WAYNE STATE UNIVERSITY

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Developing and Testing a Framework for Alternative Ownership, Tenure and Governance Strategies for the Proposed Detroit-Windsor River Crossing

Phase II Report

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATIONS

x_a^n :   Demand for link a in year n

τ_a^n :   Toll for link a in year n

$C_{a,c}^n$:   Construction cost for link a in year n

O_a^n :   Operation and maintenance cost for link a in year n

$\overline{A}$:   Newly constructed link(s) with toll road

φ_{rs}^n :   Consumer surplus for O-D pair r-s for the year n

q_{rs}^n :   Demand between O-D pair r-s for the year n

$q_{rs}^{-1}(\omega)$:   Inverse demand between O-D pair r-s

π_{rs}^n :   Minimum travel cost for O-D pair r-s for the year n

q^n :   Total demand (i.e. $\sum_r \sum_s q_{rs}^n$) for the whole network in year n

φ^n :   Total consumer surplus improvement (i.e. $\sum_r \sum_s \varphi_{rs}^n$) in year n

ι_{rs}^n :   Mean potential demand for O-D pair r-s in year n

σ_{rs}^n :   Standard deviation potential demand for O-D pair r-s in year n

t_a^0 :   Free flow travel time for link a

G_a :   Capacity for link a

ω :   Auxiliary variable for demand

Ω :   Expectation of eigenvalues

ψ^n :   Savings in consumer surplus for year n

γ :   Parameter which converts hourly link flows to annual link flow

θ	:	Parameter which converts time value to monetary terms
λ	:	Constant for exponential demand
ϑ, η	:	Set of eigenvalues
B^n	:	Revenue for year n
$C.I$	:	Consistency Index
c_i	:	Constant indicates weight assigned to $F(i)$
C^n	:	Total cost for year n
F_i	:	Vector of objective functions
g_j	:	Inequality constraint function
h_j	:	Equality constraint function
i	:	Objective function set
j	:	Constraint set
N	:	Analysis period
P^n	:	Profit generated in year n
RI	:	Random Index
T	:	Total Theil Index
T_b	:	Between group Theil component
T_w	:	Within group Theil component
W	:	Associated weight vector
y	:	Vector of decision variables
z	:	Random variable generated from (0,1)
α, β		Performance criteria

ABBREVIATIONS

AB: :   Ambassador Bridge

AHP: :   Analytic Hierarchy Process

AVI: :   Automatic Vehicle Identification

BOOT: :   Build Own Operate and Transfer

BWB: :   Blue Water Bridge

CBD: :   Central Business District

COV: :   Coefficient of Variation

DEIS: :   Draft Environmental Impact Statement

DRIC: :   Detroit River International Crossing

DWT: :   Detroit Windsor Tunnel

DWTF: :   Detroit Windsor Truck Ferry

EIB: :   European Investment Bank

ETC: :   Electronic Toll Collection

FAST: :   Fast And Secure Trade

GSA: :   General Service Administration

HOV: :   High Occupancy Vehicle

IRR: :   Internal Rate of Return

ISTEA: :   Intermodal Surface Transportation Equity Act

MARR: :   Minimum Attractive Rate of Return

MCS: :   Monte Carlo Simulation

MDOT: :   Michigan Department of Transportation

MOE:	:	Measures of Effectiveness
MOO:	:	Multi Objective Optimization
NEPA:	:	National Environmental Protection Act
NPV:	:	Net Present Value
OD:	:	Origin Destination
OMT:	:	Ontario Ministry of Transportation
OTG:	:	Ownership Tenure and Governance
PCM:	:	Pair-wise Comparison Matrices
PDF:	:	Probability Density Function
PPP:	:	Public Private Partnership
ROD:	:	Record of Decision
RT:	:	Rail Tunnel
SAFETEA-LU:	:	Safe Accountable Flexible Efficient Transport Equity Act- A Legacy for Users
TAZ:	:	Traffic Analysis Zone
TEA-21:	:	Transportation Equity Act
VaR:	:	Value at Risk
VOT:	:	Value of Time

EXECUTIVE SUMMARY

Transportation infrastructures are integral parts of a nation's network connectivity. Large-scale transportation projects represent major investments devoted to the construction, operation, and maintenance of facilities over an extended period. Typically, these investments are irreversible in nature and require long-term commitment by the public at large relative to utilization, maintenance, and operation.

Traditional economic analysis techniques are based upon the assumption of future cash flows that are fully deterministic in nature. Thus, there is an implicit assumption that these cash flows are not subject to any risk or uncertainty during the life of the project. In reality, many of these infrastructure projects are associated with significant uncertainties stemming from lack of knowledge about future cost streams. Revenue generation is also characterized by demand uncertainty. In emerging markets, macroeconomic, legal, institutional and regulatory concerns may add a level of uncertainty that can add complexities and introduce greater levels of risk. The term "risk" refers to situations where the decision maker can assign mathematical probabilities to the randomness relative to future outcomes. In contrast, the term uncertainty refers to situations when this randomness cannot be expressed in terms of mathematical probabilities. Transportation decisions have not typically considered risks and uncertainties in investment analysis. Current transportation literature does not indicate the availability of a comprehensive methodology in dealing with risks and uncertainties, though significant research has been conducted in economics, industrial engineering and financial management.

Historically, the highway infrastructure in the U.S. has been built and maintained by public funds with a few exceptions. Tollways and turnpikes, typically supported by private funds, constitute a small fraction of U.S. highways, and are somewhat of an exception to this rule. These facilities are generally financed by long-term bonds, and the revenue generated by the facilities is used to pay for the investment over the life of the project. However, private sector participation in infrastructure investment is gaining more popularity because of scarcity of resources at the public sector, and because of the ability of the private sector to build, operate and maintain the facilities, while sharing future risks. The concept of Public Private Partnership (PPP) is gaining momentum because it enables the public sector to use private capital in exchange of future revenues. With proper advance planning, it may be possible to use the PPP approach to the mutual benefit of three major entities involved in large-scale transportation infrastructure projects: (1) the private, (2) the public and (3) the user group, each with a different set of objectives/expectations relative to the project.

This research presents an analytic framework that can explore the merits and demerits associated with public and/or private ownership of a transportation infrastructure, where potentials for cost recovery through revenues generated appear to be high, even though the project may be fraught with risks at the other. The framework also explores various forms of joint ownership associated with the public and private enterprise. Ownership, Tenure & Governance (OTG) are three terms that incorporate the role of each entity in a strategy, where a number of OTG strategies are considered to encourage joint entity participation. The strategies vary in the degree of participation by the public and the private entity.

The analytic framework is developed based upon the principles of investment decision under uncertainty. The primary objectives of the research are as follows:

1. Develop a methodology to integrate uncertainty and risk in the transportation infrastructure investment decision making process.

2. Identify different strategies ranging from public to private to various forms of joint OTG scenarios.

3. Develop an analytic framework that can be used to test different OTG scenarios.

4. Demonstrate the methodology with a real world case study.

The methodology entails a bi-level programming approach to address uncertainty in decision making for these entities. At the upper level, the objective of each entity is optimized while at the lower level, optimal demand is obtained by elastic traffic assignment. Randomness in travel demand reflects uncertainty and used in the elastic traffic assignment procedure. The bi-level process results in the feasibility of each single entity perspective. A set of relaxation policies is proposed to form various Ownership, Tenure, and Governance (OTG) strategies reflecting the nature and level of participation of the three entities. The uncertainty analysis output serves as input to the risk analysis. Monte Carlo Simulation is used to address risks for feasible policy options selected from uncertainty analysis. The concept of Value at Risk (VaR) is used to quantify risk. A methodology is proposed to integrate uncertainty and risk.

The framework is tested on the proposed multibillion dollar international river crossing entitled as the Detroit River International Crossing (DRIC) connecting the city of Detroit in the US and the city of Windsor in Canada. The U.S. and Canada share the largest trading relationship in the world. Currently more than $200 billion of surface trade passes annually between Southwestern Ontario and Southeastern Michigan, a figure expected to grow significantly by the year 2030. More than 50% of this traffic crosses the Detroit river by trucks. This large trade volume has a significant positive effect on the local, regional and national economies through cross-border employment opportunities. The vehicular crossings between Southwest Ontario and Southeast Michigan are the busiest of all U.S.-Canada border crossings, and the Ambassador bridge ranks the highest in commercial vehicles among all U.S. border crossings. DRIC has been proposed by the Michigan Department of Transportation to alleviate the serious traffic congestion problems on the Ambassador bridge. The proposed framework, applied to DRIC shows the returns on the investments for a variety of OTG strategies, representing various levels of public-private participation.

Finally, the technique of multi-objective optimization (MOO) is proposed to incorporate the perspectives of all three entities (public, private and the user). MOO resulted in pareto optimal solutions to serve as trade-off between the participation levels of the multiple entities. To obtain the relative importance of each entity within an OTG strategy, a questionnaire survey was conducted among knowledgeable transportation professionals in the states of Michigan and Ohio. Analytic Hierarchy Process (AHP) is used as a tool to determine the relative importance of entities obtained from survey responses. AHP and MOO are integrated to determine the feasibility of OTG strategies from multi entity perspectives.

CHAPTER 1

INTRODUCTION

1.1 Background

Transportation infrastructures are integral parts of a nation's network connectivity. Large-scale transportation projects represent major investments devoted to the construction, operation, and maintenance of facilities over an extended period. Typically, these investments are irreversible in nature and require long-term commitment by the public at large relative to utilization, maintenance, and operation. Examples are mass-transit systems, freeway corridors, subways, crossings in the form of bridges and tunnels, high occupancy vehicle (HOV) lanes, and toll roads. A National Transportation Statistics report suggests that gross transportation *investment* by the federal, state and local governments reached $80 billion in the U.S. in the fiscal year 2003 (BTS 2008). Similarly *expenditures* in operating, maintaining and administering the nation's transportation facilities are over $200 billion annually. Projected federal, state and local highway *revenues* are not sufficient to meet estimates of future highway requirements (USDOT 2006). Lack of capital funds to meet the infrastructure needs of the country may result in increased private participation in such projects (Roth 1996). The investment, expenditures, and revenue from 1991 to 2003 measured in year 2000 dollars are presented in Figure 1.1 – Figure 1.3.

The potential of transportation infrastructure projects to produce economic benefits has become an increasingly important factor in the investment decision making process. Some of these large investments may also involve the private enterprise in the construction, operation and maintenance process along with federal, state and local government.
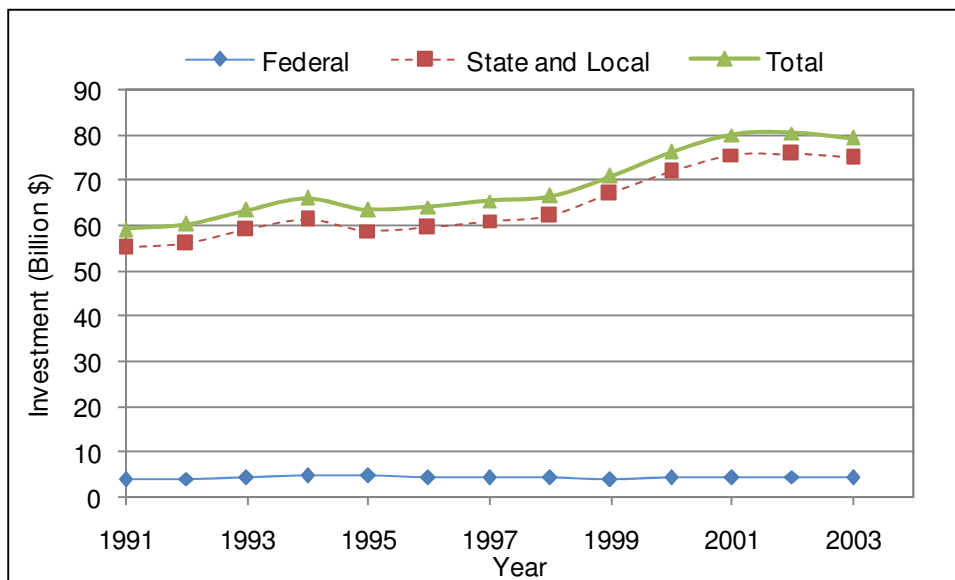
Figure 1.1: Gross investment in transportation infrastructure by level of government. (Primarily in the form of new construction) (BTS 2008)
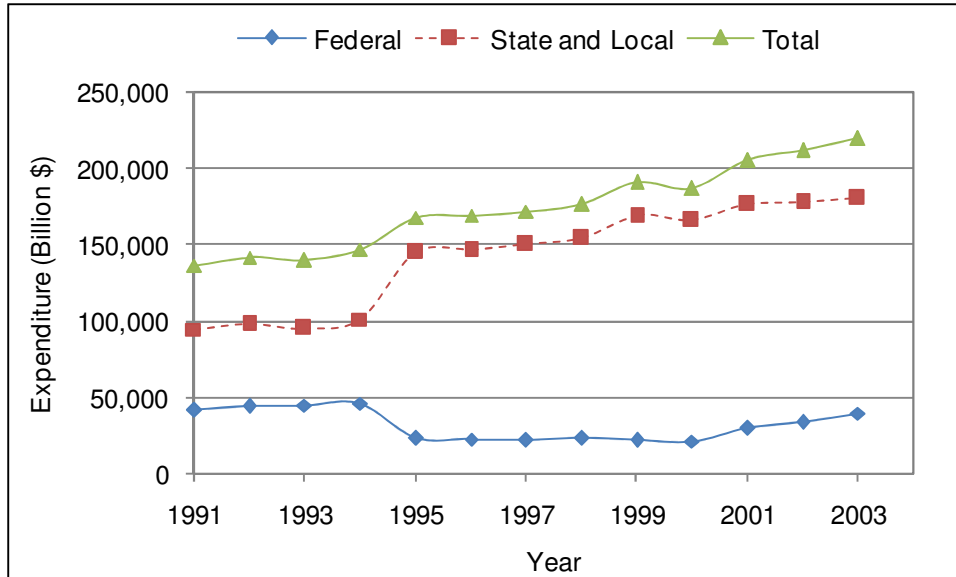
Figure 1.2: Federal, State, and Local Government Transportation Expenditures. (Primarily in the form of operation, maintenance and administration) (BTS 2008)
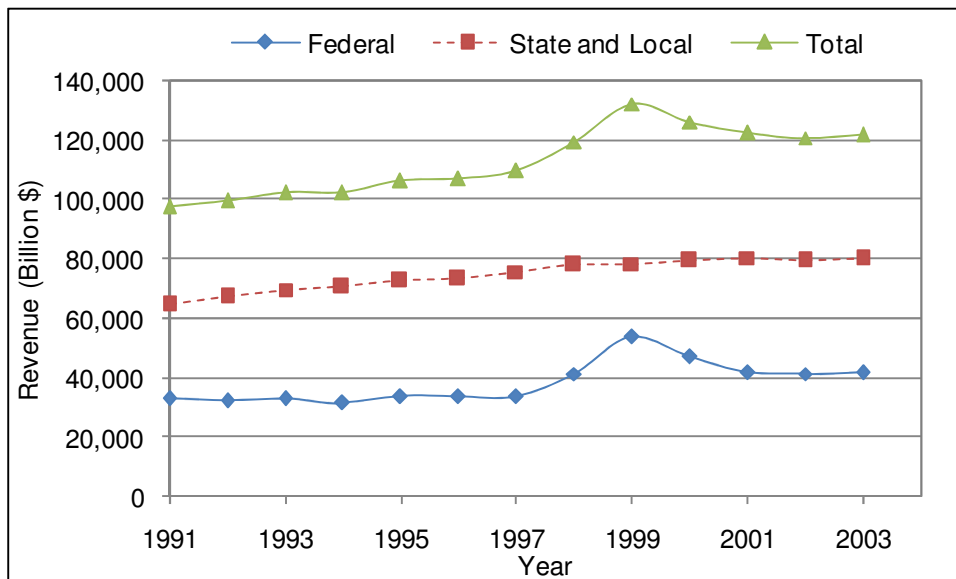
Figure 1.3: Federal, State and Local Governments Revenues (BTS 2008)

Infrastructure projects typically involve huge initial costs, take long to complete, and require sustained cash flows during the life of the project to meet financial obligations and to provide reasonable returns. In general, economic analysis techniques are used to compute future returns. Most of these techniques fall into two categories, i.e. predictive (ex ante[1]) or evaluative (ex post[2]) (Boardman, Greenberg et al. 2001). Predictive analysis is used to forecast the likely

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[1] Ex ante analysis is performed when the decision is made about whether or not to proceed with the project before its implementation.

[2] Ex analysis post is performed after all the impacts of the implemented project is realized.

economic impacts of a proposed investment, whereas evaluative techniques are used to gauge the effect of the investment after it has been implemented (Cambridge Systematics 1998).

1.2 Problem statement

Traditional economic analysis techniques are based upon the assumption of future cash flows that are fully deterministic in nature. Thus, there is an implicit assumption that these cash flows are not subject to any risk or uncertainty during the life of the project. In reality, many of these infrastructure projects are associated with significant uncertainties stemming from lack of knowledge about future cost streams. Revenue generation is also characterized by demand uncertainty. In emerging markets, macroeconomic, legal, institutional and regulatory concerns may add a level of uncertainty that can add complexities and introduce greater levels of risk. As explained later in the report, the term "risk" refers to situations where the decision maker can assign mathematical probabilities to the randomness relative to future outcomes. In contrast, the term uncertainty refers to situations when this randomness cannot be expressed in terms of mathematical probabilities (Knight 1921). Transportation decisions have not typically considered risks and uncertainties in investment analysis. Current transportation literature does not indicate the availability of a comprehensive methodology in dealing with risks and uncertainties, though significant research has been conducted in economics, industrial engineering and financial management.

The trillion dollar transportation infrastructure in the U.S. has been financed primarily by public dollars through various forms of user taxes (Garber and Hoel 2002). The Highway Trust Fund created by the U.S. Congress in the mid-1950s was used to build the interstate highway system (formally the Defense Highway System) that serves as the backbone of the nation's transportation network today and that has provided much of the stimulus for regional economic growth. Since the completion of the interstate system in the early 1990s, Congress has taken a number of landmark legislative actions to support the transportation infrastructure in the U.S.. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the Transportation Equity Act (TEA-21) of 1998, and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005 will have provided over $700 billion of support for the transportation infrastructure of the country for the period 1992 through 2010. The intent of these acts is to develop and maintain a multimodal transportation system that is economically efficient and environmentally sound, and that will enable the nation to compete in global economy.

Historically, the highway infrastructure in the U.S. has been built and maintained by public funds with a few exceptions. Factors such as improved mobility, reduced congestion, and higher safety, along with economic benefits have been used to justify these investments. Tollways and turnpikes, typically supported by private funds, constitute a small fraction of U.S. highways, and are somewhat of an exception to this rule. Typically, these facilities are financed by long-term bonds, and the revenue generated by the facilities is used to pay for the investment over the life of the project. Only limited private funding has been used in the U.S. or roadway infrastructure. Private participation is, however, more common in other modes of transportation, particularly rail, air and transit prior to 1950s. In many cases, such programs

for these modes have been characterized by sharing of costs and revenues by the private and the public enterprise.

1.3 Background Information:

The purpose of the above discussion is to provide a background of this study focusing on a proposed international crossing across the Detroit river in the Midwest, connecting the cities of Detroit, U.S. and Windsor, Canada. The Central Business Districts (CBDs) of the cities of Detroit and Windsor are currently connected by a bridge and a tunnel across the Detroit river, both built during the late 1920s. The Ambassador bridge is a privately owned four-lane suspension structure, while the Detroit-Windsor tunnel is a two-lane facility with height restriction, jointly owned by the two cities and operated by a private corporation. These two facilities constitute a major component of the vital trade-corridor between the U.S. and Canada in the Midwest. Two other facilities carry freight between Michigan and Ontario. These are: a rail tunnel under the Detroit river at Detroit and the Bluewater bridge over the St. Clair river (100 km north of Detroit), which connects Port Huron, U.S. and Sarnia, Canada

The U.S. and Canada share the largest trading relationship in the world. Currently $200 billion of surface trade passes annually between Southwestern Ontario and Southeastern Michigan, a figure expected to reach $300 billion by the year 2030. More than 50% of this traffic crosses the Detroit River by truck (MDOT 2003). This large trade volume has a significant positive effect on the local, regional and national economies, through cross-border employment, opportunities. The vehicular crossings between Southwest Ontario and Southeast Michigan are the busiest of all U.S.-Canada border crossings, and the Ambassador Bridge ranks the highest in commercial vehicles among all U.S. border crossings (MDOT 2003).

The Ambassador bridge (a four lane facility) , on an average day, carries approximately 26,500 passenger-cars and 12,000 commercial vehicles and these figures are projected to increase by more than 40% and 100% respectively by the year 2030 (MDOT 2003). The corresponding figures for the Detroit-Windsor Tunnel (a two lane facility) are 25,000 and 700 with projected increases of 100% and 30% respectively by 2030 (MDOT 2003). The long-range prediction of the trade volume clearly indicates that the two existing Detroit river vehicular crossings (and any additional crossing that may be opened in the future) will have a major part in the overall economic picture of the Southeast Michigan and Southwest Ontario region, not to mention the cities of Detroit and Windsor. Traffic volume trends of three crossings are presented in Figure 1.4, 1.5, and 1.6.
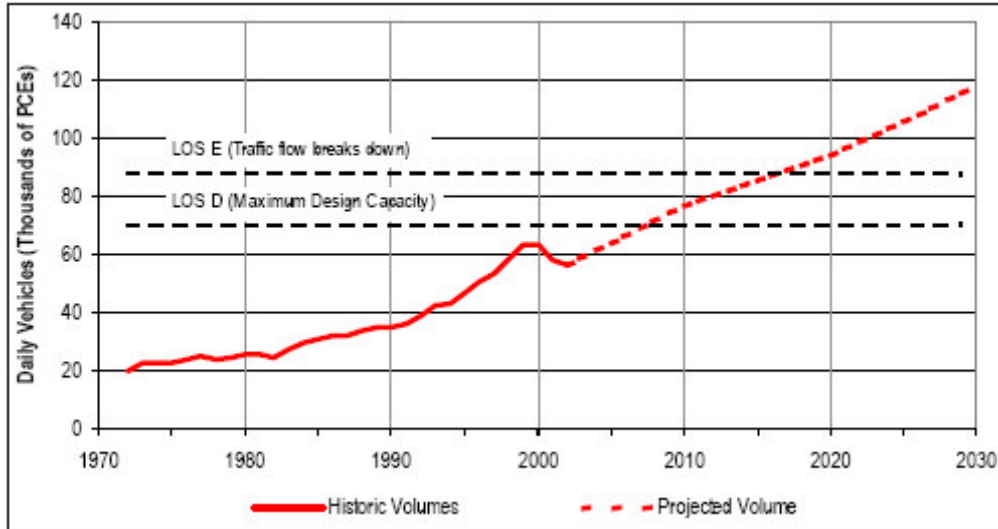
Figure 1.4: Traffic volume trend of Ambassador Bridge (Source: Final Environmental Impact Statement Report of the Detroit River International Crossing Study, March 2008)
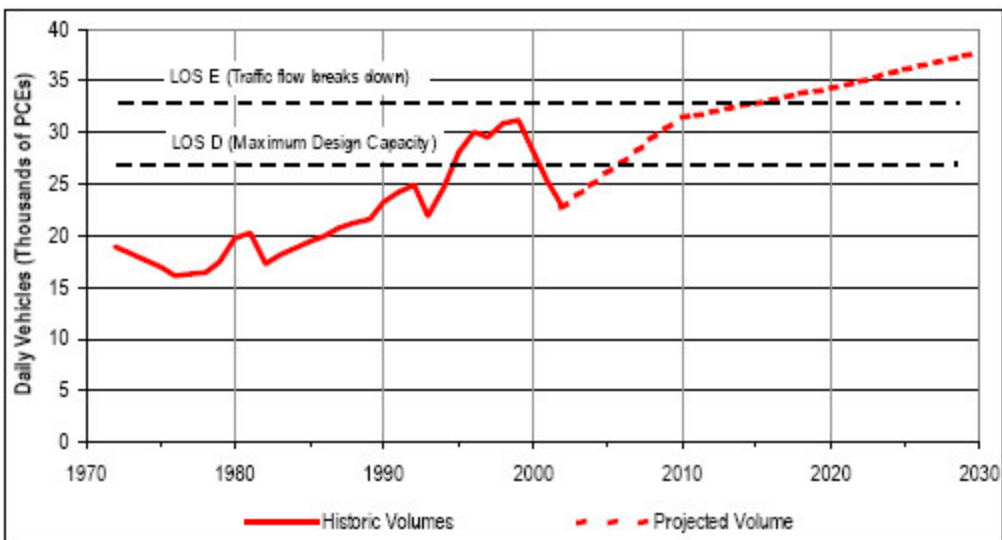
Figure 1.5: Traffic volume trend of Detroit-Windsor Tunnel (Source: Final Environmental Impact Statement Report of the Detroit River International Crossing Study, March 2008)
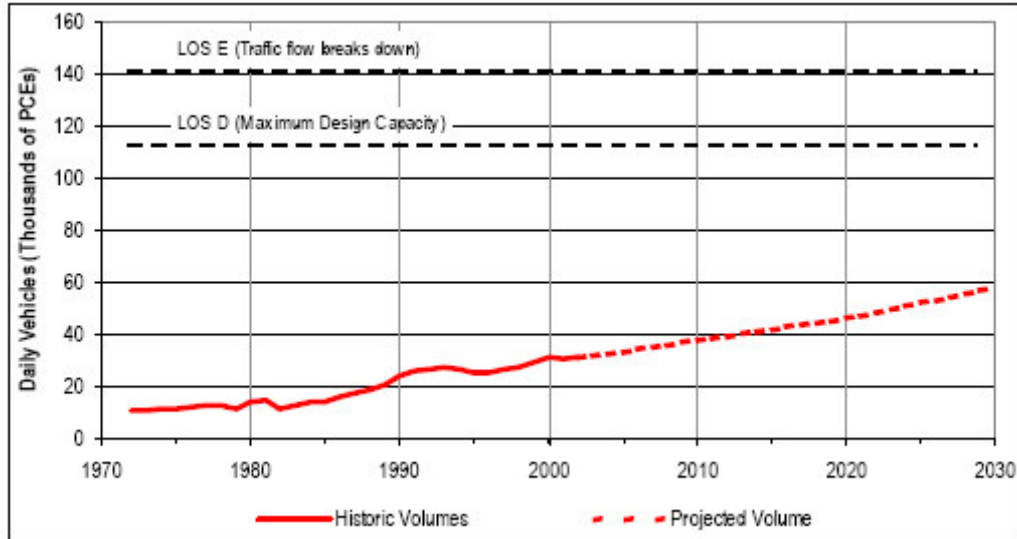
Figure 1.6: Traffic volume trend of Blue Water Bridge (Source: Final Environmental Impact Statement Report of the Detroit River International Crossing Study, March 2008)

A number of recently completed and ongoing studies sponsored by the Michigan Department of Transportation (MDOT) and the Ontario Ministry of Transportation (OMT) consider various issues related to a new Detroit river crossing. The U.S.-Canada-Ontario-Michigan Transportation Partnership Study attempted to develop long-term strategies to provide safe and efficient movement of people and goods between Michigan and Ontario (FHWA, 2003). Even though the current capacities of the Ambassador bridge and the Detroit-Windsor tunnel adequately serve the traffic needs during most hours, on specific days during peak periods, the systems do run at full capacity. Considering long-term traffic growth and the overall importance of the Detroit River crossings on the regional economy, the need for a third crossing seems immensely justified.

