding. But unlike Maryland and Virginia, the District submits its spending bill directly to the U.S. Congress for approval.

Each state and the District, as well as the MPOs, transportation modal agencies, and local government agencies, have their own planning and investment processes. Although the final investment decisions are specified in long-range plans and transportation improvement programs, the main goal of this empirical analysis is to identify the political and technical factors that drive the decision-making process, and how various agencies at different levels interact and collectively allocate transportation funds based on these factors in the DC-Baltimore region. Since investment decisions determine the shape of future transportation network, understanding the existing investment process is necessary for planner who wants to shape future transportation systems. A previous study in Minnesota has analyzed the highway investment process in the Minneapolis-St. Paul metropolitan area (Montes de Oca, Levinson 2006). As the transportation investment processes are documented for more regions, comparison of different investment processes will become possible, which should also provide valuable information for planners.

3.3 Methodology

In person interviews have been conducted with the staff of two MPOs (TPB in DC, and BRTB in Baltimore), Maryland DOT, Maryland State Highway Administration (SHA), Prince George's County and Montgomery County in Maryland, and the regional transit agency WMATA. While the in-person interviews focus more on agencies in Maryland, planning documents published by agencies in the District of Columbia and Virginia are also used for this study. In order to gather first-hand information on both documented and undocumented investment procedures, staff members in these agencies who directly participate in or supervise the planning and investment decision-making processes are chosen for the interviews. All but one interview involve multiple planners from the same agency. The interview procedure is similar to what is used in a previous study by Montes de Oca and Levinson in Minnesota (2006). The main objectives for the interviews were to identify:

- Agencies' main priorities and criteria that guide investment processes;
- Procedures for identifying needs and generating candidate projects;
- Procedure for selecting/prioritizing candidate projects;
- Methods for quantitative technical project evaluation, and the role of non-technical political influences;
- Procedures for agency interactions concerning needs identification and funding allocation.

The interviews were digitally recorded with the permission from interview participants. After interview request was approved by an agency, a list of interview questions were sent to all interview participants before the actual interview. This list of questions was customized for each agency based on its jurisdictional oversight, unique interactions with other agencies, and modes of transportation under its supervision. In general, the following core questions were asked at all interviews.

1. What is the current method for identifying transportation needs?
2. What is the current procedure for identifying and selecting projects?
3. How are candidate transportation projects generated?
4. What is the institutional procedure for proposing transportation projects?
5. What are the most important performance measures (e.g. safety, road conditions, and pavement conditions, capacity), or investment criteria that are considered in the project selection process?
6. What are the policy initiatives that influence transportation investment?
7. What quantitative scoring and ranking method (if any) does the agency use for transportation project selection?
8. What qualitative project prioritization method (if any) does the agency use?
9. How are transportation funds for different modes (e.g. highway and transit) allocated?
10. How is funding allocated among different types of transportation improvement, e.g. maintenance, modernization, capacity expansion, new facilities?

11. What are the sources of funding for transportation projects? How do the federal, state, and/or local agencies share project costs?
12. How does the agency collaborate with other agencies in the region?
13. What is the role of political considerations in the transportation investment process?
14. What is the role of public opinions in the transportation investment process?

3.4 Current Transportation Investment Decision-Making in the Washington DC Region

The following subsections summarize the transportation investment process of each interviewed agency, and the interactions among these agencies.

3.4.1 DC Transportation Planning Board

Transportation Planning Board (TPB) is the metropolitan planning organization that brings together key decision-makers in the Washington DC area to coordinate planning and funding for the region's transportation system. The TPB became associated with the Metropolitan Washington Council of Governments (MWCOG) in 1966. MWCOG was established by local cities and counties to deal with regional concerns including growth, housing, environment, public health and safety, as well as transportation. Although the TPB is an independent body, its staff is provided by MWCOG Department of Transportation Planning. The TPB's planning area covers the District of Columbia and surrounding jurisdictions within the metropolitan statistical area (MSA). The TPB's decision-makers are mayors, city council members, and county board members, representatives from DC, Maryland,

and Virginia DOTs, regional transit agency (WMATA), and the state legislatures. The TPB also includes non-voting representatives from key federal agencies, the Metropolitan Washington Airports Authority (MWAA) and the TPB's Private Providers Task Force (MWCOG 2008).

The TPB's planning process is schematically represented on Figure 3-2. Even though the TPB represents so many jurisdictions, it does not have direct control over transportation funding resources (they are mainly allocated by state DOTs as discussed later) and is not responsible for construction or maintenance of the transportation system. Nonetheless, the key transportation agencies in the region are required to submit project proposals to the TPB for conformity analysis. The TPB's role is to produce two regional planning documents: the financially Constrained Long-Range Transportation Plan (CLRP) and the Transportation Improvement Program (TIP) for the metropolitan Washington area, which both comply with environmental goals for the region. The CLRP uses a planning horizon of 25-30 years. In order to receive federal funding, transportation projects must be included in the CLRP and the TIP. Individual agencies that submit project proposals to TPB are responsible for the funding of the projects.

Project developments for the CLRP and the TIP occur at the state and local levels. The District of Columbia, Maryland and Virginia each controls its own funding streams and each has its own system for prioritizing projects. In general, the TPB has little influence on the types of projects incorporated into the plans unless that is a violation of the environmental goals. TPB "very rarely, if any at all" remove or

proposed to remove state-sponsored projects from the long-range plan, because the states provide their own funding sources for the projects.

The TIP includes all the regionally-significant projects that the states and other jurisdictions have programmed and approved for the next six years. Like the CLRP, the TIP is subject to federal review and must meet air quality conformity requirements. The CLRP and the TIP are updated on an annual basis. Each state and other participating agencies in the region have their own procedures for developing projects for the TIP, which is described later in this section.

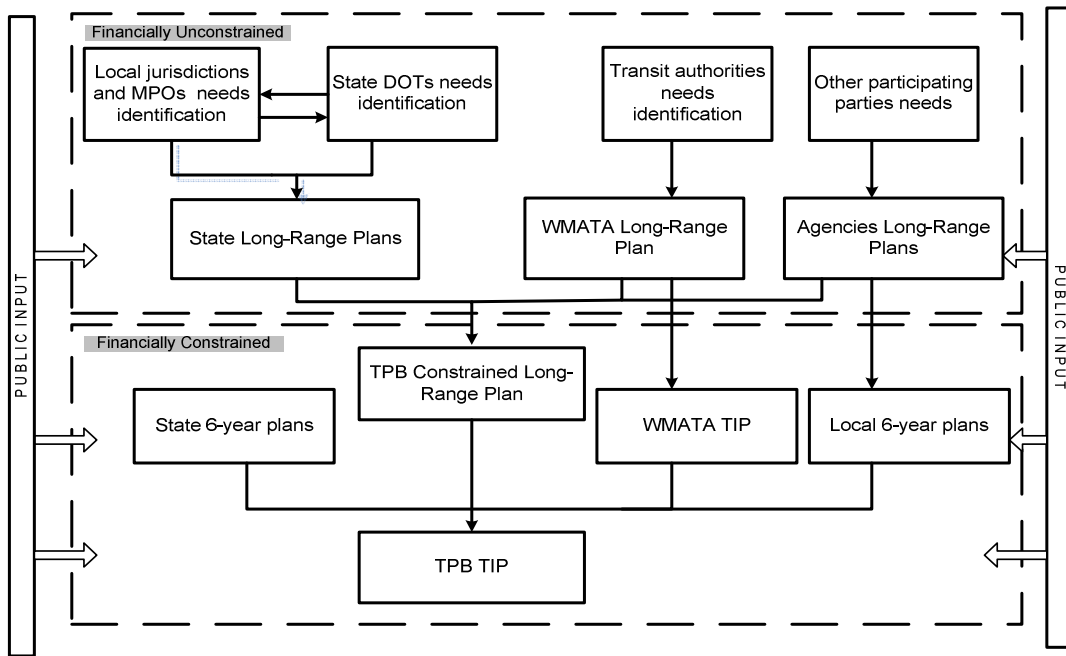


Figure3-2: The TPB Investment Decision-Making Processes

3.4.2 Baltimore Regional Transportation Board

The Baltimore Regional Transportation Board (BRTB) is the MPO for the Baltimore metropolitan area. The BRTB is a 10-member board representing the cities

of Annapolis and Baltimore, five counties in the metro area, Maryland DOT, Maryland Department of the Environment, and the Maryland Department of Planning respectively. The BRTB provides overall program management and oversight in the development of the federally mandated LRP and the TIP. For budget allocation purposes, there is a designated Budget Subcommittee that annually reviews and prioritizes projects. The current working plan is the Transportation Outlook 2035. It is the LRP for the Baltimore region prepared by the BRTB with support from the Baltimore Metropolitan Council (BMC). This long-range planning effort focuses on three categories of transportation needs: congestion management, economic growth in the region, and meeting future travel demand. The Board does not generate its own revenues, and all transportation funds for projects in the LRP come from MDOT. The BRTB gets its share of funds for project in the LRP when the regional plan is updated. The scheme of the BRTB investment process is presented in Figure 3-3.

The BRTB receives funding for two project categories: regionally significant projects and local projects (BMC 2007a). Local jurisdictions, such as counties in the Baltimore metro area, can submit projects in both categories. Regionally significant projects are classified as “critically important to all jurisdictions in the region”. These projects must meet a set of criteria and are not subject to the technical or policy-based prioritization process. These projects require coordination between local, regional and state organizations, and incorporate public inputs at all planning stages. There are five criteria for each transportation mode that a regionally significant project has to meet (BMC 2007b).

Regionally significant projects receive priority in the transportation investment process. The remaining transportation funds are then allocated to local projects. Local projects are projects that are proposed by a local jurisdiction to meet the needs in that jurisdiction, which may not have significant system-wide benefits.

Although local jurisdictions may provide full, partial, or none cost sharing for local project, all local projects go through the BRTB project prioritization process in order to qualify for federal funding. First, the BRTB sets the prioritization check-list with a set of criteria for candidate projects based on regional planning goals. Each local jurisdiction (city, county) can submit five high-priority projects, four medium-, and any number of low-priority projects. Higher-priority projects have more weights in the BRTB project prioritization process, as shown in Figure 3-3. These weights represent a mechanism through which regional and local planning priorities are jointly considered. Local jurisdictions only perform policy evaluation (in contrast to technical evaluation) and rank their local projects based on what they think are most important for the respective local jurisdictions. After local projects are submitted to BRTB, they are subject to a quantitative technical evaluation process. Local policy evaluation accounts for 60 percent of the final project score in the prioritization process, while the technical evaluation accounts for the remaining 40 percent (BMC 2007c). The criteria and measures for policy and technical evaluation, as well as their weights are summarized in Table 3-1. The prioritized project lists are determined for each mode of transportation separately, so there is no competition between different modes of transportation at this stage of the planning process (BMC 2007d). Budget allocation to different modes is determined by MDOT at a higher level.

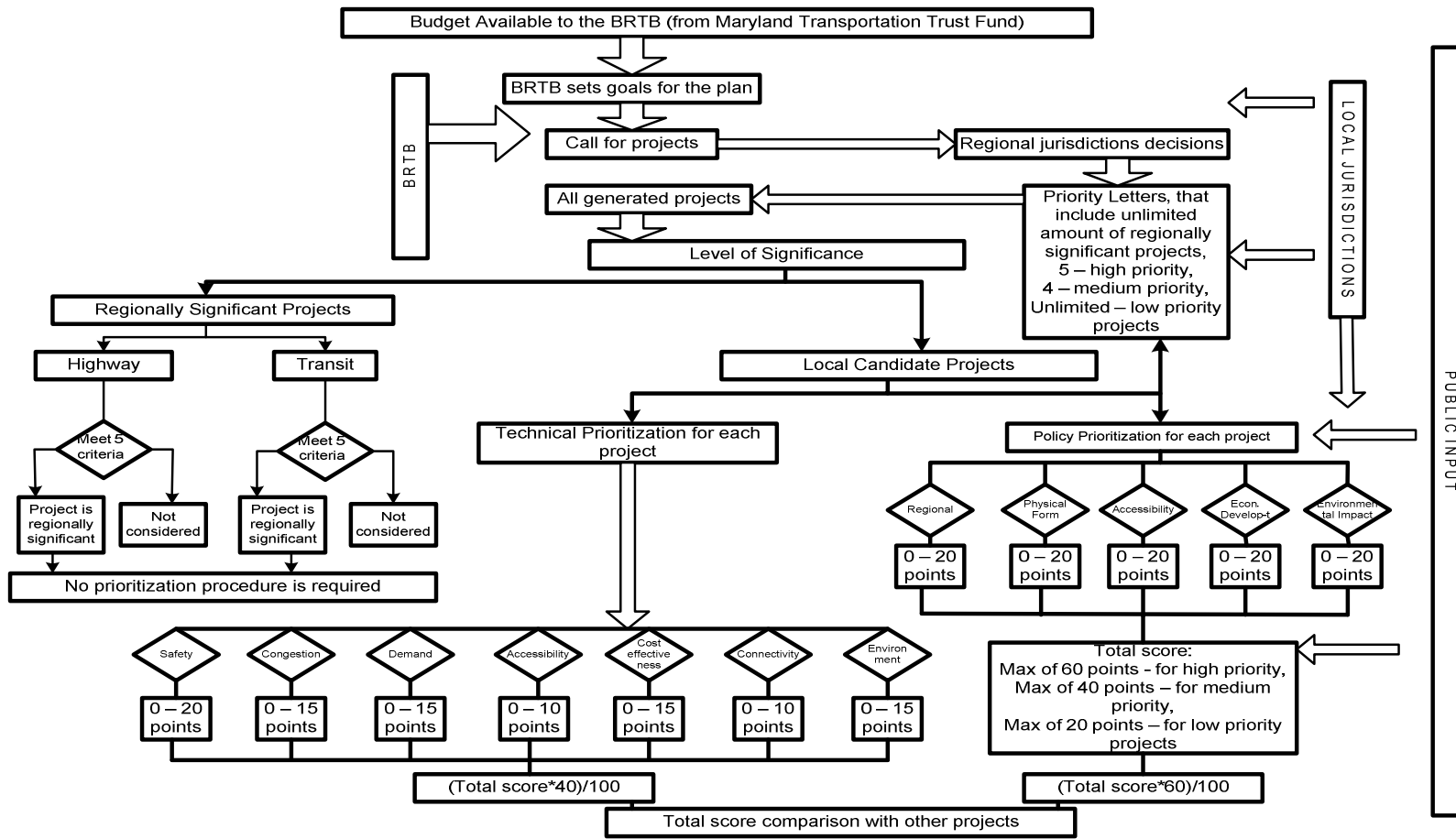


Figure 3-3: The BRTB Investment Decision-Making Processes

When policy and technical evaluations are completed, projects ranked the highest for each transportation mode will receive federal and state funding support. If a local jurisdiction proposes a project but the project does not rank high enough, the local jurisdiction may provide partial or full funding support and in doing so increase the rank of that particular project.

3.4.3 Maryland Department of Transportation

Maryland Department of Transportation (MDOT) is comprised of several modal administrations responsible for individual transportation modes. The State Highway Administration (SHA) is primarily responsible for the planning, design, construction, and maintenance of Maryland's Interstate and state highways. The Maryland Transit Administration (MTA) oversees public transportation. MTA operates and maintains the Maryland Rail Commuter (MARC) service that runs commuter trains connecting DC, Baltimore, Montgomery and Frederick counties, and West Virginia. MTA also operates commuter and local buses in the DC-Baltimore region, as a supplement to WMATA's Metro subway and Metro bus services. Other MDOT modal agencies include the Maryland Aviation Administration (MAA), which owns and operates BWI Thurgood Marshall Airport, the Maryland Transportation Authority (MdTA), which is responsible for toll facilities, the Maryland Port Administration (MPA), and the Maryland Motor Vehicle Administration (MVA).

Policy Prioritization		Technical Prioritization	
Criteria	Points	Criteria	Points
Safety		Highways and Interchanges	
Reduce fatalities and injuries	0 - 5	Crash frequency	0 - 10
Enhance mobility/reduce congestion	0 - 5	Crash severity	0 - 10
Improve intersections	0 - 5	Congestion (peak congestion per day)	0 - 15
Safety for pedestrians, bicyclists	0 - 5	Demand (peak one hour volume per lane)	0 - 15
System Operations		Accessibility (travel time savings)	
Efficiency, performance	0 - 10	Capital cost effectiveness	0 - 8
Real-time information for transportation operations	0 - 10	Operating and maintenance cost effectiveness	0 - 7
Accessibility		Road Connectivity	
Access to transportation network	0 - 4	Transit Connectivity	0 - 3
Mobility to persons with special needs	0 - 4	Air quality benefit	0 - 10
Increase of transport choices	0 - 4	Natural resources	0 - 5
Access to tourist attractions	0 - 4	Total Points	100
Access and efficient movement of freight	0 - 4	Rail Transit Evaluation	
Environmental quality		Safety	
Achievement of air quality targets	0 - 8	Congestion	0 - 10
Sustaining/cleaning the Chesapeake Bay	0 - 5	Demand (number of riders per mile)	0 - 15
Efficient use of energy resources	0 - 2	Job accessibility	0 - 15
Preservation of natural and cultural resources	0 - 5	Mode shift from highway to transit	0 - 10
System Security Improvement		Capital cost effectiveness	
Coordination between transportation and non-transportation response agencies	0 - 6	Operating and maintenance cost effectiveness	0 - 5
Security of critical transportation infrastructure	0 - 6	Intraregional transit connectivity	0 - 15
Operation of transportation system	0 - 7	Interregional transit connectivity	0 - 10

Table 3-1: BRTB Policy and Technical Prioritization Criteria and Scoring System

Policy Prioritization		Technical Prioritization	
Criteria	Points	Criteria	Points
Link Transport Planning with Land Use and Economic Development		Air quality benefit	0 - 3
Integrated land development with alternative driving options	0 - 4	Natural resources	0 - 2
Enhancement of infrastructure in designated Priority Funding Areas	0 - 8	Total Points	100
Preserving existing communities	0 - 2	Bicycle and Pedestrian evaluation criteria	
Access to business and employment opportunities	0 - 2	Demand	0 - 40
Community revitalization	0 - 2	Transportation need	0 - 25
Regional labor market expansion	0 - 2	Bike/pedestrian stress level	0 - 25
Inter-Jurisdictional Participation and Cooperation		Directness	0 - 10
Supporting regional needs and priorities	0 - 7	Total Points	100
Reflection of local needs and priorities	0 - 10		
Consensus opinion of key interest groups	0 - 3		
Total Points	140		

Table 3-1: BRTB Policy and Technical Prioritization Criteria and Scoring System (Continued)

MDOT has a somewhat unusual system for funding transportation projects. The state's Transportation Trust Fund (TTF) is a unified pot of money that provides MDOT the flexibility to fund high-priority projects across the state regardless of transportation modes. Local roads in Maryland are controlled and maintained by cities and counties. Also, MDOT provides Maryland's entire share of funding for the regional transit system in the DC area (see Section 3.4.7 on WMATA for more details). Figure 3-4 illustrates MDOT's TTF allocation between jurisdictions and modes in the state. TTF is first divided into separate funds to meet different transportation needs categories (e.g. maintenance, capital programming), and then allocated to different modal agencies, which is then subject to the investment process of these modal agencies.

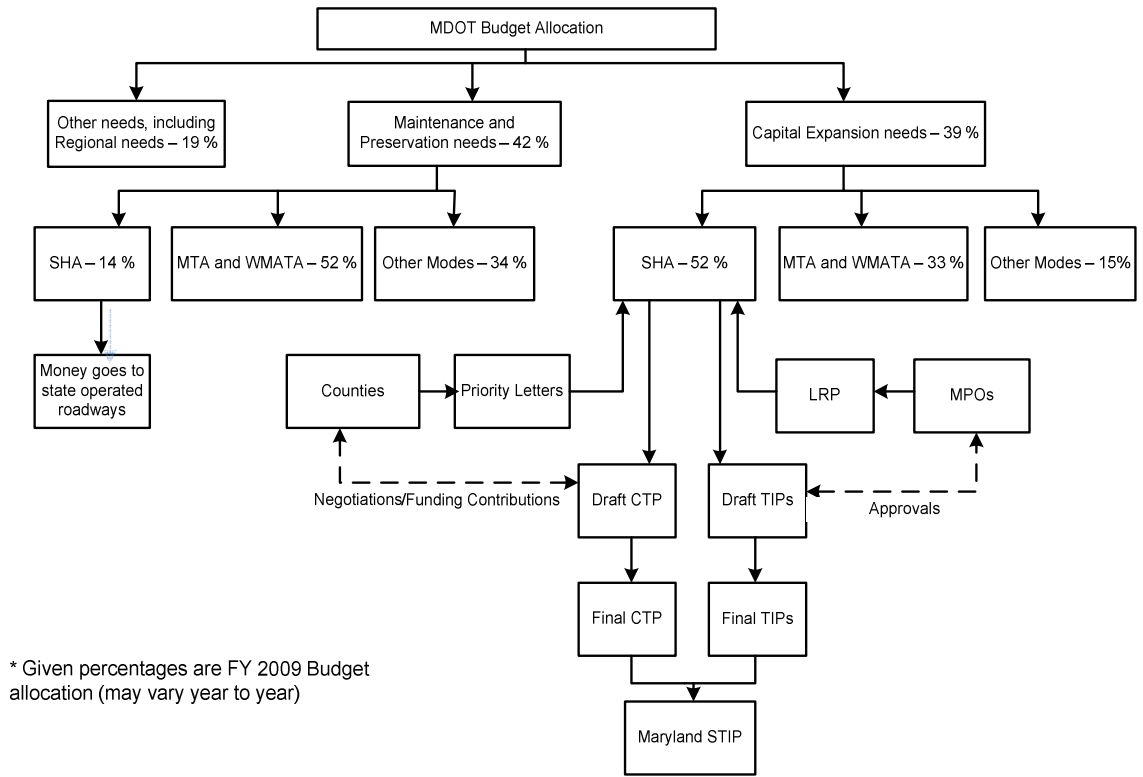


Figure 3-4: Maryland Statewide Planning Process

3.4.4 Maryland State Highway Administration

Maryland State Highway Administration received highway transportation funds from MDOT, and works with MPOs and local jurisdictions to allocate funds to meet highway preservation and capital programming needs. In the last two decades, system preservation projects have received higher and higher share of SHA's transportation funds due to aging infrastructure, and this trend is likely to continue in the future. The Administration identifies system maintenance and preservation needs through an internal technical evaluation process, and has created a large number of funding categories for different preservation and maintenance needs. For instance, SHA performs technical evaluation of pavement and bridge conditions every year, and has set the goal of keeping 84% of pavements under "acceptable conditions". While pavement and bridge maintenance consumes the majority of SHA's system preservation budget, there are also 24 smaller funding categories dedicated to specific needs including drainage, traffic signs, and community improvement. For capital improvement and system expansion projects, SHA coordinates with six MPOs (already discussed in previous sections) and local jurisdictions (through a priority-letter process discussed below and in Section 3.4.5)

The SHA transportation investment process centers on MPO-level Transportation Improvement Programs (TIPs) and the statewide Consolidated Transportation Program (CTP). TIPs represent projects within the boundary of each MPO, and SHA provides technical assistance with those projects upon request. TIPs consist of projects funded by federal money and matching state/local contributions. The CTP is a six-year program that is financially constrained by the Maryland

Transportation Trust Fund. There is a financially unconstrained predecessor to the CTP, often referred to as the 20-year state Highway Needs Inventory (HNI). The HNI is a technical document (based on performance/condition monitoring and travel demand forecasts) that identifies all required highway improvements as well as safety and structural problems on the existing highway facilities. Usually, only “serious” projects from the HNI undergo detailed engineering planning phases and cost estimation procedures. The HNI lists only major capital improvement projects (i.e. no system preservation projects), and is the main source of candidate projects for the SHA transportation investment process. Another source of candidate projects is the priority letters submitted to SHA by individual counties in Maryland. Priority letters represent each county’s internal ranking of projects based on local needs and local inputs.

All candidate projects for capital improvement from HNI and county priority letters are evaluated by SHA planners based on three main investment criteria: safety, congestion mitigation, and support for economic development, though there is no formal quantitative evaluation procedure. NEPA (National Environmental Policy Act) and political considerations also play a role in this prioritization process, though the actual influence of these two factors can only be analyzed on a project-by-project basis. Although there is a formal procedure for SHA to discuss project prioritization with counties each Fall (known as the Fall county tour during which MDOT and SHA engineers and planners visits each county and hold public meetings; there are also meetings between SHA and local jurisdiction representatives before the tour), it is possible that a county may not get any high-priority projects for the county funded by

SHA. If a project proposed by a county meets all SHA requirements but does not receive enough federal or state funding to be included into the CTP, the county may “come to the table” and share the cost with SHA. Typically, only the counties with high levels of economic development (e.g. Montgomery and Howard counties) participate financially as project sponsors. After needs-based analysis and negotiations with counties are completed, SHA submits the draft CTP each year to the MDOT Secretary, which may be revised and then submitted to Maryland State Legislature for possible further revisions and budget approval. Revisions to CTP at these later stages often originate from political influences and changes in budgetary situations. The complete process for SHA investment process including interactions with counties and MPOs are shown in Figure 3-5.