A second study, Evaluation of Alternatives from U.S. and Canadian sides of the Border– explored various alternatives for the proposed new crossing (FHWA, 2003). This study originally identified a total of 15 alternatives, depicting different bridge structures, plaza locations and connecting routes, that have been narrowed down to three, based upon context-sensitive design considerations, expert opinions, and technical viewpoint. The three alternatives are:

1. X-10 (A), (Dearborn-I75- Shortest route length, least capital intensive)
2. X-10 (B), (Springwells –I75)
3. X-11 (C), (Dragoon-I75- Highest route length , most capital intensive)

Figure 1.7: Proposed alternatives for the bridge crossing (Source: Final Environmental Impact Statement Report of the Detroit River International Crossing Study, March 2008)

This project is built upon the premise that a new crossing will be built in the near future. The central question that this research will address is *"Should the new crossing be owned and operated by a (yet to be named) public agency, so that the taxpayers can benefit from the significant revenues likely to be collected over the life of the project? Or, should the ownership and operating rights be left to the private enterprise, thereby protecting the public at large from the risks associated with this investment?"* Limited research shows that there is a strong interest on the part of the private enterprise on either side of the border to own and to operate such a new crossing, if proposed. The development of a framework to analyze the fiscal, institutional and legal issues associated with the ownership of the new crossing (Public versus. Private versus. Public Private Partnership) is the problem investigated in this study. Thus, the problem addressed relates to the issues of ownership, tenure, and governance of the proposed river crossing connecting the cities of Detroit and Windsor providing for multibillion dollar trade opportunities between the U.S. and Canada. A more detailed discussion on current activities is presented in Chapter 4.

A brief explanation of the terms public, private and joint ownership is presented below.
- Public Ownership: Public ownership is desirable when strong gains are possible, so that tax-payers can be the ultimate beneficiaries of the project. Both capital and operating costs remain the responsibility of the public sector. Hence, for projects lasting over an extended period, estimates of future costs and revenues should be adjusted to address risks and uncertainties.

- Private Ownership: Private ownership presents both advantages and disadvantages to the tax-payer. The tax-payer is neither a recipient of any monetary benefits, nor is responsible for the capital, operation and maintenance costs. The private sector that makes the investment is logically entitled to all future revenues. Because the facility is essentially for public use (to improve mobility for public at large), most experts feel that there should be some degree of regulatory control over the management and governance of the facility by the public entity, even though ownership is fully private.

- Joint Ownership: Often used interchangeably with the term Public Private Partnership (PPP), the concept of joint ownership has become increasingly popular in Europe,

Australia and more recently in Asia, as it allows part or the whole of the capital funds from private resources in exchange of future revenues (Khasnabis, et al 2008). Even though these two terms are often used interchangeably, they may not necessarily mean the same. The term joint ownership refers to the ownership of the facility, while PPP refers to some type of partnership that may or may not involve ownership. It is possible for example; for two agencies to be partners on a given project, while ownership may remain with one agency or a third agency.

Many forms of Joint ownership are feasible (depending upon the exact share of capital and operating cost between the principal and the private partners, and the governance structure mutually agreed upon). A "Build Own Operate and Transfer" (BOOT) concept, under the general umbrella of Joint ownership, is being used in a number of countries. Variations of the BOOT concept used in different countries and in different projects are discussed in the next chapter. A BOOT project is defined as (Merna and Njiru 1998, p.79).

"A project based on the granting of a concession by a Principal, usually a government, to the Promoter, sometimes known as the Concessionaire, who is responsible for the construction, financing, operation and maintenance of a facility over the period of concession before finally transferring the facility, at no cost to the Principal, as fully operational facility. During the concession period, the Promoter owns and operates the facility and collects revenues to repay the financing and investment costs, maintain and operate the facility and make a margin of profit."

A concession agreement defines the roles and responsibilities of the participating agencies, particularly the Principal (typically the Governmental agency that is ultimately responsible to the public for the project operation), the promoter (the private agency that assumes the overall responsibility on a short term or a long-term basis), and the support agencies. BOOT projects are essentially turnkey contracts financed by the contractor with extended operation and maintenance periods. The BOOT concept specifies that the project is to be transferred to the principal at the end of the concession period "at no cost to the Principal, as a fully operational facility." Thus, if the project is planned properly, the Principal or the Government agency has nothing to lose, as it essentially inherits a free facility that is "fully operational," at the end of the concession period. It is, however, important for the Governmental agency to ensure that the facility continues to generate revenue at the end of the concession period, without a major investment of resources. The private entity on the other hand, can take advantage of an investment opportunity, and generate a healthy return over the concession period.

1.4 Ownership, Tenure, and Governance Strategies

Ownership, Tenure and Governance (OTG) are the three principal components of a joint ownership. An OTG strategy can be looked upon as a mechanism to plan, design, implement, operate, and maintain a project by developing various combinations of ownership, tenure, and governance procedures where the three terms have specific meanings.

- Ownership: A legal term signifying exclusive rights of possessing, enjoying, and disposing a property or a part thereof, as recorded in appropriate governmental documents. The term 'ownership' has embedded in it, the concept of 'possession' and 'title' related to the property in question. Depending upon the nature of the PPP project, its ownership of the property/facility may belong to the public entity, private entity, or both (joint ownership), during the concession period. Ownership is also likely to change at the end of the concession period.

- Tenure: A term used in describing the condition of holding something in one's possession (such as a property, an office, a title), or the status of holding a possession for a specific period, ranging from few days to a very long time. For most PPP projects, tenure is likely to coincide with the concession period; however, exception to this general rule may be encountered.

- Governance: The term "Governance" is derived from a Greek verb meaning 'to steer', and essentially refers to the process of management, policy making, and decision rights pertaining to an organization set up with the intent of producing a pattern of desirable results, and avoiding undesirable consequences. The World Bank[3] defines governance as "The exercise of political authority and the use of institutional resources to manage society's problems and affairs." A fair governance is expected to outline the relationship between all project stakeholders ensuring the proper flow of information to permit proper review prior to critical decisions[4]. For PPP projects, stakeholders include: management, owners, employees, banks, and lenders, customers, and other project partners. Since PPP projects involve such divergent group of stakeholders, the identification of a proper governance structure is considered to be a key prerequisite to successful PPP operation.

1.5 Research Objectives

Because of the risks associated with transportation infrastructure investment, questions have been raised about the wisdom of the tax-payer investing over one billion dollars on a project, where private funding appears available. This research presents an analytic framework that can explore the merits and demerits associated with public and/or private ownership of a transportation infrastructure, where potentials for cost recovery through revenues generated appear to be high at one end, but the project is fraught with risks at the other. The framework also explores various forms of joint ownership associated with the public and private enterprise.

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[3] World Bank, "Managing Development-The Governance Dimensions" 1999, Washington, D. C. http://www.wdc.worldbank.org/external/default/WDSContentServer/WDSP/IB/2006/03/07/000090 341-20060307104630

[4] Patrick S. Renz. Project Governance: Implementing Corporate Governance and Business Ethics in Non-Profit Organizations". Heidelberg:Physcia-Verb 2007 (Contributions to Economics).

The analytic framework is developed based upon the principles of investment decision under uncertainty. The framework is sensitive to the issues of tangible and intangible effects of the investment upon the owner, the users of this facility, as well as the communities that are likely to be affected. The proposed framework explored means of incorporating uncertainties associated with such investment decisions. The objectives of the research are as follows:

1. Define uncertainty and risk from transportation infrastructure investment viewpoint.

2. Develop a methodology to integrate uncertainty and risk in the transportation infrastructure investment decision making process.

3. Identify different strategies ranging from public to private to various forms of joint OTG scenarios.

4. Develop an analytic framework that can be used to test different OTG scenarios.

5. Demonstrate the methodology with a real world case study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Transportation infrastructure investments, typically undertaken by the public sector, have recently attracted private entities, thereby forming a joint participation commonly referred to as Public Private Partnership (PPP). Financing techniques are developed to provide various forms of ownership, tenure and governance (OTG)[1] strategies. There are a number of reasons for the growing trend of private participation in public projects. These include, the scarcity of fiscal resources at the public sector level, the perception that the private sector is more efficient in managing (construct, operate, and maintain) large projects, and the advantage of jointly sharing risks and uncertainties, thereby reducing exposure levels to financial losses for both entities.

Most investment decisions share three important characteristics in varying degrees. First, the investment is partially or completely irreversible in that the funds invested are completely "sunk" in the project. Thus the agency or agencies responsible for managing the project, must be fully committed to the project once the investment is made. Second, there are uncertainties over the future outcome from the investment. One way to address this is to assess the probabilities of the alternative outcomes resulting in varying degrees of profits (or losses) for the investor(s). The third characteristic is related to timing of the investment. With proper planning, investment decisions can be postponed until credible information about future outcomes may be available. These three characteristics interact to determine the optimal decision of investors (Weston and Brigham 1976).

Typically risks result from uncertainties. Risk involves situations where the probability of a particular outcome is known, while uncertainty exits when the probability is not known (Choobineh and Behrens 1992). Risk is the consequence of taking an action in the presence of uncertainty, while uncertainty is the manifestation of unknown consequences of change (Sarper 1993). Risk exists in economic analysis because each input element may have a number of possible outcomes, thus relating risk to uncertainty of outcome. Uncertainty analysis is performed as part of the decision-making process to enable the decision maker assess the degree of confidence in the decision and associated project risks (Winston 2000; Borgonovo, Apostolakis et al. 2003). The framework presented in this study attempts to incorporate the effect of uncertainties associated with future outcomes.

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[1] An OTG strategy can be looked upon as a mechanism to implement PPP projects.

Though the terms risk and uncertainty are often used interchangeably, their implications from an investment viewpoint are somewhat different. There are several definitions of risk and uncertainty in the literature, as these terms are associated with investment decisions in various fields of engineering, business and management. *Risk* is quantifiable with a measurable probability of deserving / not deserving certain returns.

Uncertainty is associated with the lack of any information / knowledge about future outcomes (Ayyub 2003). Various methods are used to measure risk and uncertainty. This chapter focuses on a review of the state of the art on four major aspects of PPP focusing different OTG concepts: (1) Joint ownership, (2) Uncertainty, (3) Risk, and (4) OTG strategy.

2.2 Joint ownership

Traditionally transportation infrastructures are designed, planned, financed, and administered by the public entity at the federal, state, and local levels. Toll roads, on the other hand, are typically financed by 'borrowed funds', and the revenue generated is used to pay off the debt. The revenue predicted for future years in the form of toll is not necessarily deterministic in nature, involving greater uncertainty. With scarce financial resources of public entity, and uncertain returns of future revenues, there is a growing trend world-wide of PPP in building and managing infrastructure projects today.

> "*PPP is a technique to attract private capital in a public project that would otherwise be beyond the scope of the public entity*".
> (Yescombe 2007)

The PPP approach has been successfully deployed to infrastructure (Geltner and Moavenzadeh 1987; Nijkamp and Rienstra 1995; Fortner 2001), health industry (Victoria 2001), maintenance projects (USDOT 2006). The approach is gaining popularity in the US and around the world. Some examples in the US are: the SR-125 project in San Diego County California (Garin 1995), the city of Cleveland for the long term sustainable development (Goss 2002), a road rehabilitation and expansion project in Orange County California (Henk 1998), a light-rail transit system in Portland, Oregon (Landers 2002), a 10 mile express lane on existing State Route 91, California (Levy 1996), a 14 mile toll road extension in Leesburg, Virginia (Euritt, University of Texas at et al. 1994), Las Vegas Monorail (USDOT 2006). Other examples around the world are: a large city link toll road project in Melbourne, Australia (Alonso-Conde, Brown et al. 2007), the Mexico City-Guadalajara project, a toll road in Mexico (Huang 1995), the Keping toll road in Malaysia (Walker and Smith 1995), highway in Pearl Delta River region China (Yang and Meng 2000), tunnel projects in Hong Kong (Zhang and Kumaraswamy 2001), and a series of toll bridge projects in India (Malini 1999), the Mumbai-Pune expressway in India (Khasnabis, Dhingra, Mishra and Safi 2010).

2.2.1 Forms of PPP

There are number of ways in which a private agency can be involved in a successful PPP venture. A PPP is characterized by the degree to which the public and private sectors share the risks, responsibilities, obligations, and benefits of project. A number of structural options for PPP in road are discussed in the literature (Huang 1995; Hakim, Seidenstat et al. 1996; Sanchez 1998; Subprasom 2004; Alvis 2006; NCPPP 2008). A comprehensive list of different PPP sources is presented in Table 2.1 with discussions to follow.

Table 2.1: PPP Forms

Sl	PPP Form	Full Form
1	BOT	Build Operate Transfer
2	BTO	Build Transfer Operate
3	BBO	Buy Build Operate
4	BC	Build Construct
5	BT	Build Transfer
6	BLO	Build Lease Operate
7	BLT	Build Lease Transfer
8	BOOT	Build Own Operate Transfer
9	BOOS	Build Own Operate Sale
10	BOLT	Build Own Lease Transfer
11	BOO	Build Own Operate
12	BOST	Build Own Subsidize Transfer
13	DB*	Design Build
14	DBM*	Design Build Maintain
15	DBO*	Design Build Operate
16	DF	Design Finance
17	DBFO*	Design Build Finance Operate
18	DCMF	Design Construct Manage Finance
19	LDO	Lease Develop Operate
20	LP*	Lease / Purchase
21	SL	Sale / Leaseback
22	LRT	Lease Rehabilitate Transfer
23	LOT*	Lease Operate Transfer
24	OM*	Operate Maintain
25	OMM	Operate Manage Maintain
26	MOT	Modernize Own/Operate Transfer
27	OP	Outright Privatization
28	ROT	Rehabilitate Operate Transfer
29	ROO	Rehabilitate Own Operate
30	TOR	Transfer of Operating Rights
31	ITF	Inside the Fence Projects
32	TURNKEY	Turnkey
33	EUL	Enhanced Used Learning

Note: * Most common forms designated by FHWA[2]

[2] http://www.fhwa.dot.gov/ipd/p3/defined/index.htm

1. Build-Operate-Transfer (BOT)

The private entity builds a facility as per the specifications agreed to by the public entity, operates the facility for a specified time period under a contract or franchise agreement with the agency, and then transfers the facility to the public agency at the end of the specified period of time.

The private partner may provide some, or all, of the financing for the facility, so the length of the contract (commonly known as concession period) must be sufficient to enable the private partner to realize a reasonable return on its investment through user charges. At the end of the concession period, the public entity can assume the operating responsibility for the facility.

2. Build-Transfer-Operate (BTO)

In BTO structure, the private entity transfers the project to the public entity after completion of construction for a specified payment (as per contract). Following the construction, the private entity operates the facility and the public entity pays for the operation of the facility.

3. Buy-Build-Operate (BBO)

In BBO structure, the facility is transferred to the private entity, usually under a contract for the upgrading/rehabilitation/expansion and operation of the facility for a specified period of time. Little or no public interaction is involved during the life of the contract.

4. Build-Contract (BC)

In BC structure, the public entity only bids out a construction contract. The contractor selected builds the project as per the specifications of the construction contract, and upon technical completion[3], the constructed project is transferred to the public entity. Such form of PPP utilizes the expertise of the private entity such as building proficiency, competitive bids, effective construction, thereby reducing the exposure level of the public entity to risk.

5. Build-Transfer (BT)

In BT structure, the private entity is responsible for construction of the facility and transferring the project to the public entity for operation and maintenance. The public entity either uses the toll revenue to pay off or may involve the private entity in the bidding process of another project to help retrieve the investment capital with a reasonable profit.

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[3] If the construction is not performed adequately or on time, the public entity only pays at the end of construction, commonly referred as technical completion.

6. Build-Lease-Operate (BLO)

In BLO structure, the private entity builds the facility and then leases the facility for operation (either to public / another private entity). In this case, the private entity takes the construction risk (also takes a step beyond BC). This structure of PPP allows the public sector to transfer the risk on construction, operation and financing to the private sector.

7. Build-Lease-Transfer (BLT)

BLT is similar to the BLO structure, with the provision that the private entity takes the risk on construction, but not necessarily on operation.

8. Build-Own-Operate-Transfer (BOOT)

In BOOT structure, the private entity builds, owns, and operates the facility. Private operation terminates at the end of concession period. The private entity receives revenues from the project (example: toll road) during the concession period. Unlike BOT, the BOOT structure allows the private agency to own the facility till the end of the concession period. The basic difference between BOT and BOOT is the ownership. The private entity can upgrade the facility to generate additional revenue (which is not the case in a BOT structure).

9. Build-Own-Operate-Sell (BOOS)

In BOOS structure, the project is built, owned, and operated by the private entity before it is sold back to the public entity at a specified price (considered to the worth of the facility at the time of sale). This structure allows the private entity to operate the facility to generate revenues and to sell the un-depreciated investment back to the public entity at a specific time point.

10. Build-Operate-Lease-Transfer (BOLT)

In BOLT structure, the private entity builds and operates the facility for a specified period of time, and at the end of the period leases it back to the public entity. The public entity takes over the facility and pays periodical amounts to the private entity till end of the concession period before permanently owning it.

11. Build-Own-Operate (BOO)

In BOO structure, the project is built, owned, and operated by the private entity. The public entity awards the private entity rights to use the assets (example land for toll road) and build the facility. The BOO structure is not intended to be transferred back to the public entity; although maintenance of the facility is typically the outcome of negotiations between the public and private entity.

12. Build-Own-Subsidize-Transfer (BOST)

In BOST structure, the private entity builds, and operates the facility for a specified period of time. It shares the operation and maintenance with the public entity before transferring the facility. Because of insufficient resources at its disposal, the private entity shares few fiscal responsibilities with the public entity. The advantage to the public entity is the reduced risk in capital investment in construction.

13. Design-Build (DB)

In DB structure, the private entity provides both design and construction of a project for the public agency. This type of PPP structure can reduce time, save capital, provide stability and reduce project risk to the public entity. It also reduces conflict by having a single entity responsible to the public owner for the design and construction. The public entity owns the facility and has the responsibility for the operation and maintenance of the facility for rest of the service life.

14. Design-Build-Maintain (DBM)

DBM structure is similar to DB with the additional stipulation of the maintenance of the facility by the private entity for some period of time. The benefits are similar to those of DB with maintenance risk being allocated to the private entity. The public sector partner owns and operates the facility.

15. Design-Build-Operate (DBO)

The DBO structure is an integrated partnership that provides the private entity the responsibilities of Design-Build procurements with operations. The DBO approach facilitates private-sector financing of public projects supported by user fees generated during the operations phase.

16. Develop-Finance (DF)

In DF structure, the private entity finances the construction of the public facility in exchange of the right to build residential, commercial, and/or industrial facilities at/near the facility. The private entity contributes capital and may operate the facility under the oversight of the government. The developer gains the right to use the facility and may receive future income from end users.

17. Design-Build-Finance-Operate (DBFO)

In DBFO structure, the private entity is responsible for the design, finance, and construction of the facility under a long term lease, and for operating the facility during the assigned term. The private entity transfers the facility to the public entity at the end of the lease period.

18. Design-Construct-Manage-Finance (DCMF)

In DCMF structure, the private entity is responsible for design, construction and management of the facility. It also finances the upgrading of the facility for a specified period of time before it transfers the facility to the public entity.

19. Lease-Develop-Operate (LDO)

In LDO structure, the private entity leases or buys an existing facility from a public agency; invests its own capital to renovate, modernize, and/or expand the facility; and then operates it under a contract with the public agency. A number of different types of municipal facilities have been leased and developed by the transit industry under the LDO form of PPP.

20. Lease / Purchase (LP)

LP structure is an installment-purchase contract where, the private entity finances and builds a new facility, which it then leases to a public entity. The public entity makes scheduled lease payments to the private party, and accrues equity in the facility with each payment. At the end of the lease term, the public agency owns the facility or purchases it at the cost of any remaining unpaid balance in the lease. Depending upon the specific arrangement, the facility may be operated by either the public agency or the private developer during the term of the lease.

21. Sale / Leaseback (SL)

In SL structure, the public entity sells the facility to the private entity, and subsequently leases it back from the private entity. The agencies may enter into a sale/leaseback structure for a variety of reasons. An innovative application of the technique is the sale of a public facility to a private entity for the purpose of limiting governmental liability under certain statutes. Under this arrangement, the public entity that sold the facility leases it back and continues to operate it.

22. Lease-Rehabilitate-Transfer (LRT)

In LRT structure, the private entity takes the responsibility to build/improve/ rehabilitate the facility. The private entity pays lease charges to the public entity, rehabilitates the project, and then transfers the facility to the public entity after a specified time period.

23. Lease-Operate-Transfer (LOT)

In LOT structure, the private entity leases and operates the facility for a number of years before finally transferring the facility to the public entity at the end of the contract period.

24. Operations and Maintenance (OM)

In OM structure, the public entity contracts with a private partner to operate and/or maintain a specific service. Under this option, the public entity retains ownership and overall management of the public facility.

25. Operate-Maintain-Manage (OMM)

In OMM structure, the public entity contracts with a private entity to operate, maintain, and manage the facility. Under this option, the public entity retains ownership of the facility, but the private entity may invest its own capital in the upgrading of the facility. Any private investment is carefully calculated in relation to its contributions to operational efficiencies and savings over the term of the contract. Generally, the longer the contract term, the greater is the opportunity for increased private investment because of greater prospect to recoup the investment and to earn a reasonable return.

26. Modernize Own/Operate-Transfer (MOT)

In MOT structure, the private entity renovates the facility; operates it for a specific period of time and returns back the facility to the public entity.

27. Outright Privatization (OP)

OP structure attracts the private entity to benefit from existing public infrastructure. The application of OP is more common in the telecommunication industry, where privatization has provided a forum for delivering a revamped infrastructure from the owners to the users. Such approach allows the public entity to privatize the system via licensing and to benefit the end user.

28. Rehabilitate-Operate-Transfer (ROT)

In ROT structure, the private entity rehabilitates, operates, and transfers the project to the public entity after a specified time period. The basic difference between ROT and many other similar structures (such as BOT, BOOT, BTO, etc.) is the concession of an existing project as opposed to building a new project. This is more common in developed countries with aging infrastructure.

29. Rehabilitate-Own-Operate (ROO)

In ROO structure, the private entity rehabilitates, owns and operates the facility for a specific period of time. The maintenance of the facility during this period is the responsibility of the private entity (difference from MOT). The facility is returned back to the public entity at the end of the concession period.

30. Transfer of Operating Rights (TOR)

In TOR structure, the public entity transfers the right to use the existing assets of a divesting project to the private entity and enters into an agreement with the private entity to purchase the output of the project. The private entity must invest capital, repair/expand the project; and compensate the existing facility employees (public employees) if or

replacement reduction of the work force of the project is required.

31. Inside-The-Fence (ITF)

ITF structure is a new form of emerging PPP, where industrial consumers require infrastructure for their operation and bid on the public facility for the overall operation. Such self-built infrastructure can be financed benefiting both the private and public entity.

32. TURNKEY

In TURNKEY structure, the public entity contracts with a private entity to design and build the project in accordance with specified performance standards and criteria. The private entity commits to build the facility for a fixed price and absorbs the construction risk of meeting that price commitment. Generally, in a turnkey transaction, the private entity may use fast-track construction techniques and is not bound by traditional public sector procurement regulations. This combination often enables the private partner to complete the facility in significantly less time and for less cost than could be accomplished under traditional construction techniques.

33. Enhanced-Use-Leasing (EUL)

The EUL concept originally developed as an asset management program in the Department of Veterans Affairs (VA), and can include a variety of leasing arrangements, typical of PPP programs (e.g. lease/develop/operate, build/develop /operate). EULs enable the VA to lease VA-controlled properties to the private sector over a long-term.

As mentioned earlier, the information presented in this section is compiled from the current literature (Huang 1995; Hakim, Seidenstat et al. 1996; Sanchez 1998; Subprasom 2004; Alvis 2006; NCPPP 2008).

2.2.2 Participants of PPP

PPP projects consist of various participants as explained below.

- The Public Entity: The primary participant of any transportation infrastructure project is the public entity, that may include different branches of the federal, state, and local governments. The government must be fully responsible for the project, enact legislation that permits the creation and operation of the project, provide necessary support throughout the life of the concession. In case of default, the public entity may have to take over the project (Sanchez 1998; Yescombe 2007).

- The Private Entity: The private partner of a PPP project is generally an organization composed of one or several large corporations, lending institutions, insurers, institutional investors and other types of equity investors. They are entitled to construct, operate and maintain the facility during the concession period as per the agreement between the public and private entity. The two most important entities are the lenders and developers; who play key roles in the implementation of the

project.

- The lenders: Private and public lenders provide debt financing for the private developers, and will normally require guarantees to assure themselves that the project will actually generate enough cash flow to service the debt. Some of the private debt sources are commercial and investment banks, institutional investors, commercial financial companies, leasing companies, investment management companies, and money market funds (Dias Jr and Ioannou 1996). Other sources include the World Bank, the European Investment Bank (EIB), and the Export-Import Bank of the U.S.

- The developers: These are the entities who generate the project ideas and promote the ideas to their fruition. A number of private organizations can assume the roles of project developers, including the financial institutions, corporations, private investors, construction companies, engineering / design firms, and equipment/material suppliers (Ock 1998). The goal of private developers is to maximize personal and/or institutional objectives, with minimum amount of risk.

- The equity investors: Equity investors provide cash for the project by buying equity shares for profits. Equity investors include project developers, institutional investors, investment and commercial banks, utility subsidiaries, local investors and developers, and international agencies such as the World Bank (Tiong, Yeo et al. 1992). The participation of local investors and developers as equity investors in a project is important not only for financing the project, but also on its management and operation.

- Local Partners: Some host governments require the use of local labor, contractors, etc. The participation of local members, especially if they are politically well connected, is a major advantage.

- Construction Consortiums: Because a PPP project is capital intensive and complex, it may require participating construction companies to assume some degree of the project risk.

The advantages and disadvantages of PPP projects are discussed below.

Advantages

- Additional funds for road construction: Private financing enables governmental agencies to raise more money for road construction than would be possible through regular public financing (OECD 1987).

- Enhanced performance: Countries with toll roads have been found to provide better quality maintenance than those with comparable free facilities (OECD 1987). The reason for this is that the typical finance arrangement for a BOT concession requires periodic inspection and maintenance reports to protect users and lenders.

- Construction cost and schedule: Private toll roads are likely to be built sooner and at less cost than projects financed through public agencies (Roth 1996).

- Ability to finance expansion: Private providers have access to sources of funds seeking profitable investments. These funds can be used to improve and extend the road. The public sector, on the other hand, can be subject to political constraints on expansion for a variety of reasons (Roth 1996).

- Other economic considerations: Tolls can be used as a method of congestion pricing, encouraging users to make more efficient route choices or use alternative transportation modes (OECD 1987).

Disadvantages

- Costs of toll collection: Manual toll collection causes indirect costs such as delays and increases fuel consumption, by requiring vehicles to stop or slow down at toll plazas. Besides, direct costs can absorb up to a third of total revenues (Roth 1996). Recent advances achieved in automatic vehicle identification (AVI), and electronic toll collection (ETC) will progressively make toll collection easier and less costly (OECD 1987).

- Increased traffic costs: Traffic cost can increase due to longer traveling distances. Some users may choose longer trips to avoid toll roads, resulting in increasing congestion on the parallel "free" roads (OECD 1987).

- The myth of free road: Very seldom do toll roads become free roads, even after they have been paid off. Once a road has been perceived as a secure source of income, it is difficult for governmental authorities to surrender the extra revenue.