3.4.5 Prince George’s and Montgomery Counties

All counties and City of Baltimore in Maryland participate in the State and MPO transportation planning process. These local jurisdictions often have their own local transportation processes. County- and city-level priorities may differ from MPO- and state-level priorities. The influence of local priorities in the MPO and state transportation investment processes often depends on local jurisdictions’ own financial capability and the urgency of local transportation needs as determined by the metropolitan planning and state transportation agencies.

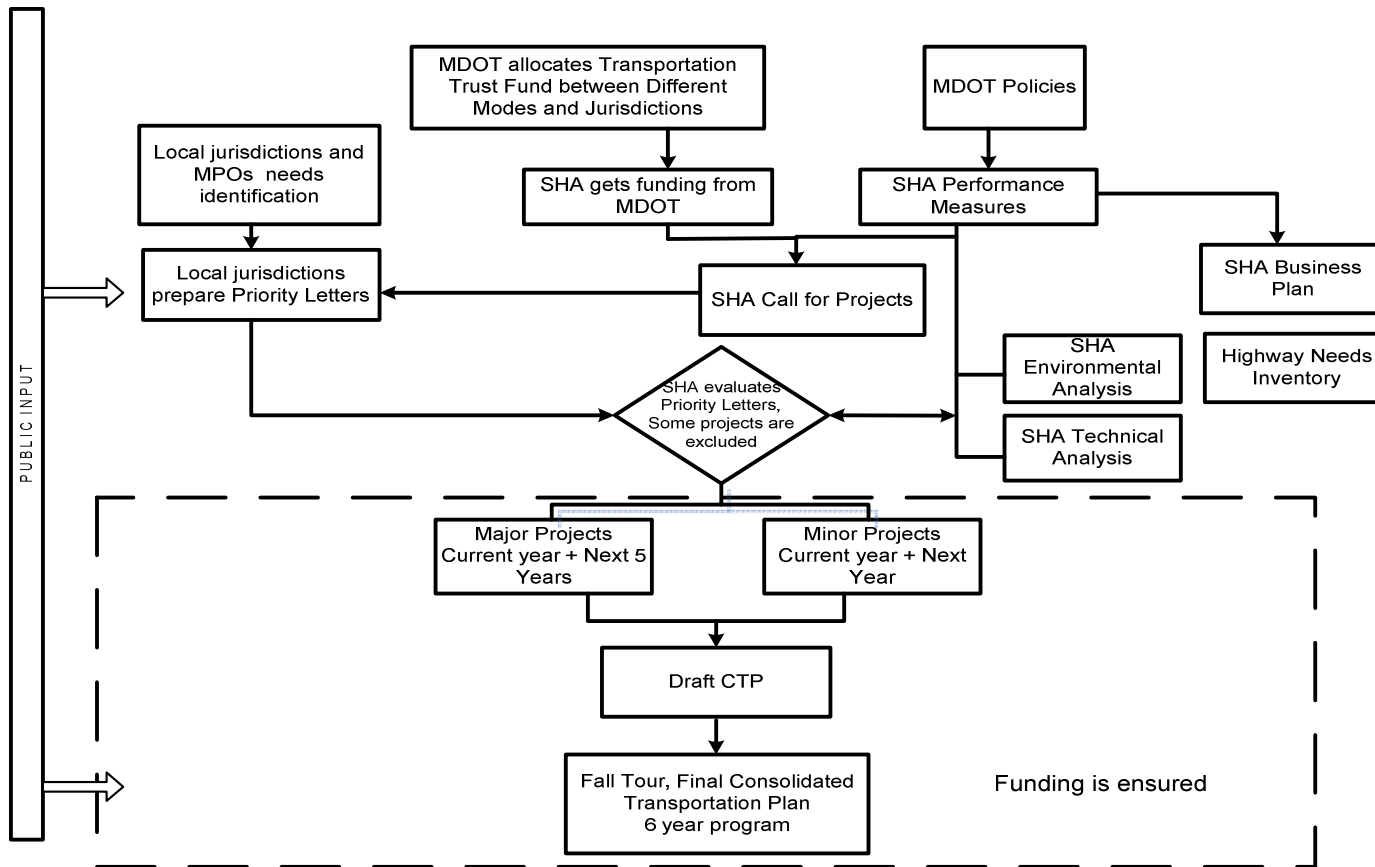


Figure 3-5: SHA Investment Decision-Making Processes

Two counties have been interviewed so far, which have different economic conditions: Montgomery County which is the third richest county in the nation, and Prince George's County which is doing well economically by national standards but has relatively lower level of economic development compared to Montgomery County. Figure 3.6 summarizes the transportation investment processes in these two counties, and their relationships with the MPO and state investment processes.

Prince George's and Montgomery Counties both submit County Priority Letters with eligible projects to the SHA to qualify for federal funding. The projects that can be included in the Priority Letters are projects related to new economic development, bridge projects, safety or capacity expansion projects on State highways or county roads intersecting with State highways, or projects with strong political support. Not all counties received equal share of the state transportation trust funds for their projects. Information gathered during the interviews suggest that in 2008 none of the project in Prince George's County priority letter was funded by the state transportation investment process, while a number of projects in Montgomery County priority letter were funded. Although this may be explained by higher levels of economic development and greater transportation needs in Montgomery County, this could create tensions between state and local agencies. Local jurisdictions that receive less funding naturally would want more direct local control of transportation funding resources.

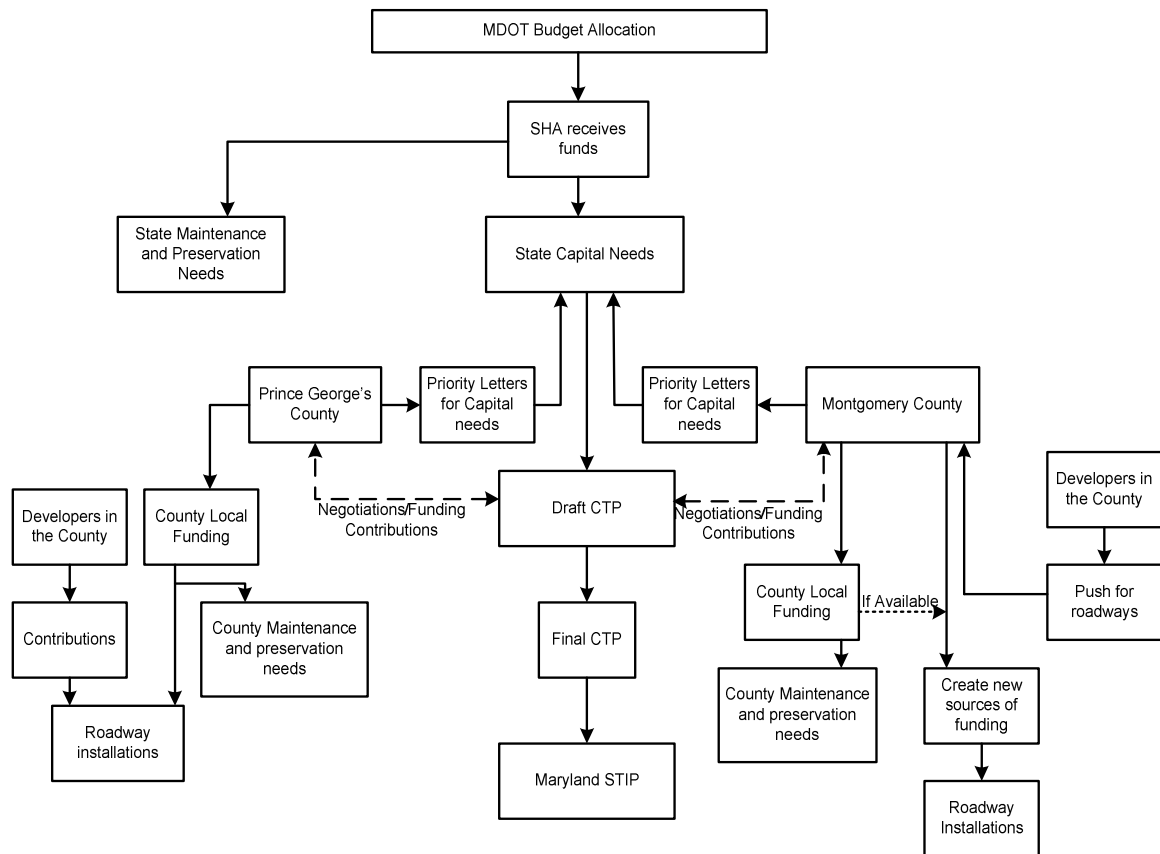


Figure 3-6: Prince George's and Montgomery County Planning Processes

Along with the statewide CTP investment process, the Prince George's County produces a list of its own high priority projects in the county planning process. These projects go into the county Capital Improvement Program (CIP) and are not related to the county priority letter. The CIP is a six-year plan for the providing new facilities and meeting infrastructure needs within the county, and is fully supported by county funds (bonds 35%, Federal and State aids 33%, developer contributions and other sources). Candidate projects for the CIP are proposed based on county planning model forecasts, public opinions, and county engineers' experiences, and prioritized based on safety, capacity expansion needs, and project

costs. Political considerations in the county also have strong influence in the county investment process in terms of project proposition and ranking outcomes. Due to limited county transportation funds, safety needs override other needs if there is a competition for funds. In addition, system preservation needs override all capital improvement needs. New roadways in the Prince George's County are constructed only by developers at this time. Local bus services in the county are supported by Federal subsidies which are shared with other counties in Maryland (see Section 4.6 for more details on Maryland transit investment processes). Also, some funds for transit operations come from transit tax and the fare box.

Montgomery County currently has no comprehensive transportation investment process other than the Priority Letter process. Its capital improvement needs are partially funded by the State. Montgomery County receives a larger share of the state TTF than other counties. This is because the State views Montgomery County as an economic engine in the state, and businesses only pay property taxes to the county, and other taxes to the State. The county's operational and maintenance needs are funded by local resources. The State also provides funding for Montgomery County's transit system as well. Under special circumstances, County districts may exercise taxes or issue bonds to raise revenue and finance local projects. While the county publishes an annual report on the most congested roads, the investment priority is given to new developments that demands new roadway facilities. Capacity issues on existing road are addressed only if there is remaining revenue. The county just started pavement and intersection condition monitoring two years ago.

Apparently, supporting new economic development is the focus of the transportation investment process in Montgomery County.

3.4.6 Maryland Transit Administration

The Maryland Transit Administration (MTA) is a modal agency under MDOT with oversight responsibility for transit operations in all areas in Maryland (MTA 2007). The core MTA transit service is bus transit. For instance, the MTA operates 78 local, express, and commuter bus routes throughout the Baltimore area. MARC rail service primarily accommodates commuting needs between Washington DC and Baltimore, and between DC and Montgomery and Fredrick counties.

Transit funding and management in Maryland is predominantly State function. Transit systems are funded through the State's TTF. Transit typically receives 35% of total MDOT budget (MTA 2007) for operational and capital improvement needs. MDOT allocates money for transit operating and capital needs separately, which means that capital improvement projects do not directly compete with operational needs for funding at the project level. Capital expenditures are used for construction, equipment, vehicles, fuel, stations, and other supporting facilities. Operating expenditures defray personnel, maintenance, preservation, and other employee-related costs. Currently, transit investment comprises half of the State's transportation operating/maintenance budget and about 30% of the State's capital improvement budget. MTA's transit investment process is illustrated in Figure 3-7.

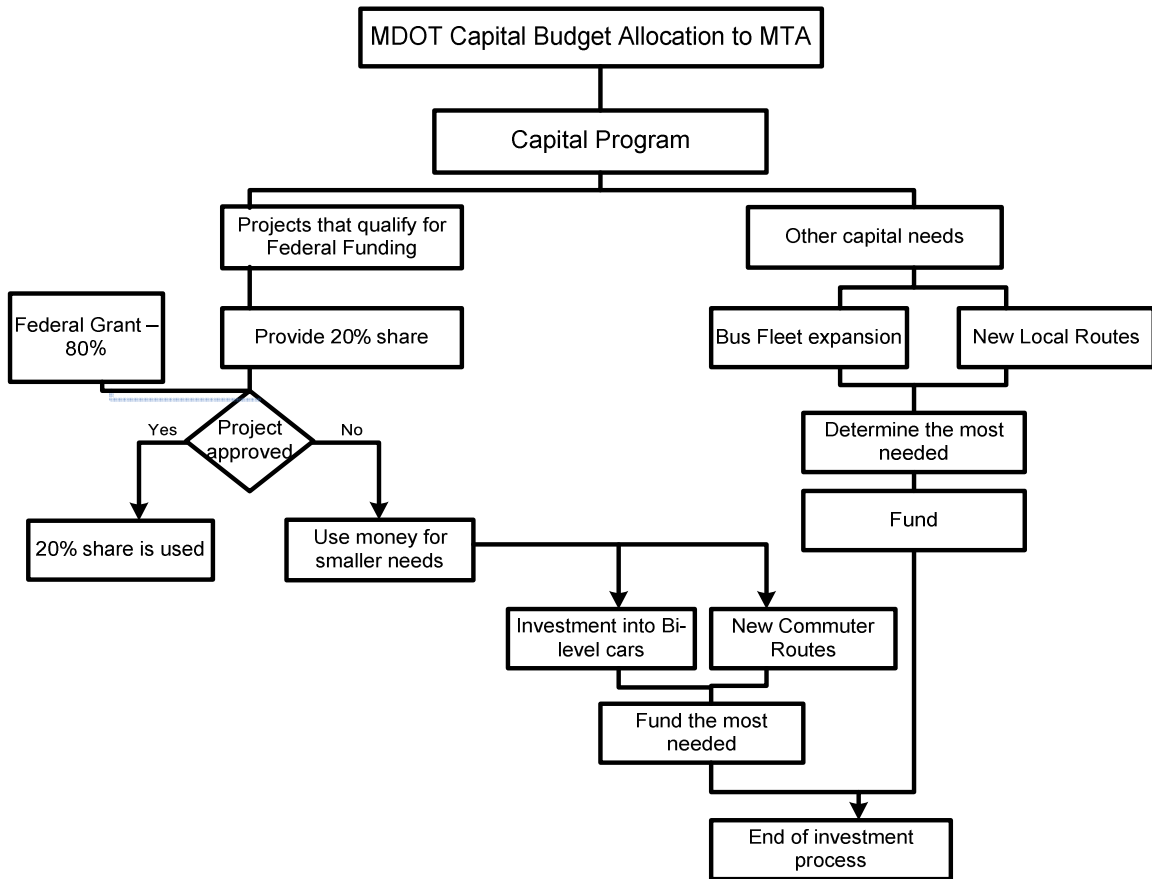


Figure 3-7: MTA Budget Allocation Process

For capital improvement projects, MTA provides only 20% of total funding with Federal grants covering the rest. Federal transit fund is divided into several different grant programs with each program targeting a different transit market. However, Federal grants may or may not be available in a year depending on the Federal budget and ongoing major transit projects in the state. Due to the current budgetary situation, transit investment is largely based on needs analysis for routing investment decision-making. There are no major capital improvement projects. When there are major capital improvement projects, they usually rely on dedicated funding resources. Recently, Maryland State Legislature authorized \$300 million dollars for

new transit projects, which is a rare scenario when a systematic transit investment process is required. A procedure for extensive public involvement and decision-making based on public surveys was developed to help allocate transit investment funds. Due to the length restriction on this paper, the details of that procedure will be presented in a subsequent paper.

3.4.7 Washington Metropolitan Area Transit Authority

The Washington Metropolitan Area Transit Authority (WMATA) operates 86 metro subway stations with a 106-mile subway network, and provides three types of transit services: Metrorail subway, Metrobus regional bus, and MetroAccess paratransit (WMATA 2008a). WMATA transit services cover the District of Columbia, and many counties and cities in Maryland and Virginia. WMATA is governed by its Board of Directors, which consists of 12 members representing different jurisdictions in the Washington metropolitan area.

Metro's annual budget consists of three budgets: reimbursable-projects budget, operating budget, and capital budget (WMATA 2008b). The *reimbursable projects* are the services or programs for which separate funding has been arranged. The most common of these projects are expanded bus services paid for by one of Metro's state and local government partners. The *operating budget's* focus is on the cost of operations, expanding services to meet growing demand, and improving efficiency of services. Funding for the operating budget comes primarily from passenger fares and advertisements in the Metro (about half) and subsidies from Metro's state and local government partners (the other half). The operating budget is

allocated using six subsidy-allocation formulas for regional buses, non-regional buses, rail, paratransit, and debt services (WMATA 2008b). The *capital budget* focuses on new infrastructure needs, including Metro's buses, rail cars, stations, track, maintenance facilities, power systems, etc. About half of the capital budget comes from federal government, and the other half is from Metro's state and local jurisdictions.

WMATA's Office of Long-Range Planning is developing a new Capital Improvement Program (CIP) for the years of 2011 to 2020. The new CIP has four program elements (WMATA 2008b).

1. **Infrastructure Renewal Program** maintains, rehabilitates, and replaces Metro subway facilities.
2. **Eight-Car Train Capital Initiative** allows Metrorail to have fifty percent of its peak hour trains operating in an eight-car configuration, which increase system capacity.
3. **Bus Improvement Capital Initiative** is for increasing bus fleet of the Metrobus system.
4. **Program Management** funds general and program administration costs for the CIP.

In order to maintain a comprehensive inventory of capital improvement needs, WMATA also develops the Capital Needs Inventory (CNI) to address performance, demand and customer needs. The CNI is generated based on outreach to each WMATA department, life-cycle costs, current conditions, future demand, and technical evaluations. There is also the Asset Management Database that contains the

conditions and life expectancy of different projects and that is used for generating and selecting projects for the CNI. The WMATA transit investment process is summarized in Figure 3-8.

The metropolitan transportation planning model at MWCOG provides future transit demands to assist WMATA in transit investment decision-making. The main demand/congestion measure for the Metro rail system is the passenger load at a maximum load point. WMATA also measures the passenger loads on different stations and routes to determine how level of service matches the established standards, and if the number of people per rail car is under certain threshold. The performance measures for improving bus services are: customer complaints, travel time, and ridership increase. These performance measures are used to prioritize transit capacity investment projects at WMATA. Recently, WMATA has adopted a systematic project prioritization process based on system monitoring and expert opinions, but could not share the details with us at the time of the interview.

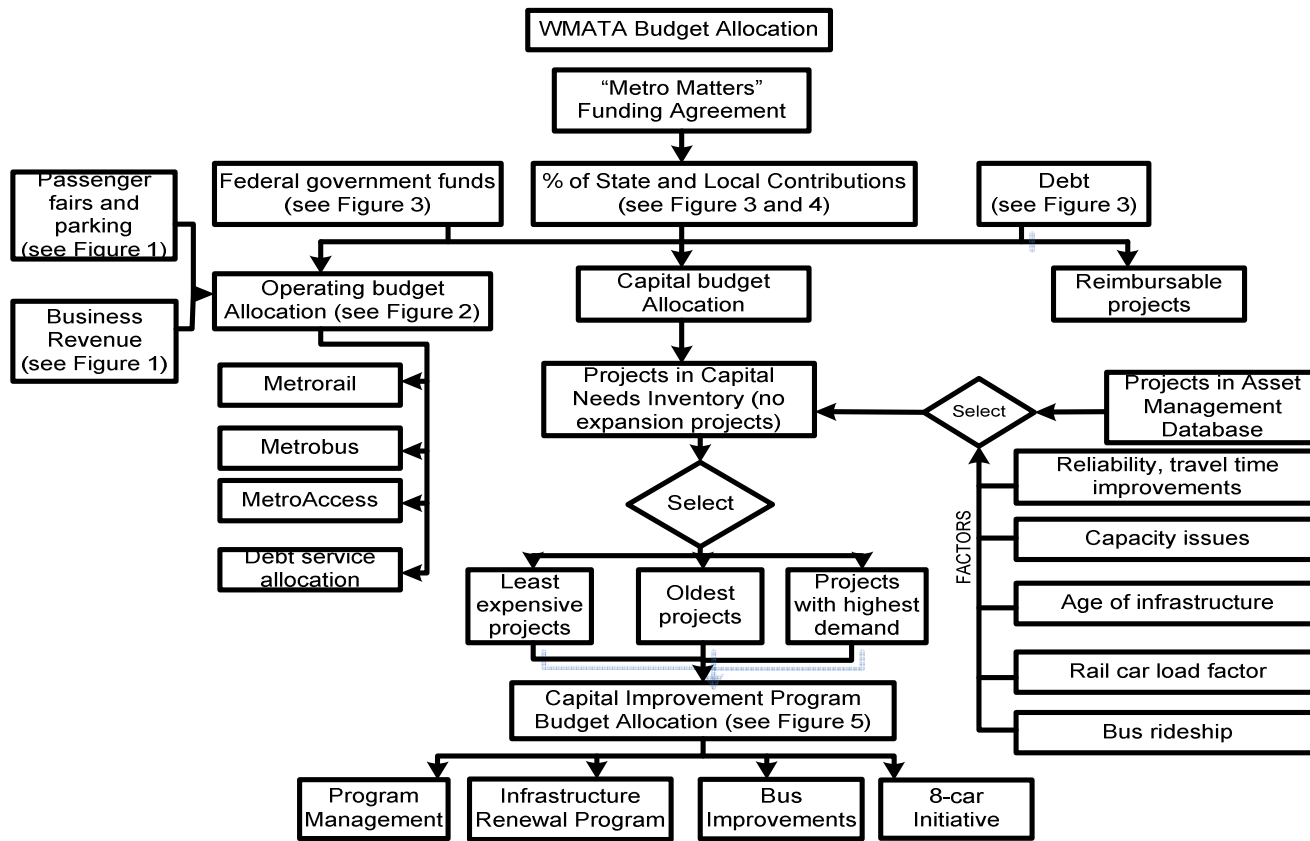


Figure 3-8: WMATA Investment Decision-Making Processes

3.5 Discussion on Existing and Alternative Investment Processes

Several interesting observations in the existing transportation investment process in the Washington DC-Baltimore region are discussed in this section, as well as alternative investment procedures that deserve further analysis in future research.

3.5.1 Multiple State and Local Jurisdictions

Transportation investment in the Washington DC-Baltimore region involves three state DOTs, two large MPOs, six small MPOs, more than a dozen counties, and regional and state transit authorities. There could be a large number of alternative organization structures that allocate different levels of decision-making power to different agencies. The existing investment process favors state DOTs and regional transit agencies. The large MPOs primarily provide technical assistance. For metropolitan areas that cross state boundaries such as Washington DC, a stronger MPO should result in an investment process that can better address critical transportation issues in the metro area that are not regarded as urgent by all state agencies (DC, MD and VA).

In addition, the needs of local jurisdictions that may not be obvious at the regional and state levels are often not met. This creates tension between state DOTs and many local jurisdictions, and between local jurisdictions themselves. There exists the perception that transportation funds are not distributed fairly. The state-county priority letter process in this region provides a platform for communication, coordination, and cooperation. However, in the end, it is the agency that has direct control over transportation revenue that makes the final decisions. There are regions

where MPOs or local jurisdictions have more influence in the project selection process. The merits and pitfalls of these alternative organizational structures should be evaluated. The research question is – do we need more centralized or more decentralized transportation investment process?

From an efficiency point of view, an objective that appears proper is to create an institutional structure that can best address critical transportation problems in the region. If the major transportation issues are region-wide and state-wide issues, it makes sense to strengthen state DOTs and regional planning organizations. The trend of incorporating environmental and sustainability objectives into transportation planning and investment should favor a more centralized approach toward transportation planning. On the other hand, equity considerations and the fact that local issues are best understood by local agencies suggest local jurisdictions should be involved in the investment process. There is proposal for local jurisdictions to be able to directly compete for federal funding without going through the state DOTs. This is an interesting and practical scenario, but its impact needs to be analyzed.

3.5.2 Multimodal Transportation Investment

Multimodal transportation planning has received significant attention lately. Historically, highway and transit projects have their own separate funding resources, and at the project level there is no competition between highway and transit projects. This is also the case in the DC-Baltimore area where funding allocation between multiple transportation modes occurs at the highest level of the planning process. Although the merit of considering multimodal transportation improvement

alternatives is apparent, to change the existing process and to allow more completion between multimodal alternatives based on cost-effectiveness would require some restructuring within or between the existing transportation agencies. For instance, integrated corridor planning at state DOTs and MPOs represents an opportunity to encourage the comparison of highway, transit, and operational alternatives at the corridor level. There could still be separate funds for different modes, but the actual allocation of transportation revenue to different models in a region may depend on the outcome of corridor- or project-level scenario analysis. Improved communication between state DOTs, MPOs and regional transit agencies should also improve multimodal transportation investments. For instance, WMATA, being a regional transit agency, has no interests in comparing transit and highway alternatives. State DOTs and MPOs may conduct multimodal analysis, make project recommendations to WMATA, and incorporate the outcomes of such analysis in the determination of state contributions to the WMATA budget.