Definitely there are advantages of PPP, but the major challenge is a realistic prediction of future revenues. For transportation infrastructure, the source of revenue is toll, which is generally proportional to the traffic demand. In a transportation network, the determination of toll and demand is not deterministic in nature. For example, higher toll rates may result in lower demand, (assuming the availability of alternate facilities) hence lower revenue. So the determination of the appropriate toll and corresponding demand is a combination of optimization and traffic assignment problem. In the next section the determination of optimal toll under uncertain demand condition is discussed.

2.3 Uncertainty

Uncertainty in investment decisions is well documented in literature, since the application is widespread in the fields of finance, business, and management. Examples of uncertainty in investment decisions on non- transportation fields include studies on: efficient evaluation of capital cost (Hirshleifer 1964); stock market equilibrium (Diamond 1967); private ownership stability and equilibrium (Dreze 1974); decisions from a firms viewpoint (Abel and Eberly 1997); urban land prices (Titman and Housing 1984); bank asset and liability management (Ouzsoy and Güven 1997); equilibrium prices and preferences for stock market (Kübler et al. 2002); developing strategies in the energy sector (Bjornstad 1996).

In general, transportation infrastructure investments are modeled under the assumption of deterministic environment, considering future cash flows to be 'fixed' during the planning horizon. However, this assumption may not be valid in reality, or may not be viable. There may be several uncertainties associated with the variables included in the estimation of forecasted measures of effectiveness (MOE). Uncertainty can be quantified in a probability distribution, which results from treating the inputs as random variables. These uncertainties could, therefore, result in the variation of traffic demand and thereby could adversely affect the future MOE (Subprasom 2004).

Recent literature on uncertainty in transportation infrastructure investment includes the work on highway pricing and capacity (Yang and Meng 2000); private toll roads on variable demand (Chen and Subprasom 2007); social surplus calculation for public investor under variable demand (Zhang and Ge 2004); marginal cost pricing for uncertain demand (Zhao and Kockelman 2006); optimal link tolls for various traffic assignments (Yang 1999); network capacity (Ukkusuri and Waller 2006); and optimal link tolls for traffic equilibrium (Yang and Huang 2004).

2.3.1 Travel Demand

Estimated return of a PPP project is heavily dependent on the forecasted travel demand. Travel demand is uncertain because of its implied relationship with many uncertain factors, such as economic and social development, road network condition, land use pattern, travelers' driving behavior, etc (Yang 1999; Yang and Meng 2000; Subprasom 2004; Yang and Huang 2004; Ukkusuri and Waller 2006). Zhao and Kockelman 2006). Sources of significant uncertainty or potential error should be identified. Even though uncertainty is inevitable, it can be modeled to improve predictive quality (Barton Aschman Assoc. and Cambridge Systematics (2001). Travel demand model uncertainty can result from the choice of inappropriate variables and approximations, and the use of the incorrect mathematical expressions for representing the real world situation (Subprasom 2004). There could be other sources apart from travel demand that could affect the outcome of future returns.

2.3.2 Travel Time

Travel time is a key determinant of the choice of modes and routes in a transportation network. Therefore, variations in travel time will eventually affect in evaluation of MOE's in a PPP project. Mode-specific users will have different perspectives of travel time and the process is complex for demand uncertainty (Zhao and Kockelman 2006). Trip making depends on travel time and willingness to pay. The value of time follows certain distribution and normally corresponds to socioeconomic characteristics of travelers (Yang and Zhang 2002; Subprasom 2004).

Recent work on network equilibrium models attempt to incorporate the effect of different values of time (VOT) by including user heterogeneity in route choice models. These models simulate the way users select a route among the competing paths which are differentiated on the basis of two cost criteria: journey time and monetary cost. There are generally two lines of approaches when dealing with the tradeoffs between money and time in simulating users' responses to toll charges. A first line of approach consists of differentiating several discrete classes of users, each one with a VOT belonging to some interval (Dafermos 1973 and Daganzo 1983). The second line of approach assumes a continuously distributed VOT across the users (Dial 1996; Dial 1997).

2.3.4 Cost estimate

The majority of the capital investment in transportation infrastructure is made through the construction cost; followed by operation and maintenance cost. Variations in cost estimate can be caused by events that are difficult to control, such as political turmoil, labor strike, availability of materials, and delay in land delivery by the host government (Chang 1996). Maintenance-operating cost variation can unexpectedly increase due to damages of structure or equipment from some kind of natural disaster or from increasing cost of improperly installed or manufactured equipment. Construction and maintenance-operating costs exceeding original estimates may lead to cost overrun risk. Ideally, models should be structured to incorporate variation in cost estimates for both uncertainty and risk.

2.4 RISK

Each project embodies unique type of risks that need to be identified and analyzed. The term risk is defined in literature in many ways. Few definitions are presented below;

- "The exposure to the chance to occurrences of events adversely or favorably affecting project objectives as a consequence of uncertainty" (Al- Bahar 1988).

- "The term risk in statistics is defined as a situation where there are two or more possible outcomes, and a probability associated with each outcome" (Newman 1983).

- Risk is an expression or possible loss over a specific period of time which may be indicated by the probability of loss in dollars or other operating units. (Hammer 1972)

- A measure of probability and severity of adverse effects. (Lowrance 1976)

- "A function of two major factors: (a) the probability that an event, or series of events of various magnitudes, will occur, and (b) the consequences of the event(s)". (Petak and Atkisson 1982)

- "The exposure to possible economic loss or gain arising from involvement in the construction process" (CII 1988).

- "The exposure to the possibility of economic and financial loss or gain, physical damage or injury, or delay as a consequence of the uncertainty associated with pursuing a particular course of action" (Chapman 1991).

- Risk is a measure of the probability and consequence of achieving a defined project goal (Kerzner 2005).

- Risk is basically a mathematical description of the frequency and severity and the variability of the risk, summarized using a probability distribution function (PDF) (Sanchez 1998).

2.4.1 Risk Identification

The most important phase of a risk analysis process is the identification of risks. A risk that is not identified cannot be quantified, controlled or transferred (Construction Industry Institute (CII), 1988). Elements of risks that are likely to affect the project, need to be identified and their characteristics should be documented. The end product is a comprehensive description of risk events and elements. The major risk concerns of the primary parties involved in the project (host government, sponsors, financiers, and contractors) must be addressed to identify all potential risks. Some of these risk elements may include initial construction cost, construction schedule, operation and maintenance costs, through traffic, toll prices, qualification of contractors, regional economic stability, and availability and cost of financing (Sanchez 1998).

2.4.2 Sources of Risk

There are three generic sources of risks (1) The project, (2) Management Actions, and (3) State of the World Risk. These are explained below.

1. The Project: Risks vary with the amount of new technology, size, location, regulations,

funding and other factors that arise as the amount and complexity of data increases. Despite new management techniques and tools, and advanced information technology, there may be large uncertainties that increase project cost. The following are some vital project segments that involve risk:

- New technology. The greater the amount of new technology, the larger the risk. This is not very likely to be an important risk in a toll road.

- Size and location. Larger projects and constructing in unfamiliar (or confined) locations tend to create risks beyond those initially anticipated. For example, different new circumstances must be dealt when constructing a toll road in a developing country rather than in a developed country, or an urban versus rural toll road.

- Regulations. If the duration of a project stretches through several years, the possibility of changes in regulations that may adversely affect the project must be considered. The project's risk posture must change to meet technology and increased public safety demands.

- Funding. The availability of financing and adequate cash flow is a major concern of all project participants. This concern also extends to factors such as interest rates, cost of borrowing capital, internal rate of return and net present value.

- The concession agreement and other contracts. As the binding force among the parties, these documents require a great deal of attention from each party. The contracts are essentially a risk allocation tool. However, the contract itself may be the source of risk when it is not clearly drafted or when contract administration is not efficient. These legal documents must clearly define and assign the risks borne by each party.

2. Management Actions. The management and administration of the project is another major source of risk. There are factors that can affect the overall project risk:

- Cost and schedule estimates. Inaccurate estimates or schedules yield unrealistic goals and inefficient project planning.

- Human errors. These include omissions, poor judgment, methodological errors, lack of knowledge and also misunderstandings.

- Timely decisions. Lack of prompt management action in case of problems increases risks to all project participants.

3. State of the world risks. There are sources of risk that are outside the limits of the project and beyond the control of its participants. This category includes risks such as inflation, political and labor issues, marketplace factors.

- Inflation and currency exchange rates. The general economy of a country definitely impacts the risk level of a toll road project, reaching aspects such as financing, construction costs, traffic demand.

- Political issues. The political environment of the country where the project is to be built affects exposure to risks. These issues include risk of government appropriation of the project, retention of dividend remissions, political unrest.

- Marketplace. The marketplace forces that determine the traffic demand likely to sustain through the toll road are a critical risk concern.

2.4.3 Risk Identification Techniques

Every infrastructure project is unique in nature. Risks associated with the project can be identified from historical data, and experience from similar projects. Sometimes, historical information is not enough for careful risk identification. Experience with similar projects enables a project team to better analyze the known data and associate it with the characteristics of the current project, particularly when historical records are insufficient or not available. If neither historical data nor previous experience is available, it is necessary to rely on insight. Even when data is available, the size and complexity of a major project make insight and subjective evaluations essential elements in the risk identification process (Diekmann et al. 1988; Sanchez 1998).

2.4.4 Risk Measurement

Once the risks of the project have been identified, their magnitude must be assessed. There are two primary types of risk, first those that occur frequently and have a moderate impact, but whose cumulative impact can be substantial, and second, infrequent risks with a strong initial impact. Both of these strongly influence the feasibility of the project. Risks must be measured in order to establish whether the project is feasible or not, whether it should be further studied or abandoned, to assess the level of detail deemed by the analysis, and the acceptable level of risk for the project (Diekmann et al. 1988). Risk measurement (quantification) can be described as the process of determining adequate measures of risk by assessing the likelihood of occurrence of all the outcomes associated with the risks identified, as well as the magnitude of such outcomes (Diekmann et al. 1988).

2.4.5 Measures of Risk

Risk can be measured by the single or combined probability distribution functions (PDF) involved. There are a wide variety of forms and types of PDFs, each of which describes a range of possible values and their probability of occurrence. These include normal, lognormal, beta, uniform and triangular distributions. The measures of risk represented as PDF must conform to the rules of traditional probability theory. These rules are summarized

by (Diekmann et al. 1988) as follows: "1) the sum of the probabilities for all possible events must sum to 1.0, 2) the probability of any event must be a number between zero and one, 3) the impossible event has a probability of zero, and 4) the probability of joint events is the product of the probability that one event occurs and the probability that the other occurs, given that the first has occurred".

Detailed information is needed about a variable to know the exact shape of the probability function. Since such precise information is seldom known, it has to be subjectively determined or assumed. The two most crucial parameters of a PDF are the mean and the standard deviation. The mean (μ) is a measure of central tendency for the variable, and the standard deviation (σ) is a measure of the dispersion of the variable. For a given mean value, the larger the range of the variable, the larger the standard deviation. Hence, all other factors being equal, variables with large standard deviations are riskier than those with small standard deviations.

The mean is also known as the expected value of a variable. It can be seen as the weighted average value of the random variable, where the weighting factors are the probabilities of occurrence (Park 1997). Other PDF parameters include the mode and the median, which are two other measures of central tendency, and the third and higher moments about the mean that characterize standard deviation, the skewness, and other features of the distribution function.

2.4.6 Risk Measurement Techniques

There is a variety of methods that can be used to measure risk. The choice of one depends mostly on the objectives of the analysis to be performed. The risk measure can be quantified by determining the combined effects of risk in traffic, economic factors, cash flow needs, construction and maintenance costs, etc. Some example of risk measurement techniques are risk probability of occurrence, volatility, risk on return of capital, and value at risk. Other forms of analysis such as sensitivity and stochastic analysis, measure the tradeoff on outcome (NPV, IRR, etc.) by altering the effects of risk factors (traffic, toll, cost etc.). Sensitivity analysis is a formalized method of testing the effects of the variation in the value of an individual variable at a time, on the project's overall profitability measure. It is a technique used to identify key variables that influence the profitability of the project and to judge their relative importance (Winfrey 1964). Monte Carlo simulation is a type of stochastic analysis that uses computer programs to repeatedly sample the PDF of the variables that influence the profitability of the project.

2.4.7 Project Risk Analysis and the Simulation Approach

Project risk analysis broadens the perspective of the decision-maker from a fixed set of assumptions, (which are essentially indecisive) to a more comprehensive view of the probable outcomes. A broader view may lead to a reconfiguration of the project, assist in the

development of new strategies of meeting project objectives or responding to difficulties (Jones 1991), or in the worst case, to the definitive rejection of the project. Park defines the term project risk as the variability in the project's profitability measure (such as its NPV or IRR), or in other words, as the project's potential for loss (Park 1997). The aim of project risk analysis is to produce a PDF of its profitability measure that serves as a tool to make a better investment decision. From this PDF, the decision-maker can extract information as the expected value (mean) of the profitability measure, the extent to which other profitability measures vary from, or are clustered around, the standard deviation, and the best estimate of profit.

The investment decision can be improved by incorporating the variability information along with the expected value. The standard deviation is a measure of the dispersion of the distribution (risk); hence it is desirable to minimize it. That is, the smaller the standard deviation, the less the potential for loss (or gains) associated with the profitability measure. Therefore the ultimate investment choice depends on the decision-maker's preferences, or, how greatly he/she is willing to accept the variability to obtain a higher expected value. The fundamental question is, what is the level of risk he/she is willing to accept? This will depend on the investor's attitude towards risk (whether the investor is risk averse, risk neutral or risk seeker). The objective of risk simulation is to weigh several structures of risk factors by their probabilities, and then summarize all the possible configurations and values of the risk factors into a risk profile for the project under examination (Jones 1991). The Monte Carlo simulation method is one of the most common risk simulation techniques.

Risk simulation operates with the probabilities of the variables influencing the outcome of the problem being analyzed i.e. in this case, the project profitability measure. These subjective probabilities are based, as mentioned earlier, on expert opinion and are supplemented by data about the objective frequencies of events, where available. The key to risk simulation lies in estimating these probabilities, which already exist, since people are willing to make decisions, such as whether or not to invest in a toll road project (Jones 1991).

2.4.8 Steps in Project Risk Analysis and Simulation

Summarizing the work of several authors (Adler 1987; Park 1997), the simulation approach for project risk analysis can be defined as a process consisting of the following steps:

- Model the problem. The model developed in the decision analysis process must be translated into equations for determining cash flows, profitability index and other economic measures.

- Identify the major risk factors. The process for risk identification must be established at the outset. In order to identify the most appropriate variables, a series of sensitivity analyses on the model is performed in this step. The elimination of non-sensitive

variables will expedite the simulation process.

- Run the simulation. The performance of the investment is simulated with parameters sampled from the probability distributions developed for the various risk factors. This step can be entirely computer-based, that includes; sampling from the PDFs, forecasting variables and calculating the cash flows. After a specified iterations, the program can provide the probability distribution of the profitability measure.

- Produce Risk Profile and Analyze Results. The summary of the results of the analysis is a risk profile or PDF for the profitability measure. This PDF provides the mean profitability measure, the range of potential outcomes, and the probability that the measure will fall between a particular range.

2.5 Summary

A summary of the literature review is presented below:

- The rationale for choosing PPP is to extend the financial support of public agency to the private agency for better operation and maintenance of the facility; and for sharing possible risks if encountered in future.

- Various forms of PPP can be structured based on the responsibility shared between public and private entity. Other factors such as funds invested, benefits accrued, and tenure of operation can influence PPP strategies.

- Long term infrastructure projects are typically characterized by two factors: uncertainty and risk. The distinction between risk and uncertainty is discussed.

- Sources of uncertainty can arise from travel demand, journey time; and other cost factors.

- Risk is the outcome of uncertainty and must be identified. Risk should be properly analyzed, measured and quantified.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 Introduction

In the previous chapter, a literature review on three distinct aspects (joint ownership, uncertainty, and risk) of transportation infrastructure investment was presented. It was clear from the literature review that a formal framework for incorporating risks and uncertainties in transportation investment decision is needed. In this chapter, the methodological aspects of incorporating risk and uncertainty into transportation infrastructure investment decisions are presented.

3.2 Framework Development

A proposed framework for large scale transportation infrastructure investment decision making is presented in Figure 3.1. Such investments typically involve different types of decision makers (or investors / users) termed as entities in Figure 3.1. Each entity has different perspective from an investment viewpoint. The proposed approach calls for each entity perspective to be optimized initially to ensure individual interests, noting that individual perspectives can be completely different from one another. The uncertainty and risk involved for each entity is determined at this stage (step -1). A complete description of single entity uncertainty analysis is presented in section 3.4 and risk analysis is described in section 3.5.

Though the interests of individual entities are important, it is imperative to examine the combined interests of all entities in a single step (step-2). A multi- objective optimization is proposed to incorporate the "merging" of the objectives of all entities. The multi-objective optimization provides a set of optimal solutions as opposed to a single optimal solution. A complete discussion is presented in section 3.6.
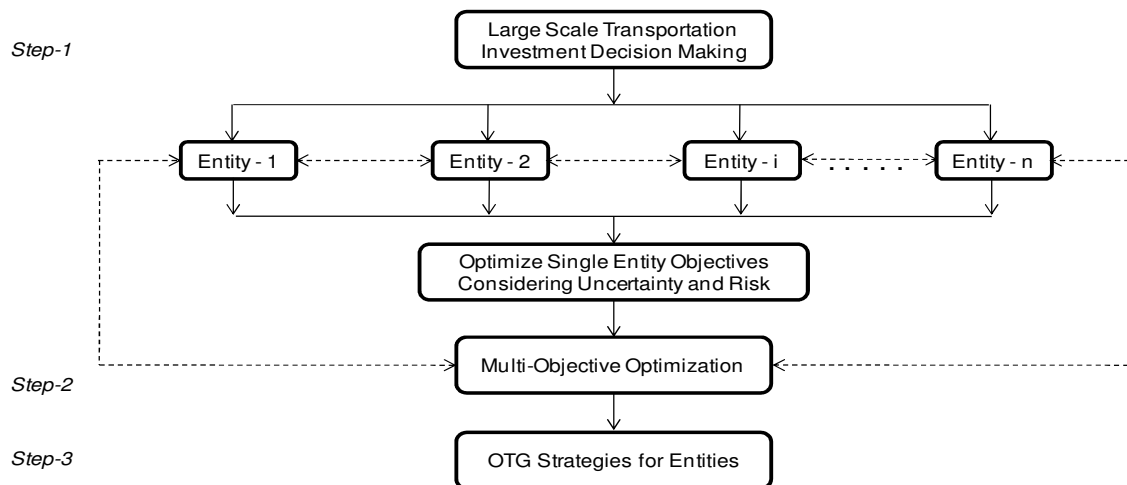
Figure 3.1: Investment Decision Making Framework for Single and Multiple Entities

Each OTG strategy represents specific roles of individual entities involved in the investment process. A methodology is proposed to interface the solution obtained from the multi-objective optimization with the OTG strategies, considering the preferences of each entity involved in the decision making procedure (step-3). A complete discussion on specific solutions for OTG strategies is presented in section 3.7.

3.3 A Framework for Single Entity Uncertainty and Risk Analysis

A framework to incorporate the concept of investment decisions under uncertainty and risk is presented in the section. A framework in this case, is a system of procedure/algorithms integrated together through appropriate linkages to produce a desired output. For large scale systems, these linkages are developed through many iterations of applications that require computationally efficient algorithms. An initial framework developed is illustrated in Figure 3.2 and categorized into two steps;

- Step 1: Uncertainty Analysis
- Step2: Risk Analysis

Step-1: Uncertainty Analysis

The uncertainty analysis (step-1) is further divided into three sub-steps:

Step - 1.1: Policy Options

Step - 1.2: Bi-level Programming for uncertainty analysis

Step - 1.3: Feasibility Analysis

Step 1.1 represents an examination of the investment policy options recommended by the Federal and state levels relating to new transportation projects. Each policy option may represent a specific PPP where the responsibilities of the public and private agencies may vary widely. At one end of the spectrum, the public entity may have all the major responsibilities with the private agency playing a minor role. At the other end, the roles may be reversed. Various other combinations may form the intermediate range.

An evaluation of the proposed policy options can be viewed as a bi-level process (Step 1.2). The policy maker (upper level) is assumed to have knowledge on how the road users (lower level) would respond to a given strategy. However, the strategy set by the policy maker can only influence (but not control) the road users' route choice (or use of the proposed facility). In other words, policy options and route choice decisions to some extent are inter- dependent and can be represented as a bi-level program, where, the upper level involves policy maker's decision to determine the toll value and the lower level assigns number of road users to the proposed facility for the toll structure determined at the upper level. This is an iterative process carried out until a
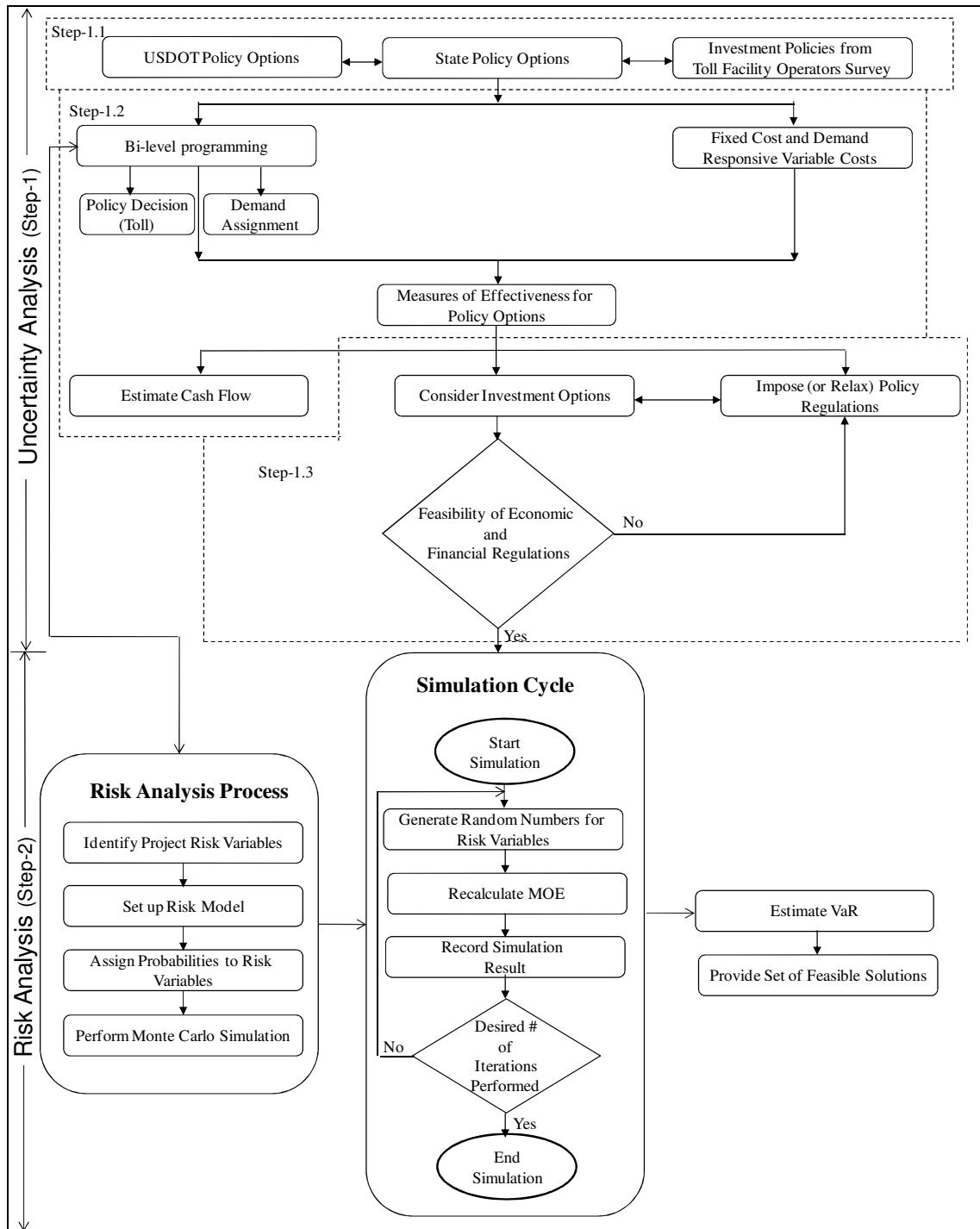
Figure 3.2: Proposed Methodology for Single Entity Uncertainty and Risk Analysis

specific toll value and traffic volume determine the optimal benefit subject to various constraints imposed by construction, operation and maintenance costs. Cash flow diagrams over the entire life cycle of the facility are considered. Economic and financial measures of effectiveness (MOE) are used to check the viability of the project.

Various investment options identified in step 1.1 can be considered. Policy regulations such as construction cost subsidy, concession period extension, (or similar relaxation policies) can be considered if the project is not viable to enlist sufficient private entities interest in the investment. After relaxation of policy regulations, viability of the project can be re-assessed and a set of OTG strategies can be developed and tested (Step 1.3). The first three steps take into account the uncertainty in demand (number of road users using the facility) subjected to various toll values.

Step - 2: Risk Analysis

In step 2 risks associated with set of OTG strategies are determined. The term "Value at Risk" (VaR) for a policy option is used to denote the maximum expected loss over a given horizon at a given confidence level. Risky policy options are avoided at this step and feasible ones are considered as favorable for future investment. Following the 'minimax' concept, the ideal strategy here would be to adopt the policy that minimizes the maximum loss.

3.4 Decision Tool for Uncertainty Analysis

Investments in major transportation infrastructure are often complex, with a mix of public and private finance, when the respective agencies may have different missions and motivations. The public sector may consist of national, state and local administration with intent to adopt a social welfare perspective. The public and private entities are interested in exploring optimal tolling strategies that may yield different solution (Hyman and Mayhew 2008; Palma et al. 2006; Rouwendal and Verhoef 2006; Wong et al. 2005). While the public entity always would like to maximize the consumer surplus[1] (social welfare); the private entity is likely to be interested in maximizing the net profit. Private participation will occur only if the investment is attractive to maximize its profit. Since the public sector will be eventually the owner and operator of the facility; it must ensure that the facility attracts users and serve the needs of the community (Yang and Meng 2000). Finally, the optimal toll must be viable to the ultimate end users. From basic user perspective, the toll value should be such that motorists are attracted to the facility to meet the mobility needs of the community, thereby ensuring spatial equity among users. The methodology for uncertainty analysis is presented in Figure 3.2 (Step - 1.1 – Step - 1.3). In the bi-level process, the upper level is subdivided into three categories considering the nature of project; (1) Private Investor's perspective, (2) Public Investor's perspective, (3) Road User's perspective. The objectives of these three entities are different. For example, the private entity perspective is to maximize profit, while the public entity perspective is to maximize consumer surplus, and the user

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[1] The additional value or benefit received over and above the expenses actually made is known as consumer surplus. (Wohl and Hendrickson 1984)

perspective is to minimize inequality in the distribution of the benifits. While the designed toll value for all the three perspectives will be different at the upper level, the lower level is a user equilibrium assignment problem with elastic demand which is designed to consider uncertainties in travel patterns.

Sources of uncertainty in the transportation infrastructure investment can arise from the determination of future cost and revenue and their distribution among the participating entities. Bulk of the cost element is from construction cost which is incurred before the facility is opened to traffic; other future cost elements such as regular operation and maintenance; and periodic operation and maintenance depend on future travel demand. On the other hand, revenue is directly dependent on travel demand and toll. Uncertainties related to both cost and revenue are primarily generated from travel demand. In this research, a framework is proposed to address uncertainty by considering random expected potential and variance of travel demand from one zone to the other. Further, the travel demand is used in the bi-level optimization process to determine optimum toll, corresponding traffic volume and future operation and maintenance cost.