3.5.3 System Preservation versus Capacity Improvement

Our interviews in the DC-Baltimore area reveal that in an era of needs-budget gap, all agencies have decided to give priority to system preservation needs, and only allocate the remaining revenue to system capital improvement projects. This is relatively uncontroversial as the life-cycle cost of postponing necessary system preservation activities can only be higher. Agencies have seen larger and larger share of their resources dedicated to system preservation needs, due to aging transportation infrastructure, cost increase, and stagnating revenue. The reduction in capacity

improvement funding is expected to worsen mobility and accessibility in the long run. While resolving the funding issue is way beyond the scope of this paper, it is worth mentioning that not all existing facilities should be maintained at the current level of service. For instance, it may not be cost-effective to maintain a local or rural road that has very low volumes at a high level of service. Degenerating certain segments of the existing transportation system may become a good decision as demand patterns change over time.

3.5.4 Qualitative and Quantitative Methods for Project Prioritization

Qualitative project prioritization is more flexible in considering policy initiative and political factors, and therefore valued by all local, metropolitan, and state agencies in the DC-Baltimore region. Quantitative methods are often adopted by agencies for the technical evaluation of candidate projects (e.g. impact on safety and congestion). Several agencies indicated at the interviews that they would like to either introduce or strengthen objective quantitative procedures in their investment decision-making processes (e.g. BRTB, Prince George's County, WMATA), while other agencies do not see an imperative need in changing the current qualitative methods (e.g. SHA, Montgomery County). All agencies acknowledge that an exclusively quantitative procedure will not meet their needs and objectives. The BRTB process assigns explicit weights to policy/political consideration and technical evaluation scores, which represent a transparent way of balancing political and technical factors. There have been interests among academic researchers in applying multi-objective decision-making theories and methods to transportation investment decision-making.

Such attempts should take into consideration agencies' desire for some flexibility, and the multi-jurisdictional and multimodal nature of transportation investment.

3.5.5 Transportation Investment Criteria

For capacity expansion and capital improvement, the following three investment criteria are adopted by most agencies in the DC-Baltimore region: improving safety, mitigating congestion, and supporting economic development. The actual performance measures corresponding to these investment criteria, however, differ from agency to agency. Other investment criteria mentioned include environmental preservation, project cost, cost sharing, community improvement, accessibility, intermodal connections, and freight mobility. In the existing investment process, project cost estimates influence the planning process at a very late budget-allocation stage after projects are already prioritized. Environmental considerations only impact the decision-making process as conformity constraints, which highlight the federal role in promoting environmental stewardship.

3.6 Examples of Investment Processes in Other States

After reviewing several studies on planning processes of transportation agencies at different levels of government throughout the United States, it was found out that in some states investment decisions are made in a similar way as our paper describes, and in others – the investment processes have some unique features that

can be recommended for realization in the Washington DC – Baltimore region or at least transportation planners can think of when dealing with budget constraints or project prioritization issues.

3.6.1 Florida Practices in Transportation Planning and Investment

Florida Department of Transportation (FDT) issued an investment policy focused on the Strategic Intermodal System (SIS) which focuses on facilities of commercial service airports, spaceport, deepwater seaports, freight rail terminals, passenger rail and intercity bus terminals, rail corridors, waterways and highways (Kramer, Bond 2008). This new investment policy requires that seventy-five percent of all new state capacity funding is spent on SIS and SIS-related transportation facilities. This investment policy restricts the availability of funds for capacity and non-capacity highway projects not on the SIS. In order to qualify for funding under SIS program, Florida MPOs consider three methods for project prioritization:

- *Weighting*: SIS related facilities are assigned a very high score that places them above all other projects;
- *Inclusion*: deficiencies of SIS facilities are ranked on the same scale as other projects; and
- *Separation*: SIS facilities with expected deficiencies are matched to expected SIS funds and displayed in a separate funding table.

This SIS policy initiative shows clearly what priority the FDOT values most when it comes to budget allocation and reduces influence of political processes on

local level in the planning process when local governments want to promote projects to meet their own needs.

In terms of funding, MPOs rely on federal and transit planning funds from state and local sources. Typically funds available to MPOs are provided as reimbursements. It means that MPOs spend money first and then request for reimbursement. Therefore, MPOs require local sources of funds to pay for expenses before requesting and receiving reimbursement from the state or federal government. The sources of local funds vary for each MPO. For example, an MPO can collect money through local sales taxes, additional gas taxes, bond sales and loans, or collect money per capita (\$0.25 per capita in First Coast MPO) from each of the member counties on the basis of population estimates (Kramer, Bond 2008).

Florida MPOs have developed a system of institutionalized interagency coordination: MPOs are coordinating with their neighbors, members, and peers to help guide the transportation planning process. Moreover, Florida MPOs are finding these cross-agency relationships valuable (Kramer and Hopes 2007). A good example of interagency coordination is when MPOs have joined multi-MPO coordinating bodies in the state. The multi-MPO agencies take responsibility of jointly approving a list of important regional facilities, and each constituent MPO places a high emphasis on those facilities in the modeling and project selection components of its individual LRTP. MPOs are also participating collaborative efforts with their neighboring MPOs. This kind of multi-MPO coordination would be of great benefit to the Washington DC-Baltimore Region where coordination is mostly limited to Priority Letter process.

3.6.2 Kansas City Practices in Planning and Investment

For the purposes of this study it was interesting to look at the area in the US that has city or district where two or more states participate in the transportation planning and decision-making process. This area is Kansas City, which is located in two states and transportation planning is supervised by the Mid-America Regional Council (MARC) that functions like an MPO. MARC contains a group called the Total Transportation Policy Committee (TTPC), which advises the MARC Board on transportation issues. In spite of the role of MARC, much of the decision-making happens at individual states' priority committees of Missouri and Kansas. An interesting thing here is that the scoring process for ranking projects is not the same for the two state subcommittees. The positive aspect of this is that political influences are not as prevalent and projects are chosen on the consensus basis between DOTs and MARC. However, MARC does not just approve projects proposed by DOTs, but puts constraints on budget allocation to different project categories (Final Report 2001). For example, MARC can request from DOTs that their priority lists of projects contained 40% of capacity improvement projects (new roads, widening roads), 40% of rehabilitation and renovation and 20% of transportation system management projects. These budget allocation constraints can be different for two DOTs. For instance, it can be requested by MARC that one DOT would have 40% of their priority projects be capital facilities, and the other would have 45% of projects on the list as capital projects. This means that political process is prevalent to some degree in relationship between MARC and DOTs, but not as much between DOTs, who actually control the money flow.

The Missouri and Kansas Departments of Transportation are very different from each other. Kansas DOT (KDOT) has a limit on the number of road miles they can control, so the focus of KDOT is primarily on freeways and other major intercity connectors. KDOT has all of its major functions in the central office, with the Districts having a more limited role.

In Kansas, local governments submit projects to both MARC and KDOT, and at the same time KDOT submits pretty much the same projects to MARC. For KDOT an objective, data-driven computer application called the “priority formula” is used for selection of highway projects (Final Report 2001). Using data about the conditions of the state’s highway system, the “priority formula” identifies those highway sections most in need of improvement due to deficiencies in pavement conditions or problems related to traffic volume or safety concerns. The highest priority projects are chosen based on mathematical formulation and within the limits of available funds. This process of projects selection is performed once every 10 years which makes it problematic to add new emerging projects when they are needed. Also, the KDOT formula evaluates road sections based on engineering deficiencies only, and doesn’t evaluate project impacts on communities.

The Missouri Department of Transportation (MoDOT) operates roads with a much broader range of functional classifications and is much more decentralized than Kansas, with planning, public involvement, and other functions. MARC receives applications for projects, while MoDOT processes agreements and approves projects. In Missouri it is not even necessary for a project to be on a long-range plan to qualify for funding (Final Report 2001). Needs prioritization is based on the goals in

Missouri's LRTP. MoDOT districts and planning partners annually prioritize regional needs, therefore making it easier to add emerging projects to the priority list upon their need. Both regional and statewide needs are prioritized primarily on objective data. Using the results of the prioritization process as a starting point, MoDOT districts and planning partners divide needs into three categories: high, medium and low priority. Even though the priority needs can be constrained, it is not guaranteed that projects will be implemented. Each time needs are prioritized, existing needs are re-evaluated.

In relation to coordination between the MPO and local counties and governments there is very little funding that goes down from the MPO to local jurisdictions. Projects that are purely locally funded and that have impacts across jurisdictions are generally evaluated for their impact on the entire system by the MPO. If the local government is willing to fund the project then the project will generally become part of the regional TIP. Local project selections do not currently have a real planning procedure for determining priorities but the regional government has common policy level direction.

3.6.3 Minnesota Transportation Investment Prioritization

In Minnesota every level of government has different priorities. For instance, at the state level MnDOT is driven by its strategic plan which looks primarily at 3 priorities: preserve, manage, and expand (Montes de Oca, Levinson 2006). When it comes to large capacity expansion projects MnDOT examines the previous plans before it considers performance criteria. Another rule assumes that if MnDOT has

reconstructed or added capacity to a roadway section in the last 10 years or is in its current STIP, that roadway is not going to be considered for funding within the next 30 years.

The DOT identifies the needs, based on performance measures and targets, for a twenty to twenty-five year horizon with both a financially constrained and unconstrained plans. By setting aside some funds, Mn/DOT attempts to ensure that projects related to satisfying safety needs get funded. Safety issues more often lead to expansion than to management investments. State planners try to make investments that serve multiple aims. System plans have set aside specific percentages of dollars available every time; these percentages are 50 to 60 percent for preservation, about 20 to 25 percent for management and 30 to 15 percent for expansion.

For local projects, participating agencies submit applications for funding which are then reviewed by MnDOT. These projects are separated by categories: preservation, management, improvement and expansion, which are in MnDOT's priority order. However, not all preservation projects get selected before management projects. Within each category there is ranking system. In order for a project to score better among other projects, the local agency seeking federal funding would adopt the Metropolitan Council criteria.

At the county level the good example of investment planning is the Ramsey County in Minnesota where political processes in the planning process are absent (Montes de Oca, Levinson 2006). In this county Public Works Technical Advisory Committee (TAC) ranks all transportation projects. The TAC is comprised of city engineers and administrators representing cities of small, medium and large

population within the county. The TAC and the County's Public Works Department use a list of rating factors to determine a rating/prioritizing score for projects. Rating factors are well described which makes the project selection process easy to follow. Politicians are informed on how the project selection process works and all selection criteria are well documented. In turn, counties in DC-Baltimore region currently are just developing uniform ranking systems and it is hoped to see greater advancements in this area of policy-free prioritization in the near future.

3.6.4 Ohio Small MPO Investment Processes

In Ohio the number of MPOs and their different population ranges (less than and more than 200,000 people) pose a challenge for transportation funding distribution in the State. According to the Intermodal Surface Transportation Efficiency Act (ISTEA) the distribution formula for the newly designated Surface Transportation Program (STP) funds is allocated to MPOs with populations exceeding 200,000. However, as there are several MPOs in Ohio with the population less than 200,000 the Ohio Department of Transportation (ODOT) has decided to allocate STP funds to these smaller MPOs as well on per capita basis. ODOT has recognized that the smaller MPOs have unique problems which demand creative and flexible funding scenarios (Rushley 2009). Several alternatives have been employed between the State and the MPOs as transportation partners to bring local project constructions to reality.

In Ohio the ability to fund projects varies with the size of MPOs. Because of the high costs of some transportation projects, some MPOs have become creative in

how they make use of their available funds. For example, an MPO can borrow funds from Ohio's State Infrastructure Bank (SIB). Ohio's SIB was initialized by the U. S. DOT as the nation's first pilot SIB. Using second generation funds from the SIB, the MPO can borrow the necessary funds through bonds issued by the SIB. This option includes initializing costs and interest payments which raise the overall cost of the funds. In this case, a project requesting SIB funds should justify additional interest costs. Another ways of funding projects is when small MPOs can request a loan from the ODOT or any larger MPO in any given year and then repay using next annual allocation funds. In the situation, when a small MPO does not have a priority project to implement, it can loan to another MPO and, in the next year, can accumulate funding for two allocation periods through return.

These examples of how small MPOs in Ohio have developed solutions to funding larger projects within the fiscal constraints of annual allocations can be applied to any other states where counties or MPOs struggle with funding constraints.

3.7 Conclusions

Based on a series of literature review and agency interviews, this chapter examines the complexity of the multimodal and multi-jurisdictional transportation investment process in the Washington DC-Baltimore region. Representative highway and transit agencies at the local, metropolitan, regional, and state levels are interviewed, and their existing investment processes summarized in this research effort. The chapter's focus is on how multiple transportation and planning agencies in

a region make transportation investment decisions based on their own objectives and interactions with other agencies. The value of this type of research is two-fold. First, if conducted in several regions, it would allow comparison of alternative transportation planning and investment processes, and lead to improved processes. Second, understanding the existing investment process is necessary for modeling long-term transportation system changes, and for answering important planning questions (e.g. how will the transportation system evolve under current or alternative investment processes).

The main conclusion that emerges from this empirical analysis and indicates areas in which improvements could take place (by looking at examples of other states and demonstrated modeling concept) is that collaboration between different levels of government is a key to creating a comprehensive regional land use and transportation plan that would meet needs throughout the Region, and not only focus on places that are more attractive from economic or political perspective, but create an environment for better resource allocations. Establishing innovative rules of engagement for planning and investment, defining new roles in the county and MPO decision-making process, recognizing that every agency in the Region is important, managing or reducing political procedures while maintaining the integrity of the State investment process – are the ways when decision-making process can become more or less unbiased. One of the ways of improved planning is, for example, through giving more power to MPOs and/or counties by allocating funding directly to them so that money could be used on locally selected projects. By doing so, decentralized planning

schema may be appropriate in these conditions, but additional research is needed to see if the decentralization of planning and investment would be truly beneficial.

Chapter 4: Modeling Agent-Based Transportation Network Growth

This chapter provides a background on agent-based network growth model that integrates transportation demand with public and private sector investment processes. In particular, it describes the background components of the models, such as demand and supply modules, cost and performance measures necessary for modeling investment prioritization processes of public and private sectors before introducing game theoretical approach. Agent modules of public and private investment processes and their interactions are just briefly mentioned in this chapter, and described in greater details in Chapters 5 and 6. The methodology for demand module considers user choices with a traditional four-step demand model and econometric cost structures, and for supply module – agent-based approach for modeling pricing and capacity choices by public and private roads.

4.1 Dynamics of Transportation Network Growth

As was acknowledged earlier, the primary challenge in understanding the various ramifications of roadway privatization is to model the interdependencies among travel demand, roadway costs, roadway capacity supply, pricing, and private entity market entry decisions in a dynamic mixed-ownership network with both public- and private-sector decision-makers to predict network growth patterns in the future. For instance, in many real-world transportation networks, government

agencies collect transportation revenues in the form of fuel taxes. However, if roads were autonomous, it would be beneficial to maximize transportation profits through collection of road tolls. On the other hand, if revenues were collected by individual links, they might not be pooled together for investment purposes depending on the underlying institutional structure of the network. Generally, longer, faster, and high-demand (traffic flow) links are able to generate more revenues.

Specific revenue and cost structures in a transportation network provide inputs for supply decisions. The rate and extent of these decisions is constrained by the cost of those improvements (maintenance and construction) and limited budgets (revenues). From a market economy point of view, transportation investment decisions induce supply (capacity) increases - as population grows and preferences shift, leading to higher demand. If a link is expanded, travel increases on that link both due to re-routing and rescheduling and due to induced or latent demand (Noland 1998, Strathman et al. 2000, Fulton et al. 2000, Parthasarathi et al. 2002). As travel costs for commuters are lowered, the number of trips and their lengths increase. The expanded link with increased travel demand can generate even more revenue which may later result in further expansion on that link. Improving one link can also cause complementary (upstream and downstream) links to have greater demand. This again highlights the importance of considering the full ramification of network expansion on future infrastructure decisions. This type of network effects suggests the analysis has to be iterative. Previous changes of the network, economy, demography, and even travel behavior cause a new travel demand pattern and hence new link revenues.

Accordingly, when a new set of supply decisions is made, it generates new network changes.

In this research, the integrated agent-based growth model is developed that brings together all the relevant components, such as travel demand module, transport supply module, public and private road suppliers, regulation policies, and their interactions to simulate road expansion and resulting network changes. If we look at transportation network growth process through the evolutionary perspective, this model's work-flow can be presented in the following way (see Figure 4-1): the travel demand module predicts link-level flows based on the network, socio-economic and demographic information. Based on the demand forecasting results, links calculate revenues and costs. The transportation supply module then operates and activates public sector decision and private sector decision modules by providing information on available revenues. Public sector module generates information on how much funding would go to maintenance and construction needs based on associated costs, and then allocates money based on selected performance measures (the procedure for public sector funding allocation is described in detail in Chapter 5). In the private sector module it is decided whether it would be profitable to enter the market and fund maintenance and construction of existing and new links in the system. This decision is highly dependent on the regulation policies in place at any particular moment through public-private agreement and how much profit the private sector would be able to generate (the procedure for private sector funding allocation and regulatory policies are described in detail in Chapter 6).

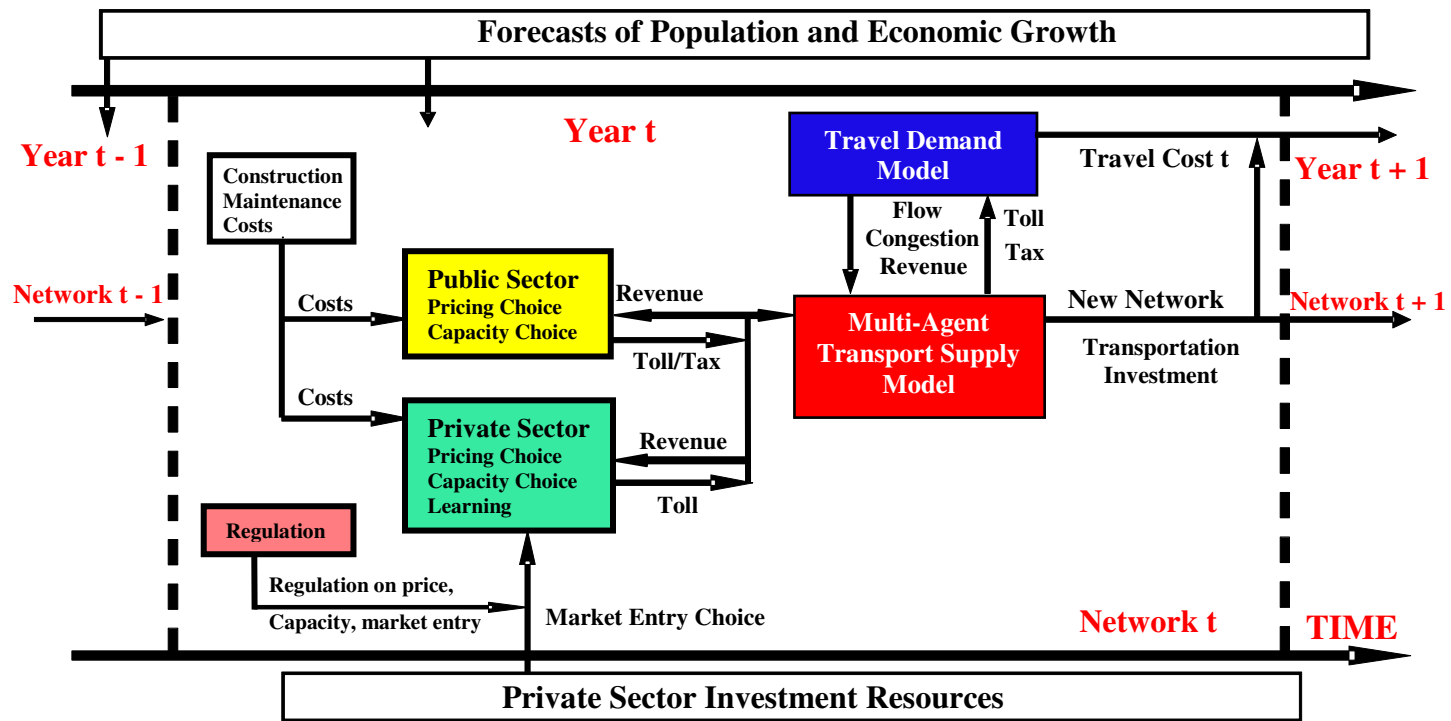


Figure 4-1: Integrated Network Growth Model

After the decisions on capacity expansion and investments are made, all this information from public and private sectors is passed back to the transport supply module, after which actual transportation investments take place. Also, the transportation supply decisions cause network growth changes, which result in new travel demand patterns, produce new estimate for travel cost, new socio-economic information, new demand for infrastructure, and in turn affect future network growth. It is assumed that all decisions are annual decisions and that in each year the transportation system achieves a short-run equilibrium wherein travel demand, transportation costs, and investments are equilibrated. However, other updating intervals can also be used. But yearly supply changes correspond to budgets which are typically decided every fiscal year.

A more detailed description of individual model components is presented in the subsequent paragraphs.

4.2 Travel Demand Module

A traditional four-step forecasting model is used to predict travel demand at the link level, taking exogenous land use, socio-economic variables, and the existing network as inputs. A zone-based regression structure is used for trip generation. Such characteristics, as link length, link capacity, free flow speeds, population and employment density, are used as initial inputs for travel demand model. The origin-destination (OD) cost table obtained from the previous year traffic assignment is used for trip distribution in the current year based on a doubly constrained gravity model

(Haynes and Fotheringham 1984, Hutchinson 1974). The computation of the new OD demand table takes into account the historical impacts of past travel behavior.

In contrast to a traditional equilibrium models, the evolutionary demand updating procedure does not require supply and demand to be solved simultaneously. On the contrary, the new OD demand is updated by a process similar to the method of successive averages (MSA) (Sheffi 1985, Smock 1962) in traditional traffic assignment procedures. The weights in equation (4.1) are specified in such a way that OD demand tables in all preceding years are weighted equally toward the current year

(i) OD demand:

$$q_{rs}^i = \left(1 - \frac{1}{i}\right) q_{rs}^{i-1} + \left(\frac{1}{i}\right) m_r O_r n_s D_s d(t_{rs}^i) \quad (4.1)$$

Where:

q_{rs}^i - demand from origin zone r to destination zone s in year i ;

O_r - number of trips produced from zone r ;

D_s - number of trips destined for zone s ;

m_r, n_s - coefficients in the gravity model;

t_{rs}^i - generalized travel cost of traveling from zone r to s ;

$d(.)$ - travel cost impedance function in the gravity model; $d(t_{rs}^i) = e^{-\gamma^* t_{rs}^i}$

γ - coefficient in the impedance function.

The resulting OD table is loaded onto the current year transportation network through the origin based user equilibrium traffic assignment algorithm (OBA)

developed by Bar-Gera and Boyce (2002). In this case, generalized link cost function comprises two parts, a BPR travel time component and a vehicle toll.

$$t_a^i = \lambda \frac{l_a}{v_a^i} \left[1 + \theta_1 \left(\frac{f_a^i}{F_a^i} \right)^{\theta_2} \right] + \tau_a^i \quad (4.2)$$

Where:

t_a^i - generalized travel cost on link a in year i ;

λ - value of travel time constant (dollar/hr);

v_a^i - free-flow speed of link a (km/hr) in year i ;

F_a^i - capacity of link a in year i (veh/hr);

l_a - the length of link a (constant) (km);

f_a^i - average hourly flow on link a in year i (veh/hr);

θ_1, θ_2 - coefficients of the BPR travel time function;

τ_a^i - link toll per vehicle.

The OBA algorithm derives link flows at user equilibrium and generates a new OD cost table which will be used for trip distribution in the next year.

4.3 Initial Revenue and Travel Costs

Revenue is collected at the link level through vehicle tolls (whether gas tax equivalent for public sector, or private sector roadway toll). The annual revenue is simply the product of the toll and annual flow. The amount of the toll should depend

on the length of the link and the level of service. Therefore, the following revenue equation is proposed:

$$E_a^i = \tau_a^i \cdot (\psi \cdot f_a^i) \quad (4.3)$$

$$\tau_a^i = \rho_1 \cdot (l_a)^{\rho_2} \cdot (v_a^i)^{\rho_3} \quad (4.4)$$

Where:

E_a^i – revenue of link a in year i (dollar),

ψ – coefficient to scale average hourly flow to annual flow,

ρ_1 – scale coefficient related to the toll level (dollar·hr $^{\rho_3}$ / km $^{\rho_2+\rho_3}$),

ρ_2, ρ_3 – coefficients indicating economies or diseconomies of scale.

As the free-flow speed of a link increases, travelers are able to save travel time and hence willing to pay a higher toll. However, speed improvements have decreasing returns. For instance, if speed triples from 8 to 24 km/hr, time spent traveling 1 km drops 5 minutes from 7.5 min to 2.5 min. If speed increases 16 km/hr from 88 km/hr to 104 km/hr, the time drops from 41 seconds to 35 seconds – merely 6 seconds – which hardly seems worth considering. Therefore, coefficient ρ_3 should be between 0 and 1.

In the case of public sector, where revenues are collected through fuel taxes, therefore represent centralized revenue collection mechanism, coefficients ρ_2 and ρ_3 would be equal to 1 and 0 respectably.