Policy Option-1: Private Investor's Perspective

The objective of the private investor is to maximize profit. The annual profit for demand uncertainty is the difference between benefit and cost and is presented as following (Chen and Subprasom 2007).

$$P^n\left(\tau, x(\tau, \varepsilon)\right) = B^n - C^n \tag{3.1}$$

Where, P^n is the profit generated in year n, which is a function of the demand (x) and toll (τ). B^n and C^n are corresponding revenue and cost for year n respectively. The revenue generated is a function of uncertain demand and toll, while the cost can be presented in the form of capital and operation and maintenance cost. A revised equation (3.1) can be represented as:

$$P^n\left(\tau, x(\tau, \varepsilon)\right) = \sum_{n \in N}\left[\sum_{a \in A} \gamma x_a^n(\tau)\tau_a^n - C_{a,c}^n - O_a^n\left(x_a^n\right)\right] \tag{3.2}$$

where, γ is a parameter which converts hourly link flows to annual link flow, x_a^n, τ_a^n $C_{a,c}^n$, O_a^n are the demand, toll charge, construction cost and operation and maintenance cost for year n on link a respectively, N is the analysis period and $\overline{A}$ is a set of newly implemented links subjected to toll. The objective function for profit maximization can be formulated as:

max. $P^n\left(\tau, x(\tau, \varepsilon)\right)$ (3.3)

subject to: $\tau, x(\tau, \varepsilon) \geq 0$ (3.4)

where, $x(\tau, \varepsilon)$ is determined from the lower level program and suggests that the toll value and the volume cannot be negative.

Policy Option-2: Public Investor's Perspective

    The objective of the public entity is to maximize social surplus / consumer surplus. The additional monetary value over and above the price paid is termed as consumer surplus (Wohl and Hendrickson 1984). For a trip making purpose, what an individual is usually willing to pay is a little more than actually charged or than one's payments in time, effort and money. Consequently, the user will receive a little extra value, an amount equal to the consumer surplus. The term consumer surplus and social welfare are used interchangeably in this report. The additional consumer surplus expected to be obtained from the extra resources spent to bring the change (lower fair from public entity perspective). Consumer surplus for a transportation network improvement is presented in Figure 3.3.
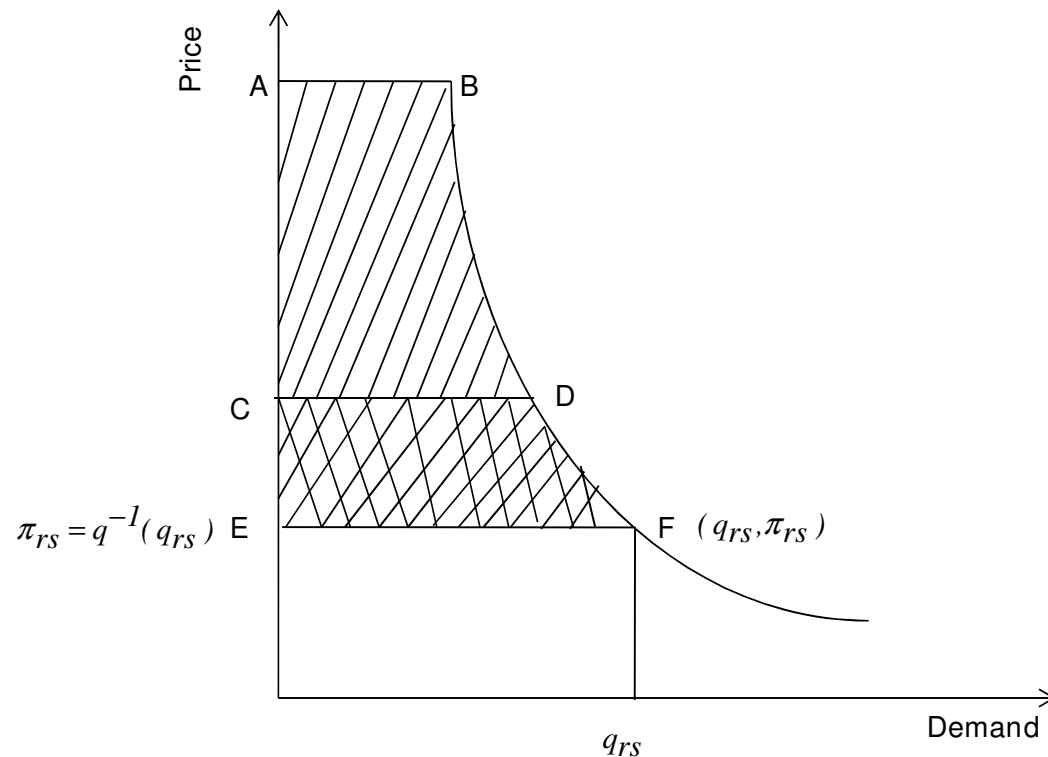
Figure 3.3: Consumer Surplus   (Ukkusuri and Patil 2009)

Note: Area AEFB is the consumer surplus for the public entity for demand q_{rs}. ACDB is the consumer surplus with no improvement. CEFD is the increase in consumer surplus due to improvements.

Area AEFB is the consumer surplus for the public entity for demand q_{rs}. ACDB is the consumer surplus with no improvement. CEFD is the increase in consumer surplus due to improvements. Consumer surplus for an O-D pair r-s for an improved case is given by (Ukkusuri and Patil 2009):

$$\phi_{rs}^n = \int_0^{q_{rs}^n} q_{rs}^{-1}(\omega) d\omega - q_{rs}^n \pi_{rs}^n \tag{3.5}$$

where, ϕ_{rs}^n is the consumes surplus for the O-D pair r-s for the year n, q_{rs}^n is the demand between O-D pair r-s for year n, $q_{rs}^{-1}(\omega)$ is the inverse demand function for O-D pair r-s, and π_{rs}^n is the minimum travel cost between O-D pair r-s. The first term of the equation (3.5) represents the user willingness to pay to travel from r-s and the second term is the amount user actually paid (or minimum travel cost to travel from r-s). The consumer surplus is a measure from the public entity perspective used in a number of studies in transport network design (Chen and Subprasom 2007; Ukkusuri and Patil 2009; Yang and Meng 2000; Zhang and Ge 2004; Zhang and Kumaraswamy 2001; Zhao and Kockelman 2006) .

The consumer surplus for the total network can be represented as:

$$\sum_{rs} \phi_{rs}^n = \sum_{rs} \int_0^{q_{rs}^n} q_{rs}^{-1}(\omega) d\omega - \sum_{rs} q_{rs}^n \pi_{rs}^n \tag{3.6}$$

The annual consumer surplus in monetary terms can be represented as:

$$\sum_{rs} \phi_{rs}^n = \frac{\gamma}{\theta} \left[\sum_{rs} \int_0^{q_{rs}^n} q_{rs}^{-1}(\omega) d\omega - \sum_{rs} q_{rs}^n \pi_{rs}^n \right] \tag{3.7}$$

where, θ is a parameter which converts time value to monetary terms, γ is the parameter that converts hourly to annual demand. The savings in consumer surplus can be defined as the difference between the consumer surplus and the cost of the project (Chen and Subprasom 2007; Yang and Meng 2000). This can be represented as;

$$\psi^n(\tau, x(\tau, \varepsilon)) = \varphi^n - C^n \tag{3.8}$$

where, ψ^n is the savings in consumer surplus. A higher consumer surplus is better for the public investor. The public entity perceives the user benefit equivalent to a value which travelers expect to receive from making trips as measured by the gross amount paid by the travelers in making a

trip. The consumer surplus is not viewed as a performance measure from private entity perspective. The objective function for consumer surplus maximization can be formulated as:

$$\text{max. } \psi^n\left(\tau, x(\tau, \varepsilon)\right) \tag{3.9}$$

$$\text{subject to: } \tau, x(\tau, \varepsilon) \geq 0 \tag{3.10}$$

where, $x(\tau, \varepsilon)$ is determined to maximize the consumer surplus from the lower level program.

Policy Option-3: Road User's Perspective

Equity (or inequality) refers to the fairness and justice (or lack thereof) of the distribution of the impacts (benefits and costs) of an action on two or more units. Equity can be referred to individuals or groups. For groups, one can use collective units, such as households, land-use type, or regions, and characteristics, such as income, travel cost, population, or age. The concept of equity has been extensively used in different disciplines, e.g., geography (Keeble et al. 1982; Truelove 1993), medicine (Bloom 2001; Rosero-Bixby 2004), sociology (Frederickson 1990; Kokko et al. 1999), economics (Atkinson 1975), and political sciences (Maniquet and Sprumont 2005). In decision making, equity measures are commonly used to assess the economic and social impacts of different development scenarios.

Assessments of transportation investment from a "social efficiency" viewpoint are often ignored from transportation policy analysis. The role of transportation infrastructure investment on the provision of activity opportunities to all the zones in a transportation region is imperative from policy considerations. In addition to optimal allocation, equally important is the distribution of benefits in terms of infrastructure facilities and related quality of service to reach desired destinations within an acceptable amount of time, and cost.

Equity can be classified into two broad categories considering the distribution of costs and benefits (Todd 2007):

- *Horizontal equity* is concerned with whether or not each individual or group is treated equally, assuming that their needs and abilities are comparable. It implies that costs should be borne by users *unless* a subsidy is specifically justified.

- *Vertical equity with regard to income and social class* considers the allocation of costs between different socioeconomic classes, assuming that public policies should favor economically disadvantaged groups.

In transportation engineering, until the end of the nineties, equity issues were limited to the evaluation of the economic impacts of policies. The policy impacts between different social groups in the case of the introduction of road prices in some links of the network design can be found in the literature (Szeto and Lo 2006; Yang and Zhang 2002). Meng and Yang demonstrated that the benefits of capacity enhancement in some selected links can lead to an

increase in travel costs for some (O-D) pairs. The debate surrounding equity issues in transportation network design has become more intense in recent times (Meng and Yang 2002). Similar observations were made for congestion pricing problems resulting in significant differences between the benefits of some (O-D) pairs. Spatial equity can be incorporated to transportation planning to overcome the problem of inequitable distribution of benefits to some O-D pairs (Yang and Zhang 2002).

Examples of equity studies in transportation include: the distribution of accessibility gains across population centers in an accessibility-maximization model (Antunes et al. 2003), spatial equity as a constraint in a link capacity improvement problem with demand uncertainty (Chen and Yang 2004), integration of equity in a time-step network design problem with social and user equity for different periods of time (Szeto and Lo 2006), and incorporation of horizontal and vertical equity in transportation planning (Feng and Wu 2003).

From the road users perspective, the benefits and costs of an infrastructure project for all OD pairs must be reasonably distributed to establish spatial equity. If a project only benefits a small section of travelers in the study area, then the distribution will not be called as equitable. There is variety of indices that measures inequality in distribution of such benefits. The Theil's index, one of the common indices used in measuring such inequities in distribution was used in the study. The rationale for choosing Theil's Index is its flexible structure compared to other similar measures (Theil 1967).

$$T = T_b + T_w \qquad\qquad (3.11a)$$

where, T_b is the between group component and T_w is the within group component. Within group Theil's index is very difficult to estimate as it deals with data at individual traveler level. By considering Traffic Analysis Zones (TAZ) as the subject groups, the Theil's index between the groups is can be estimated as (Theil 1967);

$$T_b^n = \sum_r \left(\frac{\sum_s q_{rs}^n}{q^n} \right) \cdot \left(\frac{\sum_s \phi_{rs}^n}{\phi^n} \right) \cdot ln \left(\frac{\sum_s \phi_{rs}^n}{\phi^n} \right) \qquad\qquad (3.11b)$$

where, q_{rs}^n is the travel demand of OD pair r-s in the nth year, q^n is the total demand (i.e. $\sum_r \sum_s q_{rs}^n$) for the whole network, ϕ_{rs}^n is the consumer surplus improvement for OD pair r-s in the nth year, ϕ^n is the total consumer surplus improvement (i.e. $\sum_r \sum_s \phi_{rs}^n$). If every zone has same benefit then the Theil's index is zero (perfect equality), and if the benefit is concentrated at one (perfect inequality) zone then the Theil's index is $ln\, q^n$. Lower the Theil's index more equitable is the project.

The within group Theil's Index can be estimated as (Theil, 1967) :

$$T_w^n = \sum_r \left(\frac{\sum_s \phi_{rs}^n}{\phi^n} \right) T_w^{n'} \tag{3.12a}$$

where, unweighted Theil's $T_w^{n'}$

$$T_w^{n'} = \sum_p \left(\frac{\sum_s \phi_{rs}^{np}}{\phi^{np}} \right) . ln \left(\frac{\left(\frac{\sum_s \phi_{rs}^{np}}{\phi^{np}} \right)}{\left(\frac{\sum_s d_{rs}^n}{d^n} \right)} \right) \tag{3.12b}$$

where, $\sum_s \phi_{rs}^{np}$ is the consumer surplus individual p travelling from zone r to s in the year n. The within group Theil's Index requires individual traveler information within the zone and has received limited application in transportation engineering related studies. The objective function for user inequality (between groups) minimization can be formulated as:

min. $T_b^n \left(\tau, x(\tau, \varepsilon) \right)$ \hfill (3.13)

subject to: $\tau, x(\tau, \varepsilon) \geq 0$

where, $x(\tau, \varepsilon)$ is determined from the lower level program.

While the upper level program determines the toll for various perspectives considered, the lower level determines the route choice of users for a designed toll value subjected to uncertain demand. The lower level problem is a user equilibrium traffic assignment with elastic demand (Sheffi 1985).

$$\min_{x \to (\tau, \varepsilon)} \sum_{a \in (A - \bar{A})} \int_0^{x_a} t_a(w) dw + \sum_{a \in A} \int_0^{x_a} \left(t_a(w) + \theta \tau \right) dw - \sum_{rs} \int_0^{q_{rs}} q_{rs}^{-1}(w) dw \tag{3.14}$$

subject to:

$$\sum_k f_k^{rs} = q_{rs} \tag{3.15}$$

$$f_k^{rs} \geq 0 \tag{3.16}$$

$$q_{rs} \geq 0 \tag{3.17}$$

$$x_a = \sum_r \sum_s \sum_k f_k^{rs} \delta_{a,k}^{rs} \tag{3.18}$$

$$\delta_{a,k}^{rs} = \begin{cases} 1 & \text{if link } a \text{ is on path } k \text{ between O-D } r\text{ - }s \\ 0 & \text{Otherwise} \end{cases} \tag{3.19}$$

The objective function in expression (3.14) minimizes the travel time of the network till equilibrium is achieved. The first two terms are the link performance function of all non-tolled and tolled links in the network respectively. The third term is the inverse demand function associated with the OD pair r-s, which is a decreasing function of the OD travel times. Expression (3.15) is a flow conservation constraint to ensure that flow on all paths connecting each OD pair has to equal the trip rate. Expression (3.16) and (3.17) are non-negativity constraints to ensure that the flow cannot be negative. The definitional relationship of link flow from path flows is presented in expression (3.18) and (3.19). The minimization problem in expression (3.14) consists of toll value (τ) which is a function of a set of link flows ($x_{a\,(\tau,\varepsilon)}$) and a set of OD demands ($q_{rs\,(\tau,\varepsilon)}$). Flow in lower level is a function of toll in the upper level (recall three policy perspectives specified in upper level).

Demand Elasticity and Uncertainty

Addition of new links or improvement of the road network will reduce the travel cost between origin and destination. The improvement can result in increasing demand between the corresponding OD. An exponential demand function can be used to estimate the annual demand (Sheffi 1985).

$$q_{rs}^n = \tilde{q}_{rs}^n \, exp\left(-\lambda \pi_{rs}^n\right) \tag{3.20}$$

Where, $\tilde{q}_{rs}^n$ is the random potential demand between r-s, π_{rs}^n is the minimum travel cost between r-s which includes the designed toll value, λ is a positive constant.

Uncertainty in travel is incorporated by random sampling of demand with predefined mean and variance. Random numbers are generated with predefined probability distribution function (i.e. normal distribution). This is performed exogenously from the lower level traffic assignment (Chen and Subprasom 2007).

$$\tilde{q}_{rs}^{n} = \overline{\tilde{q}_{rs}^{n}} + z\sigma_{rs}^{n} \tag{3.21}$$

Where, $\overline{\tilde{q}_{rs}^{n}}$, σ_{rs}^{n} are the mean and standard deviation of random potential demand for OD pair r-s, and z is a random variable generated from normal distribution with mean zero and unity variance. The link travel time used in the lower level traffic assignment problem is the Bureau of Public Roads function, denoted as (Sheffi 1985):

$$t_a^n\left(x_a^n\right) = t_a^0\left(1 + 0.15\left(\frac{x_a^n}{G_a^n}\right)^4\right) \tag{3.22}$$

where, t_a^0 and G_a is the free flow travel time and capacity for link a.

3.5 Decision Tool for Risk Analysis (DTRA)

In the first step of the proposed methodology (Figure 3.2), the demand and corresponding toll under uncertainty are determined. The implication of these investments, when subjected to risk, should further be tested. Risk analysis could provide a wide range of potential revenue outcomes to the project under consideration which may identify the undefined levels of risk. Accordingly, risk analysis should be undertaken to identify the probability of revenues reaching particular levels in specified planning periods.

Risk is often defined as the probability of occurrence of an undesirable outcome. A multiple variable stochastic approach is proposed in this study. Risk analysis consists of simulating the various inputs for the life of the project and finding the present value. This process is repeated number of times using Monte Carlo Simulation (MCS) to incorporate risks from multiple sources both on revenues as well as costs. In this manner, the MOE associated with the project is obtained.

The proposed methodology for DTRA is presented in the step-2 of Figure 3.2. In the proposed risk analysis, a MCS model is used, which employs pre- defined probability distributions[2] to analyze the effect of indecisive inputs on outputs of the modeled system. The volatility of

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[2] The pre-defined probability distribution functions are obtained from the uncertainty analysis.

inputs is expressed through defining their bounds according to the data points required by the input distributions. For example, triangular distribution requires high, low, and most likely values. Output variables resulting from computer simulations are also characterized by probability distributions having means (averages) and standard deviations (measures of internal dispersion). A cumulative distribution function describes the total probability or likelihood of occurrence at any level of output variable. Thus a MCS risk analysis describes the effect of the volatility of input variables on the simulation output.

MCS is a stochastic simulation process that uses continuous probability distribution for input variables to predict every possible outcome by randomly generating associated variables. In general, risk analysis of projects include four steps: a) Developing a model by building of project; b) Identifying the model inputs project risk variables such as interest rates, exchange rates, completion dates, and costs; c) Specifying the risk variables, their possible values with probability distributions, and identifying the results for the analysis; d) Analyzing the model with simulation to determine the range and probabilities of all possible outcomes for the results of a project.

Measure of Risk

Risk can be quantified and measured in different ways (Mun 2006). Value at Risk (VaR) is one of such methods and used in Decision Tool for Risk Analysis (DTRA). VaR can be defined as the maximum expected loss over a target horizon, with a given level of confidence (Jorion 1997). VaR describes the quantile of the projected distributions of gains and losses over the target horizon. If α is the selected confidence level, VaR corresponds to the *1- α* lower tail level. For example for 90 percent confidence level, VaR should be such that it exceeds 10 percent of the total number of observations in the distribution.

VaR can be computed once the price path is simulated, and the resulting MOE (say NPV or IRR) can be developed at the end of the selected horizon. The simulation can be carried out in the following steps.

- Generate random numbers of variables from which the prices are computed as St+1, St+2, …. St+n.

- Calculate the value of the infrastructure under this particular sequence of prices at the target horizon.

- Repeat steps 2 and 3 for higher number of iterations.

- Choose a stochastic process and parameters.

3.6 Multi-objective Optimization

A single objective optimization is imperative from a specific entity perspective. The optimum solution thus obtained might not be best suited to other entities. A multi-objective optimization (MOO), the process of simultaneously considering two or more objective functions each with a specific optimization defined, is proposed considering perspective of all three entities. The MOO approach may produce conflicting solutions (trade-offs) among different objectives. A solution that is optimal with respect to one objective might require a compromise for others. MOO provides a pareto-efficient front to choose from a set of sub optimal solutions.

A multi-objective optimization process can be used to attain an optimal solution in the presence of two or more conflicting objectives (Deb 2001; Sawaragi et al. 1985). Examples of multi-objective optimization in transportation application include: scheduling of trains for single and multiple tracks with varying capacity of trains to platforms (Ghoseiri et al. 2004), vehicle routing and scheduling for hazardous material transportation (Meng et al. 2005), optimal transit network design (Fan and Machemehl 2006), optimal responsive plans for traffic signal coordination (Abbas and Sharma 2006), optimum project selection model from portfolio (Doerner et al. 2004; Doerner et al. 2006; Lee and Kim 2001; Ringuest and Graves 1989; Santhanam and Kyparisis 1995).

The multi-objective approach can be divided into two categories: (1) exact methods and (2) heuristic method. Examples of exact method include: weighted sum method, ε-constraint method, weighted metric method, value function method, and goal programming method (Deb 2001). The exact method does not use any a priori information in estimation of pareto optimal solution. The approach is applied to a number of MOO problems. Examples include: traffic assignment and traffic flow (Lee and Pulat 1991), shortest path problem (Aneja and Nair 1979; Diaz 1978; Isermann 1979; Srinivasan and Thompson 1976), minimum spanning tree problem (Neumann and Wegener 2006).

The exact method can be formulated as (Ehrgott and Gandibleux 2000):

Maximize

$$F(y) = \sum_{i=1}^{r} c_i F_i(y) \tag{3.23}$$

subject to:

$$\begin{aligned} g_j(y) &\leq 0, \quad j = 1,2...,m \\ h_j(y) &= 0, \quad j = 1,2...,p \end{aligned} \tag{3.24}$$

where,

$F_i = [F_1, F_2, …, F_r]$ is the vector of objective functions,

$y = [y_1, y_2, …, y_r]$ is the vector of decision variables,

c_i is a constant indicating the weight assigned to F_i, such that $\sum_{i=1}^{r} c_i = 1$, and $0 \leq c_i \leq 1$

g_j is the jth inequality constraint function

h_j is the jth equality constraint function

On the other hand, heuristic method requires less computation load but does not guarantee optimality. Few examples of heuristic algorithm include constrained logic programming, genetic algorithm, simulated annealing, tabu search, and neural networks. Heuristic methods are extensively used in applied research (Deb 2001).

3.7 Decision Making from Pareto-Optimal Solution

The multi-objective problem solution strategy involves combining the objectives of each individual entity perspective to a single form. The multi- objective formulation will include a set of decision variables considering the objective of each entity, subjected to a set of constraints. The outcome of multi- objective optimization is not a unique solution as in the case of single objective optimization but a set of solutions for the decision maker to choose from.

The decision making process usually involve trade-off analysis with six components (Keeney and Raiffa 1976):

- A goal, the decision maker would like to achieve

- Opinion of a group of decision makers (or stakeholders)

- A set of evaluation criteria (objectives)

- A set of decision alternatives

- A set of independent variables

- A set of outcomes associated with alternatives

Multi-objective decision making will identify a single preferred alternative or rank alternatives as per decision maker's preference. A methodology is proposed to evaluate such transportation investment decision making with alternatives consisting of conflicting objectives.
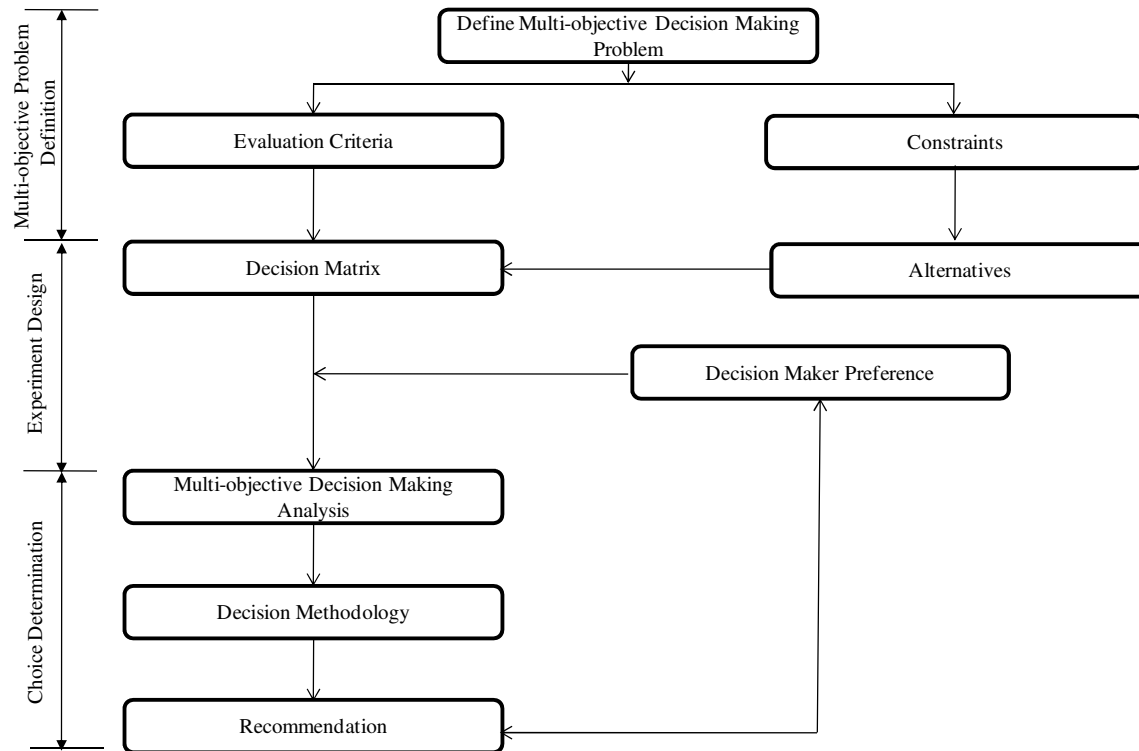
Figure 3.4: Proposed Methodology Framework for Multi Entity Decision Making

The framework is presented in Figure 3.4. The proposed methodology consists of three steps: (1) Multi-objective problem definition, (2) experimental design, (3) choice determination. The three steps are described below.

Multi-objective Decision Making Problem Definition

The multi-objective problem definition consists of objectives of three entities (private, public, and user) in the transportation investment decision making. The details of objective of three entities are described in section 3.3.

<u>*Experimental Design*</u>

The experimental design step is an intermediate step in multi-objective decision making process. The output from the multi-objective optimization is considered as input to the

experimental design stage. There are a number of techniques[3] to incorporate multi-objective decision making depending upon how to combine and utilize the data. Analytical Hierarchy Process (AHP) is one of the widely used techniques for analyzing and supporting decisions with multiple and competing alternatives in a multi-objective decision making process.

AHP allows the decision maker to model complex problems with defined goals, criteria, sub-criteria, and alternatives (Saaty 1980). A schematic diagram of AHP is presented in Figure 3.5. AHP is a multi criteria evaluation tool that can be used to evaluate the relative performances of defined alternatives based on a set of chosen criteria. AHP is a tool capable of solving a number of decision choices encompassing numerous variables that may affect the decision making process. When the number of variables increases, the need to prioritize and weight the variables increases so that the complex decision-making process becomes manageable. The process begins with establishing hierarchies. The main problem to be solved resides at the top of the hierarchy scale. The levels below the main problem are the criteria and sub criteria, with each level supporting the one above it. The bottom level of the hierarchy becomes the alternatives or, "scenarios" for solving the main problem (Saaty 1980). The priorities, in the form of weighted values, are calculated at each level until the lower level alternatives are rated or prioritized as the best solution to the main problem listed at the top of the hierarchy (Saaty 1980).
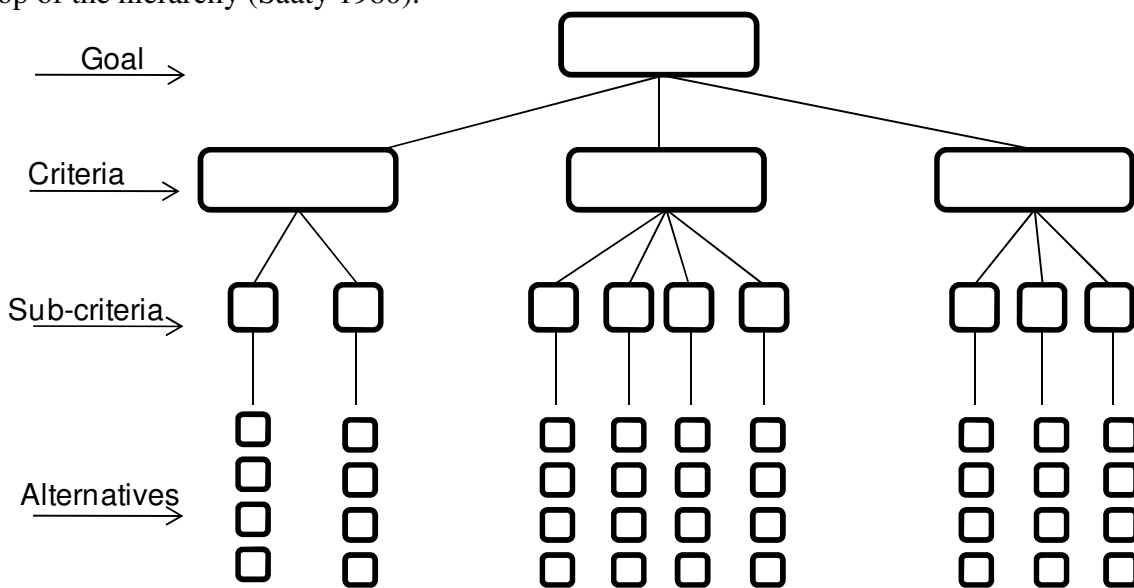
Figure 3.5: Decision by Objectives (Forman and Selly 2001)

Examples of AHP include, decision support system for transportation investment (Caliskan 2006), provision of accessible transportation alternatives (Lan 1996), ranking of public transportation projects (Arslan 2009), incorporation of uncertain and incomplete information in transportation alternative evaluation (Tanadtang et al. 2005), evaluation of

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[3] Examples of multi-objective decision making methods include: ranking method, rating method, simple additive weighting, utility function method, ideal point method, outranking method (ELECTRI III, IV, PROMETHEE I, II), and goal programming.

logistics performance for intermodal transportation (Hanaoka and Kunadhamraks 2009), shipping selection of maritime transportation industry (Kandakoglu et al. 2009), systematic decision making in elimination of overpasses (Keemin 2008), selection of project scope for video logging and pavement condition data collection (Larson and Forman 2007), transit system performance assessment (Khasnabis et al. 2002).

Alternatives are scored by a pairwise comparison, with statements such as "alternative A is x times better that alternative B," in a set of pairwise comparison matrices (PCM). The PCM's are determined according to the analyst's judgment and scores of alternatives are determined by the AHP procedure. The alternative with highest score is chosen as the preferred alternative. The analyst uses layers of criteria to describe various aspects of the decision making model framework. AHP allows one to construct more detailed hierarchies to express complex relationships between objectives and alternatives.

The AHP theory has been used for a number of different types of studies and has withstood the test of time as a valid measure and means for solving complex problems by requiring decomposition of the problem, using comparative judgments for multi-criteria objectives, and synthesizing priority results (Saaty, 1986).

3.8 Pairwise Comparison in AHP

The following equations are adapted from the literature (Saaty 1995). Pairwise comparisons between two performance criteria α and β can be represented as the following matrix;

$$
A = \begin{bmatrix}
1...a_{1\beta}...a_{1\Omega} \\
\vdots \quad \vdots \quad \vdots \\
a_{\alpha 1}...a_{\alpha j}...a_{\alpha\Omega} \\
\vdots \quad \vdots \quad \vdots \\
a_{\Omega 1}...a_{\Omega\beta}...1
\end{bmatrix}_{\Omega\times\Omega}
\tag{3.25}
$$

where, each entry $a_{\alpha\beta}$ is the decision maker's quantified judgment of the relative importance of two criteria α and β on the basis of a scale. The element of the diagonal has a value of unity because it represents the comparison to the criterion itself. The matrix A, alternatively can be written as;

$$
A = \begin{bmatrix}
w_1/w_1...w_1/w_\beta...w_1/w_\Omega \\
\vdots \quad \vdots \quad \vdots \\
w_\alpha/w_1...w_\alpha/w_\beta...w_\alpha/w_\Omega \\
\vdots \quad \vdots \quad \vdots \\
w_\Omega/w_1...w_\Omega/w_\beta...w_\Omega/w_\Omega
\end{bmatrix}_{\Omega\times\Omega}
\tag{3.26}
$$

The matrix A has three basic properties: (1) $a_{\alpha\beta} = w_\alpha/w_\beta$ for α, $\beta = 1, 2, 3\ldots n$. (2) $a_{\alpha\beta} = 1$ for $\alpha = \beta$, (3) $a_{\alpha\beta} * a_{\alpha\beta} = 1$. Typically a nine or ten point scale[4] is used in AHP to express judgments in pairwise comparison. The relative weight vector can be denoted as $W = [w_1, \ldots, w_j, \ldots, w_\Omega]$. Weights can be estimated by solving the eignvector equation:

$$AW = \eta w \tag{3.27}$$

Where W is the eigenvector of A and η is the associated eigenvalue. The response matrix A might not be consistent, as the entries are based upon subjective judgments of the decision makers rather than exact measurements. As a result the relationship can be modified as

$$AW = \vartheta W \tag{3.28}$$

Where, ϑ is the set of eigenvalues of the matrix A such that

$$\sum_{i=1}^{\Omega} \vartheta_i = \Omega \tag{3.29}$$

For a perfectly consistent matrix A, all the eigenvalues (ϑ_i) are zero with the exception of one which is Ω. On the other hand, because of subjective judgments of decision makers, the matrix A might be inconsistent leading to the largest eigenvalue as ϑ_{max}, which is close to Ω, and the remaining eigenvalues are close to zero. Estimation of W for inconsistent estimation should satisfy:

$$AW = \vartheta_{max} W \tag{3.30}$$

To establish the degree of randomness in the judgments of decision makers, logical consistency of the pairwise comparison can be measured by consistency index ($C.I$):

$$CI = \frac{\vartheta_{max} - \Omega}{\Omega - 1} \tag{3.31}$$

The overall consistency of AHP can be determined by consistency ratio:

$$CI = \frac{\vartheta_{max} - \Omega}{(\Omega - 1)(RI)} \tag{3.32}$$

---

[4] 1, equal importance; 3, slightly favorable importance, 5, moderate importance; 7, strongly more importance; 9, extremely importance

where, *RI* is the random index which is determined from the order of matrix used (Saaty 1995; Sinha and Labi 2007). A consistency ratio of 0.1 is considered to be acceptable.

3.9 Integration of Multi-objective Optimization and AHP

A set of solutions obtained from the multi-objective optimization is taken as input to formulate a decision matrix (Multi-objective decision making problem definition step in Figure 3.4). Further, the decision matrix will contain the OTG strategies associated with the alternatives under consideration (Experimental Design step in Figure 3.4). The objective of designing the decision matrix is to obtain the decision maker's preference to the objective of each entity embedded within each alternative. The preferences of the decision makers are analyzed by AHP (choice determination step in Figure 3.4) to obtain OTG strategy specific solution, with each OTG strategy consisting of role of the entities involved.

3.10 Summary

The proposed methodology presented in this chapter can be summarized as follows;

- Three principal entities involved in the success of a PPP project are the private; the public and the road user. Objective of these three entities are different. The private entity would like to maximize profit (tangible). The objectives of the public entity and the user are to maximize social surplus (both tangible and intangible), and to minimize inequality respectively.

- The uncertainty analysis approach is designed in a bi-level programming approach; where the upper level considers various entity perspective (profit maximization; welfare maximization, and inequality minimization), and the lower level considers the uncertainty in travel demand.

- Uncertainty in transportation infrastructure is primarily generated from travel demand, which has a direct effect on the profit. Travel demand uncertainty is considered by traffic assignment with elastic demand.
- The uncertainty analysis results in optimal design of toll structure for three entities of interest (private, public, and user). If the toll structure does not attract private investors, relaxation on policies can be proposed. Policy relaxation includes reduction in construction cost share for private entity; increased concession period.

- Risk follows uncertainty, and the expected loss in various scenarios need to be estimated. A stochastic risk analysis approach is proposed. A Monte Carlo Simulation approach is used to estimate the VaR.

- The result of uncertainty and risk analysis can be used to evaluate different OTG strategies and to identify most desirable form of joint ownerships for transportation infrastructure investment.

- The preferences of single entities can be "merged" to a multi-objective optimization and a set of Pareto-optimal solutions can be obtained. The Pareto-optimal solutions can be analyzed by AHP to determine the role of entities in each OTG strategies.

CHAPTER 4

STUDY AREA

4.1 Introduction

A proposed international bridge between the city of Detroit in the U.S. and the city of Windsor in Canada is selected as the case study area. This chapter provides information on the existing travel network, traffic pattern, and demographic data.

4.2 Study Area Background

The U.S. and Canada share the largest trading relationship in the world. Thirteen states in the U.S. share borders with Canada. In Figure 4.1, these states are presented in numbers and length of border with Canada for each state is shown in Table 4.1.Next to the state of Alaska, Michigan has the longest common border with Canada.

A total of 26 bridge/tunnel crossings, eight rail crossings, and 11 ferry crossings operate for surface trading with Canada. The border crossings between Southeastern Michigan in the US and Southwestern Ontario in Canada are the subject of interest in this study.

Surface trade between Southwestern Ontario and Southeastern Michigan exceeded 200 billion in 2004 and is expected to increase significantly by the year 2030. 70 percent of trade movement between the U.S. and Canada is by trucks. Approximately 28 percent of surface trading is by trucks for the crossings between Southeast Michigan and Southwest Ontario. Majority of the trade is for the crossings in the Detroit River area, connecting the city of Detroit in the U.S. and the city of Windsor in Canada. This large trade volume has a significant positive effect on the local, regional and national economies, through cross-border employment opportunities.
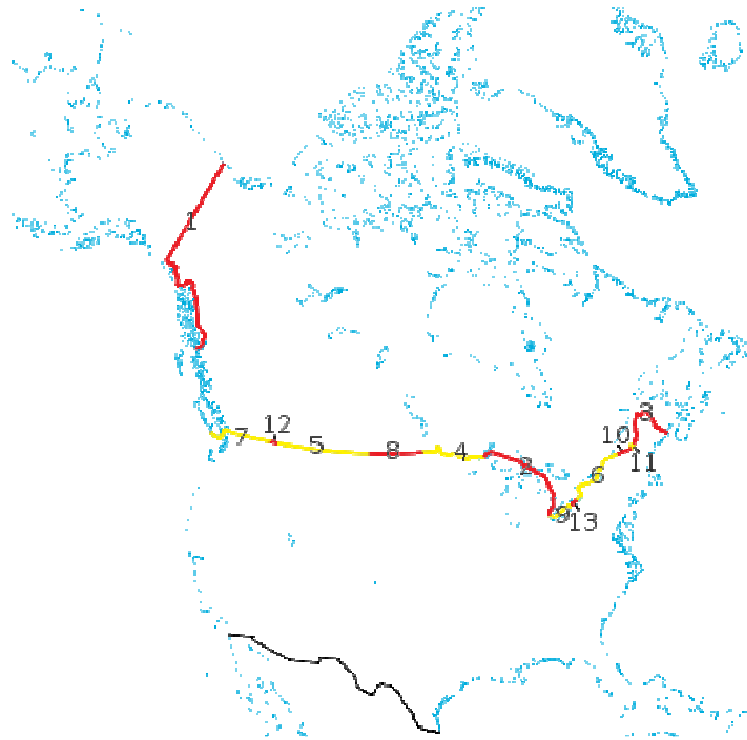
Figure 4.1: States sharing borders with Canada

(Source:
http://en.wikipedia.org/wiki/Canada_%E2%80%93_United_States_border)

Table 4.1: Boarder Length with Canada

Map Location	State	Length of Border with Canada (miles)
1	Alaska	1,538
2	Michigan	721
3	Maine	611
4	Minnesota	547
5	Montana	545
6	New York	445
7	Washington	427
8	North Dakota	310
9	Ohio	146
10	Vermont	90
11	New Hampshire	58
12	Idaho	45
13	Pennsylvania	42

(Source: http://en.wikipedia.org/wiki/Canada_%E2%80%93_United_States_border)

4.3 Commercial Vehicle Demand

A recent MDOT study shows that out of the total Detroit River area and St. Clair River crossings, 66 percent of commercial vehicles presently use the Detroit River area crossings. This proportion is projected to remain stable in the future, given the anticipated travel demand growth and assumed infrastructure improvements. In the near-term, a diversion toward the Detroit River area crossings is expected with the easing of border delay following the opening of new customs booths at the Ambassador Bridge. But, this benefit is likely to erode in time as congestion builds on the access roads. The results of the analysis of trade show a 128 percent increase in truck traffic at the Detroit River area crossings over the study period from 3.5 million trips in 2004 to 8.1 million by 2035 (an annual growth of 2.8 percent). The current 55 percent-to-45 percent directional split is likely to sustain during the next 20 years with the balance still in favor of the Canada-to-U.S. direction.

4.4 Regional Population, Employment, and Household

Population for Southeast Michigan is expected to grow over 5.4 million by 2030. The regions development patterns are expected to have profound effect on the future transportation infrastructure. Suburbs are expected to have larger growth than the central business district. Changes in population and in employment from 2000 to 2030 are shown in Figure 4.2 and 4.3 respectively. The transportation system needs to be designed for providing dual role of access and movement of people and goods. Along with regional population and employment, the household size is expected to be two fold (SEMCOG 2004).

4.5 Future Capacity Needs

The Detroit River International Crossing (DRIC) study, conducted by the Michigan Department of Transportation, has analyzed the future international travel demand from Southeast Michigan to Southwest Ontario. Access road capacity, border processing and crossing capacity of the two countries are shown in Table 4.2. The study also summarizes the future demand and need for transportation infrastructure as follows:

- *Border Crossing Capacity*

The binational partnership[1] estimates the commercial vehicle volume to increase 120 percent by 2030. Significant transportation infrastructure will be needed to meet the future demand along the border.

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[1] Southeast Michigan and Southwest Ontario conducted a binational transportation planning project commonly referred as 'Binational Partnership'.

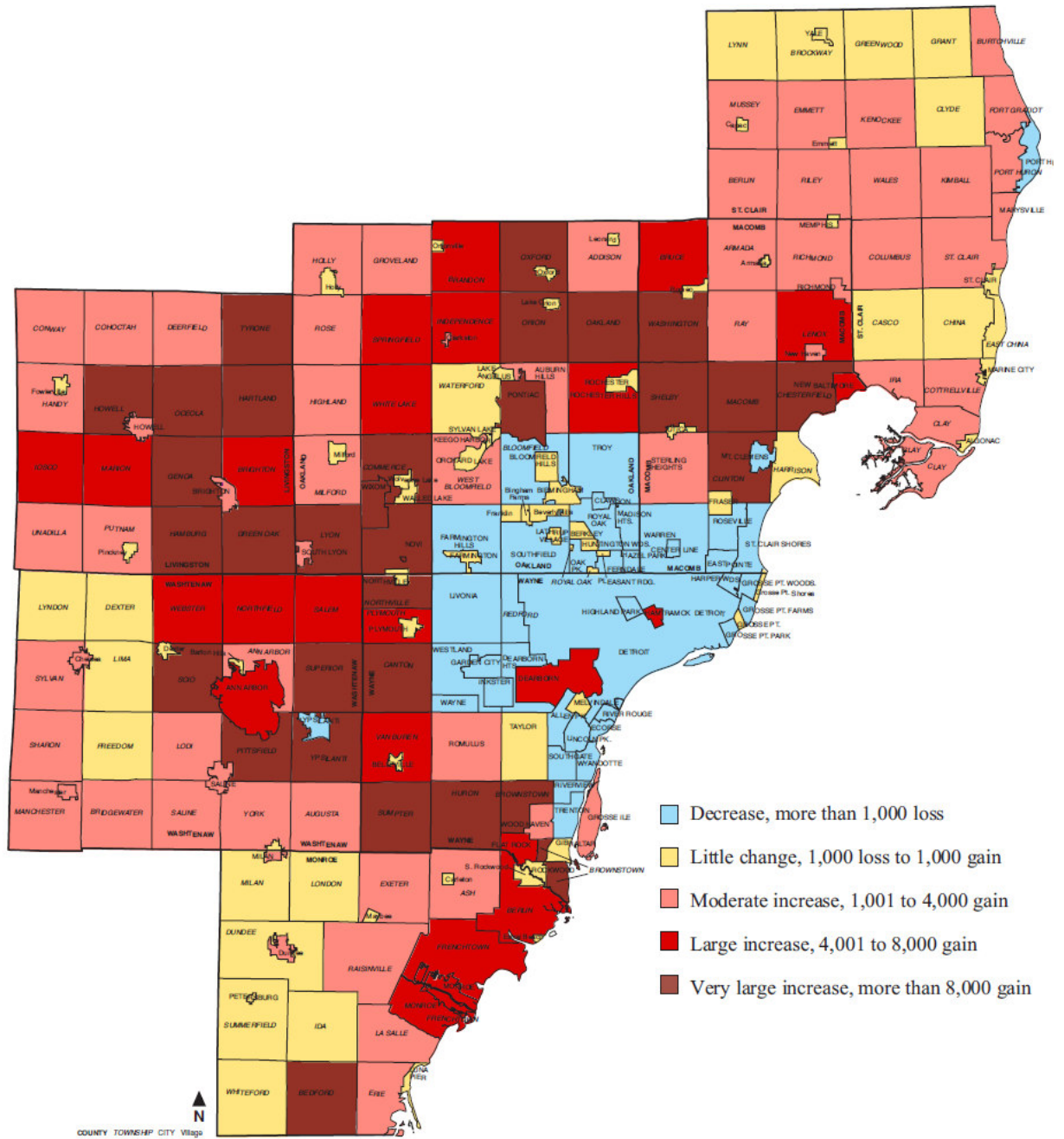Figure 4.2: Population Change by Community 2000-2030, Southeast Michigan
(Source: SEMCOG Regional Transportation Plan 2030)
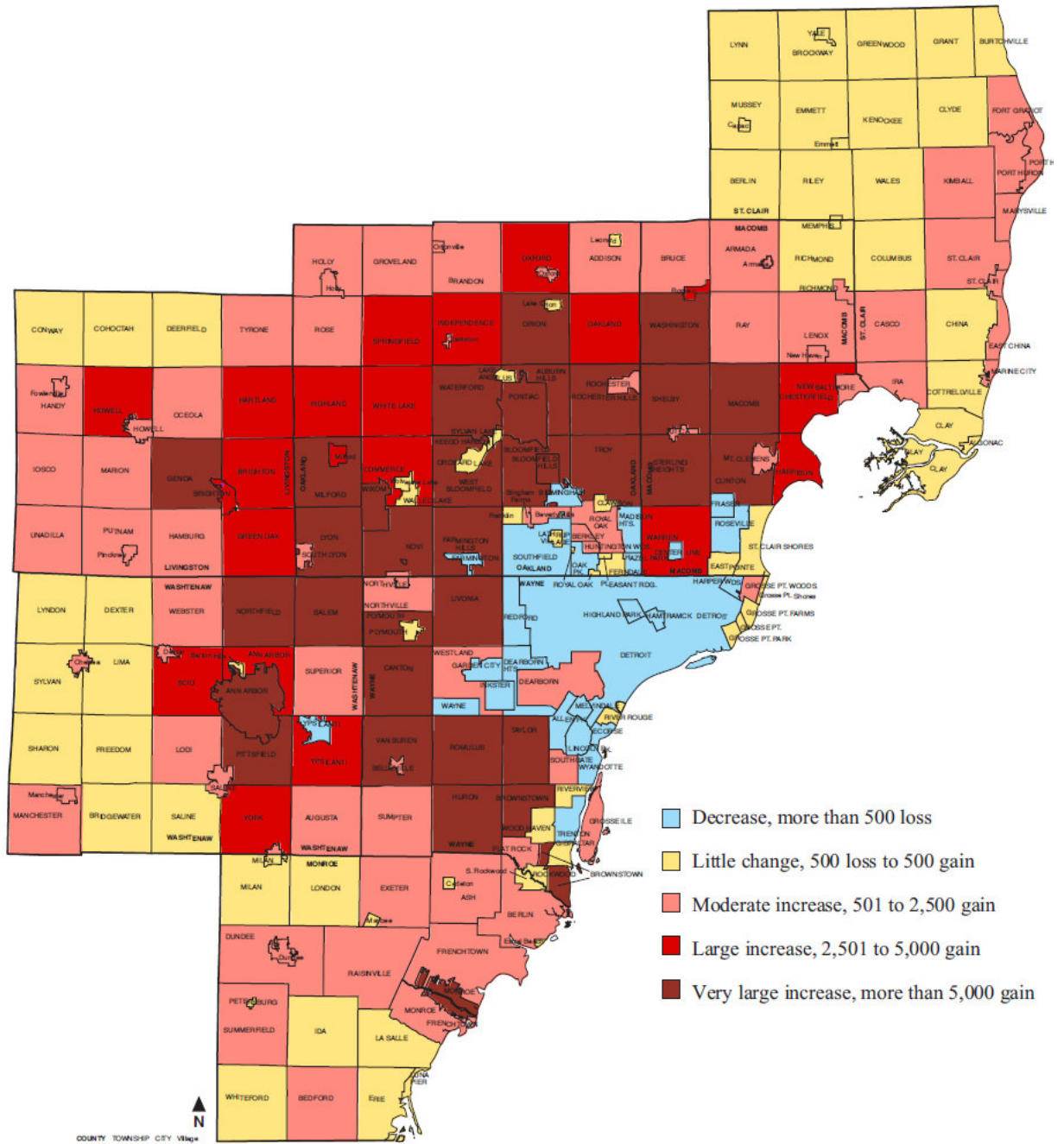
Figure 4.3: Employment Change by Community 2000-2030, Southeast Michigan
(Source: SEMCOG Regional Transportation Plan 2030)

- *Access Road Capacity*

  Access road capacity connecting Detroit-Windsor crossing may not be sufficient to meet the demand in five years. The Gateway Project[2] on the US side aims at alleviating long run congestion mitigation and providing access to the bridge from the freeways and arterials. Another similar study is focusing on congestion free access to the Blue Water Bridge.

- *Border Processing*

  Considering the international customs processing and procedures, both countries have tightened the security measures. As a result, the queue build up at the plaza creates congestion on the bridges. Both countries have adapted Fast and Secure Trade (FAST) and Nexus programs, designed to enhance security and to provide efficient traffic flow.

Table 4.2: Border Crossing Capacity, Southeast Michigan

Crossing	U.S. Access Road Capacity	U.S. Border Processing	Bridge/Tunnel Capacity	Canada Border Processing	Canada Road Access Capacity
Ambassador Bridge	Beyond 30 years*	Within 5 years	10 to 15 years	Within 5 years	Within 5 years
Detroit-Windsor Tunnel	Within 5 years	Within 5 years	10 to 15 years	Within 5 years	Within 5 years
Blue Water Bridge	Beyond 30 years	5 to 10 years	Beyond 30 years	15 to 20 years	Beyond 30 years

Source: Detroit River International Crossing Study

* Assumes Ambassador Bridge Gateway Project is completed

4.6 Traffic Analysis Zones

The zonal structure of the area encompassing the Detroit and Windsor incorporates the following (SEMCOG 2004):

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[2] The goal of the Gateway project is to provide better traffic flow to Ambassador Bridge. The construction of freeway interchanges, service drives, and rehabilitation of arterials is expected to relieve congestion on access to Ambassador Bridge.

- There are a total of 960 Traffic Analysis Zones (TAZ) in the Detroit (U.S.) side of the border.
- There are a total of 527 TAZs in the Windsor (Canada) side of the border.
- There are 23 External TAZs.
- The complete study area has a total of 1510 TAZs as shown in Figure 4.4. An enlarged version of TAZs is shown in Figure 4.5.

Figure 4.4: Traffic Analysis Zones of the Study Area
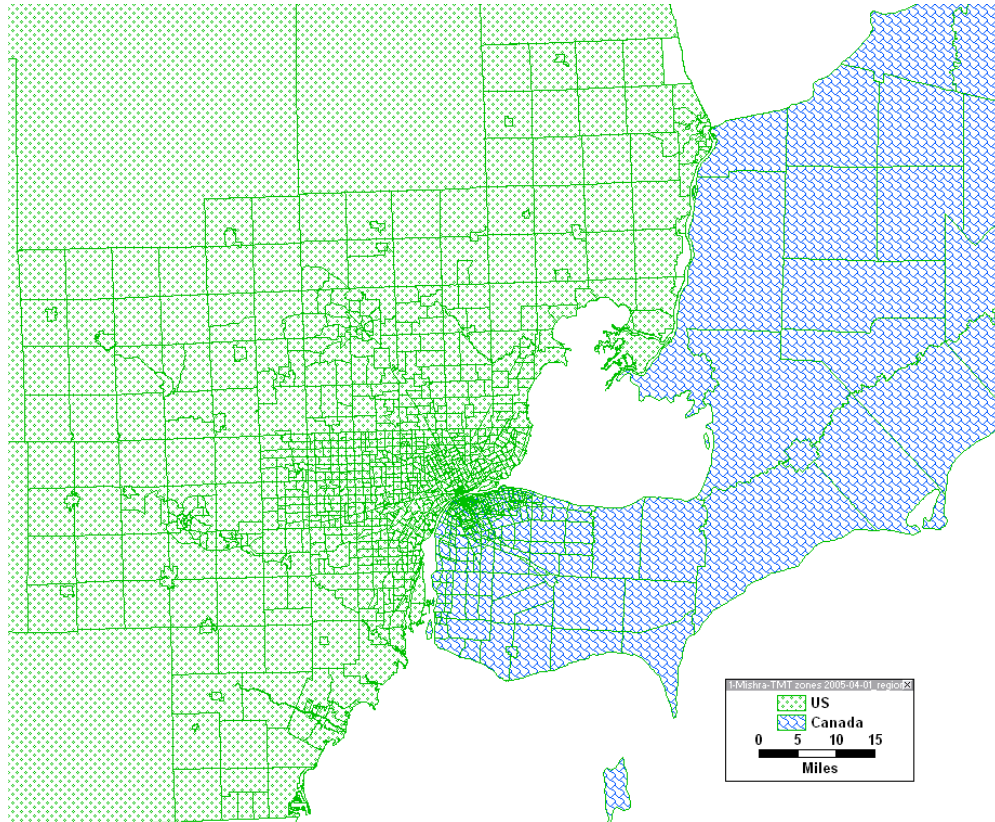
Figure 4.5: Traffic Analysis Zones of U.S. and Canada

4.7 Network System

The network system is shown in Figure 4.6 and the summary is described below (SEMCOG 2004);

- Total number of links: 25,505
- Total number of nodes: 17, 344
- Total number of centroids: 1,510
- Total number of centroid connectors: 1,510
- Total distance covered in the network: 19,736.4 miles
- Total number of river crossings
  - Existing: 3
  - Proposed: 1

4.8 Origin Destination Matrices

The origin destination matrices (OD) for the years 2004, 2015, 2025, and 2035 were obtained from the MDOT's ongoing study on DRIC. Trip tables were available for all three peak hours (AM, Mid day and PM) of the day for cars and trucks. Trip tables are extrapolated for the years 2045 and 2050. The following OD matrices were available for this study;

59

Blue Water Bridge

Entire Network

Detroit Windsor Tunnel

Ambassador Bridge

Proposed DRIC

Figure 4.6: Network of Study Area

- US domestic trips (U.S.-U.S.)
- Canada domestic trips (Canada-Canada)
- International trips (U.S.-Canada and Canada-U.S.)