4.4 Road Construction and Maintenance Costs

Road construction and maintenance costs are modeled separately. The specification of the construction cost function is based on recent empirical findings in Levinson and Karamalapati (2003), who estimated a Cobb-Douglas cost function based on more than 100 recent highway construction projects. Their findings suggest that the cost structure exhibits increasing returns to scale with respect to lane miles of construction, and it is more expansive to construct higher level roads (often with higher level of existing capacity). The following specification captures these effects:

$$K_a^t = \phi \cdot (l_a)^{\sigma_1} \cdot (F_a^t)^{\sigma_2} \cdot (F_a^{t+1} - F_a^t)^{\sigma_3} \quad (4.5)$$

Where:

l - kilometers of roadway construction, $F^{t+1} - F^t$ - additional capacity added,

F^t - existing road capacity,

ϕ - technology factor,

t - the index of time.

Few academic studies have empirically estimated the maintenance cost of individual facilities. We assume that it depends on the length, and the capacity of the specific road. Furthermore, it is assumed that maintenance cost has constant returns to scale with respect to length, and decreasing returns to scale with respect to

capacity. The technology factor (μ) can be adjusted so that the total base year maintenance cost matches observed base year observed maintenance cost.

$$M_a^t = \mu \cdot (l_a)^{\theta_1} (F_a^t)^{\theta_2} \quad (4.6)$$

4.5 Public Sector Module

Users of existing public roads pay fuel taxes, vehicle sales and registration taxes, and driver license fees, and even general taxes for travel. I convert all taxes and fees users pay on public roads to an equivalent distance-based toll at about 2.5 cents per kilometer based on the 2009 federal and state gas tax rates, and average vehicle fuel efficiency.

The actual investment rule employed by the public-sector transportation agencies for prioritizing road construction projects typically involves multiple decision makers (e.g. state DOT, MPO, local governments) and multimodal objectives (e.g. congestion mitigation, safety, supporting economic development). Based on in-depth interviews and quantitative processes currently employed by state, metropolitan, and local government agencies in the Washington DC-Baltimore region, a rule-based investment model has been developed to simulate the current business-as-usual decision-making processes (see Chapter 5). These rules depend on the most valued by government agencies three performance measures, which are: safety, congestion and accessibility. Safety is determined through links accident rates. After comparing various accident prediction models used in the literature and application of those models to the data, the Poisson models for arterial and freeway

links from the study done by Chen et al. (2003) are used in this research for safety evaluation in public investment process. Arterial links safety is ranked based on the following estimated Poisson model:

$$Y = 4.61215 - 0.085300X_1 + 0.327695X_2 + 0.027944X_3; \quad (4.7)$$

Where:

Y - Accident rate in peak or off-peak hours;

X_1 - Annual average volume per hour during peak and off-peak periods;

X_2 - Median type (divided or not);

X_3 - Intersection density (defined as the ratio of number of intersections to Link length).

Safety of freeway links is ranked based on the following estimated Poisson model Chen et al. (2003):

$$Y = 5.81252 + 0.1140E-03X_1 - 1.358E-02X_2 + 0.142474X_3 - 0.064002X_4; \quad (4.8)$$

Where:

Y - Accident rate during peak or off-peak hours,

X_1 - Volume per lane;

X_2 - Median width;

X_3 - Auxiliary lane ratio (the total length of auxiliary lanes on a link to the length of the link);

X_4 - Number of through lanes.

Congestion of links is determined through volume to capacity ratio:

$$X_i = V_i/C_i; \quad (4.9)$$

Where:

V_i – volume on a link i ,

C_i – capacity on a link i .

Accessibility is usually referenced as the measure by which travel costs are determined (e.g. the impedance function from gravity models applied to the travel time between two zones) and, also a spatial element reflecting the distribution of the activities in a region. In this model two standard measures of job and residential accessibility are adopted to convert travel time changes into accessibility shifts. Accessibility changes due to changing travel costs between origins and destinations, jobs and houses located in a specific zone may become more (or less) accessible relative to other zones in the region, which leads to increased (or decreased) level of future jobs and houses in that zone. The models for residential and employment distributions are adopted from Zhang et al. (2009) and as follows:

The population of the zone i after accessibility changes:

$$P_i^2 = P \frac{P_i^1 \exp[b(A_{i,E}^2 - A_{i,E}^1)]}{\sum_i P_i^1 \exp[b(A_{i,E}^2 - A_{i,E}^1)]} \quad (4.10)$$

Where:

P - Total study area population,

P_i^1 - Initial population of the zone i ,

b – Calibrated sensitivity coefficient of accessibility measure,

$A_{i,E}^1$ – Initial accessibility to work of zone i ,

$A_{i,E}^2$ – New accessibility to work of zone i .

Employment in the zone i after accessibility changes:

$$E_i^2 = E \frac{E_i^1 \exp\left(\frac{A_{i,P}^2}{A_{i,P}^1}\right)^b}{\sum_i E_i^1 \exp\left(\frac{A_{i,P}^2}{A_{i,P}^1}\right)^b} \quad (4.11)$$

Where:

E – The fixed total study area employment,

E_i^1 - Initial employment of the zone i ,

$A_{i,P}^1$ – Initial accessibility to house of zone i ,

$A_{i,P}^2$ – New accessibility to house of zone i .

In the public investment model population and employment growth are evaluated for each zone, and then zones are scaled and ranked based on their future estimated populations and employments. The links connected to zones with highest growth are prioritized for funding.

Whenever public transportation agencies perform investment procedures, first they make sure that all maintenance needs of the network are met. Only after that, they start investing into the capacity expansion projects based on the above described

three performance measures, which in their own turn depend on the performance of each individual link. Links performance evaluation summary is passed to the multi-agent transport supply module, which activates and causes transportation network to grow and expand in places most in need for congestion, safety and accessibility improvements. A link with the highest needs is funded first, then next “in line” link is funded, and so on. The investment process continues till the point when the public budget is exhausted. In case, if there is still money left after previous links’ investments, but that amount is not sufficient to fund the next link “in line”, then that link is dismissed by its successor link and the cost of improvement for successor link is compared against available funding. If the cost is matched, then the link is financed, otherwise – a new link down the scale is selected.

4.6 Private Sector Module

In the agent-based network growth model private sector derives the price and capacity choices of private roads by examining the information available to private roads and allowing private roads to adjust their decisions over time as more information becomes available. Cooperation between private roads is assumed away, and each private road is only interested in its own profit. Private roads maximize short-term profits by setting the appropriate tolls given the current capacity levels. The profit-maximizing toll depends on travelers’ demand elasticities with respect to tolls, which depend on all substitutional and complementary effects in the network. To accurately estimate the demand elasticities on private roads for the current and

future years on complex networks is hard due to intrinsic demand uncertainties, network complexity, and data availability for forecasting. Under these circumstances, private roads can better achieve their profit objectives by learning demand responses adaptively as they accumulate information on historical tolls, the resulting traffic flows, and profit levels. It is therefore assumed in the model that private roads employ price (toll) and quantity (flow) information in the previous time periods to estimate the underlying demand curves.

4.6.1 Market Entry

Private investment companies interested in transportation financing will base their market entry decisions on the estimated long-run returns of investment of individual private road projects. Their pricing and investment decisions are modeled using a normative approach. The total profit (π) a private investor can expect from a candidate private road project a build with capacity F and toll rate τ is:

$$\pi(\tau_a^t, F_a^0) = \sum_{t=0}^T [\lambda^t(t) \cdot \tau_a^t \cdot f_a^t] - K_a^0(F_a^0) - \sum_{t=0}^T [\lambda^t(t) \cdot M_a^t(F_a^0)] \quad (4.12)$$

Where:

T - expected life span of the project,

t - index of year,

f - traffic volume on the road,

λ - discount factor so that the profit is expressed as the present value,

τ - toll rate,

a – road project index.

The first term on the right hand side is the total revenue, the second term construction cost according to equation (4.5), and the third term maintenance cost according to equation (4.6). It is assumed that $T = 30$ years, and the discount rate is 6% which defines discount factors in all years. The life span of a private toll road should be the minimum of the structural life and the concession period. For instance, the concession period is 30 years for Route-3 in Massachusetts, 35 years for SR-125 in California, 42.5 years for the Dulles Greenway in Washington, DC, and 99 years for Route-895 in Virginia (FHWA 2006).

In the model, the private sector will solve this optimization problem each year for each candidate or existing toll road projects, and determine the profit-maximizing toll and capacity investment under all applicable regulatory constraints. The maximum profit can be obtained at the optimal private road capacity (F_a^0), and optimal tolls (τ_a^t) in all future years within the life span of the project, subject to: (1) the future travel demand; and (2) the capacity and price choices of the parallel public roads which are specified through the regulatory policies.

Once the expected profits and immediate investment requirements (the construction costs) are determined, the rates of investment return on all candidate private toll road projects can be computed. The private investment companies (modeled as a collective whole) will construct a private toll road if the investment return rate is higher than that of all alternative investment opportunities (assumed to be 6%).

4.6.2 Capacity Choice

It is assumed that once a market entry decision is made, a private toll road will be constructed and becomes operational in the next year (i.e. one-year design-build time). As travel demand grows and the private toll roads learn more information about the “actual” (in the model) demand elasticities, they may be expanded by the investor if capacity expansion is profitable and regulatory policy allows doing so. If the new capacity is higher than the current capacity, and if the return rate of the additional capacity investment is higher than the base rate (6%), the particular private toll road will be expanded to the new capacity. However, both the initial construction and subsequent expansion decisions are irreversible even if a private road is losing money. Although new capacity choices can be made at any time, it is assumed that they are considered once a year by the private investor because the public sector at most updates its transportation investment plan once a year.

After private company has decided to invest into the public network, the information on candidate links for privatization is passed to the multi-agent transport supply module, and network changes take place, such as some links in the public network become privatized and expanded. However, private investor’s tolling and capacity decisions are both subject to regulatory policies when privatizing public roadways. Three most-widely adopted regulatory schemes on private toll roads in the U.S. are considered in this research (and described in greater detail in Chapter 6): price ceiling, revenue sharing and concession agreement.

4.6.3 Pricing Strategy

When setting tolls, private roads under decentralized ownership take road capacity as given and seek to maximize their short-run profits in an imperfectly competitive market. In a market economy consisting of many private roads, any individual private investor does not possess perfect knowledge about other investors' road pricing and capacity expansion decisions, which causes uncertainty about the demand curves on individual private roads. Their private pricing behavior is modeled as the outcome of an adaptive learning process. In this approach, a private link in the network copes with uncertainty and imperfect information by learning demand patterns from historical road usage data under road tolls set in the past. The collective influence of the decisions by other private roads is represented by the shape of the link-specific demand curve (i.e. link flow versus generalized link travel cost). The process through which the private link adjusts its toll to maximize profit is depicted in Figure 4.2. Due to traffic growth and/or new pricing/investment decisions by other links, the demand curve on the private link shifts over time. Therefore in each time period, the private link estimates a new demand curve based on its own link flows and tolls in the previous time periods (represented by crosses in the graph) with linear line-fitting techniques. The previous tolls fall into a range $[P_{low}, P_{High}]$. The estimated demand curve can be extrapolated beyond this toll range (the dashed portions on the demand curve). Based on this empirical demand curve learned from experience, a standard quadratic optimization procedure finds the theoretical profit-maximizing toll, P^* , for the next time period (Zhang and Levinson 2007). If $P^* \in [P_{low}, P_{High}]$ (Case A in Figure 4.2), it is directly implemented as new toll. However, if P^* is in a

new price territory (Case B), the link will take caution and adjust its toll toward P^*_B only by a conservative small step j to $P_{Low}(1 - j)$, where j is a parameter. Similarly, if P^*_B is higher than P_{High} (not shown in Figure 4-2), the new toll would be $P_{High}(1 + j)$. This pricing rule assists private roads to maximize profit and keep the price changes smooth. The impact of toll regulations can also be easily incorporated when a price-ceiling regulation is introduced. However, the heuristic nature of this adaptive pricing rule may introduce estimation biases when demand curves shift abruptly or consistently in the same direction for a long period of time.

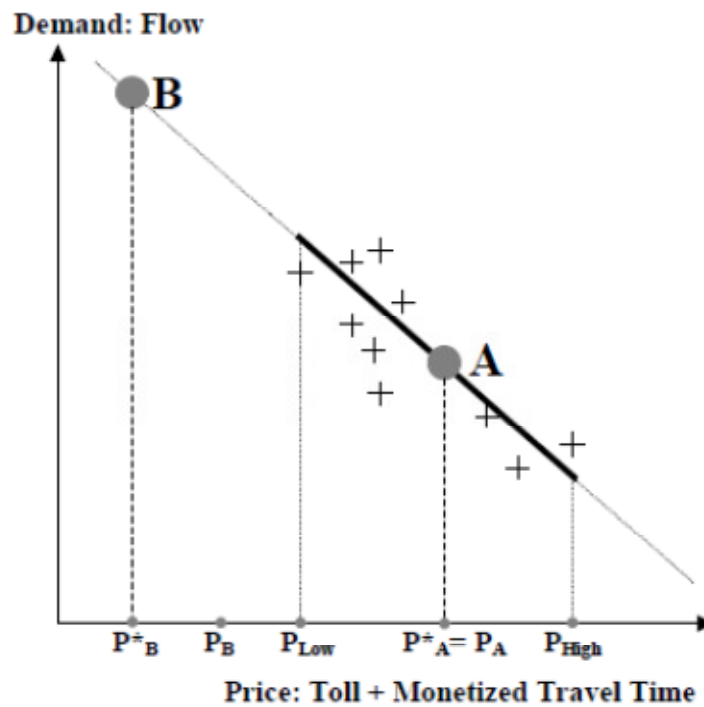


Figure 4-2: Profit Maximizing Private Pricing (Zhang and Levinson 2007)

4.7 Welfare Measures

Since in the agent-based network growth model I consider two types of road owners, public and private, it is essential to measure the true benefits associated with the introduction of private sector into the publicly owned network, especially from the consumer point of view. Therefore, it is important to study the welfare impacts of road privatization arrangements. In the model it is assumed that private road authorities maximize profits, and public road authorities maximize social welfare without budget constraint or discounting. In this case the general welfare function for a network growth process over a period of time would take the following form:

$$W = \sum_b (\int_0^q P(q) dq) - \sum_a C(f^a, F^a) \cdot f^a + \sum_a \tau^a f^a - \sum_a S \cdot \Delta F^a \quad (4.13)$$

Where b , q , and a are indices OD pairs, users of an OD pair, and roads respectively, and delta indicates capacity changes. The first term is users' willingness to pay. The second term is user cost including toll. The third term is total revenue for the facility provider, and the last term is facility provision cost. A private road company simply maximizes total profits that are produced from all roads it owns:

$$\pi = \sum_a \tau^a f^a - \sum_a S^a F^a \quad (4.14)$$

If public sector makes socially-optimal investments (which is not the case in the real world), it would perform system-wide benefit cost analysis that considers all quantifiable benefits and costs. With socially-optimal investment, the public sector first is supposed to collect revenue from fuel taxes and other public-sector revenue streams, use the revenue to cover roadway maintenance and operations costs, and finally direct the remaining revenue to expand the roads with the highest benefit cost ratios until either the revenue is exhausted or all remaining projects have benefit cost ratios less than one. In the later case, the residual revenue is saved for future investment.

The measure of benefits consumers experience with public and private, and public-private ownership regimes is presented in the following way:

$$CS^y = \sum_{v=1}^V \frac{1}{2} * (p_v^o - p_v^y)(q_v^o + q_v^y) \quad (4.15)$$

$$p_v^y = \frac{\sum_{j=1}^{q_v^y} (\tau_j^y + VOT_j \cdot t_j^y)}{q_v^y} \quad (4.16)$$

Where:

CS^y – consumer’s surplus,

y - index of simulation periods,

v - index of OD pairs,

V - total number of OD pairs in the network,

p_v^y – generalized cost paid by users of OD pair v ,

q_v^y - Total number of users in OD pair v ,

j - Index of users in OD pair v ,

t - travel time,

τ - toll,

VOT_j - value of time of user j .

This measure of consumers' surplus is sensitive to travel time savings that take place after links capacity expansion by public and private sectors, and to toll setting changes, which are a subject to public sector's regulation policies and private sector's profit maximizing goals.

4.8 Conclusions

So far, a complete cycle of the agent-based network growth process has been presented. This cycle repeats itself year after year. Simulation of these cycles can reveal various emergent properties of transportation network growth as well system wide implications of utilizing private sector financing into publicly owned infrastructure.

This research originates from the need to consider transportation demand and supply jointly in a coherent theoretical and modeling framework. Understanding the true relationships between demand and supply in single or mixed ownership environment in transportation systems is the crucial task in theoretical development of transportation models. This research models network growth as a bottom-up

process by which the expansion of roads is driven by interdependent decisions of transportation authorities and private firms. The agent-based simulation method is an appealing modeling approach for analyzing the simultaneous and interactive changes of demand and supply changes over time. This modeling approach is very suitable when evaluating transportation management decisions and policies. The detailed description of public and private supply modules and simulation experiments of the agent-based network growth model will be presented in the following chapters.

Chapter 5: Public Sector Network Growth Model of Transportation Investment Processes

5.1 Introduction

In this chapter a quantitative model with agent-based techniques is developed, which forecasts future transportation networks and their performance under both existing and alternative transportation planning processes. The existing planning process is modeled based on empirical analysis of in-depth interviews with state, metropolitan, and local transportation agencies in the Washington DC-Baltimore Region described in Chapter 3. In order to convert qualitative information of decision-making to quantitative structured model, the agent-based approach is adopted to closely replicate investment procedures of the public transportation agencies. Revenue generation, project selection process, policy and technical prioritization as well as agents' interaction processes are modeled after current investment practices of the transportation agencies in DC-Baltimore Metropolitan Area. Agents in the model are divided into two groups to represent state and local governments. While transit agencies were interviewed for the empirical analysis, this agent-based model considers only highway investments. The model's effectiveness is also compared with that under alternative planning processes characterized by different distributions of power (i.e. who controls the investment resources) among

state, metropolitan, and local agencies. The key agents of the Model and their rules are described below.

5.2 Multimodal MDOT Agent

The Maryland Department of Transportation (MDOT) is one of the State's largest agencies "committed to delivering a balanced and sustainable multimodal transportation system" for Maryland's residents and businesses (MDOT 2009). MDOT handles partnerships across modes and with partner agencies to support statewide plans. MDOT retains responsibility for decisions on capital investments as well as operating and planning activities that reach across all modes of transportation and is responsible for distributing the state's transportation budget between the modes. At the same time the Transportation Secretary's Office (TSO) establishes transportation policy in the State (MD TIP 2008). MDOT represents the MDOT Agent in our model. MDOT Agent tries to achieve the most efficient use of the existing transportation system: maintenance and preservation are prioritized over other needs to extend the useful life of facilities and equipment in existing budget shortfalls. MDOT has a unified pot of money - Transportation Trust Fund (TTF) - that provides flexibility to fund high-priority projects across the state regardless of transportation modes. Nowadays, system preservation accounts for 42% of MDOT Agent's expenditures (MD TIP 2008). It means that only about 39% of the MDOT's budget goes to capital programming (keeping in mind that about 19% of the budget usually goes to debt payments and to local governments and the state general fund).

In the future, system preservation may require even greater portion of the budget if new sources of funding are not being identified for both maintenance and capital expansion needs. However, U.S. Department of Transportation will be awarding grants under the Interim Transportation Investments Generating Economic Recovery (TIGER) Guidelines for the projects meeting certain criteria (2009). These grants will be helpful in achieving a better state of the transportation system in Maryland. To qualify for the TIGER grants the projects should demonstrate significant long-term benefits (state of good repair, livability, sustainability, safety) and lead to creating new jobs and economic development in the Region. These criteria help to assume that the percentage of budget allocated to Maryland's system preservation and capital expansion activities will remain on about the same level as nowadays, as the TIGER program favors both types of expenditures. Also, this grant program will continue supporting the current transportation policy practices in Maryland, keeping safety, congestion mitigation and accessibility improvements as top priorities in project selection process. Of the 42% MDOT Agent allocates to system preservation where the Maryland SHA gets 14% and 52% goes to transit needs of Maryland Transit Administration (MTA) and WMATA (MDOT 2009).

MDOT Agent's capital expenditures which, as was mentioned earlier, account for 39% of total expenditures, are also distributed among different state modes, where the SHA receives the biggest chunk - about 52% (according to current transportation program), and 33% goes to meet WMATA and MTA needs. (See Figure 5-1 for schematic representation of MDOT's budget allocations) Once funding is distributed to the mode administrations, then the process of budget allocation to different

improvement activities and projects begins. Each mode administration, in particular the SHA, MTA and WMATA, has their own investment processes based on the policy priorities of the MDOT. These processes are explained in the subsequent sections.

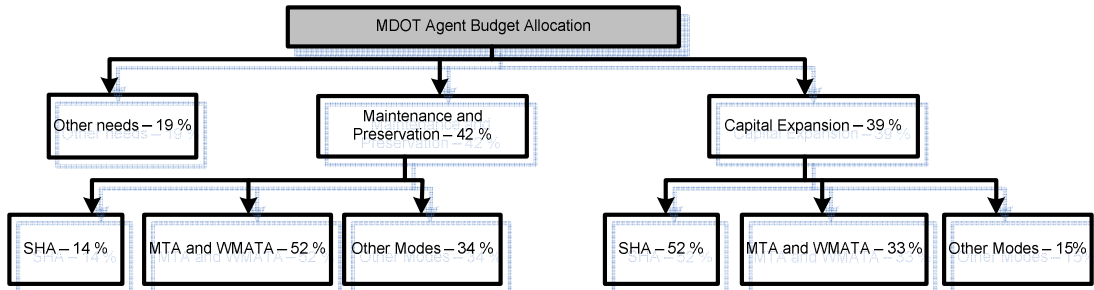


Figure 5-1: MDOT Agent Budget Allocation between Highway and Transit

5.3 State and Local Agents in Charge of Highway Investments

When the SHA, which represents State Agent in the model, receives funding from the MDOT for maintenance and preservation needs, it decides on its own how to use that money. The State Agent first ensures that the roads belonging to state system are properly maintained. Only after investing into structural deficiencies, State Agent can put money into capacity expansion activities. Usually State Agent relies on its Highway Needs Inventory that includes the list of all structural deficiencies in the system. As it is almost impossible to fund all of those deficiencies due to budget shortfalls, the projects from the Inventory are mostly selected based on 2 measures: road/pavement roughness and age of bridges in the system. It is important to mention

here, that from the interview with the SHA staff it was found out that bridges usually require twice as much funding as pavements do. This leads to an assumption that two thirds of available operational funding is spent on bridges, and one third – on pavements. Road roughness quality is measured using the International Roughness Index (IRI). It is a measurement of the “bumpiness” of the road. Low values (0-94) indicate a very smooth riding quality, while higher values (above 220) indicate a rougher riding road. The range of IRI for each category of roads is based on limits set by the Federal Highway Administration. Assuming the State Agent inspects IRI on all state links, the first candidates for funding would be links with the highest IRI. The State Agent tries to maintain about 84% of pavements in the system in “acceptable” condition. As for bridges, the more time has passed since its last maintenance, the higher the possibility the bridge requires improvement works. Therefore, bridge projects from the Inventory are assumed to be selected for funding based on their maintenance schedule. At the same time, all the bridges (about 2500 bridges) in the system should be in safe conditions. It is also worth mentioning here that while pavement and bridge maintenance consumes the majority of State’s system preservation budget, there are 24 special smaller funding categories dedicated to specific needs including drainage, traffic signs, and community improvement. As we do not know the percentage of funding going to these “small” needs, we assume that money for these activities comes from State Agent’s own budget. For capital projects State Agent is required to work in coordination with state counties and MPOs (they represent Local agents in the model). Local agents are responsible for generating their own revenues through various local taxes and fees and are required to perform regular

evaluation of the roads within their jurisdictional boundaries. Some of the roads in local jurisdictions may qualify for State agent's funding, which is determined through the policy and technical prioritization process.

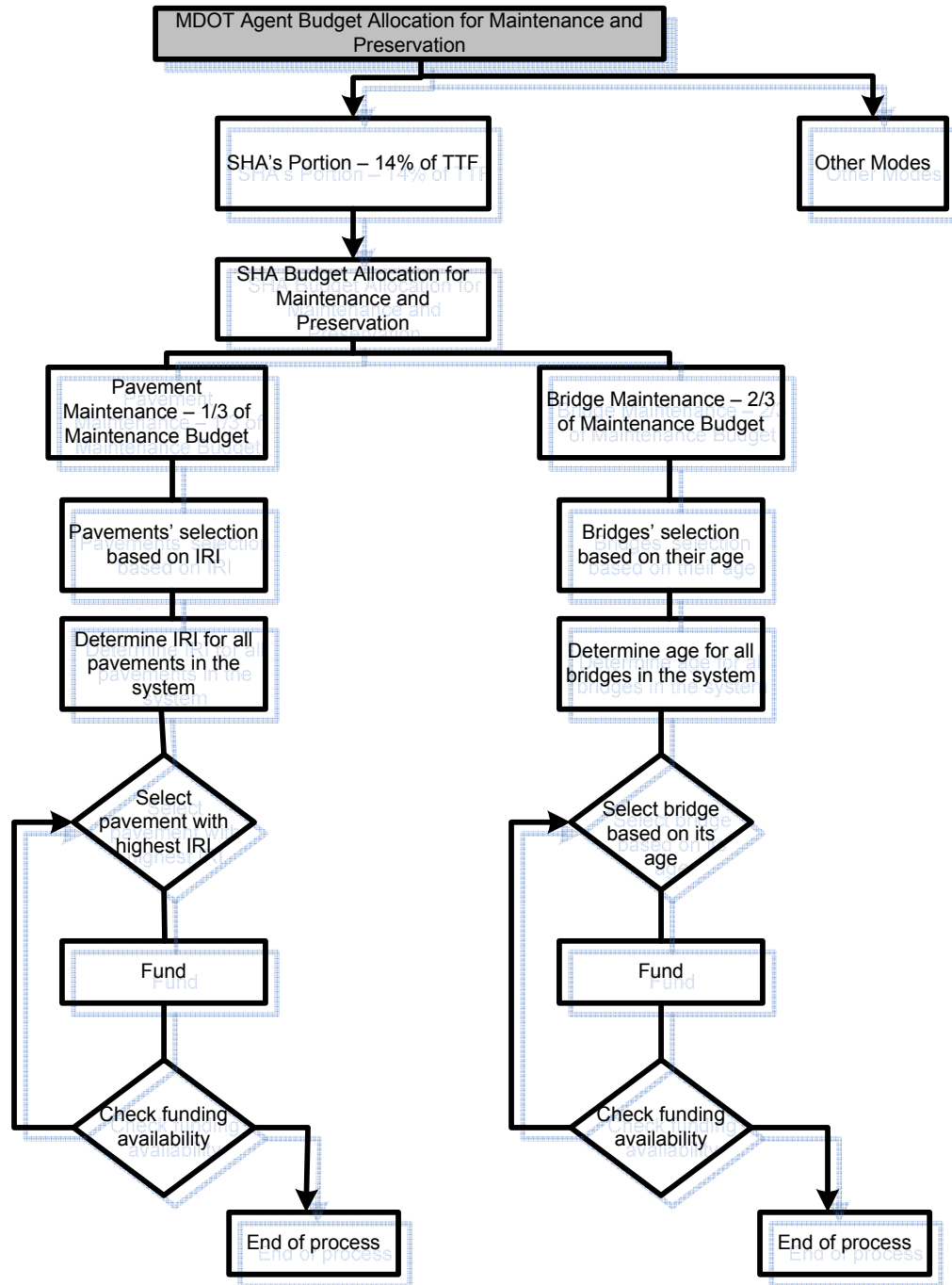


Figure 5-2: State Agent (SHA) Maintenance Budget Allocation

Each local jurisdiction (e.g. counties and cities; referred to as Local Agents in the model) may propose a project for state funding for a variety of reasons, such as being very important for local needs as well as state development, but still it cannot be guaranteed to be sponsored due to the State agent's policy considerations, limited financial resources and technical evaluation. In reality, some projects move forward when the SHA selects them as preferred alternatives in studies, in other cases - projects are delayed or dropped because funding is unavailable, because other "more important" projects emerge, or simply because there is controversy from policy point of view whether the State benefits from a particular project or not. Sometimes locally proposed transportation improvements are listed for years in local or state plans before any action is taken to get them funded. This is largely due to the lack of financial resources and the "black box" of political decisions that produce unpredictable decisions on funding.

In the model the State Agent considers 2 factors when selecting capital projects for funding (whether they are state or local): policy factor and technical evaluation. For each factor a project gets a score. For policy factor a score can be as high as 60 points, and for technical evaluation – a maximum of 40 points. A score for policy factor depends on who is promoting a project: the State Agent or a Local Agent. If State Agent proposes a project, than that project always gets 60 points for policy factor. If a Local Agent – then a score will depend on how important a project is for local needs (policy score given by a Local Agent), its score obtained from State Agent technical evaluation and the amount of contribution a Local Agent is willing to pay if the State agent fails to identify enough resources for that project.

The State agent's technical evaluation is based on three performance measures, which are safety, congestion and accessibility improvements. A project can get up to 15 points for safety performance, 15 points – for congestion and 10 points – for the need of accessibility improvements in particular zone. Capital projects submitted by Local Agents and projects in the State agent inventory undergo the same technical evaluation.

Whenever the SHA performs investment procedures based on the above described measures, which in their own turn depend on the performance of each individual link, the transportation network grows and expands in places where links score the highest for policy and technical factors. Policy factor has higher weight than technical evaluation (60 points versus 40 points), which explains why in some cases there no action is taken for technically “needed” projects. A link with the highest combined policy and technical score is funded first, then next “in line” link is funded, and so on. The investment process continues till the point when the budget is exhausted. In case, if there is still money left after previous links' investments, but that amount is not sufficient to fund the next link “in line”, then that link is dismissed by its successor link and the cost of improvement for successor link is compared against available funding. If the cost is matched, then the link is financed, otherwise – a new link down the scale is selected. From interview observations, it can be stated that the performance measures of the Local Agents are the same with the State, but the point distributions are different as they are determined through the processes of Local Agents' budget allocations. When selecting state links that might qualify for the State funding, Local agents perform not only the technical evaluation, but also the

policy evaluation. And again, policy factor has higher weight than technical factor (60 points versus 40 points). Local agent’s policy evaluation is also some kind of “black box” of decisions, which means that this process is very subjective.

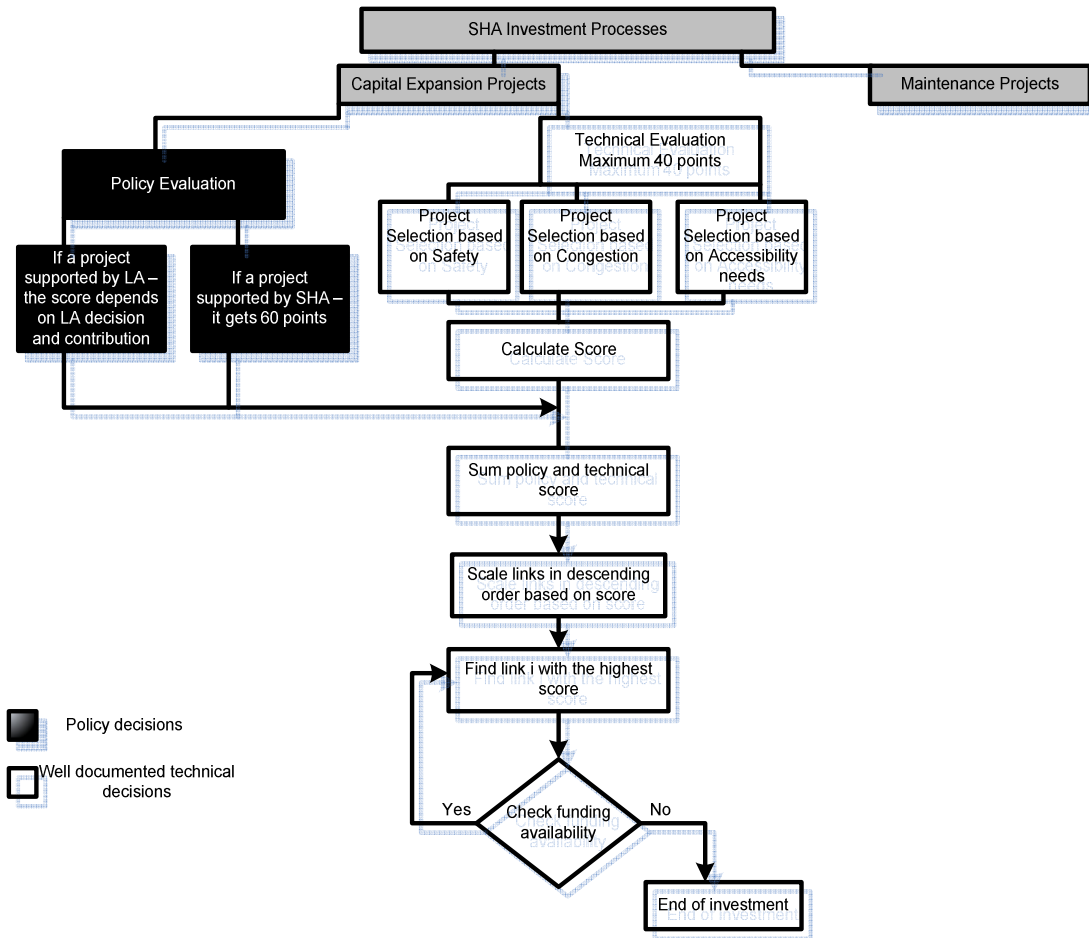


Figure 5-3: Summary of the State Agent (SHA) Investment Processes

Projects from which a Local Agent benefits the most are given the highest scores, but it is difficult to predict which project a Local Agent will consider beneficial and which – not. However, each Local Agent can not submit unlimited number of projects with high scores and neglect projects with low policy scores. To remind, the final decision on funding is after the SHA, and Local Agent’s low policy score may turn out to be high score when the SHA re-evaluates locally proposed

projects. Therefore, to closely reflect reality, in our model we assume that every Local Agent submits 5 projects with policy score 60, 4 projects with policy score 40 and 3 projects with policy score 20. When performing technical evaluation, a Local Agent considers the same three measures as the State agent does, but the point assignment is different. The total number of scores a particular project can get for overall performance is 40.

Link scores obtained from Local agents' technical evaluation are summed with the corresponding policy scores given by each Local Agent. After that Local agents submit a list of qualified links. To remind, each agent can submit 12 projects (5 projects with policy score 60, 4 – projects with policy score 40, and 3 – with score 20). Combined with the technical score, these 12 projects will need to have the following number of scores:

- 5 projects with scores greater than 80, where 60 points would come from policy factor,
- 4 projects with scores 61 – 80, where 40 points would come from policy score,
- 3 projects – with scores 41 – 60, where 20 points would be from Local Agent's policy evaluation.

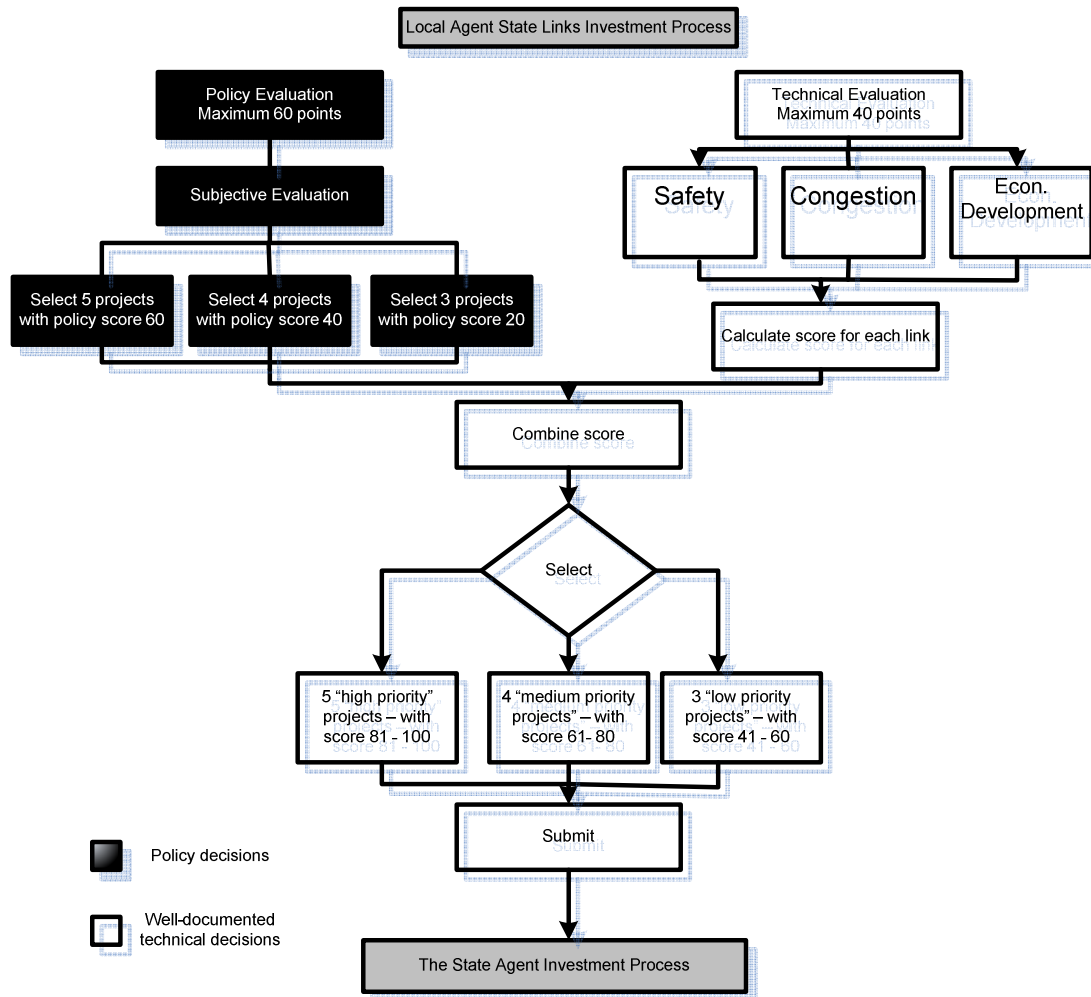


Figure 5-4: Local Agent (Counties) Project Prioritization for State Agent Funding

5.4 State-Local Agency Interactions in the Highway Transportation Planning Process

Agent-based planning is when multiple agents coordinate their activities. It involves: 1) agents' planning for a common goal – the future state of the transportation network, 2) the State agent's coordinating and compiling the plans of others into the general merged plan, and 3) a Local agent refining its own plan while negotiating priorities or resources with the SHA agent in the general merged plan.

The general idea of multi-agent planning is to combine a planning method for each agent with an auction for delegating investment priorities in the shared transportation system.

In this research model the agents are making their investment plans independently of what the other agent is planning but they have to coordinate their efforts in creating one merged plan based on those independent plans as it is done in the real world. The performance measures valued by each individual agent determine which links in the network qualify for funding and therefore are included into their plans.

In the agent-based planning process the agents' primary characteristics are:

1. Each agent does not have the accurate abilities to solve the whole problem, i.e. each agent cannot determine all the links in the system that requires investment.
2. Data about links are not centralized, so they must be shared by all agents.
3. Each agent has his own ranking system for determining candidates for investment.
4. All agents in the system are designed to be self-interested and myopic. That is, in making a decision, such as selecting a particular link into a plan, the agents are only concerned with their own needs. Agents have no way to estimate other agent's needs but have an idea of what would benefit to the global welfare of the system. The main goal of the Local agent is to prioritize links based on performance measures, and the main goal of the State agent is to reevaluate that prioritization and assign funding.

The links in the system are organized in a priority queue, sorted by the performance measures of Local agents, and then the links are sorted again by the State agent. In detail, the negotiation process between agents can be described as follows:

1. First, each agent, whether State or Local, ensures that all the links in the system are properly maintained. Each agent uses its own budget for maintenance needs.
2. After maintenance, each agent selects candidate projects for capital expansion. Each Local agent observes all the links under his supervision, ranks links based on performance measures as was described earlier and submits links to the State agent for further consideration. State Agent performs technical evaluation for his own links as well.
3. Each Local agent submits 5 “high priority” projects, 4 – “medium priority”, and 3 – “low priority” projects for State’s evaluation.
4. The State agent evaluates the condition of Local links again but based on his own performance measures. During this process, links can get higher scores than was assigned to them earlier, or can get much lower scores even if a link was originally claimed to be “high priority”. Therefore, some of a Local agent’s links get funded and some of them not. If a particular link is not funded, it is sent back to a Local agent. In this case, a Local agent funds this link if it was high priority and budget still allows after maintaining links within local system. Otherwise, this link may be left for next year investment process.

It is important to note, that all the agents are subjectively rational when making decisions. And in many cases they make preferences based on their policy considerations, rather than technical assessment.

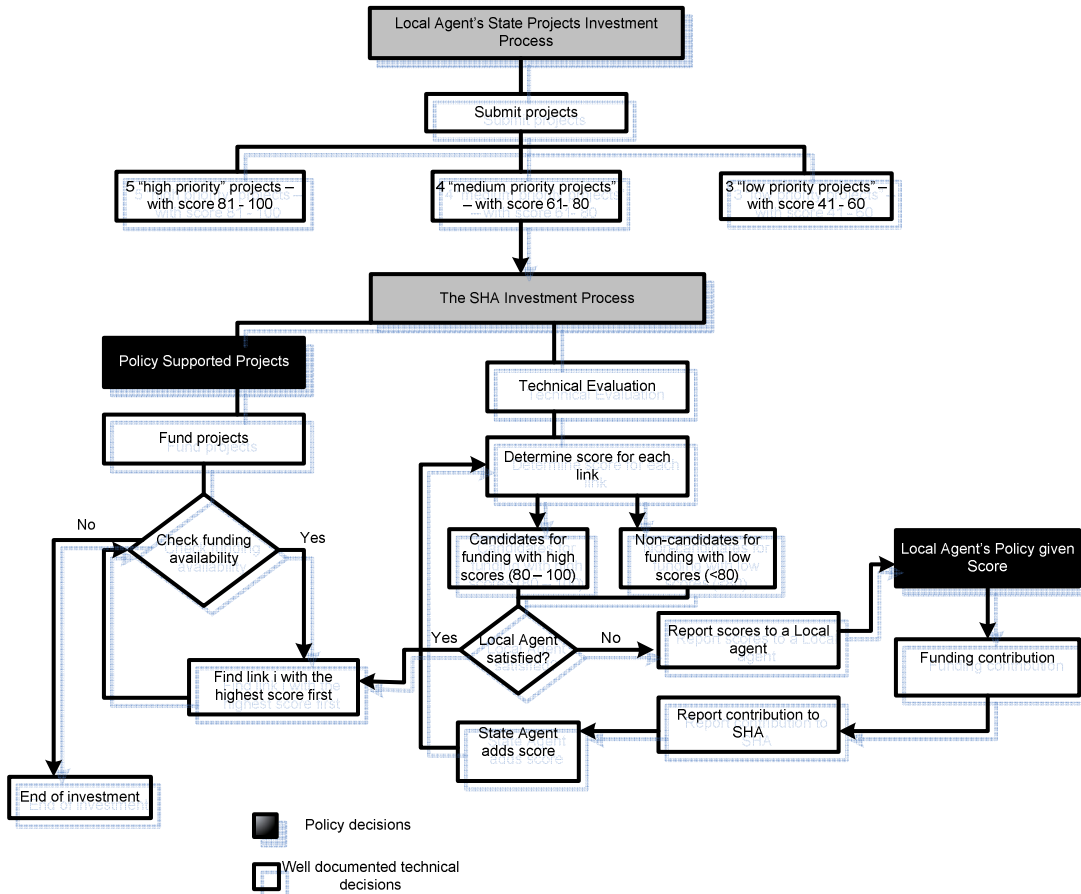


Figure 5-5: The Complete Existing Highway Investment Decision-Making Process with State and Local Agents

5.5 Benchmark Scenarios

Although the proposed model structure can evaluate most investment scenarios in real world networks, this paper considers a hypothetical city with grid network for ease of interpretation, and focuses on the comparison between current

investment regime and alternative centralized state regime, where all roads are controlled by state government, and decentralized local regime, where each local jurisdiction controls investments into its own roads. The hypothetical city network consists of 10 by 10 grid road way links of 2-mile in length and an initial capacity of 775.5 vehicles/hour on each link. In the city a uniform initial land use pattern is assumed, and each node has 100 residents and 100 jobs. Each network link is assigned to either the State Agent or one of the five Local Agents. Based on the existing planning process, the State Agent controls all major state highways, represented by two north-south corridors, two west-east corridors, and a beltway system in the stylized network. All other links are assigned to the five Local Agents with one local agent in the city center and each of the four other local agents occupying one of the four corner areas in this stylized network.

When the agent-based simulation is executed, the travel demand model first predicts link-level flows. Based on the demand forecasts, revenues available to state and local agents are computed respectively based on the existing revenue policies (i.e. fuel tax, registration fees, and some general funds). After that the investment model, developed in Section 4, operates and forecasts investment decisions based on the current planning processes adopted by state and local agents. After each round of investment decisions, the network is updated with improved capacities for links selected for investment. Network performance measures are also computed for each investment cycle (one cycle per year), including total travel time, total distance traveled, average speed, total revenue collected, user benefits/consumer surplus, and net total social benefits. A time horizon of 50 years was chosen for the simulation

experiments to observe the effects of current and alternative investment processes on future network performance. Three transportation planning and investment processes are considered:

1. **Base Case:** This scenario represents the existing transportation planning and investment process in the DC-Baltimore Area;
2. **State Control Case:** The State agent has centralized control over all links in the system and makes decisions for the entire budgeting and investment process. And
3. **Local Control Case:** State agent has no influence in the transportation planning process at all. Each of the five local Agent monitors and budgets the links within its jurisdictional boundaries.

5.6 Results

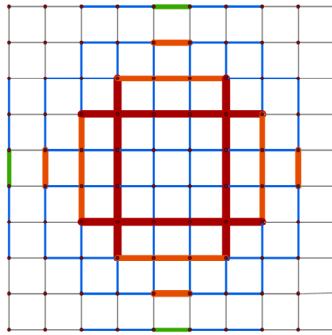
Figure 5-6a illustrates the transportation network changes and capacity increases over a 50-year period when transportation investment decisions are made according to the current planning process in the DC-Baltimore region wherein state and local agencies share power and engage in negotiations. This planning process has resulted in a hierarchical network with two major north-south freeways, two major west-east freeways, and a beltway system also with higher capacities. This network topology is consistent with that in many U.S. urban areas.

Figure 5-6b presents the transportation network changes under complete State Control where the state agent makes all investment decisions only based on technical

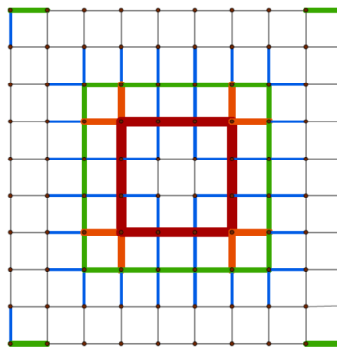
considerations such as safety, congestion and accessibility. Overall, the future network under State Control is similar to that under the current planning process, which is consistent with our empirical observations that state DOT and State Highway Administration are the dominate decision makers in the current planning process and controls most of the resources. Further examination reveals that under complete State Control, there are fewer investment projects on the periphery of the network compared to the existing planning process. Clearly, state agent invests in peripheral roads under the existing planning process only because these projects are high-priority projects for the individual local agents.

Figure 5-6c plots the transportation network changes under decentralized Local Control. Recall that in this case the state agent has no power at all and each local agent controls the resource from its own jurisdiction and makes investment decisions solely based on the interests of its own jurisdiction. Unsurprisingly, the resulting future network is much less hierarchical and capacities are much more evenly distributed in all areas of the region.

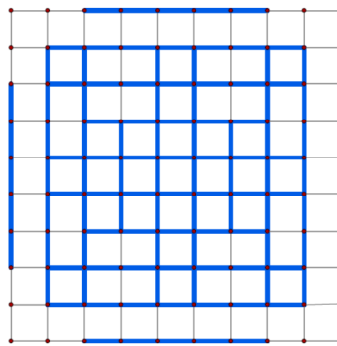
Local agents apparently have no incentives to building major high-capacity freeways that primarily serve through traffic. Under this type of decentralized local control, the future network most likely consists of many major arterial roads with moderately high capacity. It should be pointed out that this network topology under Local Control has a lot more redundancy (i.e. good alternative routes) than that under the current planning process or under State Control, and therefore should be more resilient to traffic accidents, disasters, and targeted attacks.



a: Base Case Scenario



b: State Control Scenario



c: Local Control Scenario

Capacity (veh/hour)



Figure 5-6: Future Networks under Alternative Transportation Planning Processes

Numerical results summarizing the performance the future networks are provided in Table 5-1. Compared to the two alternative planning processes, the current transportation planning process will produce a future network that is inferior by all performance measures: higher total vehicle hours traveled, lower vehicle kilometers traveled, lower average speed, lower total revenue, lower user benefits, and lower net social benefits. These finding based on the stylized grid network suggests reform of the current transportation investment process.

Performance Measures	Base Case	State Control Case	Local Control Case
VHT (Million hours/year)	190.1	189	142.5
VKT (Million km/year)	5947.4	6092.7	6480.2
Average Speed (km/hour)	31.3	32.3	45
Number of Trips per Day	990001	990000	989999
Revenue (\$Million/year)	69.8	71.9	81.7
Amortized Expansion Cost (\$Million/year)	42.4	56.8	34.3
User Benefits/Consumer Surplus (\$Million/year)	201.7	274.7	293.8
Net Social Benefit (\$Million/year)	248.2	323.2	341.5

Table 5-1: Future Network Performance under Alternative Transportation Planning Processes

It is to our surprise that the Local Control scenario is shown to be the most effective based on all measures: lower vehicle hours traveled, higher vehicle

kilometers traveled, higher average speed, higher total revenue, higher user benefits and net social benefits. This implies that the current top-down investment process is less efficient, while more locally distributed funding allocation and the possibility of investments into the projects considered mostly by local jurisdictions delivers superior overall network performance results. Also, the strategy by state agencies that focuses on expanding the capacity of the most congested bottlenecks may not be a very good long-term policy. It is probably more effective to address the congestion problem on a particular road by expanding the capacity of its parallel roads, which in the long run produces a transportation network with a more balanced capacity distribution, not a very hierarchical one.