Based upon the zonal structure described before, the U.S. domestic OD matrix is of the size of 960x960, whereas the Canadian OD matrix is of the size of 527x527. The international OD matrix is of the size of 1510x1510. All the three OD matrices were converted to 1510x1510 structure for computational convenience. The truck OD matrix was converted to 5 axle trucks (medium size) trucks.

4.9 Fare Structure

The fare (toll) for the year 2008 for three crossings is presented in Table 4.3 – Table 4.5. Among the three crossings, toll for the Ambassador Bridge is the highest, and that for the Blue Water Bridge is the lowest. As mentioned earlier, trucks are not allowed to travel through the Detroit Windsor Tunnel because of height constraints. Historical data on toll values were also collected.

Table 4.3: Ambassador Bridge Fare

Travel Mode	Fare (2008 US $)
Autos, Passenger Vehicles including driver and passengers	$4.00
Passenger vehicle with trailer	$8.00
Motorcycle, including driver and passengers	$4.00
Bus, including driver and passengers	$8.25
Commercial vehicle, Motor truck, tractor, trailer, including driver and passengers	
Class A 0 - 38,000 lbs.	$ 2.75/axle
Class B 38,001 lbs. - 56,000 lbs.	$ 3.25/axle
Class C 56,001 lbs. - 145,000 lbs.	$ 4.50/axle
Wide Loads 9 ft. - 14 ft.	$ 50 plus axle charge

(Source: http://www.ambassadorbridge.com/an_overview_toll_rates_usf.html)

Table 4.4: Detroit Windsor Tunnel Fare

Mode of Travel	Fare (2008 US $)
Taxis, vans, and limos	3.75
Buses	7
Trucks and Tractor Trailers Minimum vehicle fare	3.75
Ambulances	3.75
Armored Car with Guard	3.75
Vehicle with Trailer or vehicle in tow	5.5
Vehicles towed by Tunnel Company equipment	3.75

(Source: http://www.dwtunnel.com/Content.aspx?p=toll/crossing-rates)

Table 4.5: Blue Water Bridge Fare

Vehicle	Fare (2008 US $)
Cars	$1.50
Extra Axles	$1.50
Trucks & Buses	$1.75 Per Axle

(Source: http://www.michigan.gov/mdot/0,1607,7-151-9618_11070-25258--,00.html)

4.10 Proposed Crossings

Finally, the DRIC study has narrowed down to X-10(B) as the preferred alternative based on convenience on access roads, location of plaza, and other factors. In this report, X-10(B) is considered as the proposed new crossing in the following chapters.

4.11 Current Status

The DRIC study undertaken by the MDOT, FHWA, Ontario Ministry of Transportation and Transport Canada was initiated a number of years back to establish the need of a second bridge connecting Detroit and Windsor, to identify and evaluate alternative location and types of crossing, and to prepare Draft Environmental Impact Statements (DEIS) for the feasible alternatives. The DEIS thus generated were subjected to public review process as required by law.

A Jan 15, 2009 press release by MDOT shows that USDOT has approved plans for a second border crossing between Michigan and Ontario. The Draft Environmental Impact Study (DEIS), undertaken as a part of DRIC has resulted in a Record of Decision (ROD) signed on Jan 14, 2009. The ROD represents environmental clearance for the DRIC study for the border crossing between Detroit and Windsor, north of Zug Island. The ROD is also considered as the last step under the National Environmental Protection Act (NEPA)

for project approval following public hearings, traffic and environmental studies. This ROD will provide the gateway for the state (MDOT) to start the process of acquisition of the right of way, needed for planning and construction of the bridge. The tentative date of opening of the bridge is during the year 2015.

A second news item reported in the Detroit Free Press on January 29, 2009 states that USDOT has approved plans proposed by the owner of the privately owned Ambassador Bridge to "borrow nearly $800 million to pay for the construction of a second span next to the Ambassador Bridge". The news article also mentions that the USDOT also agreed on the final environmental approval to build a publicly owned bridge between Detroit and Windsor. This publicly owned bridge is the bridge for which approval was granted to MDOT by way of the ROD mentioned earlier.

Clearly, there is sufficient interest both at the public and the private level to build a second bridge. Although the proposed locations are different, they are close proximity of each other. It is also abundantly clear that long term demand projections can justify only one bridge (either the Zug Island bridge or the second Ambassador Bridge), but not both. The above developments underscore the importance of a PPP approach, and the development of appropriate OTG strategies to implement the construction, operation and maintenance of the proposed bridge.

4.12 Summary

Detailed information about the study area, traffic characteristics, population, employment, and transportation network is provided in this chapter. This information is used in the following chapters for;

- Identification of Various OTG strategies of the proposed Detroit River crossing infrastructure, ranging from public ownership, private ownership and joint ownership concepts.

- Development of an analytic framework to test the economic consequences of various OTG strategies, along with data requirements, and Measures of Effectiveness.

- Testing implications of uncertainty and risk on feasibility of OTG strategies subject to the interest of the entities involved.

- The integration of uncertainty and risk effects on the feasibility of OTG strategies.

CHAPTER 5

CASE STUDY, RESULTS, AND DISCUSSION

5. 1 Introduction

The methodology discussed in chapter 3 to address uncertainty and risk is tested for proposed DRIC. The chapter is organized in four sections.

- Input data

- Uncertainty analysis

- Risk analysis

- Integration of uncertainty and risk analysis

5.2 Input Data

As discussed in the previous chapter, it is assumed that the X-10(B) is the preferred alternative for the proposed river crossing. Two types of bridges are proposed for X-10(B): (1) suspension bridge, and (2) cable-stay bridge. The costs of the bridges are $1809 million and $1814 million respectively. This case study is based upon the assumption that the suspension bridge will be the preferred alternative. The cost difference between the two bridges is negligible relative to the total cost of the bridge, so that the assumption will not make much difference in the analysis. The cost components of the proposed suspension bridge categorized into four broad types; construction cost, planning/design/construction engineering, property acquisition/ remediation, and general service administration (GSA) plaza cost are shown in Table 5.1. The planning process for the DRIC was started in the year 2004. A part of the planning/design/construction engineering cost is already incurred. Property acquisition and construction are likely to start after 2010. The construction is expected to be complete by 2014 and the DRIC is expected to start its operation in 2015. The cost elements shown in Table 5.1 are only for the US part of the bridge (MDOT 2008a).

Table 5.1: Cost Components for DRIC (MDOT 2008a)

Cost Item	Million Dollars
Construction Costs	
Detroit River Bridge (U.S. Cost Only)	$399
Toll and Inspection Plaza	$57
Interchange and Local Roadways	$190
Enhancements	$21
Utilities	$157
Management Reserve (5percent)	$40
Planning/Design/Construction Engineering	
Final Design and Permits (10percent)	$80
Construction Engineering (10percent)	$80
Initial planning, design and other costs	$173
Property Acquisition/Remediation	
Property Acquisition	$365
Remediation	$17
Inflation ROW	$35
GSA Plaza Costs	$200
Grand Total Cost	$1,814

5.3 Travel Demand Uncertainty

The Origin-Destination (O-D) matrices for the study area are obtained from MDOT for the years 2015, 2025, and 2035. The analysis period for the case study is considered as 35 years (2015-2050). The OD matrices for the years 2045, and 2050 were projected by considering the growth trends from each TAZ.

A coefficient of variation[1] of 0.15 is considered to incorporate variance in travel demand. The potential[2] OD matrix was not available. All The OD matrices were increased by ten percent to obtain the potential OD matrix.

The standard deviation of the OD matrix is obtained from the coefficient of variation and the expected demand of the OD matrix.

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[1] The coefficient of variation (COV) is the ratio of the standard deviation and the mean. For this research a COV of 0.15 is assumed by observing the variation in demand over time for ten years.

[2] The potential OD matrix contains the maximum possible trips that can be made if the travelers are not sensitive to the user cost. In elastic traffic assignment the potential OD matrix is used to test the sensitivity of demand with respect to the user cost (both travel time and travel cost).

Solution Approach for Demand Uncertainty

A Monte Carlo Simulation (MCS[3]) procedure was used to simulate the OD matrix. The potential OD matrix (expected demand matrix) and the variance OD matrix served as the input to the MCS. The OD matrices were subjected to 200 realizations and each realization was recorded (Equation 3.21). From the distribution of OD matrix, the median matrix was chosen for further analysis. However, one can use any percentile from the OD matrix distribution. This procedure was followed for all the horizon years. The resulting OD matrix from MCS contains the variation in travel pattern and incorporates uncertainties in travel demand that form the basis of elastic traffic assignment procedure, is defined later.

The simulated demand for an example OD pair is presented in Figure 5.1. The OD pair 8-24 is considered as an example to demonstrate the simulated demand over the analysis period. Two observations can be made from Figure 5.1: (1) the shift of expected value of OD demand over the analysis period, and (2) the variation in demand as the analysis period progresses. The higher variances in the farther years can be explained by the magnitude of the mean demand and the corresponding variances. As an example, it can be observed that the variance is higher for the year 2050 when compared to the year 2015.
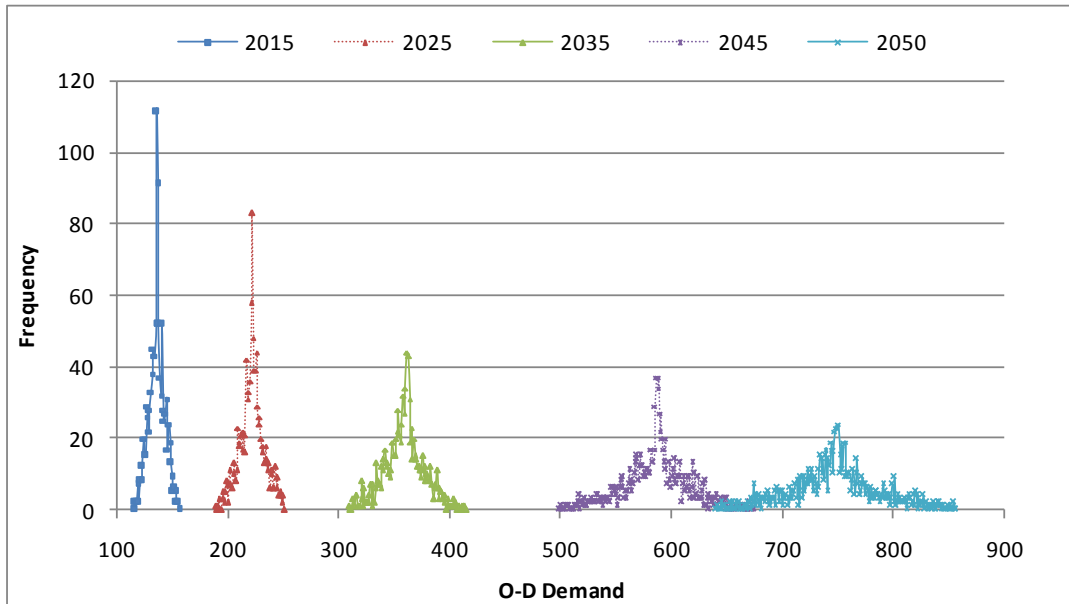
Figure 5.1: Simulated demand for OD pair 8-24

5.4 Single Entity Perspective Decision Making Under Uncertainty

For a viable transportation investment, the interest of three decision making entities (public, private, and user) should be satisfied. The objectives of three entities from investment viewpoint are different. Their implications are discussed below.

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[3] A Monte Carlo method is a technique that uses random numbers and probability of variables to determine the outcome of a particular measure.

<u>Solution Approach for Single Entity Perspective Decision Making Under Uncertainty</u>

The investment decision making can be viewed as a bi-level process. The preference of the decision maker (leader) is considered at the upper level. For example, the objective of the private entity is maximization of profit. Further, profit is a function of toll and travel demand. The toll value is considered at the upper level. Estimation of traffic volume for a given toll value is a traffic assignment problem, and is considered at the lower level. While the preference (profit maximization, consumer surplus maximization, and inequality minimization) of various entities are different at the upper level, the lower level represents an elastic traffic assignment problem for all entities (The term "elastic" signifies the sensitivity of the travelers with respect to the user cost). It should be noted that both toll and travel demand are random and uncertain in the bi-level problem. The elastic traffic assignment procedure incorporates randomness and uncertainty by considering variability in the OD assignment. The details of elastic traffic assignment procedure are explained in Chapter 3.

As the objective of each entity is different, the optimum toll value from each perspective is different. There exists a unique relationship between toll and travel demand. If toll value is very low, then the ridership will be very high resulting in an increase in travel time per trip. On the other hand, higher toll values will result in lower ridership assuming the availability of alternate paths. Extreme toll values (very high or very low) are thus undesirable. The bi-level process determines the optimal toll and ridership for different entities. For the river crossing, the assignment procedure consists of multiple modes (Table 4.3 through Table 4.5) of travel and toll value for each mode is different. The result of each single entity perspective is presented in the following section.

Three entity objectives are used in the upper level and the ridership determination is used in the lower level. The bi-level process is solved in TransCAD (Caliper 2008). A GISDK (GISDK is a computer programming language used in TransCAD to solve transportation planning problems) script is written to solve the bi-level model in TransCAD. The output of the upper level (toll value and the entity-specific objective function) served as the input to the lower level (ridership estimation). The bi-level process can be viewed as a non-linear problem reflecting the nature of the objective functions at the upper and the lower level. The elastic traffic assignment procedure is solved by user equilibrium method using Frank Wolfe Algorithm[4] (Sheffi 1985).

<u>Calibration Results</u>

Results of calibration for the proposed traffic assignment model (Equation 3.14 to 3.19) for the base year 2004 are presented in Table 5-1. Because of height restriction DWT cannot carry truck traffic; therefore the toll and volume for DWT trucks are left

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[4] The Frank–Wolfe algorithm is a convex combination algorithm, is a procedure for solving quadratic programming problems with linear constraints.

blank in Table 5.2. Actual toll values for the cars and trucks for the year 2004 are utilized to determine the assigned volume on the existing river crossings in the network. The proposed elastic traffic assignment model (on page 65 through 67 in chapter 3) and the potential OD matrix for the year 2004 is utilized to determine the assigned volume for cars and trucks. The observed car and truck volumes are obtained from MDOT (MDOT 2003). The relative closeness of assigned and observed volumes at the respective crossings shown in Table 5.2 demonstrates the calibration of the model.

Table 5.2: Calibration Results

Year (2004)	Toll ($)			Assigned Volume (peak period volume/hr)			Observed Volume (peak period volume/hr)		
	AMB	DWT*	BWB	AMB	DWT	BWB	AMB	DWT	BWB
Cars	4.00	3.75	1.50	1497	1263	671	1535	1221	681
Trucks	20.00	-	7.50	564	-	347	581		319

Note: *: Detroit Windsor Tunnel does not carry truck traffic.

5.4.1 Base Case:

The base case scenario refers to exclusive entity participation. Table 5.3 represents the results for the base case scenario for the three entities for different horizon years during the analysis period.

For private entity, the objective is profit maximization. For profit maximization strategy, it is assumed that the total cost (both capital and operation and maintenance cost) will be borne by the private entity. As explained in the Chapter 3, the profit maximization is solved by the bi-level process. In the upper level toll values are set and in the lower level ridership is determined. For example, in the profit maximization strategy, toll values of $2 per car and $14 per truck resulted in an annual revenue[5] of $68.54 million in the year 2015. In computing the annual revenue, the Peak Hour factor was assumed to be 8 percent, so that; Annual Revenue = (Toll charge*Peak Hour Volume*365)/0.08. For the same toll values the consumer surplus and Theil's index are estimated to be $346.07 million and 0.86 respectively for the year 2015. The toll values are obtained in an iterative manner with directional search to obtain the optimum value of the objective function for profit maximization and inequality minimization.

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[5] Revenue is considered as the surrogate of profit and the in the remainder of the chapter revenue is used in the cases of profit maximization. Revenue is defined here as the monetary benefit obtained by the toll/fare collection only.

When the objective of the public entity is considered, the optimal toll is $0.5 per car and $4.33 per truck (year 2015, second row, Table 5.3) that resulted in an optimal consumer surplus of $730.36 million, which is higher than the estimated consumer surplus for profit maximization. The consumer surplus allows more travelers[6] to use the facility in lowering the difference between willingness to pay and what the travelers actually pay. The revenue and Theil's index for toll values of $0.5 per car and $4.33 per truck are estimated to be $25.78 million and 0.79 respectively.

Table 5.3: Base Case Entity Objective Results (MDOT 2008a)

Year	Car Toll ($)	Truck Toll ($)	Annual Revenue (Million $)	Annual Consumer Surplus (Million $)	Theil's Inequality Index
2015					
Private Perspective	2^7	14^8	68.54^9	346.07	0.86
Public Perspective	0.5^{10}	4.33^{11}	25.78	730.36^{12}	0.79
User Perspective	0.25^{13}	1.04^{14}	7.412	258.62	0.70^{15}
2025					
Private Perspective	3	15	118.22	550.98	0.88
Public Perspective	0.78	5.28	43.65	1091.91	0.81
User Perspective	0.52	2.06	19.53	352.60	0.68
2035					
Private Perspective	4.5	19	199.30	681.45	0.88
Public Perspective	1.28	6.75	73.70	1343.04	0.79
User Perspective	0.86	3.35	40.02	464.08	0.72
2045					
Private Perspective	6.00	21.00	281.95	802.24	0.86
Public Perspective	1.75	7.41	105.42	1594.95	0.80
User Perspective	1.26	4.52	68.13	565.78	0.74
2050					
Private Perspective	8.73	22.25	330.63	936.19	0.88
Public Perspective	1.93	7.82	125.19	1664.37	0.72
User Perspective	1.60	5.70	96.22	685.32	0.67

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[6] It should be noted that more travelers using the facility does not necessarily increase the revenue, because revenue is the product of toll value and the corresponding ridership.

[7] Represents the Optimal value of car toll from the Private Perspective

[8] Represents the Optimal value of truck toll from the Private Perspective

[9] Represents the maximum value of Revenue from the Private Perspective

[10] Represents the Optimal value of car toll from the Public Perspective

[11] Represents the Optimal value of truck toll from the Public Perspective

[12] Represents the maximum value of Consumer Surplus from the Public Perspective

[13] Represents the Optimal value of car toll from the User Perspective

[14] Represents the Optimal value of truck toll from the User Perspective

[15] Represents the minimum value of Theil's value from the User Perspective

Similarly, when the objective of the users is considered (year 2015, third row, Table 5.3) the optimal toll values obtained are $0.25 per car and $ 1.04 per truck, resulting in a Theil's's index of 0.70 (minimum of the three Theil's index values) for the year 2015. For the toll value of $0.25 per car and $1.04 per truck the corresponding revenue and consumer surplus are estimated at $7.412 and $258.62 million respectively.

Three distinct toll values are obtained for three different entities each of which results in optimum value for each objective function defined in equations 3.3, 3.9, and 3.13. The highest toll value resulted for the profit maximization, and the least toll value for the Theil's Index, thereby demonstrating how the respective objectives of the private investor and the users are satisfied. Additionally, the toll value for the public entity perspective is lower than that for the private perspective. Similar trends are observed for the other horizon years during the analysis period presented in Table 5.3.

Increased travel demand in subsequent years resulted in higher toll values, higher revenue and higher consumer surplus in succeeding years. The same is generally true in Theil's Index, although there are some exceptions in the trends of the Theil's index value. The Theil's Index is considered as a minimization function and is based on the concept of uniformity of distribution of trips among the TAZs in the study area.

5.4.2 Effect of Public Entity Price Regulation Policies

The objective of the public entity price regulation policies is to assess the feasibility of the project for toll values (or price) used in similar facilities in the state or in the country. This analysis will provide insights on the possible outcome of the different toll values on the future revenue. The results of this policy analysis are presented in Table 5.4. The toll values for the base year are assumed to be as $2 per car and $15.00 per truck (as these are the actual toll value for other publicly owned other international river crossings in the state of Michigan). The toll value is increased in future years according to a fare structure released by MDOT for similar facilities in the state (MDOT 2008b). In Table 5.4, Column (1) represents the base and horizon years in the analysis period. Columns (2) through (4) represent the optimal values of the entity-specific revenue, consumer surplus, and Theil's Index, resulting from the bi-level programming, presented in Table 5.3. The corresponding toll values are presented in parenthesis in the same columns. The entity-specific results for the public entity price regulation are presented in columns (5) through (7) along with the corresponding toll values. Unlike the base case optimal entity specific results, the toll values for public entity price regulation policy are the same. The percentage difference in the values of the objective function (revenue, consumer surplus, and Theil's's Index) for the base case and the public entity price regulation are presented in columns (8) through (10). The corresponding percentage differences in the toll values are also presented in parenthesis in columns (8) through (10).

For the year 2015, the maximum revenue obtained is $68.54 million for the car toll of $2 and truck toll of $14 for the base case (column 2, Table 5.4). As per public (or

MDOT in this case) regulation, a toll value of $2 for cars (same as base case) and $15 for trucks resulted in a revenue of $58.88 million (column 5, Table 5.4), for a -14.9percent change {(58.88 - 68.54)*100/68.54} (column 8, Table 5.4). This shows an increase in truck toll (from $14 to $15) has resulted in a decrease in revenue from $68.54 million to $58.88 million in the year 2015. The percentage difference in car and truck tolls compared to the base case are 0 and 7.14 respectively (column 8, parenthesis) [(2-2)/2 is 0 percent and the truck toll (15 - 14)/14 is 7.14 percent].

For the year 2015, the maximum consumer surplus ($730.36 million) was obtained for a toll value of $0.5 for cars and $4.33 for truck, as discussed in the previous section (column 3, Table 5.4). A toll value of $2 for cars, and $15 for trucks resulted in a consumer surplus of $412.52 million (column 6, Table 5.4). The percentage change in the value of the objective function (consumer surplus) is -43.52percent (column 9, Table 5.4), resulting from a percentage difference in car toll of 300percent, and in truck toll of 246.42 percent (column 9, Table 5.4).

For the year 2015, a minimum Theil's index obtained for a toll value of $0.25 for cars and $1.04 for trucks is 0.70 (column 4, Table 5.4). For the public policy toll regulation (car toll of $2 and truck toll of $15), the Theil's index obtained is 0.83 (column 7, Table 5.4). The percentage difference in the value of the objective function is 18.57percent (column 10, Table 5.4), for a percentage difference in car toll of 700percent, and truck toll of 1342.31 percent (column 10, Table 5.4).

It should be noted that the percentage differences in revenue and in consumer surplus are negative, because, the base case represents maximization functions, and the maximum value occurred at a special toll value (Table 5.3), that is different from that assumed for the public entity price regulation (Table 5.4). But the user inequality is a minimization function, and the minimum value of Theil's Index occurred at a different toll than that for the public entity price regulation, resulting in a positive percentage

Table 5.4: Public Entity Price Regulation Results

Year	Base Case Optimal Results			Public Entity Price Regulation			% Change in Objective		
	Revenue (Million $) (a, b)	Consumer Surplus (Million $) (a, b)	Theil's Index (a, b)	Revenue (Million $) (c, d)	Consumer Surplus (Million $) (c, d)	Theil's Index (c, d)	Revenue (%) (e, f) = [(5)-(2)]*100/(2)	Consumer Surplus (%) (e, f) = [(6)-(3)]*100/(3)	Theil's Index (%) (e, f) = [(7)-(4)]*100/(4)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2015	68.54 (2.00.,14.00)	730.36 (0.50,4.33)	0.70 (0.25,1.04)	58.88 (2.00,15.00)	412.52 (2.00,15.00)	0.83 (2.00,15.00)	-14.09 (0.00, +7.14)	-43.52 (300.00,+246.42)	18.57 (700.00,+1342.31)
2025	118.22 (3.00,15.00)	1091.91 (0.78,5.28)	0.68 (0.52,2.06)	97.86 (2.69,20.16)	589.42 (2.69,20.16)	0.8 (2.69,20.16)	-17.22 (-10.33,+34.39)	-46.02 (+244.87,+281.79)	+17.65 (+417.31,+878.58)
2035	199.30 (4.50,19.00)	1343.04 (1.28,6.75)	0.72 (0.86,3.35)	143.85 (3.61,27.09)	705.56 (3.61,27.09)	0.81 (3.61,27.09)	-27.82 (-19.73,+42.59)	-47.47 (182.20,+301.36)	+12.50 (+320.03,+708.71)
2045	281.95 (6.00,21.00)	1594.95 (1.75,7.41)	0.74 (1.26,4.52)	211.33 (4.85,36.41)	843.2 (4.85,36.41)	0.82 (4.85,36.41)	-25.05 (-19.09,+73.38)	-47.13 (177.40,+391.35)	+10.81 (+285.28,+70.5.51)
2050	322.71 (8.73,22.25)	1677.43 (1.93,7.82)	0.68 (1.60,5.70)	309.64 (6.52,48.93)	936.46 (6.52,48.93)	0.81 (6.52,48.93)	4.05 (-25.27,+119.91)	-44.17 (238.04,+525.71)	+19.12 (307.75,+758.43)

Note: a, b: Base case entity specific optimal tolls for cars and trucks

c, d: Public entity price regulation tolls for cars and trucks (the toll values remain same for all entity perspectives)

e, f: % change in toll values from public entity price regulation to the base case

difference. Similar trends are observed for other horizon years presented in Table 5.4. These results support the premise of optimization used in computing the tolls and revenues presented in Table 5.3.

5.4.3 Equitable Distribution of Benefits

In this policy, the equity of distribution is considered at the upper level. The objective of this policy is to get insights on the effect of private and public entity when the equity distribution is given a threshold value for the base and horizon years in the analysis period. Results of this policy analysis are presented in Table 5.5.

For the base case scenario, different Theil's Index values were obtained for different years. (last column of Table 5.3). In this policy option, the user inequality is assigned more relaxation to supplement the revenue generation, thereby strengthening the opportunity for private participation. In the user inequality minimization, the user pays the least amount to equally distribute the benefits. In this policy option, the upper limit of the Theil's index is kept same for the base and the horizon years. The maximum Theil's Index obtained for the base case during the analysis period is 0.74. The upper limit of Theil's Index for all the years is set to 0.74 and the toll value was estimated.

The results for the user inequality relaxation policy option are presented in Table 5.5. Column (1) represents the base and horizon years in the analysis period. Columns (2) through (4) represent the optimal values of the entity perspective results obtained from the bi-level programming (discussed in section 5.4.1). The corresponding toll values are presented in parenthesis for the optimal entity-perspective results. It should be noted that the toll values for the entity- specific optimal values are different for different years. Results for the user inequality relaxation are presented in column (5) through (7). The toll values resulted to obtain the Theil's Index of 0.74 are used to estimate the revenue and consumer surplus (columns (5) through (7)). The percentage differences in the values of the objective function for the base case and user inequality relaxation policy are presented in column (8) through (10). The corresponding percentage differences in the toll values for the two cases are also presented in parenthesis in columns (8) through (10).

For the year 2015, the maximum revenue obtained is $68.54 million for a car toll of $2 and a truck toll of $14 (column 2, Table 5.5). A Theil's index of 0.74 was obtained for a toll value of $0.39 for cars and $2.25 for trucks with a resulting profit of $14.58 million (column 5, Table 5.5). The percentage difference in revenue when compared to the base case is -78.73percent (column 8, Table 5.5). The percentage differences in car and truck toll compared to the base case are presented in the parenthesis as -80.50 percent and -83.93 percent respectively (column 8, Table 5.5).