5.7 Sensitivity Analysis with Regard to Public Revenues

A sensitivity analysis comparing decreases/increases in revenue sources of public sector and lane kilometers changes are shown in Figure 5-7. The graphical representation is provided. All other variables were held constant at their assumed levels during the analysis. The decrease/increase in revenue was varied for each case scenario (“business-as-usual network ownership”, state control case scenario and local control scenario). The resulting changes in lane kilometers of public roads are presented after 50 year period simulation.

In “Base Case” scenario we can see some changes in increase/decrease of capacity with regard to changes in revenue streams; especially we can see a huge increase in lane kilometers of public roads after available funds increase more than

5%. It is a good indicator that currently highway capacity is highly under-invested. In “State Control” scenario we do not see as much new lane kilometers built as in the “Base Case”, due to possible inefficient resources allocation. Since in this case we have only one decision-maker – the State, there is no cooperation/coordination present, therefore the State may choose to spend majority of its funds for maintenance needs, rather than capacity expansion.

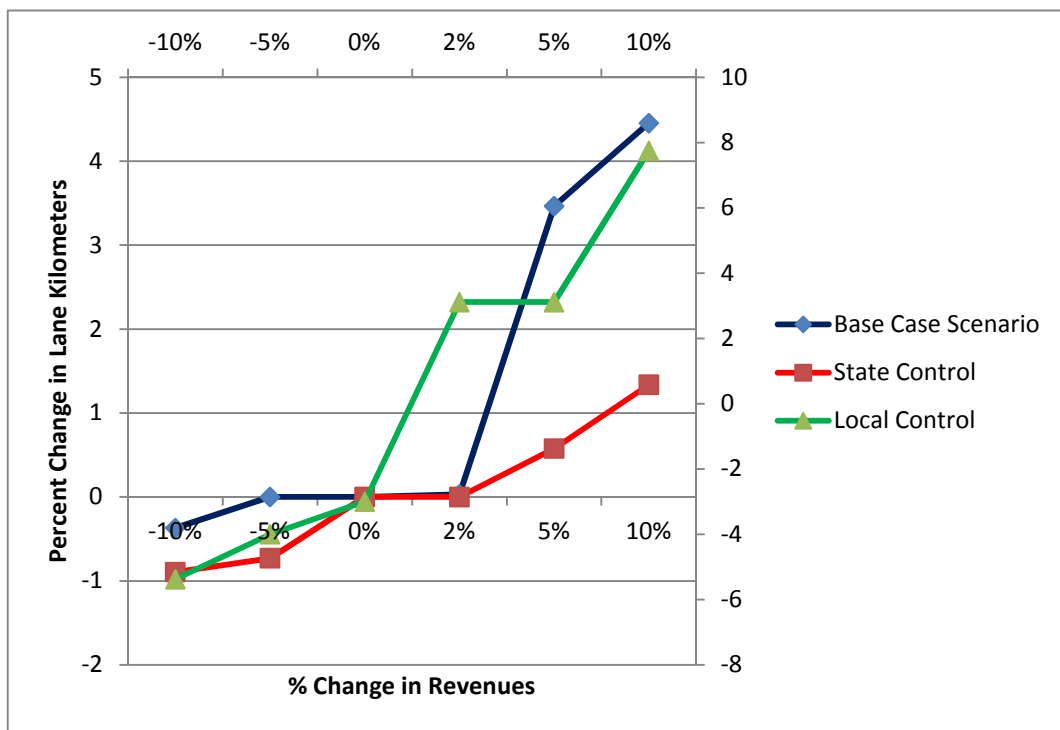


Figure 5-7: Sensitivity Analysis with Regard to Public Revenues

“Local Control” scenario results show that even small changes in revenues can increase lane kilometers of public roads. It can be explained by the fact, that when funding is allocated directly to local jurisdictions, State does not participate in money allocation. And local jurisdictions are interested in improving their road

conditions due to competition in economic development. When dealing with decreased amount of revenue, all the scenarios respond with decrease in lane kilometers built on the network.

5.8 Conclusions

This chapter demonstrates the feasibility of developing quantitative models that can forecast future networks under current and alternative transportation planning processes. The current transportation planning process is modeled based on empirical information collected from interviews with key transportation agencies and planning documents published by these agencies. The investment decision-makings rules of and interaction/negotiations among state and local transportation authorities are explicitly considered in the proposed agent-based model. Results on a test network show the current transportation planning process can be improved in several different ways. Either a more centralized or more decentralized planning process can improve investment decision-making and enhance the performance of future transportation networks.

It would be naïve to believe a major reform of the current transportation planning process will happen anytime soon. After all, it is a process driven by political considerations, air quality concerns, economic development, safety, and engineering efficiency. While it is certainly feasible to employ the proposed model to evaluate alternative planning processes out of intellectual interests, the most likely practical application of this type of models is probably the evaluation of the impact of

a particular group of investment projects on future network performance. Another application is to forecast future networks for long-range transportation planning and policy scenario analysis. Currently, there is not a general method for generating future transportation networks 30 or 50 years from now, though this kind of planning horizon is often required for land use, greenhouse gas, and sustainability policy analysis. The model developed in this chapter can fill this methodological gap.

Chapter 6: Agent-Based Model of Private Sector Investments with Regulatory Policies

6.1 Introduction

As was mentioned earlier, a wide range of approaches and models have been proposed to study socio-economic effects of private ownership, but few studies have been devoted to the detailed analysis of the ownership structure and its resulting socio-economic outcome. This chapter extends the previous work on modeling public-sector investment decision-making and the research on long-term evolution of mixed-ownership roadway networks (Zhang and Levison 2006, Zhang 2008, Zhang et al. 2008, Zhang and Yusufzyanova 2011) to analyze the impact of roadway privatization on users, investors, and social welfare under regulation.

The analytical tool developed here is an agent-based model that jointly considers capacity expansion and pricing decisions by public and private sectors, market entry decisions by the private sector, user demand responses, roadway construction and maintenance cost structures, and regulation on private-sector investment. In every iteration of the agent-based simulation, each decision-maker (private roads, public roads, and system users) adjusts its own behaviors/decisions based on available historical system information and its self-interests. For instance, users attempt to maximize utility and minimize travel times. Private roads seek to maximize profits. Public agencies adopt business-as-usually or welfare-maximizing pricing and investment decisions. These micro-level agent decisions collectively drive

the macro-level dynamics of the mixed-ownership roadway system. Each agent and decision-maker is modeled with unique characteristics and preferences (e.g. different values of time for users). Private investors base their market entry decisions (i.e. to invest or not to invest in roadways) on the estimated returns of investment on candidate roadway privatization projects under regulation, their capacity investment decisions on long-run profit-maximizing goals, and pricing/tolling decisions on current capacity levels and short-run profit-maximizing objectives.

The initial condition is an existing road network controlled entirely by the public sector. As the private sector gradually builds new toll road projects under regulation and without, the network shifts to a mixed-ownership regime. Several scenarios are being developed here to explore the possibility of equitable network ownership within the framework of current transportation system revenue generation and resource allocation. The proposed scenarios are described below.

6.2 Introducing Private Entity to the System

The essence of effective road network management with multiple players is the ownership structure. To be effective, ownership has to be assigned to a clearly defined entity, which can be private or public, or a combination of both. Owners generally find it their responsibility to maintain their assets, but owners also have the right to sell, lease or abandon them. In the case of roads, responsibility under existing real-world arrangements is often unclear, especially in the case of the US interstate

highway system, when owners (states and local authorities) depend on others (central government) for most of the funding generation and distribution.

A key element in any ownership is the existence of individuals who lose if their asset's condition gets worse, or gain if the asset increases welfare. In the case of publicly provided roads, it is unclear who should become worse off if the roads become congested or deteriorate, since the system is set up in such a way that even when it is understood, who is responsible for which roads, the current funding allocation process contradicts to existing network ownership structure. This creates tension not only between state and local entities themselves, but also between road users and state/public officials, who fail to deliver well-functioning system through tax revenues.

This implies that effective and efficient road system should have certain characteristics. Some of them can be stated as follows:

- Road network has well established ownership structure;
- It is financially self-supporting;
- Revenues generated from roads (whether user charges or tax fees) should go to the “owners” of those roads;
- Roads have common standards for interconnectivity and performance criteria (e.g. congestion, safety, accessibility);
- There is a possibility of private road ownership with certain restrictions or constraints.

The key research question here is to design such a network ownership structure as well as to suggest regulatory policies on private-sector investment in

order to maximize overall network performance in terms of social welfare and private and public revenues. The ownership scenarios with various regulatory constraints are presented below.

6.3 General Framework for Scenario Setting

In all scenarios it is assumed that network development is the result of the interactions between public agent and private entities negotiating over network ownership. Considering a situation where links are with different capacities, the negotiation process is assumed to be organized as follows: public agent considers link i to be converted to private ownership at initial price x (A). From the moment an interested private agent signs up, the actual negotiation starts. The process of negotiation is one in which the public and private agents alternatively make counterbids until the parties reach an agreement or until one withdraws from the negotiation. If the negotiation turns out successful, the link i goes to private ownership. If not, the public agent starts negotiating with another interested private party. During each negotiation round, every agent can perform three types of actions: it can accept a bid, reject a bid, or propose a counterbid. The bidding process is done over the selling price of a particular link, i.e. private agent's lump-sum payment to the public agent, over the price ceiling and over the concession period.

It is assumed here that all agents select the action from which they expect to derive the maximum utility, whether it is maximizing social welfare or maximizing profit and reducing expenditures. This utility depends, among other things, on the

expected final price at which the link is given and, thus on the perceived net present worth of any particular link. Private agent will be interested in at least recovering its investment if the following conditions are in effect:

- There should be no significant external benefits or costs to building or using transportation service (such as noise, air pollution by non users, and external benefits might be congestion relief on competing modes or facilities);
- Investment must be optimal or near optimal for current demand (when demand does not change drastically);
- There should be constant returns of scale in the firm's long-run costs of building and expanding the new facility.

These conditions will also ensure that private agent will not seek excessive profitability from toll facility. Public agent, on the other hand, will try to sell any particular link for the price no less than the amount of funding used to construct, maintain and operate this link for existing capacity to meet the up-to-date traffic demand.

During negotiation process the actions have to be based on agents' beliefs. A belief means that an agent classifies the phenomenon of interest into a set of discrete states or outcomes and assigns some subjective value to each possible outcome of the phenomenon, for example, regarding the price of a link falling within some predefined price category. With each new bid, the state agent receives new information about private agent, on the basis of which it can update its beliefs regarding the behavior of this private agent. Agents can at all times decide to stop the negotiation process—for example, due to private agent's budget constraints.

6.4 Regulatory Policies

A private investor's tolling and capacity decisions are both subject to regulatory policies when privatizing public roadways. Three most-widely adopted regulatory schemes on private toll roads in the U.S. are considered.

Price Ceiling: Price ceiling are probably the most common regulation on private toll roads. It states that the toll rate on private roads cannot exceed a certain maximum level, defined as a monetary value for a toll facility or as a per-km ceiling rate. This simply adds a constraint to the private-sector profit-maximization problem (Equation 4.12).

Revenue Sharing: In some cases, a private toll road may be required by contract to share a certain percentage of their revenue or profit with the public authority (e.g. state DOT), referred to as revenue sharing regulation. We can model this regulation and its effect on the transportation system by multiplying the percentage of revenue sharing with the first term (representing actual private-sector revenue) in Equation 4.12.

Concession Agreement: Concession agreement requires the private sector to transfer the ownership of a toll road to the public authority after a pre-determined concession period. This type of regulatory schemes has been recently observed on the Chicago Skyway and Indiana Toll Road PPP agreement. To model concession periods (C), T in Equation 4.12 is replaced by the $\text{minimum}(C, T)$.

6.5 Development of Roadway Privatization Scenarios

Four policy scenarios are developed in this chapter, including two roadway privatization scenarios and two benchmark scenarios for comparison purposes.

6.5.1 Benchmark Scenario 1: Base Case

The base case scenario represents the status quo in public-sector road financing in the U.S. without private-sector investment (i.e. no roadway privatization). Only the public sector makes pricing, maintenance, and capacity investment decisions. The pricing model in this scenario considers average-cost user pricing, which is consistent with current federal and state fuel taxes and other public-sector transportation revenue streams (e.g. registration fees) in the U.S. The user charge is almost entirely independent of when and where the driving takes place. The business-as-usually investment rules are adopted for the base case to represent the existing multi-agency public-sector roadway investment decision-making process. In the base case scenario, multiple public-sector agencies are modeled, which represents state and local transportation agencies that have different objectives (i.e. regional transportation goals versus local transportation goals). This multi-agency nature of current public-sector transportation decision-making is likely to make the final investment decisions less effective than those made by a single public-sector agency controlling all roadways.

6.5.2 Benchmark Scenario 2: Socially Optimal

The socially optimal scenario assumes welfare-maximizing pricing and investment decisions, and therefore produces the theoretically maximum social welfare. In this scenario, it is assumed that all roadways are controlled by a single welfare-maximizing agency. Marginal cost pricing based on congestion externalities is implemented throughout the entire roadway network. Revenue generated from marginal-cost tolls is then invested for long-run maximum net social benefits.

6.5.3 Privatization Scenario 1: Private Takeover of Existing Public Roads

In the first privatization scenarios, the public sector may decide to lease existing public roads to the private sector for a predetermined period of time, i.e. concession period, and allow the private sectors to charge user tolls during the concession period. The private road tolls cannot exceed a certain pre-set price ceiling. In exchange, the private sector pays the public sector a certain amount of money in a lump-sum at the beginning of the concession period. The amount of lump-sum payment is negotiated between the public and the private-sector decision-makers, and should be correlated to the long-run return on the private-sector investment and the market value of the public road being contracted out. The lump-sum payment could be considered as a form of revenue sharing before the toll revenue is actually realized. While the private investor may further expand the capacity of the road during the concession period, the incentive to do so may be very limited because of the fixed concession period and lack of competition in this case. Private toll roads may expand their capacity only if there is significant travel demand increase, which makes

capacity expansion profitable. With the lump-sum payment from the private sector, the public sector is assumed to reinvest the lump-sum payment into the maintenance and/or capacity expansion of public roads. It should be noted that if the lump-sum payment is used for non-transportation purposes (e.g. paying off debt, or investing in other sectors), the transportation system benefits of this privatization scenario are expected to decrease significantly. Once the concession period is over, the private sector returns the private toll roads to public ownership. This scenario is modeled after the recent Chicago Skyway and Indiana Toll Road PPP projects in the U.S.

6.5.4 Privatization Scenario 2: New Private Toll Roads

In the second roadway privatization scenario, the private sector is allowed to invest into the construction of new toll roads, charge users subject to price ceiling, and operates the toll roads for a certain concession period, and finally return the new toll roads to public ownership after the concession period is over. The private sector must invest in new roadway capacity to enter the market. There is no lump-sum payment that the private sector needs to make to the public sector at the beginning of the concession period in this case. Private toll roads are also required to share a certain percentage of their profit with the public-sector. Public roads will likely not expand as much capacity as in the previous privatization scenario due to the absence of initial lump-sum payments from the private sector. This scenario is modeled after new privately-invested express toll lanes and high occupancy toll lanes in the U.S.

In both privatization scenarios, the public sector is assumed to adopt business-as-usually pricing and investment decisions already discussed in previous sections.

Chapter 7: Simulation Results of the Agent-Based Model of Private Investments

7.1 Test Network and Model Execution

In this chapter the agent-based model of private sector investments is being tested on a hypothetical city network. Here the model is applied to the grid roadway network for ease of interpretation. System-level patterns can also be more easily identified in the grid network than real-world networks. The hypothetical city network consists of a 10-by-10 roadway grid with each directional roadway link measuring 2 miles in length and having an initial capacity of 775 vehicles/hour. This capacity value corresponds to a typical one-lane directional road in U.S. cities. A uniform land use pattern is assumed, and each of the 100 nodes has 100 residents (for trip production) and 100 jobs (for trip attraction).

When the agent-based simulation for each of the four policy scenarios is executed, the travel demand model first predicts link-level flows based on land use and current roadway network attributes. Based on demand forecasts and current pricing strategies, revenues available to various public- and private-sector agents in the system are then computed respectively. These revenues are employed to maintain existing roads, expand roadway capacity, and/or produce revenue surpluses or profits based on public- and private-sector investment rules. After each round of investment decisions, the network is updated with improved capacities. Network performance measures are computed for each investment cycle (one cycle per year), including lane

miles of private and public roads, mobility, accessibility, public and private road tolls, revenues collected by each road, user benefits/consumer surplus, profits, and net social benefits. A time horizon of 50 years has been selected for all simulation experiments to observe the short- and long-run effects of the base case, socially optimal, and two privatization scenarios. After 50 years, the roadway network appears to have achieved equilibrium under each of the four policy scenarios. For the two privatization scenarios, the following regulatory policies are enforced: (1) 30-year concession period; (2) 50% profit-sharing with the public sector; and (3) 4 cents/km price ceiling. This set of regulatory policies provides high user and social benefits compared to other regulatory policies tested.

7.2 Simulation Results

The evolution of the grid network under the four policies scenarios is illustrated in Figure 7-1 with lane-kilometers of roadways being the measure of network development over time. By examining the socially optimal scenario (the line on the top), one can observe that the initial network in Year 0 is significantly underinvested and the network is severely congested. With revenue from high initial marginal cost tolls, roadway capacity is soon expanded to the optimal level, i.e. almost twice of the initial network capacity. In contrast, under the base case scenario (the thickest solid line in the middle of the graph), the average cost pricing practices cannot produce sufficient revenue for optimal capacity investment. While the public sector is still able to gradually expand roadway capacity over time, additional revenue

sources would help increase the network capacity closer to the optimal capacity levels.

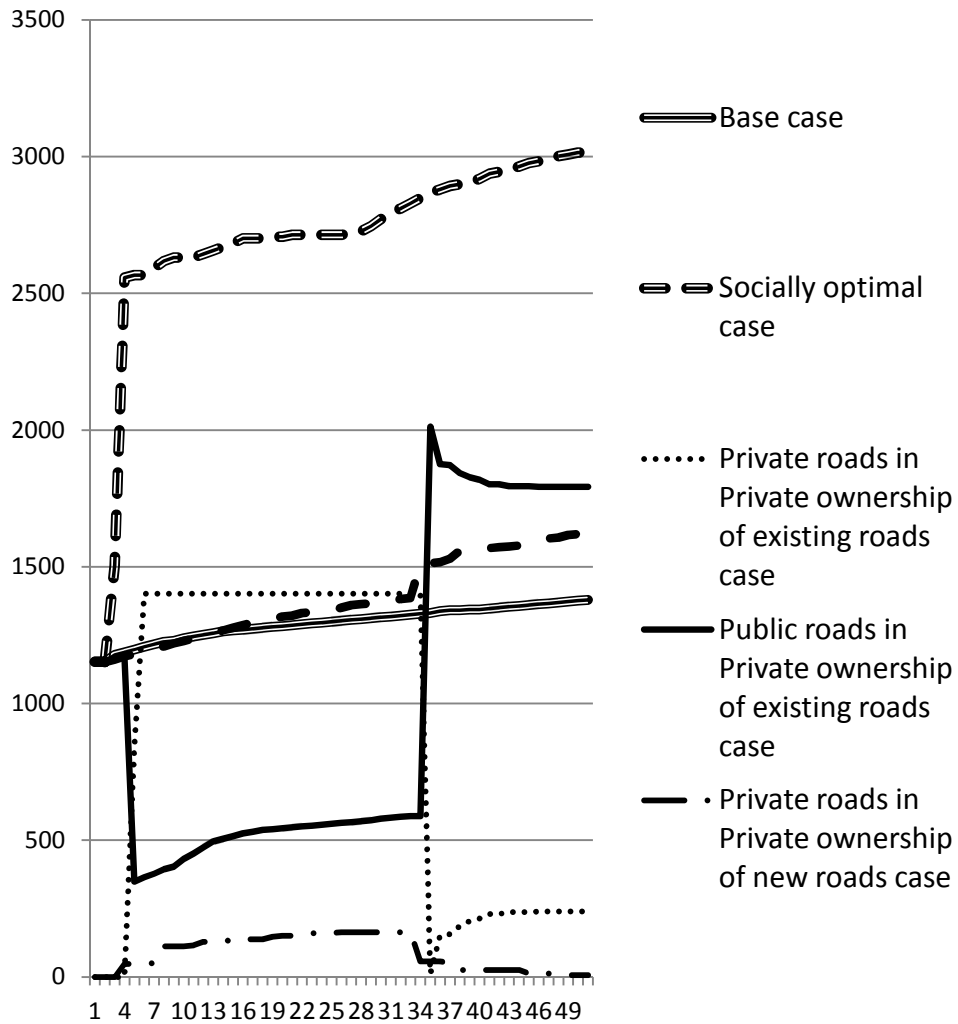
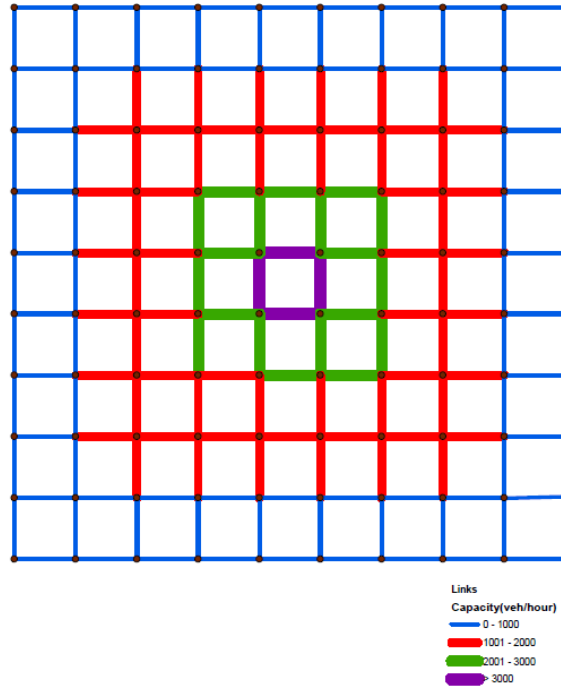


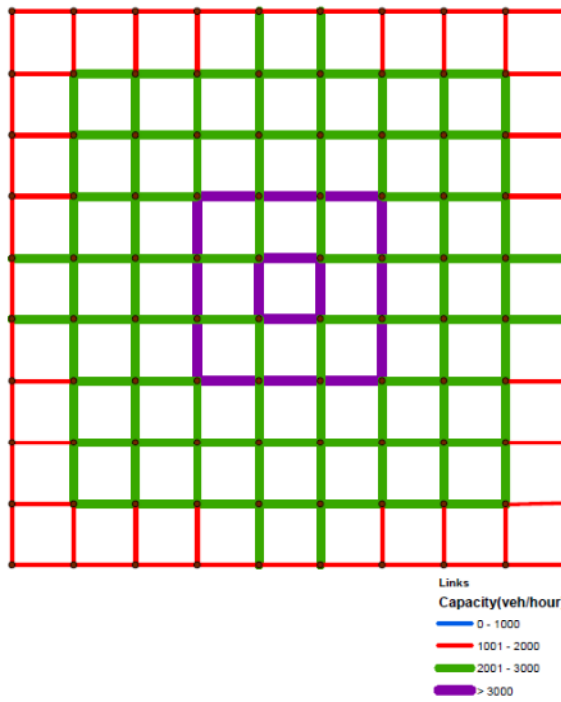
Figure 7-1: Lane Kilometers of Public and Private Roads (km)

This contrast between the base case and socially optimal scenarios is representative of the network conditions in places where private-sector investment in roadway networks has been considered or implemented. The other four lines in the graph correspond to the two privatization scenarios. The lane kilometers of private

and public roads in each of these two scenarios are plotted separately. In the scenario wherein the private sector only takes over existing public roads through leasing/concession agreement (referred to as the “private takeover” scenario hereafter), the private sector quickly takes over a large number of roadways in the network, shown by the quick increase of private road lane miles and quick decrease of public road lane miles in Figure 7-1. The spatial monopoly power of roadways promises profitability on these roadways, and the private sector quickly takes advantage of it. Interestingly, there is no future capacity expansion on the private roads throughout the 30-year concession period (the flat part of the curve between Year 5 and Year 35). Again, the spatial monopoly power of private roads in this private takeover scenario makes any capacity expansion on private roads undesirable from the profit-maximization perspective. However, the public sector, with large amounts of lump-sum payments from the private sector, is able to construct much more capacity than that in the base case scenario. In the scenario where the private sector can only invest in new private toll road capacity (referred to as the “New Private Road” scenario hereafter), the public sector can still build more capacity than that in the base case scenario, but not as much capacity as that in the private takeover case. This is because the revenue from the profit-sharing term with new private toll roads is less than that from the lump-sum payment in private takeover agreements. The equilibrium networks after the 50-year simulation period under the two privatization scenarios are illustrated in Figure 7-2.



a) New Private Roads Scenario



b) Private Takeover Scenario

Figure 7-2: Network Capacity Expansion over a 50 year Period

The majority of capacity expansion takes place near the center of the network in both scenarios, which makes sense since travel demand is the highest in the center of the network. It should be noted that for the private sector, there are also incentives to build new private toll roads or take over existing public roads near the four corners of the network, because competition from parallel roads is at the minimum in the corners. It appears the high demand effect favoring capacity expansion in the center overshadow the spatial monopoly effect in the corners in this mixed-ownership grid network.

Average link tolls (see Figure 7-3) are different in the four policy scenarios. The base case scenario exhibits the lowest user tolls, equivalent to about 1.6 cents per km in all years (i.e. no increase in fuel taxes or other road user fees). The marginal cost tolls in the socially optimal scenario are the highest, and are as high as 11.6 cents per kilometer when congestion is at its worst level at the beginning of the simulation period. Roadway privatization allows the private roads to charge higher tolls than the public roads. The overall levels of link tolls in the two privatization scenarios are closer to the socially optimal tolls than those in the base case, which is desirable from welfare-maximization point of view. The effect of price ceiling regulation can be observed in both privatization scenarios, especially the private take over scenario. The ceiling price may be increased to further improve the pricing efficiency of toll roads, but at the same time higher ceiling price may reduce user benefits in the long run (i.e. higher overall social welfare, but also with higher percentages of welfare gains allocated to the private sector). The private sector is also able to charge higher tolls under the private takeover scenario than under the private new road scenario.

This is because all new private toll roads in our test are built parallel to existing public roads (e.g. similar to new express toll lanes next to existing publicly-owned general purpose lanes). The presence of competition from parallel public roads prevents new private toll roads to charge even higher tolls.

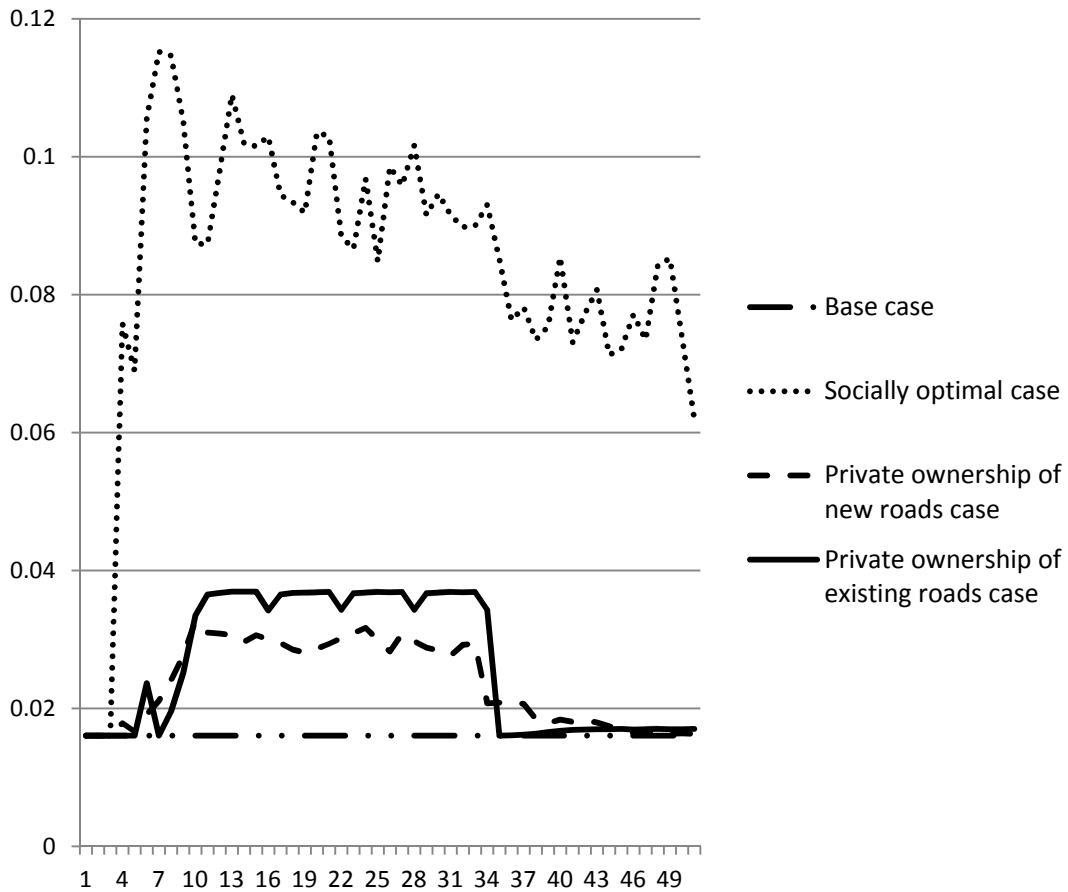


Figure 7-3: Average Link Toll (\$/km)

Now all private roads can make profits. This is true in the real world as shown by recent bankruptcy of several private toll roads in the U.S., and in this model because any private road at the time of investment decision-making in the model only has historical demand information and cannot perfectly predict future investment and pricing decisions by the public sector or its own private-sector competitors. Figure 7-

4 shows the profitability of private roads over time. In the private takeover case, almost all private roads make profits in all years due to their spatial monopoly powers (no direct competition from the public sector). This is not the case in the private new road scenario wherein the percentage of private toll roads making profits can be as low as 65%. These results highlight the value of non-compete clauses in PPP agreements for the private sector in absence of some other kinds of risk-sharing mechanisms.

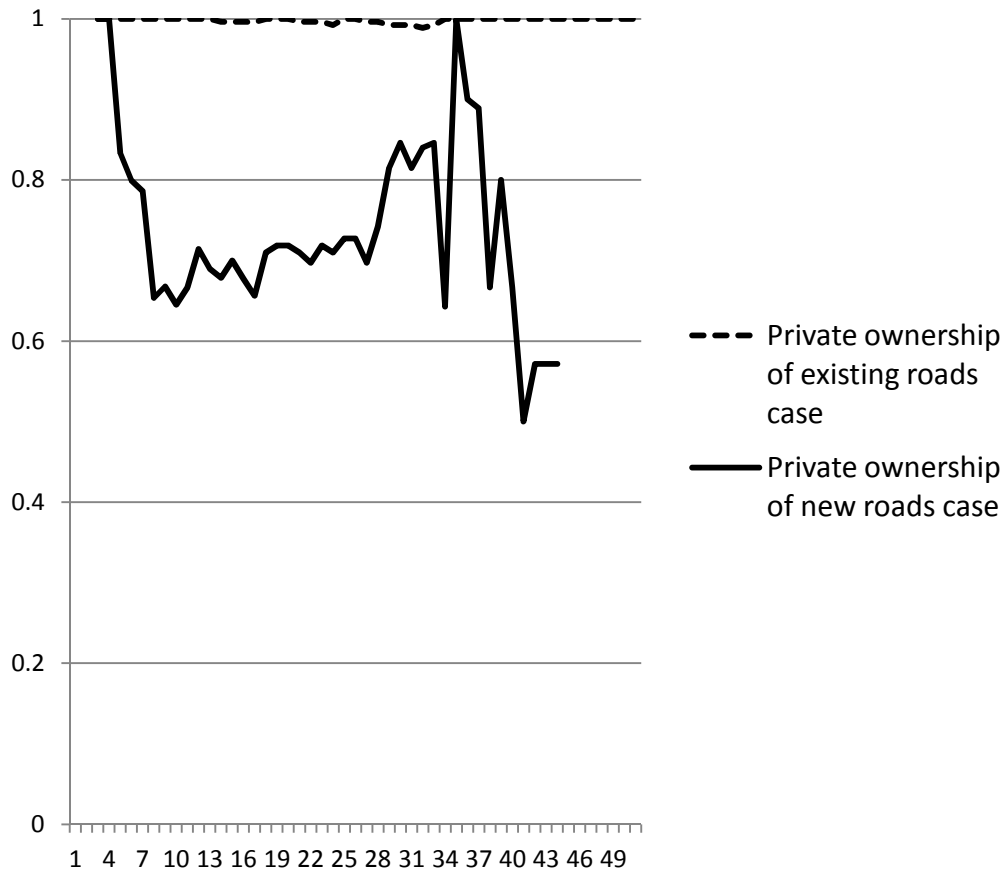


Figure 7-4: Percentage of Private Roads Making Profit (%)

A comparison of the net social benefits (i.e. social welfare = user benefit + private sector profit) in the four policy scenarios produces the following results (see

Figure 7-5). Without private-sector investment, the overall net social benefit in the base case scenario is about 32% of that in the socially optimal scenario. This percentage can be improved to 51% and 79% respectively with new private roads and private takeover policies under proper regulation. While the net social benefits are higher in the private takeover scenario than in the new private road scenario on our test network, this result may or may not be generalized to other networks for at least two reasons. First, this result is based on the assumption that lump-sum payments from the private sector are used by the public sector for much needed roadway capacity improvement and maintenance activities. This is not always true in the real world. Private-sector payments based on real-world concession agreements have been used for non-transportation purposes in the past. Second, the grid network used in our analysis tends to create significant competition among multiple parallel roads (public or private roads), which to some extent dampen the welfare-reducing effects of roadway monopoly powers. In a different network (e.g. hub-and-spoke type of network where certainly neighborhood may have to rely on few or even a single major road for access the rest of the network), the type and intensity of roadway competition and complementarities may be very different.

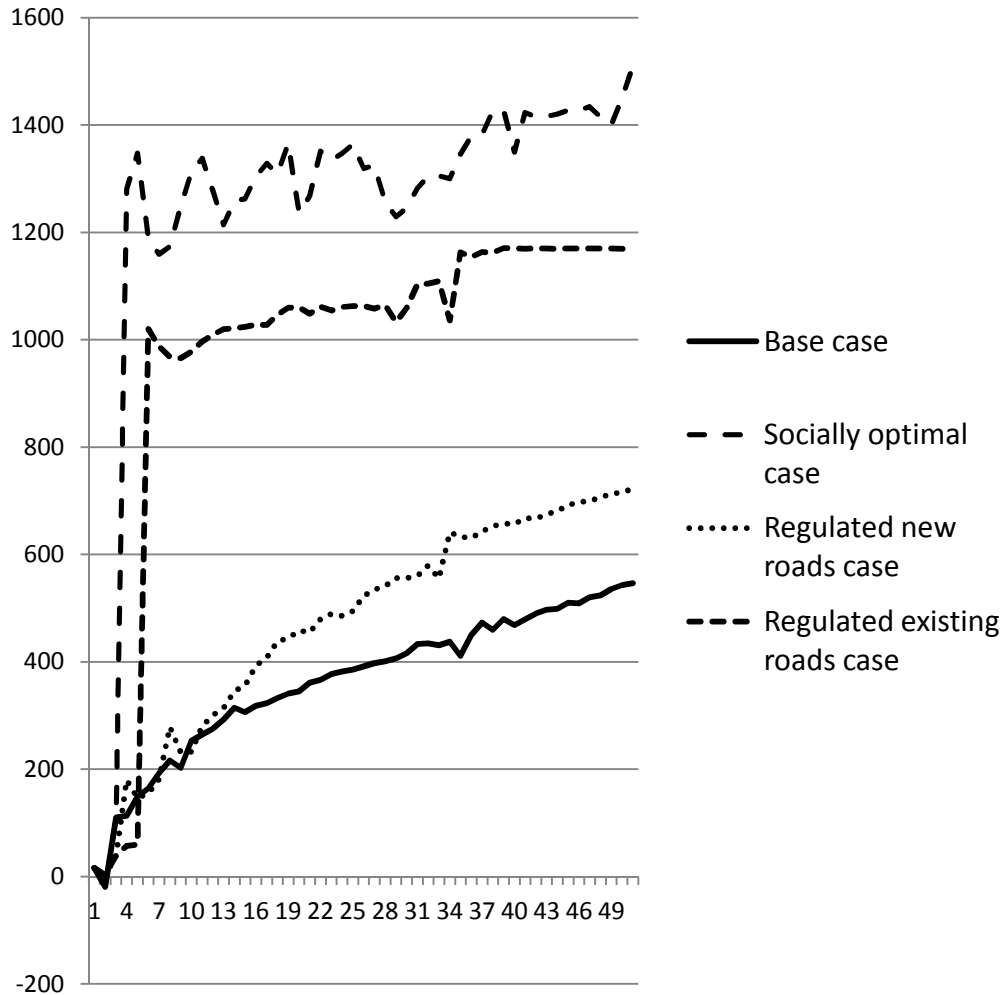


Figure 7-5: Net Social Benefits (\$1,000)

7.3 Model Summary

From a broad systems perspective, an increased involvement of private sector investment resources in transportation financing implies the transfer of private sector capitals from other investment opportunities in the economy to the transportation sector, and the relief of scarce government transportation funds for other needed transportation projects or other government financial responsibilities. It has often

been argued that when there exists an appropriate level of competition, the private sector is intrinsically more efficient than the public sector in the provision and operation of traditionally publicly-provided services. In the case of transportation, private roads with profit incentives are more likely to impose congestion-sensitive tolls, which tend to be more efficient than the existing average pricing schemes through fuel taxes. The recent emergence of more than a dozen public-private-partnerships toll-road projects across the U.S. suggests a positive momentum, and the U.S. Department of Transportation's Congestion Initiative Program has called for "unleashing private sector investment resources". An increasing number of states have removed or in the process of removing legal constraints on private toll roads.

This chapter models the price and capacity decisions of private toll roads when they compete with existing public roads on a general network. Both the analytical findings and application results on a test network are in favor of introducing private toll roads to current public road systems characterized by growing congestion, insufficient public funding, and inefficient pricing practices. The key to successful roadway privatization includes proper regulation, practical policy packages, improved transportation services to users, privatization schemes that work with local conditions, and a healthy functioning private-sector capital market.

A distinctive feature of the agent-based modeling tool developed and demonstrated in this chapter is that public/private-sector decision-makers and system users all make and adjust their behaviors according to others' decisions in a time and space continuum. The roadway network evolves in a complex and decentralized manner, and gradually transitions from a pure-ownership (public) to a mixed-

ownership (public and private) scheme when policies favoring roadway privatization are implemented. The proposed model and policy analysis approach can be applied to analyze and evaluate the user, investor, and overall social welfare impact of roadway privatization.

Chapter 8: Impact of Regulation and Network Topology on the Effectiveness of Privatization

8.1 Introduction

As was mentioned in earlier chapters, private investment resources have already found several ways to enter the U.S. roadway systems. Various PPP schemes have been adopted to finance, lease, design, build, operate, maintain, and own transfer stages. However, various considerations need to be addressed regarding the proper scope of private sector involvement in roadway financing. Roads have monopoly power because they uniquely occupy space. Private roads may exercise their monopoly power and make socially undesirable over-pricing and under-investment decisions.

The long-standing interest in measuring the spatial structure of road networks has been driven by the inherent impact of network structure on the performance of transportation systems (Mohring 1961; Marshall 2005, Xie and Levinson 2007). Specifically, typical connection patterns such as beltway and grid in transportation systems have been studied for years. Overall, there exist four general patterns of intercity highways: tree, grid, grid-diagonal and regular triangle. For street networks inside a city, various studies often classify the networks into grid, radial and circular shapes or their combinations. These hypothetical network types are often used in comparisons of their capacities, reliabilities and urban structures and other overall network properties. However not much research to date has been done on studying

the influence of network topology on privatization patterns, which is what explored in this chapter.

To reliably estimate the impact of roadway monopoly effects on roadway privatization, this chapter tests the agent-based model, developed in earlier chapters, on networks with different topologies to illustrate the influence of network topology on privatization patterns. In order to make the analysis in this chapter more relevant to current policy debates and practices in the U.S., one popular privatization scheme, namely construction and operation of new private toll roads, is modeled under concession period, price ceiling and revenue sharing regulations. The model is then tested on hypothetical city networks with grid and beltway topologies. Based on the simulation results, a number of insights are provided about impacts of ownership and network structures on the socio-economic performance in transportation systems and transportation network changes over time.

8.2 Development of Roadway Privatization Scenarios

In the analysis herein, the agent-based model of public and private investments jointly considers capacity expansion and pricing decisions by public and private sectors, market entry decisions by the private sector, user demand responses, roadway construction and maintenance cost structures, and regulation of private-sector investment. In each iteration of the agent-based simulation, each decision-maker (private roads, public roads, and system users) adjusts their behaviors/decisions based on available historical system information and self-

interests: users attempt to maximize utility and minimize travel times; private road providers seek to maximize profits and public agencies adopt business-as-usual (as in real world) or welfare-maximizing pricing and investment decisions. Each agent and decision-maker is modeled with unique characteristics and preferences (e.g., different values of time for users). Private investors base their market entry decisions (i.e., to invest or not to invest in roadways) on the estimated returns of investment on candidate roadway privatization projects under regulation, their capacity investment decisions on long-run profit-maximizing goals, and pricing/tolling decisions on current capacity levels and short-run profit-maximizing objectives (Please refer to previous chapters for detailed description of the model components).

The initial condition of the analysis is an existing road network controlled entirely by the public sector. As the private sector builds new toll road projects, the network gradually shifts to a mixed-ownership regime. Three policy scenarios are developed for each network topology, grid and beltway, including one roadway privatization scenarios and two benchmark scenarios for comparison purposes.

8.2.1 Benchmark Scenario 1: Base Case

The base case scenario represents the status quo in public sector road financing in the U.S. without private-sector investment (i.e., no roadway privatization). Only the public sector makes pricing, maintenance, and capacity investment decisions. The pricing model in this scenario considers average cost user pricing, which is consistent with current federal and state fuel taxes and other public sector transportation revenue streams (e.g., registration fees) in the U.S. The user

charge is almost entirely independent of when and where the driving takes place. The business-as-usual investment rules are adopted for the base case to represent the existing multi-agency public sector roadway investment decision-making process. In the base case scenario, multiple public-sector agencies are modeled, which represents state and local transportation agencies that have different objectives (i.e., regional transportation goals versus local transportation goals). This multi-agency nature of current public-sector transportation decision-making is likely to make the final investment decisions less effective in terms of system welfare than those made by a single public-sector agency controlling all roadways.

8.2.2 Benchmark Scenario 2: Socially Optimal

The socially optimal scenario assumes welfare-maximizing pricing and investment decisions, and therefore produces the theoretically maximum social welfare. In this scenario, it is assumed that all roadways are controlled by a single welfare-maximizing agency. Marginal cost pricing based on congestion externalities is implemented throughout the entire roadway network. Revenue generated from marginal cost tolls is then invested for long-run maximum net social benefits.

8.2.3 Privatization Scenario: New Private Toll Roads

In this roadway privatization scenario, the private sector is allowed to invest into the construction of new toll roads, charge users subject to price ceiling, and operate the toll roads for a certain concession period, and finally return the new toll

roads to public ownership after the concession period is over. The private sector must invest in new roadway capacity to enter the market. Private toll roads are required to share a certain percentage of their profit with the public sector. Public roads will likely not expand much capacity due to the absence of initial lump-sum payments from the private sector. While the private investor may further expand the capacity of the road during the concession period, the incentive to do so may be very limited because of the fixed concession period and lack of competition in this case. Private toll roads may expand their capacity only if there is significant travel demand increase, which makes capacity expansion profitable. Once the concession period is over, the private sector returns the private toll roads to public ownership. This scenario is modeled after new privately-invested express toll lanes and high occupancy toll lanes in the U.S. Here it is also assumed that the public sector adopts business-as-usual pricing and investment decisions already discussed in previous sections.

8.2.4 Network Topology Description

Grid Network

Grid network is considered one of the most popular city road network topologies, especially in US. That is why we have chosen this network structure for our analysis. Grid network in this research consists of links with 3.2 km in length and has an initial capacity of 775 vehicles/hour on each link. This capacity value corresponds to a typical one-lane directional road in U.S. cities. A uniform land use

pattern is assumed, and each of the 100 nodes has 100 residents (for trip production) and 100 jobs (for trip attraction). (See Figure 8.2 for network representation).

Beltway Network

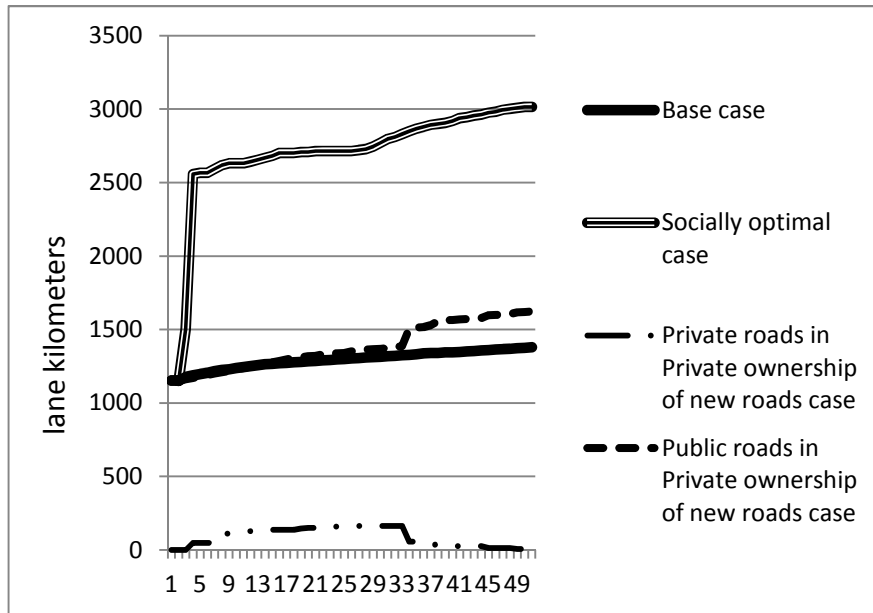
Beltway style topology is pretty widespread in Europe and Asia. This type of network has an advantage of connecting the periphery roads to city center through beltway roadways. In our analysis each link between zones is also 3.2 km in length as in grid network structure and has an initial capacity of 775 vehicles/hour on each link. A uniform land use pattern is assumed, and each of the nodes has 100 residents (for trip production) and 100 jobs (for trip attraction).

8.3 Results

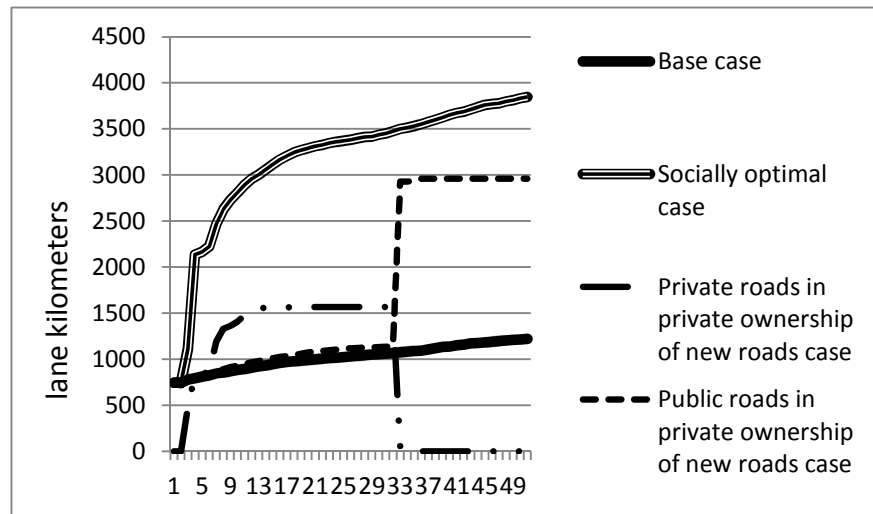
When the agent-based simulation for each of the policy scenarios is executed, the travel demand model first predicts link-level flows based on land use and current roadway network attributes. Based on demand forecasts and current pricing strategies, revenues available to various public sector and private sector agents in the system are then computed. These revenues are employed to maintain existing roads, expand roadway capacity, and/or produce revenue surpluses or profits based on public sector and private sector investment rules. After each round of investment decisions, the network is updated with improved capacities. Network performance measures are computed for each investment cycle (one cycle per year), including lane miles of private and public roads, mobility, accessibility, public and private road tolls, revenues collected by each road, user benefits/consumer surplus, profits, and net

social benefits. A time horizon of 50 years has been selected for all simulation experiments to observe the short- and long-run effects of the base case, the socially optimal case, and the two privatization scenarios. After 50 years, the roadway networks appear to have achieved equilibrium under each of the three policy scenarios. For the privatization scenario, the following regulatory policies are enforced: (1) 30-year concession period; (2) 50% profit-sharing with the public sector; and (3) 4 cents/km price ceiling. This set of regulatory policies provides high user and social benefits compared to other regulatory policies tested.