For the year 2015, the maximum consumer surplus of $730.36 million was obtained for a toll value of $0.5 for cars and $4.33 for trucks (column 3, Table 5.5). A toll value of $0.39 for cars and $2.25 for trucks resulted in consumer surplus of $363.11

million (column 6, Table 5.5). The percentage difference in consumer surplus is -50.28 percent (column 9, Table 5.5), resulting from changes in car and truck tolls amounting to -22 percent, and -48.04 percent respectively (column 9, Table 5.5).

For the year 2015, the minimum Theil's index obtained for a toll value of $0.25 for cars and $1.04 for trucks (column 4, Table 5.5) is 0.70. A toll value of $0.39 for car and $2.25 for truck resulted in a Theil's's Index of 0.74 (column 7, Table 5.5). The percentage difference in the values of the index is 5.71 percent (column 10, Table 5.5), resulting from a percentage difference in car and truck tolls of 56 percent, and 116.35 percent respectively (column 10, Table 5.5). The results in Table 5.5 demonstrate that for the user inequality relaxation policy, the entity perspective results in the values of the objective function are lower than those for the optimal values obtained for the base case. Similar trends are observed for other horizon years in the analysis period (Table 5.5).

5.4.4 Synthesis of Three Entity Preferences

Objectives of individual entity perspectives are considered in the (1) base case (2) public policy toll regulation, and (3) equitable distribution of benefits policy. The analyses resulted in following observations:

- The base case analysis resulted in optimal values for profit, consumer surplus, and Theil's Index for the base and horizon years.

- The public policy regulation provided insights to the outcome for different entity perspectives if the toll values similar to other facilities in the state are used.

- The equitable distribution of benefits resulted in relaxed user toll and the outcome is compared with the base case.

- The base case, along with the two entity perspective policies provided insights to the investment strategies for DRIC.

Table 5.5: User Inequality Relaxation Results

Year	Base Case Optimal Results			User Inequality Relaxation			% Change in Objective		
	Revenue (Million $) (a, b)	Consumer Surplus (Million $) (a, b)	Theil's Index (a, b)	Revenue (Million $) (c, d)	Consumer Surplus (Million $) (c, d)	Theil's Index (c, d)	Revenue (%) (e, f) = [(5)-(2)]*100/(2)	Consumer Surplus (%) (e, f) = [(6)-(3)]*100/(3)	Theil's Index (%) (e, f) = [(7)-(4)]*100/(4)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2015	68.54 (2.00,14.00)	730.36 (0.50,4.33)	0.70 (0.25,1.04)	14.58 (0.39,2.25)	363.11 (0.39,2.25)	0.74 (0.39,2.25)	-78.73 (-80.50,-83.93)	-50.28 (-22.00,-48.04)	+5.71 (+56.00,+116.35)
2025	118.22 (3.00,15.00)	1091.91 (0.78,5.28)	0.68 (0.52,2.06)	30.38 (0.66,3.47)	429.68 (0.66,3.47)	0.74 (0.66,3.47)	-74.30 (-78.00,-76.87)	-60.65 (-15.38,-34.28)	+8.82 (+26.92,+68.45)
2035	199.30 (4.50,19.00)	1343.04 (1.28,6.75)	0.72 (0.86,3.35)	48.24 (1.05,4.06)	518.23 (1.05,4.06)	0.74 (1.05,4.06)	-75.80 (-76.67,-78.63)	-61.41 (-17.97,-39.85)	+2.78 (+22.09,+21.19)
2045	281.95 (6.00,21.00)	1594.95 (1.75,7.41)	0.74 (1.26,4.52)	68.13 (1.26,4.52)	565.78 (1.26,4.52)	0.74 (1.26,4.52)	-75.84 (-79.00,-78.48)	-64.53 (-28.00,-39.00)	0.00 (0.00,0.00)
2050	322.71 (8.73,22.25)	1677.43 (1.93,7.82)	0.68 (1.60,5.70)	129.57 (1.93,7.82)	1677.43 (1.93,7.82)	0.74 (1.93,7.82)	-59.85 (-77.89,-64.85)	0.00 (0.00,0.00)	+8.82 (+20.63,+37.19)

Note: a, b: Base case entity specific optimal tolls for cars and trucks

c, d: User inequality relaxation tolls for cars and trucks for Theil's Index of 0.74 (the toll values remain same for all entity perspectives)

e, f: % change in toll values from user inequality relaxation to the base case

5.5 Ownership, Tenure and Governance Strategies

The economic feasibility from entity perspectives is imperative from an investment view point. The authors' initial work on the concept of OTG scenarios was presented at the World Conference on Transport Research at the Univ. of California, Berkeley in 2007 (Khasnabis, et. al 2007). Though single entity participation in large transportation projects is important, their involvement with other entities is likely to increase the overall viability of the project. The Ownership, Tenure & Governance are three terms that incorporate the role of each entity in a strategy, where a number of OTG strategies are considered to encourage joint entity participation in the DRIC project. The strategies vary in the degree of participation by the public and the private entity. The five types of OTG strategies considered are

1. OTG-1: Exclusive Private Participation

2. OTG-2: Major Private Participation

3. OTG-3: Moderate Private Participation

4. OTG-4: Major Public Participation

5. OTG-5: Exclusive Public Participation

The role of each participant OTG strategies is presented in Table 5.6. The degree of private to public participation is varied from OTG-1 through OTG-5. A number of relaxation policies are also considered to encourage joint ownership in DRIC. The significance of each OTG strategy is explained below[16]. The feasibility of OTG strategies are determined by considering the analysis period till 2050.

<u>OTG-1</u>

For OTG-1, the total capital cost is borne by the private entity. The objective of the strategy is profit maximization. After construction of the facility, the private entity collects toll, operates and maintains the facility. The private entity is permitted to collect toll throughout the concession period. The eventual owner of the facility is the public entity, even though the private entity is responsible for all the expenditures and toll collection during concession period.

The cumulative cash flow and the internal rate of return (IRR)[17] are the two MOEs plotted in Figure 5.2. The negative cost elements for 2004-2014 represent the planning

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[16] Strategy: A strategy is defined as a means to plan, design, and implement a project encompassing different mechanisms of ownership, tenure, and governance.

[17] IRR provides an estimate of the return or yield of the investment, given a set of expenditure and revenue data along with their expected dates over the life of the project. IRR is defined as the interest rate at which the Net Present Worth (or Net Annual Worth or Net Future Worth) of the investment is equal to zero.

Table 5.6: OTG Strategies and Relaxation Policies

OTG Strategy	Explanation	Relaxation Policy	Entity Objective
OTG-1	Exclusive Private Participation	No Relaxation	Profit Maximization
OTG-2	Major Private Participation	1. Toll Plaza Cost Subsidy 2. Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy 3. Construction Cost Subsidy (50percent)	Profit Maximization
OTG-3	Moderate Private Participation	1. Construction Cost Subsidy (60percent) 2. Concession Period Extension (27 years) 3. Construction Cost Subsidy and Concession Period Extension	Profit Maximization
OTG-4	Major Public Participation	1. Partly Construction Cost by Private Entity 2. Operation and Maintenance Cost 3. Construction Cost Subsidy-Public Entity	Consumer Surplus Max.
OTG-5	Exclusive Public Participation	No Relaxation	Consumer Surplus Max.

and construction of the facility. When the facility is opened to traffic, the cumulative negative value of cash flow decreases, as toll charges are collected and the break even period occurs in the year 2034. The IRR for OTG-1 strategy is calculated as 4.61 percent over the 35 years of concession period. The Minimum Attractive Rate of Return (MARR)[18] was assumed to be 6 percent. The IRR being less than the MARR lends the project economically infeasible for the exclusive private participation strategy (OTG-1) tested.
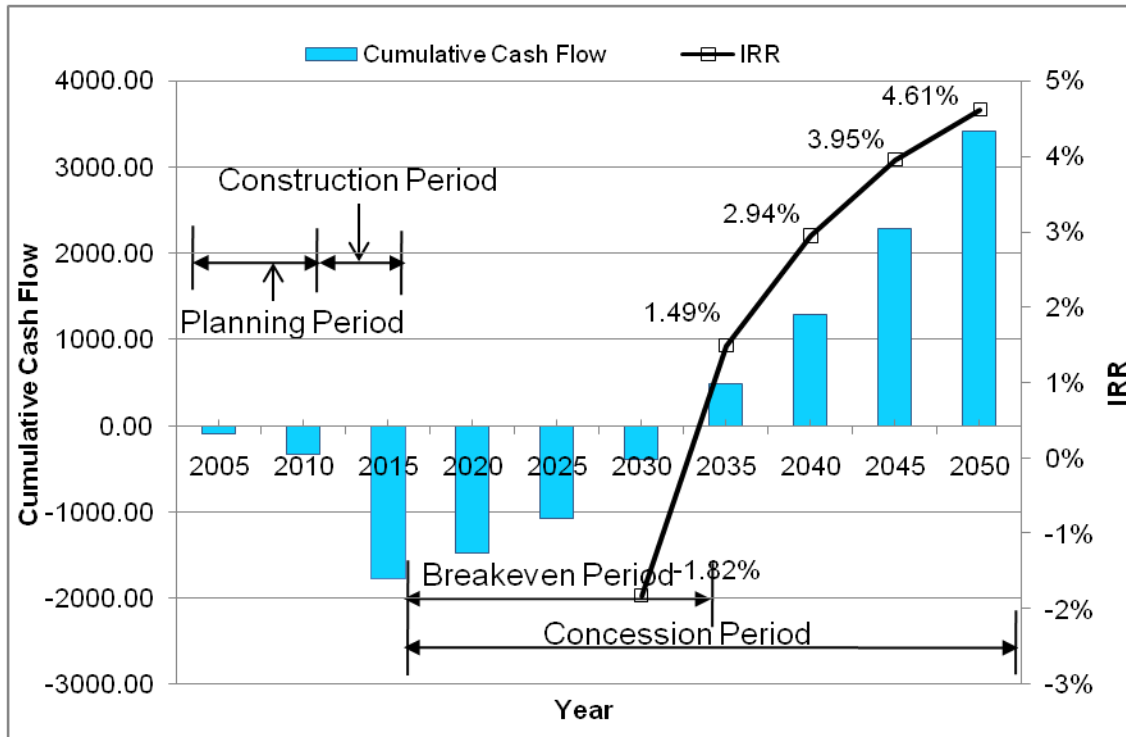

Figure 5.2: Cumulative Cash Flow and IRR for Exclusive Private Participation (OTG-1) (Note: There is no IRR value till the end of 2025 as the cost is much higher than the benefit received. The IRR at the end of 2030 is -1.82)

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[18] MARR is the rate of return below which the investment proposal is to be deemed unacceptable

OTG-2 Major Private Participation:

In OTG-2 strategy, the majority (not exclusive) of the capital, operation and maintenance cost is borne by the private entity. Unlike OTG-1, the public entity is responsible for some of the expenditures in OTG-2. As in OTG-1, the private entity is allowed to collect toll till the end of the concession period and the public entity acquires the ownership thereafter.

Relaxation in cost elements for private entity can be made in a number of ways. With the current developments in the investment scenarios for DRIC, a total of three relaxation policies were adopted:

1. Toll plaza cost subsidy

2. Toll plaza, interchange and inspection plaza cost subsidy

3. Construction cost subsidy

Toll plaza is one of the major cost components of the DRIC. In the latest developments of the DRIC investments, the Federal Government through the General Service Administration (GSA) may assume the toll plaza cost. A new scenario subtracting the cost of toll plaza from the private entity is formulated to determine the cash flow and IRR, is presented in Figure 5.3. The IRR for OTG-2, toll plaza cost subsidy is 5.14 percent. The IRR is higher than that for OTG-1, but still lower than the MARR, rendering the project financially infeasible.

The freeway interchanges are part of the federal investment system and may be considered to be a fiscal responsibility of the public entity. The inspection plaza is a part of the international customs and checking; and can be considered to be a part of the cost for the public entity. As the project is not viable with only toll plaza cost subsidy, these two cost elements are added with toll plaza cost subsidy and are relaxed from the private entity. The resulted cash flow is presented in Figure 5.4. The IRR is 5.89 percent and is less than the MARR. To make the OTG-2 feasible, 50 percent construction cost is subsidized at the next step. The resulting cash flow is presented in Figure 5.5. The IRR is estimated at 5.84 percent.
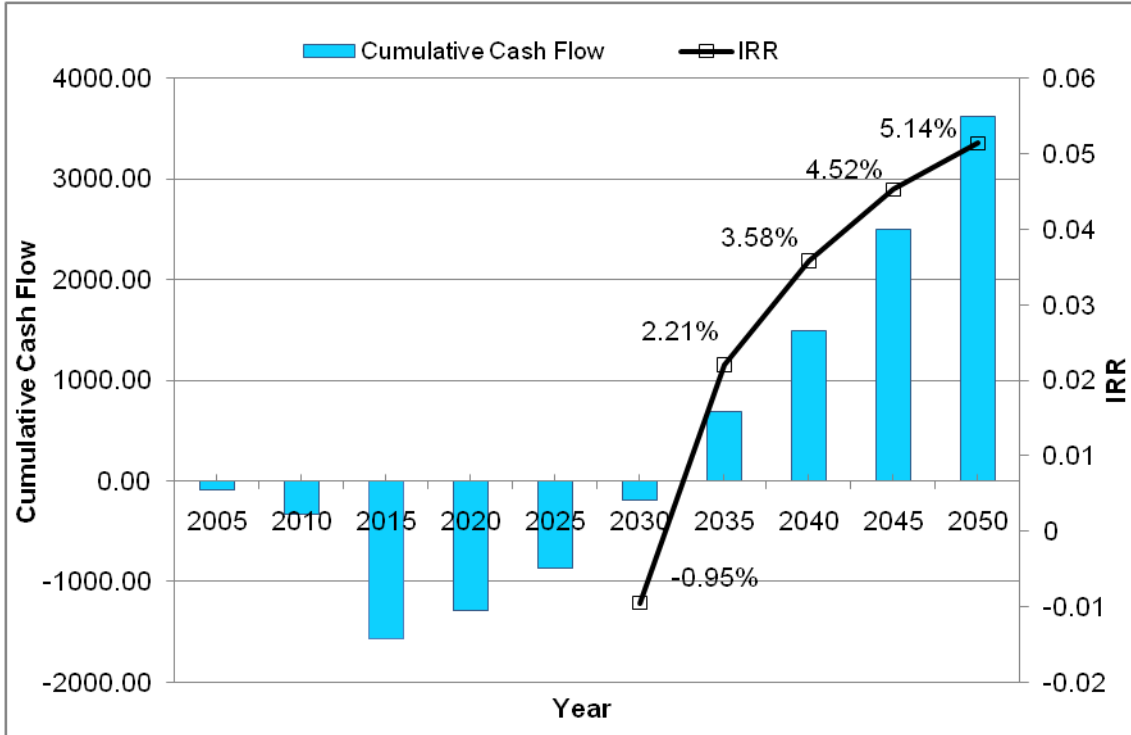
Figure 5.3: Cumulative Cash Flow and IRR Profile for Major Private Participation with Toll Plaza Cost Subsidy (OTG-2)
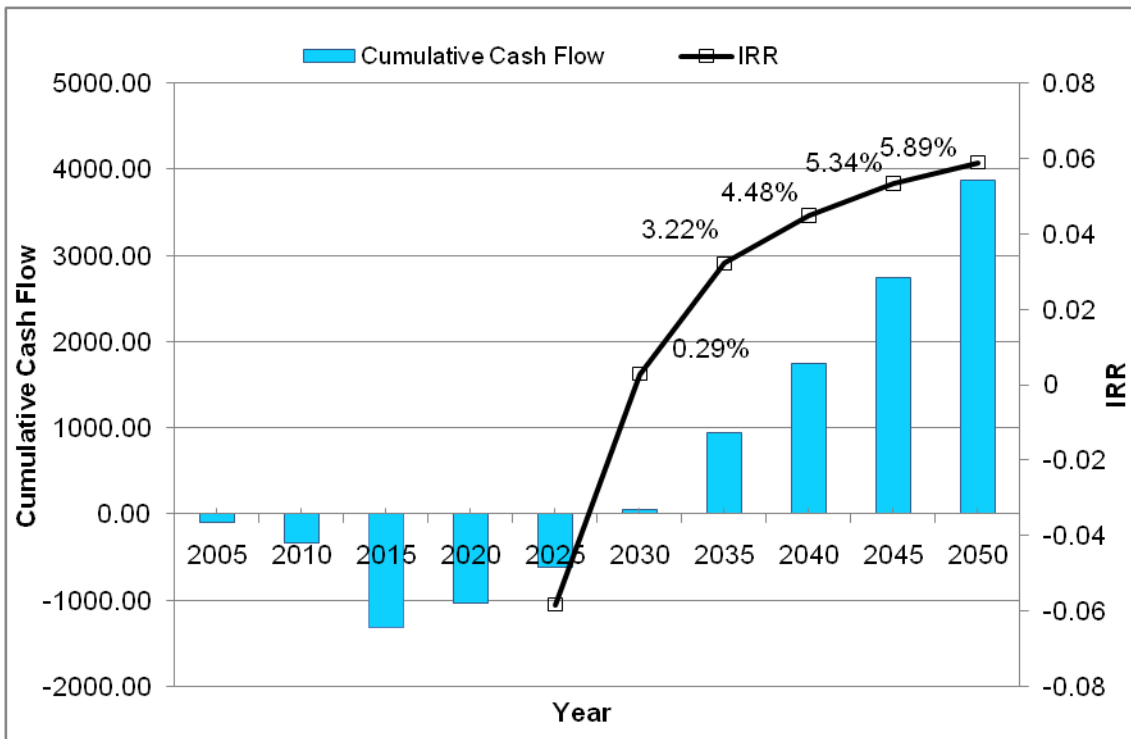

Figure 5.4: Cumulative Cash Flow and IRR Profile for Major Private Participation with Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy (OTG-2)
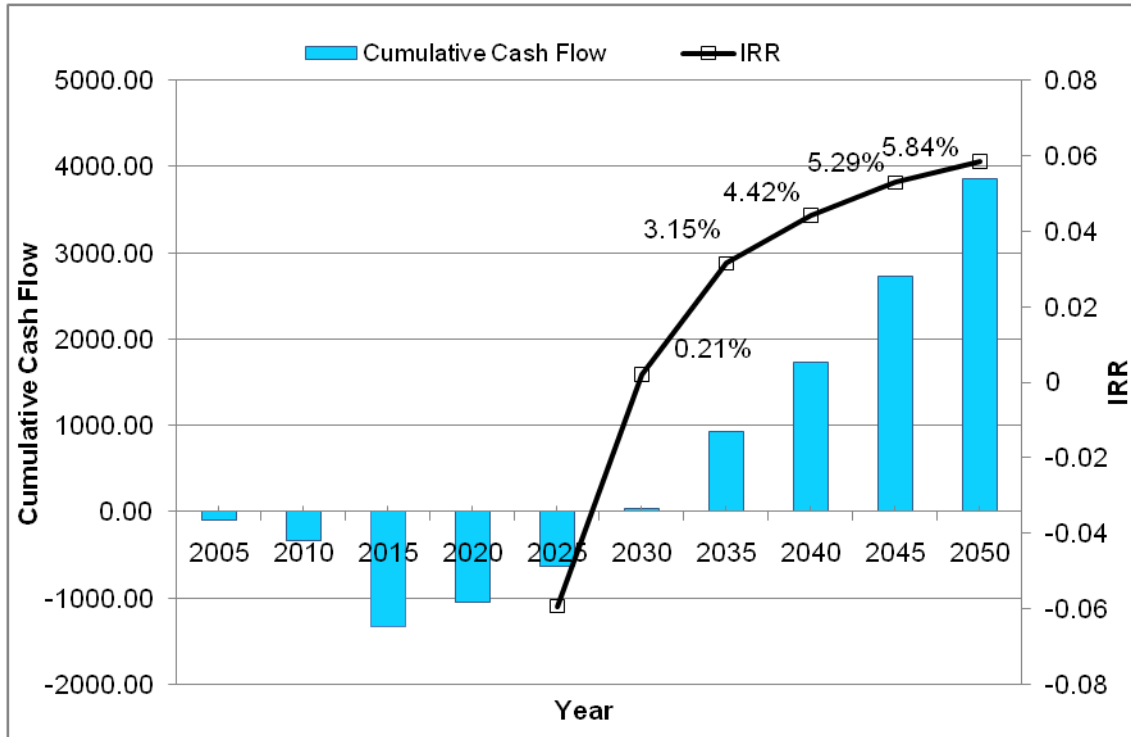
Figure 5.5: Cumulative Cash Flow and IRR Profile for Major Private Participation with Construction Cost Subsidy (OTG-2)

OTG-3 Moderate Private Participation

In OTG-3, the private participation is reduced in comparison to OTG-1 and OTG-2. In other words, the private entity expenditure is further lowered to encourage private participation. To compensate the loss of private dollars, the level of public entity expenditure needs to be raised in OTG-3 strategy when compared to OTG-1 and OTG-2. Three relaxation policies are proposed for OTG-3:

1. Construction cost subsidy

2. Concession period extension

3. Combination of Construction Cost subsidy and Concession period extension

In OTG-3, 60 percent construction cost is subsidized for the private entity. The private entity pays for 40 percent of the construction cost, operates and maintains the facility throughout the concession period with the objective of profit maximization. The private entity transfers the facility to the public entity after completion of the concession period. The 60 percent reduction in cost is a combination of various attributes of cost elements. The cash flow diagram is presented in Figure 5.6. The resulting IRR is 6.13 percent which is higher than the MARR making the project

feasible.

The second relaxation policy of OTG-3 is the concession period extension. In this policy, the concession period is adjusted in such a manner that the IRR becomes viable to the private entity. If no construction cost is subsidized from the private entity, it takes 27 years more than the analysis period, for the private entity to obtain an IRR of 6.01 percent. The cash flow diagram is presented in Figure 5.7.

The third relaxation policy is the combination of construction cost subsidy and concession period extension. This policy provides maximum flexibility to the private investor to recollect revenues during the concession period. The cash flow diagram is presented in Figure 5.8. The resulting IRR is 7.20 percent. All three policies in OTG-3 are feasible with IRR being higher than the MARR.
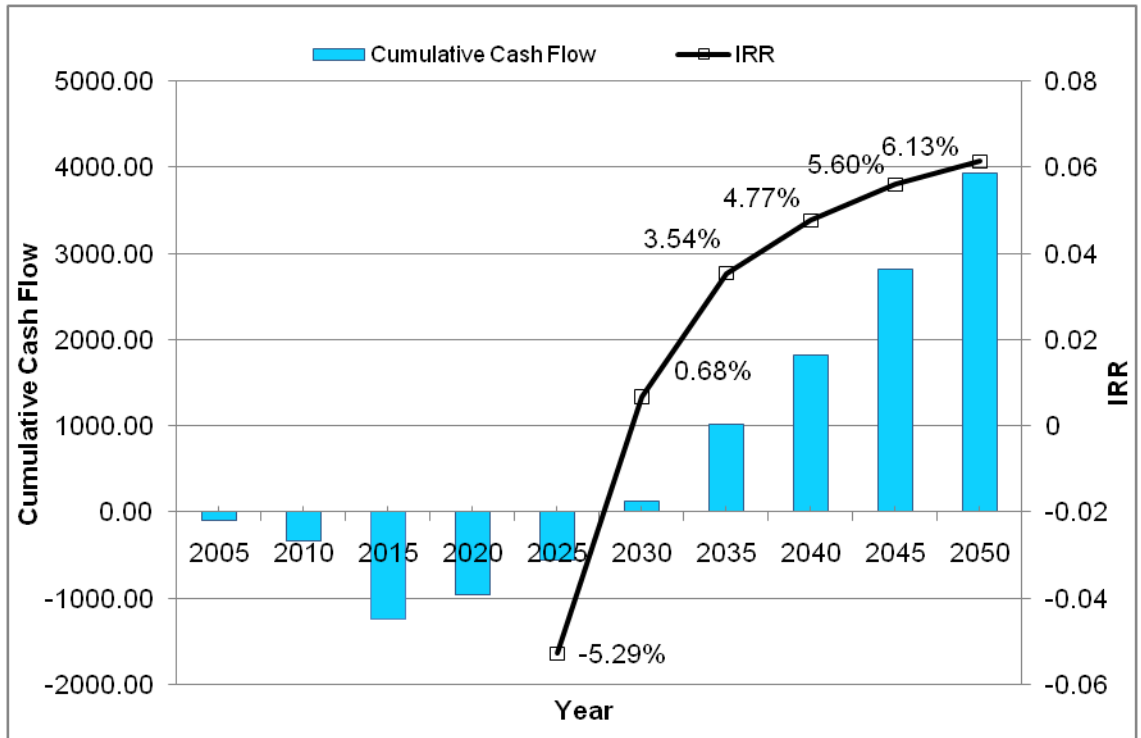

Figure 5.6: Cumulative Cash Flow and IRR Profile for Moderate Private Participation with Construction Cost Subsidy (OTG-3)
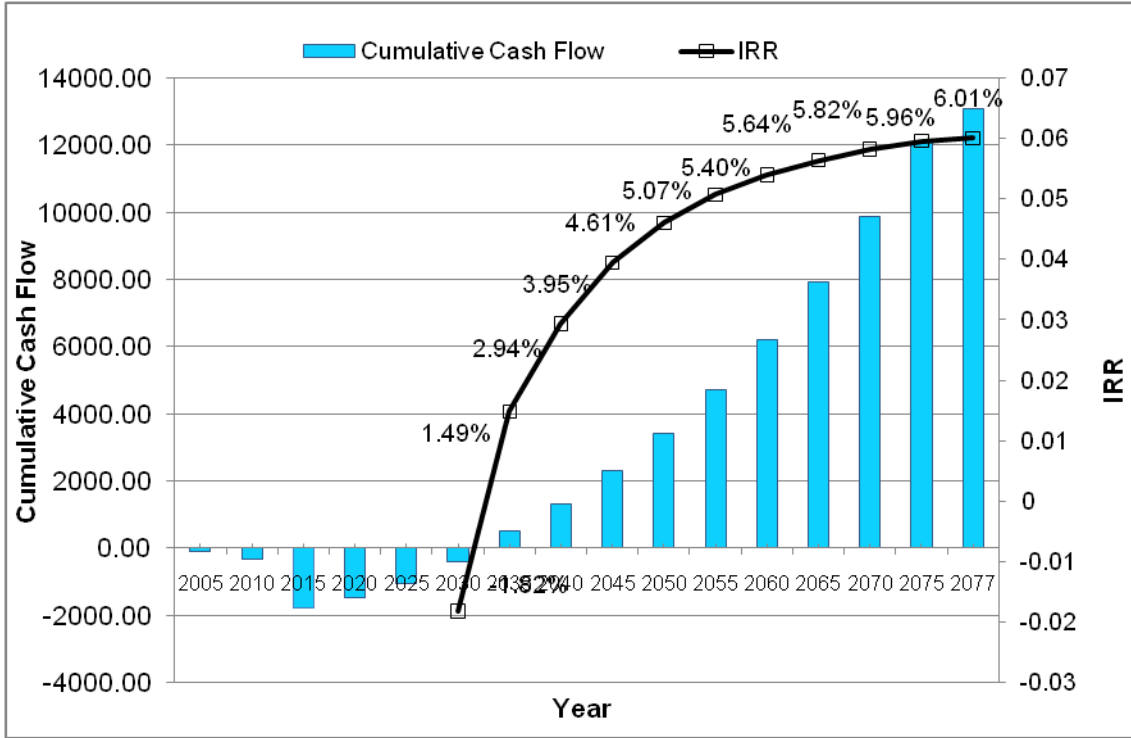
Figure 5.7: Cumulative Cash Flow and IRR Profile for Moderate Private Participation with Concession Period Extension (OTG-3)
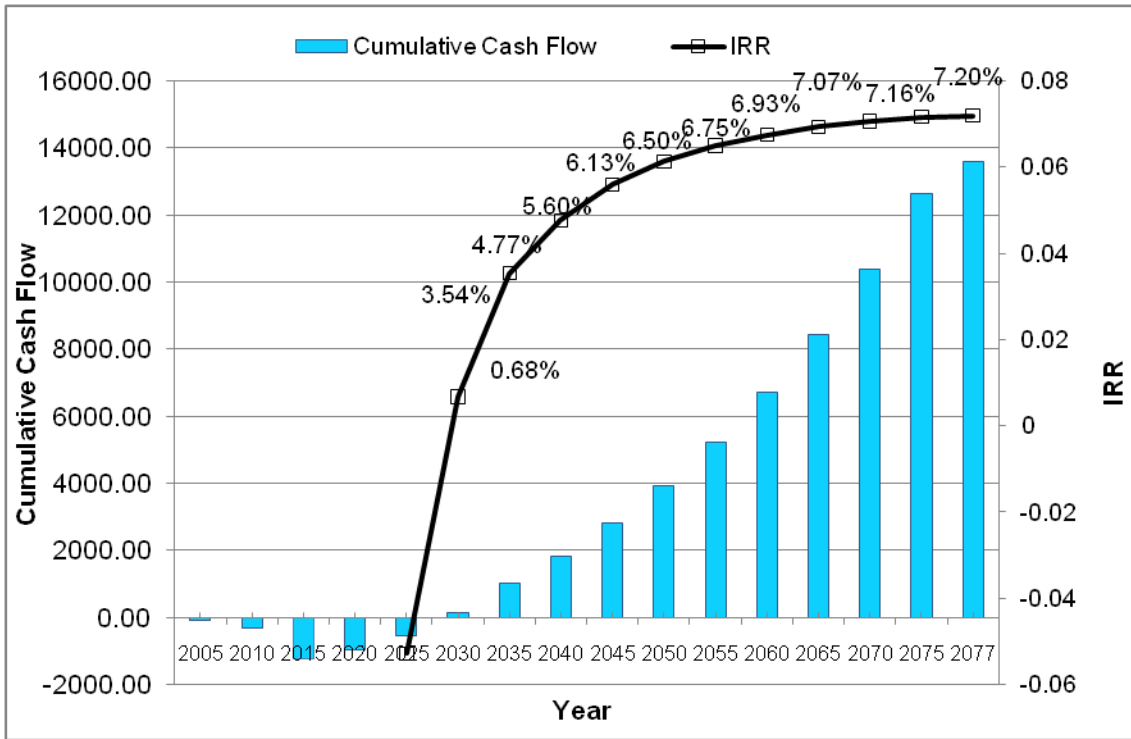

Figure 5.8: Cumulative Cash Flow and IRR Profile for Moderate Private Participation with Construction Cost Subsidy and Concession Period Extension (OTG-3)

OTG-4 – Major Public Participation

In this policy option, the public entity has more contribution in the capital, operation, and maintenance cost. The private entity is partly involved in the cost-sharing (in the form of capital cost or operation and maintenance cost) as well as in benefit/toll collection. Unlike strategies OTG-1, OTG-2 and OTG-3 the objective of this policy is consumer surplus maximization. The private entity collects toll till the end of the concession period when the facility is transferred to the public entity. Three policy options considered in OTG-4 are:

- Construction cost (partly for private entity)

- Operation and maintenance cost (for private entity)

- Construction cost subsidy (80 percent for public entity, 20 percent for the private entity)

In the construction cost option, the private entity is responsible for paying 20 percent of the capital cost. The private entity operates the facility throughout the analysis period (till end of 2050); the resulting IRR for the private entity) is 22.97 percent. The cash flow diagram is presented in Figure 5.9.