The evolution of the grid and beltway networks under the three policies scenarios is illustrated in Figure 8-1 with lane-kilometers of roadways being the measure of network development over time. By examining the socially optimal scenario (the line on the top), one can observe that the initial network in Year 0 is significantly underinvested and the network is severely congested on both networks. With revenue from high initial marginal cost tolls, roadway capacity is soon expanded to the optimal level. In contrast, under the base case scenario (the thickest solid line in the middle of both graphs), the average cost pricing practices cannot produce sufficient revenue for optimal capacity investment. While the public sector is still able to gradually expand roadway capacity over time, additional revenue sources would help increase the network capacity closer to the optimal capacity levels. This contrast between the base case and socially optimal scenarios is representative of the network conditions in places where private sector investment in roadway networks has been considered or implemented.



a) Grid Network



a) Beltway Network

Figure 8-1: Lane Kilometers of Public and Private Roads (km)

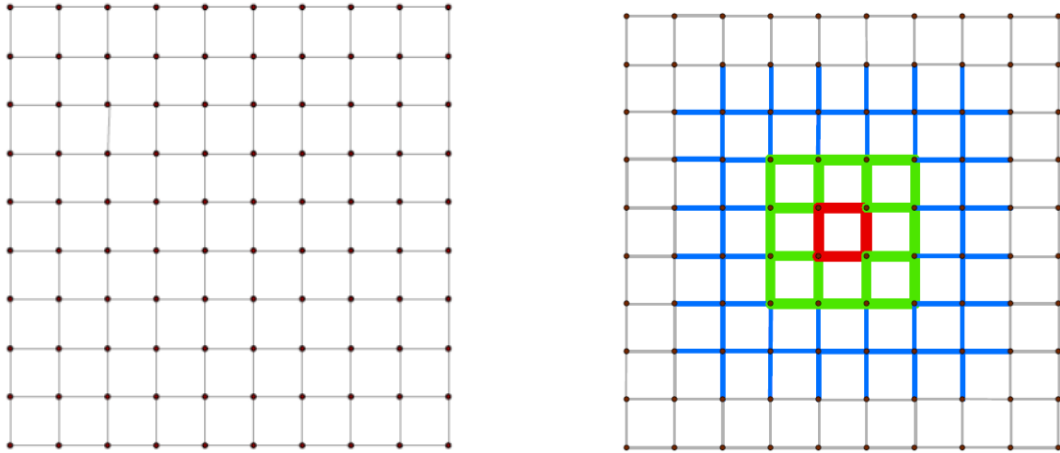
The third line in the graphs corresponds to the privatization scenarios of developing new roads. The lane kilometers of private and public roads are plotted separately. The public sector can build more capacity than that in the base case

scenario. This is because public agencies receive shared revenues from private toll roads.

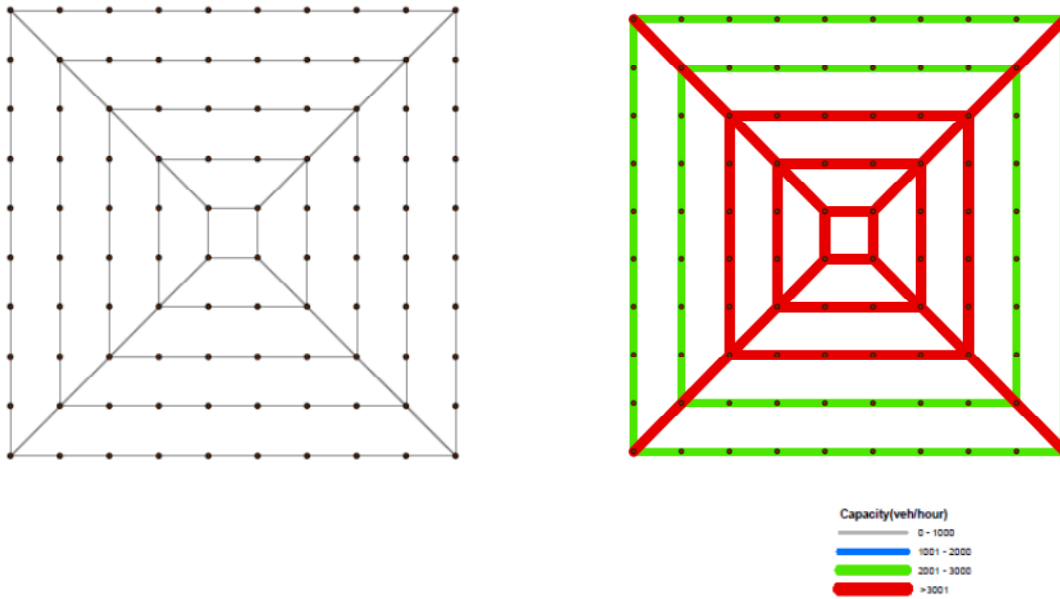
The equilibrium networks after the 50-year simulation period on two networks are illustrated in Figure 8-2. In the grid network the majority of capacity expansion takes place near the center of the network, which makes sense since travel demand is the highest in the center of the network. For the case of beltway network, we can see the most network expansion in the center of the network as well as along the hub-and-spoke connection. The expansion along the hub-and-spoke connection is essential to accommodate growing demand in the periphery parts of the network, therefore it is cost effective for the private sector to build new roads in those parts of the network.

Average link tolls (see Figure 8-3) are different in the three policy scenarios. The base case scenario exhibits the lowest user tolls. The marginal cost tolls in the socially optimal scenario are the highest, and are as high as 11.6 cents per kilometer when congestion is at its worst level at the beginning of the simulation period on grid network, and as high as 23 cents on the beltway network. Roadway privatization allows the private roads to charge higher tolls than the public roads. The overall levels of link tolls in the privatization scenario are closer to the socially optimal tolls than those in the base case, which is desirable from welfare-maximization point of view. The effect of price ceiling regulation can be also observed on both networks. The ceiling price may be increased to further improve the pricing efficiency of toll roads, but at the same time a higher ceiling price may reduce user benefits in the long run (i.e., higher overall social welfare, but also with higher percentages of welfare

gains allocated to the private sector). The private sector is also able to charge higher tolls on beltway roadway network.



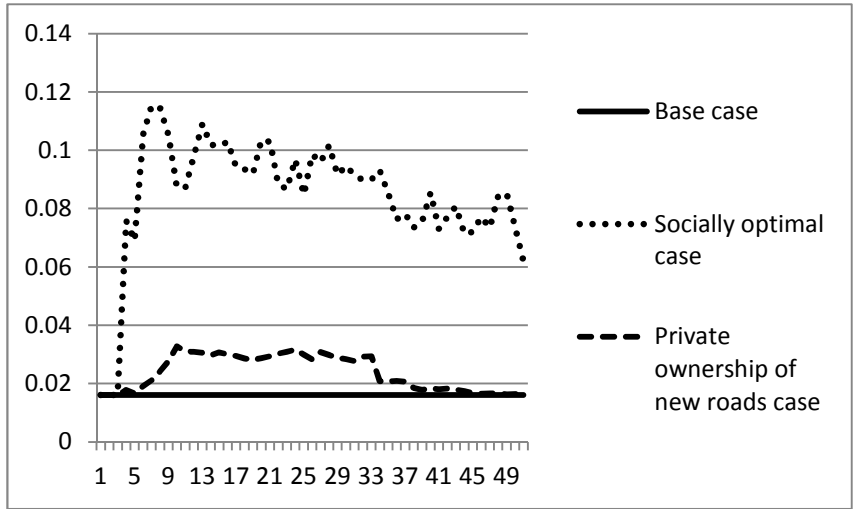
c) Private Ownership of New Roads Scenario on Grid Network



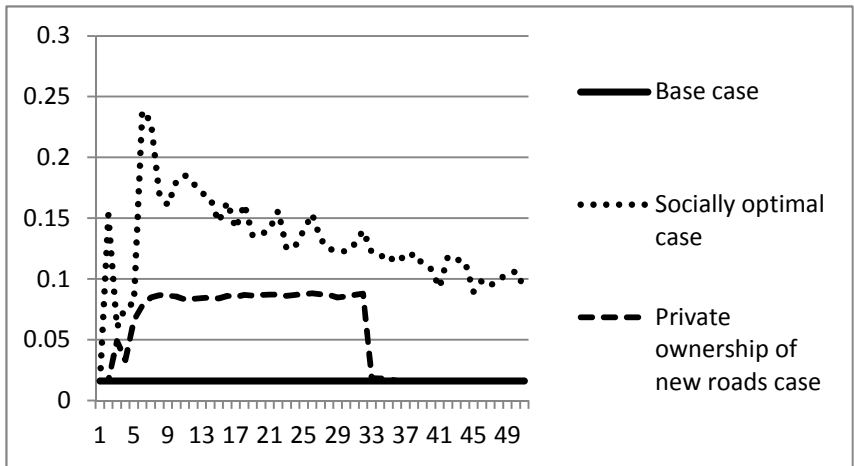
a) Private Ownership of New Roads Scenario on Beltway Network

Figure 8-2: Network Capacity Expansion over a 50 year Period

This is because all new private toll roads in our test are built parallel to existing public roads (e.g., similar to new express toll lanes next to existing publicly-owned general purpose lanes), and in beltway network this competition is less likely, since public agencies usually invest in the center of the network.



a) Grid Network



b) Beltway Network

Figure 8-3: Average Link Toll (\$/km)

Not all private roads can make profits. This is true in the real world as shown by the recent bankruptcy of several private toll roads in the U.S., and in our model because any private road at the time of investment decision-making in the model only has historical demand information and cannot perfectly predict future investment and pricing decisions by the public sector or its own private-sector competitors. Figure 8-4 shows the profitability of private roads over time.

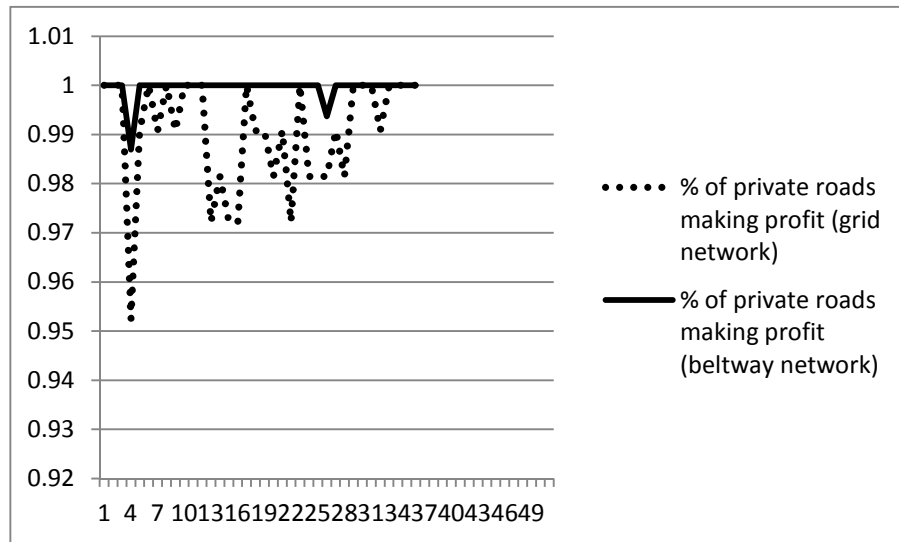
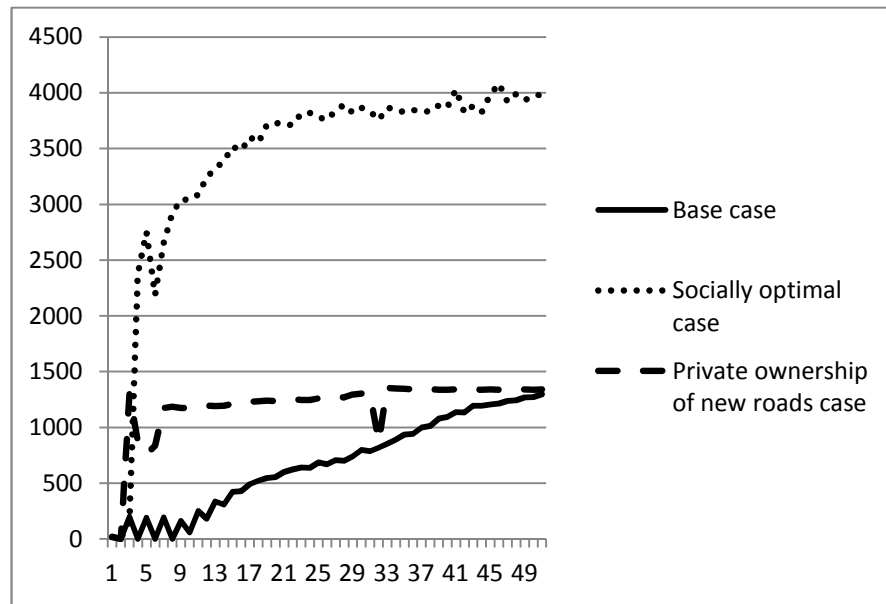


Figure 8-4: Percentage of Private Roads making Profit (%)

On beltway network, almost all private roads make profits in all years due to their spatial monopoly powers. On the grid network we can also observe many private roads making profits, however their percentage is generally lower than in beltway network case, since competition between public and private roads is higher in grid network due to public agencies spatial monopoly advantage.

A comparison of the net social benefits (i.e., social welfare = user benefit + private sector profit) produces the following results (see Figure 8-5). Without private-sector investment, the overall net social benefit in the base case scenario is about 32%

on grid network and 25% on beltway network of that in the socially optimal scenario. This percentage can be improved to 51% and 30%, respectively, with new private roads under proper policy regulation.



a) Beltway Network

Figure 8-5: Net Social Benefits (\$1,000)

Not very significant increases in net social benefits in both cases can be explained by the fact that networks used in our analysis tend to create significant competition among multiple parallel roads (public or private roads), which to some extent dampen the welfare-reducing effects of roadway monopoly powers. Additional privatization scenarios, such as taking over public roads with and without regulation, would provide a more descriptive insight into this phenomenon.

8.4 Conclusions

This chapter for the first time analyzed how different network topologies affect decisions of public and private agencies about location and expansion of the links. Both the analytical findings and application results on test networks are in favor of introducing private toll roads to current public road systems characterized by growing congestion, insufficient public funding, and inefficient pricing practices.

Findings from a grid and beltway networks show that beltway network initially is more efficient than the grid network, however in the long run grid network shows better system performance results. For the case of beltway network, we can see the most network expansion in the center of the network as well as along the hub-and-spoke connection. The availability of hub-and-spoke connection in beltway network is in favor of private companies since it is cost effective for the private sector to build new roads in those parts of the network. However, the goal of profit-maximization, the existence of spatial monopoly, complex interdependencies, and severe competition could all cause private roads to adopt socially non-optimal tolls and capacities. Private roads in a market economy are particularly robust in areas with increasing travel demand. Yet, price-ceiling regulation is shown to help overcome many of the drawbacks of a decentralized public-private ownership. In addition, on beltway network, almost all private roads make profits in all years due to their spatial monopoly powers. On the grid network we can also observe many private roads making profits, however their percentage is generally lower than in beltway network case, since competition between public and private roads is higher in grid network

due to public agencies spatial monopoly advantage. Significant competition among parallel roads (public and private) reduces the welfare effects in the system; however we still see some increases in net social benefits for users. Additional privatization scenarios, such as taking over public roads with and without regulation, would provide a more descriptive insight into this phenomenon.

Chapter 9: Summary and Conclusions

9.1 Introduction

There is an increased awareness in the U.S. and around the world that traditional sources of funding major transportation projects are no longer sufficient to address their pressing expansion, upgrade, maintenance, and operational needs. Consequently, governmental agencies are exploring alternative options available. The interaction of the unwillingness of politicians to raise taxes, the eagerness of private and other sectors to partner with governmental agencies in the delivery of services, the availability of private capital funds to invest in infrastructure projects, and the willingness of public and private partners to share the liabilities and risks is proving to be the motivating force towards the increased use of such arrangements. While privatization shows its success based on improved efficiency, some scientists are cautious of excessive reliance on such arrangements due to a lack of widespread evidence of their effectiveness. In order to relieve the public transportation financial problem, the public-private partnerships will still be a trend in the near future in the United States. After review of the current practical road privatization projects in the United States and the status of academic research in this area, it was clear that the gap between the practices and the theoretical studies is quite obvious. This dissertation tried to close this gap by identifying the driving forces behind the transportation investment decisions currently prevalent in public agencies and developing empirical and modeling tools to evaluate the effects of investment choices and capacity

decisions of public and private roads with different regulatory policy packages to help decision-makers to make a wise choice when facing a PPP toll road projects. It answered the following questions: What investment processes government agencies currently employ to fund transportation facilities? How investment decisions affect transportation network configurations in the long-run? What factors determine the utilization of private finance for highway projects? How do public and private parties shape a partnership to develop a toll road with private finance?

This chapter presents a review of the contents of the dissertation as well as a summary of its findings and conclusions. It also highlights recommendations and suggestion for future studies regarding developed methodologies.

9.2 Summary of Findings and Distinctive Features of the Research

This research developed a practical and efficient methodology for quantifying infrastructure investment decisions at state and local levels of government and developed agent-based models of public and private investment processes in highway capacity expansion and maintenance projects. The methodology included an empirical analysis of the investment decision processes of public transportation agencies. The agent-based decision-making model was developed to consider transportation investment processes at different levels of government which forecasts future transportation networks and their performance under both existing and alternative transportation planning processes. Also, various highway privatization schemes currently practiced in the U.S. were identified and an agent-based model for

analyzing regulatory policies on private-sector transportation investments was developed. The developed models were demonstrated on networks with grid and beltway topologies to reveal the influence of network topology on privatization decisions. The developed models and methodology can be used to consider all stakeholders' preferences and to support decisions related to capacity expansion and infrastructure privatization.

A thorough analysis of the multimodal transportation investment decision rules and processes adopted by various jurisdictions in the Washington DC-Baltimore area was performed to provide initial inputs into the agent-based model of public investment processes. Interviews have been conducted with staff members at the county-, metropolitan-, state- and regional-level agencies. Findings from these interviews revealed the details of the investment process in this region, and the advantages and disadvantages of the existing processes and procedures. The main conclusion that emerged from this empirical analysis and indicated areas in which improvements could take place is that a more decentralized investment-decision making process between different levels of government is a key to creating a comprehensive regional land use and transportation short- and long-range planning as well as an environment for better resource allocations. Establishing innovative rules of engagement for planning and investment, defining new roles in the county and MPO decision-making process, recognizing that every agency in the Region is important, managing or reducing political procedures while maintaining the integrity of the State investment process – are the ways when decision-making process can become more or less unbiased.

The findings from empirical analysis of investment processes have been used to develop the integrated agent-based models of public and private investment processes that bring together all the relevant components, such as travel demand module, transport supply module, public and private road suppliers, investment rules, regulation policies, and the interactions of agents to simulate road expansion and resulting network changes. The unique feature of the developed agent-based models is that they consider transportation demand and supply jointly in a coherent theoretical and modeling framework. Understanding the true relationships between demand and supply in single or mixed ownership environment in transportation systems is the crucial task in theoretical development of transportation models. This research models network growth as a bottom-up process by which the expansion of roads is driven by interdependent decisions of transportation authorities and private firms. The agent-based simulation method is an appealing modeling approach for analyzing the simultaneous and interactive changes of demand and supply changes over time. This modeling approach is very suitable when evaluating transportation management decisions and policies. The result is an agent-based model of public and private investments which is capable of handling and solving large-scale, practical, complicated infrastructure privatization decision-making problems. Both the analytical findings and application results on test networks are in favor of introducing private toll roads to current public road systems characterized by growing congestion, insufficient public funding, and inefficient pricing practices. However, what is important to keep in mind is that the key to successful roadway privatization includes proper regulation, practical policy packages, improved transportation services to

users, privatization schemes that work with local conditions, and a healthy functioning private-sector capital market.

A distinctive feature of the agent-based modeling tools developed and demonstrated in this research is that public/private-sector decision-makers and system users all make and adjust their behaviors according to others' decisions in a time and space continuum. The roadway network evolves in a complex and decentralized manner, and can gradually transition from a pure-ownership (public) to a mixed-ownership (public and private) scheme when policies favoring roadway privatization are implemented. Also, the developed methodologies allow accommodating the decision process from various decision-making groups, thus helping the decision makers to accommodate diverse judgments; the users of the models are able to run a what-if analysis at different stages of the decision process. The developed models are simple to apply and can therefore save time and avoid the costs associated with wrong decisions.

9.3 Research Contributions

This dissertation is one of the first devoted to a thorough empirical investigation of the current investment decision-making processes of transportation agencies at different levels of government, and application of this empirical findings to predicting transportation network evolution patterns in the long-run through developing the agent-based network growth model under public ownership regime. In addition, this research is one of the first that develops a modeling tool to study the

welfare impacts of road privatization projects in mixed ownership networks and allows evaluating various policy packages targeted at the private toll roads, as well as helps to reveal the financial implications for private investors and public road authorities. This modeling tool is designed through agent-based technique, which makes it unique for this matter as the idea of decentralized, local and state control, as well as private ownership distinguishes this analysis from one where a central authority maximizes global welfare. What is also noteworthy, the simulation results of public and mixed ownership agent-based models developed in the dissertation are consistent with what is empirically known about investment decisions and network financing in the real world.

Overall, the findings of this dissertation provide imperative insights to both the industry and academia. First, this research' findings have significant practical implications for mitigating the current transportation financial shortage in the U.S. The searching for nonconventional sources of funding has become inevitable with the falling of the buying power of motor fuel taxes and the growing demand for transportation investment. Utilizing private finance is a promising alternative to provide extra road capacity without further straining government's budget. For governments considering partnering with private sector, the findings on the formation and regulations of toll road partnership offer specific information about how to shape partnerships in toll road development to meet welfare maximizing objectives. Second, this research sheds light on factors that determine the use of private finance for particular projects. This is done through the following approach:

- Identifying the relationship between the investment decision and the network growth patterns;

- Developing the methodological framework that can be used to assess the financial viability of different types of public-private projects in transportation infrastructure;
- Developing the methodological framework that can be used to evaluate private toll-road projects, taking into account their socio-economic outcomes.

Third, the proposed agent-based approach for privatization and network ownership analysis poses a major challenge with regard to modeling methodology. The evolutionary nature of the investment decision-making process makes agent-based simulation appropriate for linking individual participating parties' behavior. Agent-based techniques originate from traditional computer-based simulation and cellular automata. In general an agent-based model consists of three elements: agents, an environment, and behavioral rules. It is useful for modeling how behaviors of and interactions among individual decision makers create complex system patterns.

The results of this research can be used by the various project stakeholders (the public authority, the private investors, policy makers) to gain insights on the financial viability of roadway projects and ultimately decide on its selection and future implementation. The detailed models regarding the case of private roads can be used by road authorities, private investors, and policy makers to quantitatively assess the probability of success of such projects during their planning phase and decide whether or not they should move towards privatization. Public-sector agencies can apply developed agent-based models to evaluate the welfare and user impacts of a particular regulatory policy, a set of regulatory terms in a public-private contract, or a particular private toll road project. Private-sector investors can use the models to analyze the profitability of a private toll road project under various regulatory schemes and to anticipate future public-sector road investment decisions.

9.4 Limitation of the Research

This research has made significant contributions, but there are several limitations as well. The major limitations are:

- The test data are relatively limited, and even though the Grid and Beltway Network topologies provided an insight for the developed models' performance, more cases would enable a comprehensive analysis. This limitation resulted from two main factors: (1) the application of agent-based modeling to transportation privatization is relatively new, so there are limited potential implemented cases; and (2) within this field, data from the public sector is incomplete.
- While developed agent-based models are capable of studying the welfare impacts of road privatization projects in public and mixed ownership networks and allow evaluating various policy packages targeted at the private toll roads, model validation part is missing in this research due to the relatively new concept of developing agent-based models for transport supply problems.
- This research focused on the supply side of the network growth process with various stakeholders involved, however it did not use comprehensive demand model to estimate initial network characteristics. While it does not play a major role in this research, additional improvements of the demand side model could take place, such as removing user homogeneity constraint and uniform land use pattern.

- This research modeled private sector investments and explained all used market entry criteria, however it did not account for limited private sector investment opportunities and/or the possibility of private investment into other sectors of the economy.

9.5 Recommendations for Future Research

This dissertation undertook a significant amount of work in establishing a methodological framework for the evaluation of the current and alternative investment decision-making processes and financial viability of highway privatization projects in transportation infrastructure. Several concepts were used, models were developed and assumptions were made during that process. As with every similar effort, the overall results of this dissertation are subject to the validity of these assumptions and the remaining unavoidable limitations that such efforts present due to the very nature of the modeling process, which is in the end an approximation of the real world. As a result, this dissertation research was not intended to solve all problems related to the assessment of highway investment decisions and privatization projects in transportation infrastructure. Despite significant contributions of this research and the capabilities and benefits of the developed agent-based models of public and private investments, a number of improvements would be beneficial. In general, results from this numerical example are in favor of private toll roads.

However, it is unclear to what extent these findings hold on large real-world networks where private roads would have more complex substitutional and

complementary relationships with existing public roads. The following section develops an evolutionary model to explore this issue. One of the improvements would be to model the adjustment of the behavior of public agencies (i.e. changes in their investment processes) after privatization takes place in certain areas of the network. Another recommendation would be to test the models on the real-world transportation network and other networks with alternative topologies to better study the effects of topology on privatization arrangements. Also, by building a privatization library that contains information about previous privatization experiences, history, criteria, successes, and failures, the better utilization of the models can be achieved.

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