In another policy, the private entity is responsible for operating and maintaining the facility, but the entire capital investment is the responsibility of the public entity. The resulting IRR for private entity is very high, as its investment capital is negligible compared to the benefits. But the resulting IRR for the public entity is 3.69 percent as shown in the cash flow diagram in Figure 5.10. In the construction cost subsidy for the public entity, 80 percent of the total construction cost is borne by the public entity. The cumulative cash flow is presented in Figure 5.11 and the resulting IRR is 3.95 percent for the public entity.
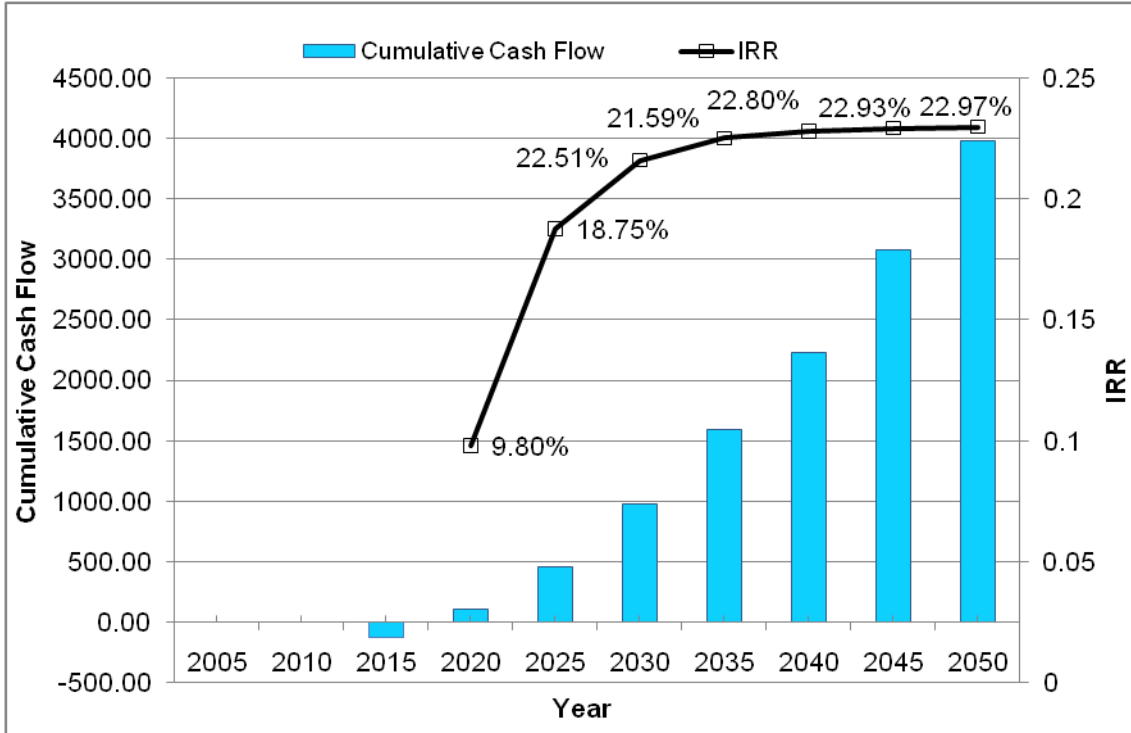
Figure 5.9: Cumulative Cash Flow and IRR Profile for Major Public Participation with Construction Cost Subsidy (IRR for private entity) (OTG-4)
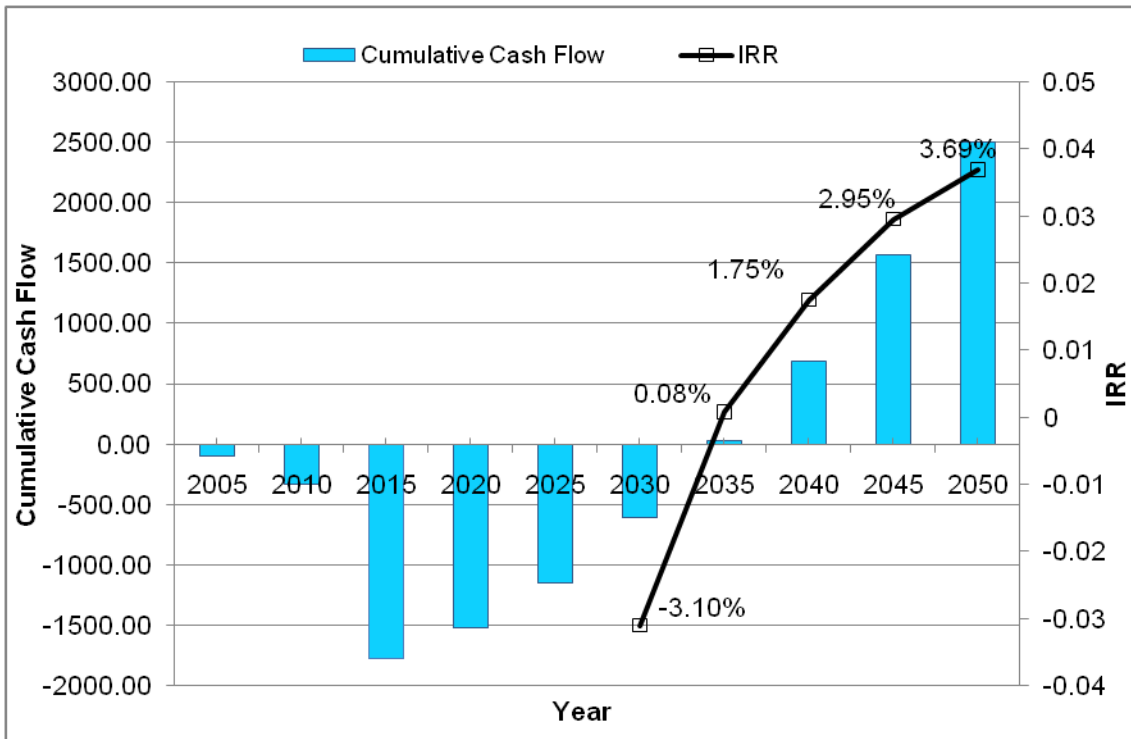

Figure 5.10: Cumulative Cash Flow and IRR Profile for Major Public Participation with Operation and Maintenance Cost Subsidy (IRR for public entity) (OTG-4)
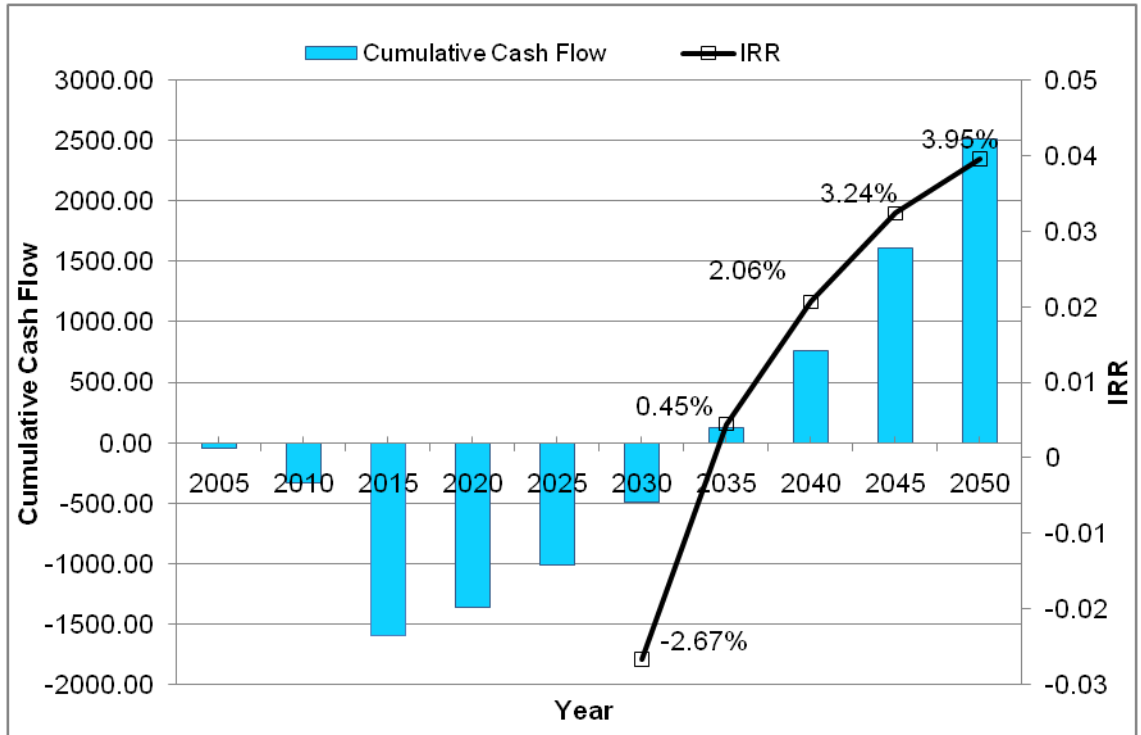
Figure 5.11: Cumulative Cash Flow and IRR Profile for Major Public Participation with Operation and Maintenance Cost Subsidy (IRR for the public entity) (OTG-4)

OTG-5:

In the case of exclusive public participation, the objective is to maximize consumer surplus instead of profit. The toll/fares charged are those needed for consumer surplus is maximum, as shown in Table 5.3. The capital cost is the responsibility of the public entity, and private entity is not involved in any part of construction. The cash flow diagram is presented in Figure 5.12. The IRR is less than the MARR. Clearly, the project is not viable for exclusive public participation, when maximization of Consumer Surplus is the sole objective. The toll charges need to be increased significantly (from those indicated in Table 5.3), to make the project economically viable.
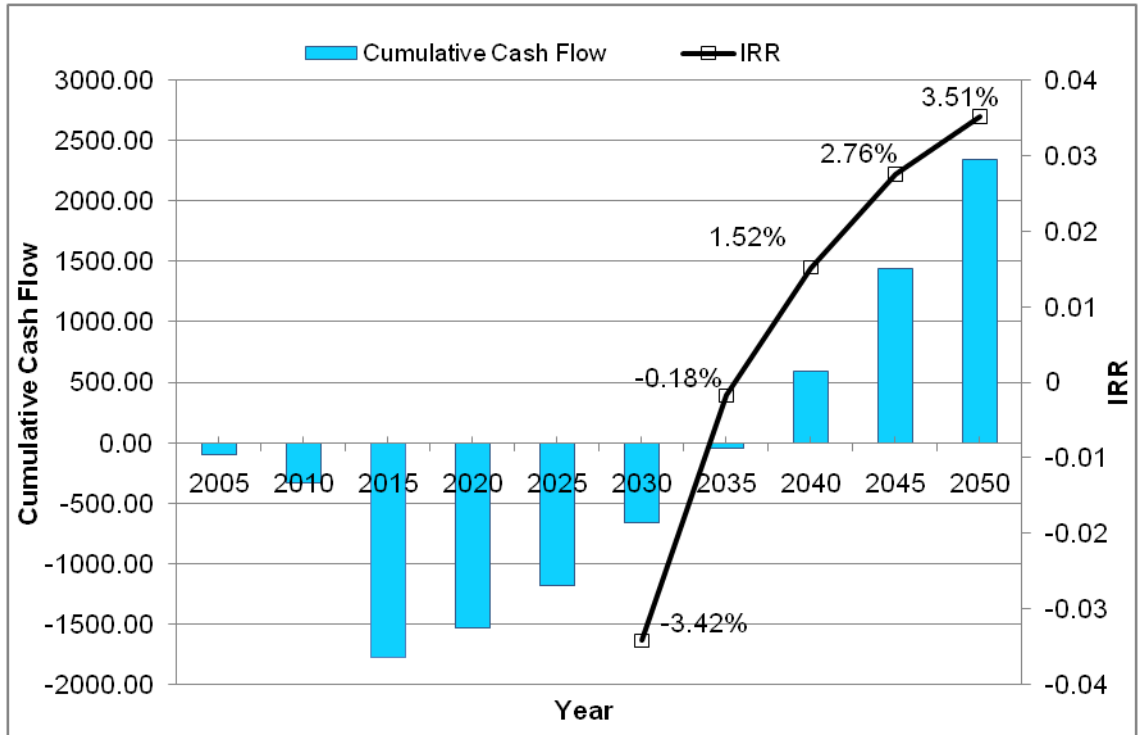
Figure 5.12: Cumulative Cash Flow and IRR Profile for Major Public Participation with Construction Cost Subsidy (OTG-5)

Synthesis of Results for OTG Strategies

The objective of OTG strategy analysis is to formulate a series of joint ownership scenarios for the public and private entities for large scale investments. Five OTG strategies (with different options within certain strategies) were proposed ranging from exclusive private participation to exclusive public participation. The analysis was conducted with an assumed MARR of 6 percent. Results of this analysis are presented in Table 5.7, and can be summarized as follows:

- For exclusive private participation (OTG-1), the project is not financially viable. Further, varying degree of relaxation are proposed in (OTG-2 and OTG-3) to encourage private participation. All relaxation policies in OTG-3 resulted in financially viable solutions for the project.

- For major and exclusive public participation (OTG-4 and OTG-5), the project is not financially viable, with the assumed levels of charges needed for the maximization of consumer surplus.

- In summary, OTG strategies representing joint ownership scenarios provided financial viability for the project analyzed.

Table 5.7: Summary of OTG Strategies

OTG Strategy	Relaxation Policy	IRR (percent)
OTG-1	No Relaxation	4.61
OTG-2		
	Toll Plaza Cost Subsidy	5.14
	Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy	5.89
	Construction Cost Subsidy (50percent)	5.84
OTG-3		
	Construction Cost Subsidy (60percent)	6.13
	Concession Period Extension (27 years)	6.01
	Construction Cost Subsidy and Concession Period Extension	7.20
OTG-4		
	Partly Construction Cost by Private Entity	22.97
	Operation and Maintenance Cost	3.69
	Construction Cost Subsidy-Public Entity	3.95
OTG-5	No Relaxation	3.51

5.6 Risk Analysis

The OTG strategies discussed earlier were incorporated in the risk analysis. Toll values for the horizon years were determined from the uncertainty analysis. The upper and lower limit of the toll value are set using an assumed coefficient of variation of ten percent. MCS technique was used to obtain the simulated cumulative cash flow for design years. Random values are generated with upper and lower limits. The values are used to generate ridership resulting from elastic traffic assignment, and the corresponding operation and maintenance cost. For each random toll value, and the appropriate traffic volume, operation and maintenance cost, the IRR value is estimated. A total of 10,000 such iterations are performed for each OTG strategy, and the corresponding IRR's are recorded. The distribution of all realizations of IRRs for OTG-3 (as an example) is plotted in Figure 5.13.

Procedure for Obtaining VaR

Figure 5.13 shows the mean value of IRR on the horizontal axis, the frequency on primary vertical axis, and the cumulative probabilities on secondary vertical axis for

OTG-3 concession period extension strategy. The mean IRR of the distribution is 6.04 percent. Mean of IRR is determined by drawing an imaginary horizontal line from the 50th percentile on the secondary Y-axis to the cumulative distribution profile. An imaginary vertical line can be drawn from the intersection of 50th percentile line from secondary Y- axis and the cumulative distribution profile to the X-axis.

The mean IRR resulted is 6.04 percent. To determine the five percentile IRR, an imaginary horizontal line can be drawn from the 5 percent of the secondary Y-axis to the cumulative probability distribution profile. Further, a vertical line can be drawn to the X-axis, to determine the five percentile IRR to be 5.99 percent. The VAR for OTG-3 concession period extension is 5.99 percent. In other words, only five times out of 100, the IRR will be less than 5.99 percent, or 95 times out of 100, the IRR will exceed 5.99 percent. The 95th percentile relative VAR is the difference between the mean IRR and the five percentile IRR, i.e. 6.04 percent - 5.99 percent = 0.05 percent.

The 95th percentile relative VaR suggests that the maximum loss in IRR at 95 percent level of confidence cannot exceed 0.05 percent for the OTG-3 concession period extension strategy. Similarly the 90th percent VaR can be determined. The VaR profiles for all the strategies are plotted in Figure 5.14 to Figure 5.24. The 95th and 90th percentile absolute and relative VaR are determined for all the strategies, and presented in Table 5.8.
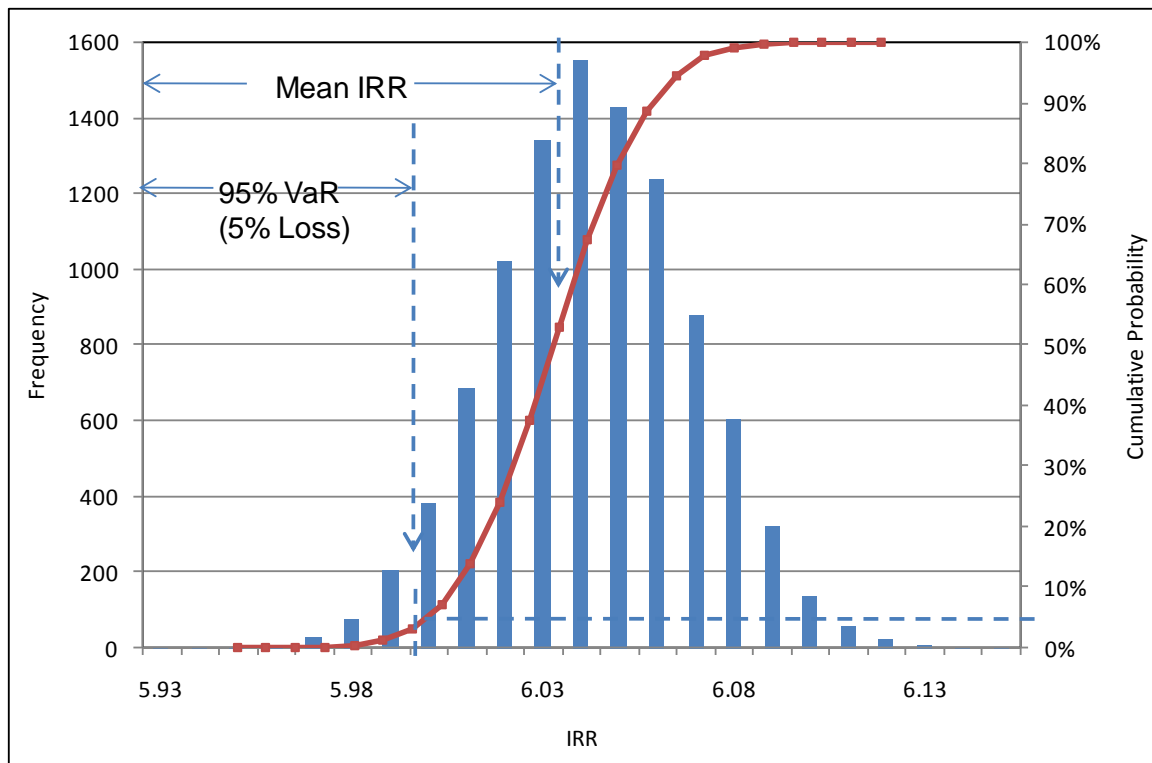
Figure 5.13: Value at Risk for OTG-3 Concession Period Extension
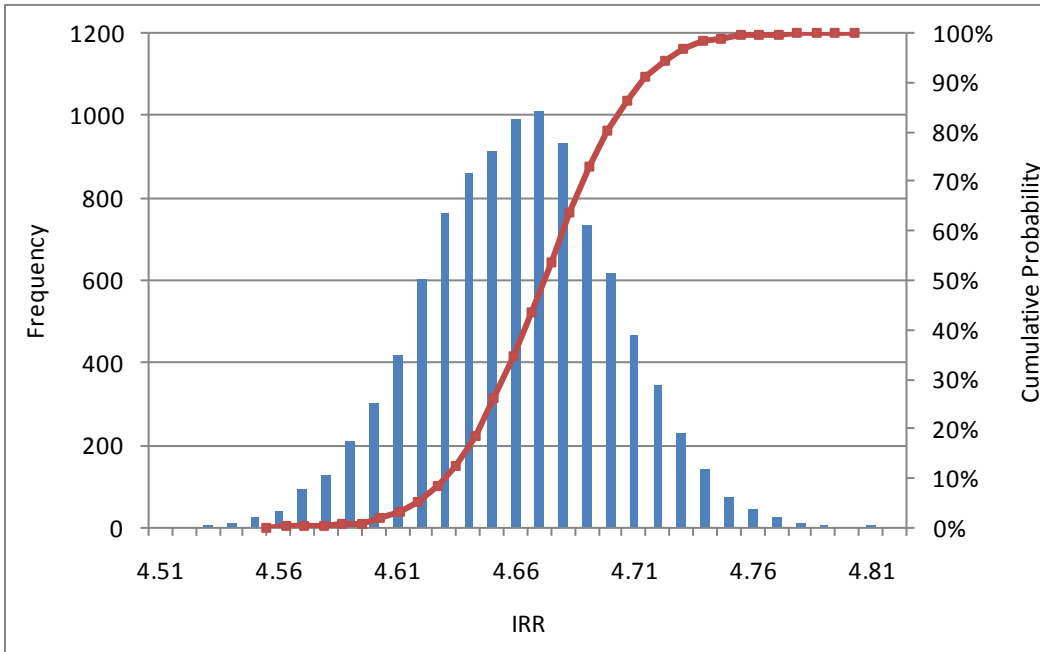
Figure 5.14: Risk Simulation Profile for OTG-1
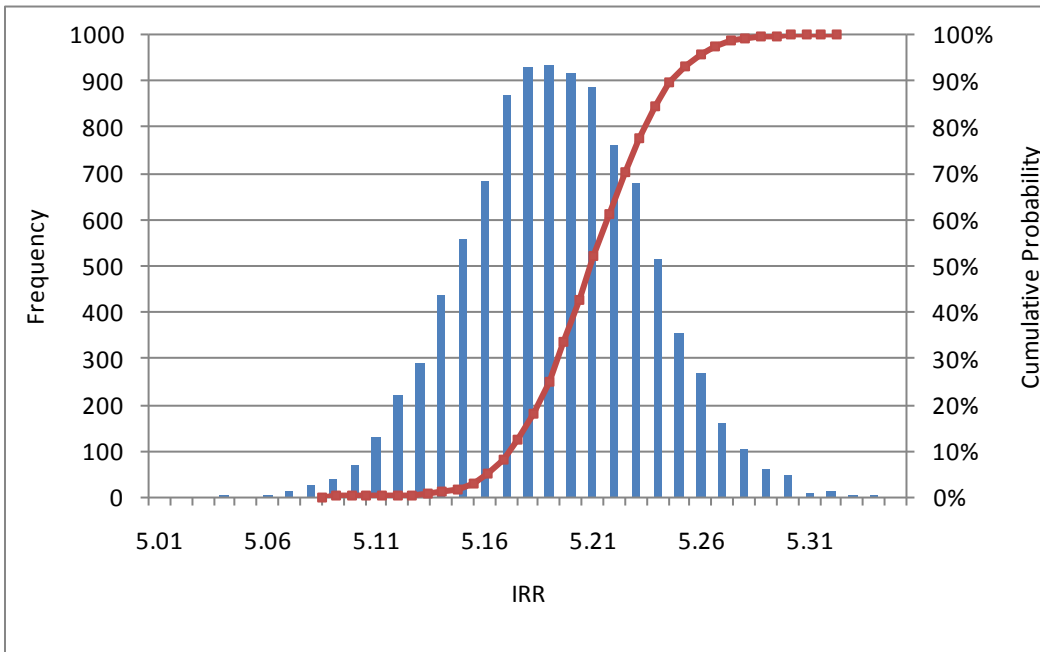
Figure 5.15: Risk Simulation Profile for OTG-2 Toll Plaza Cost Subsidy
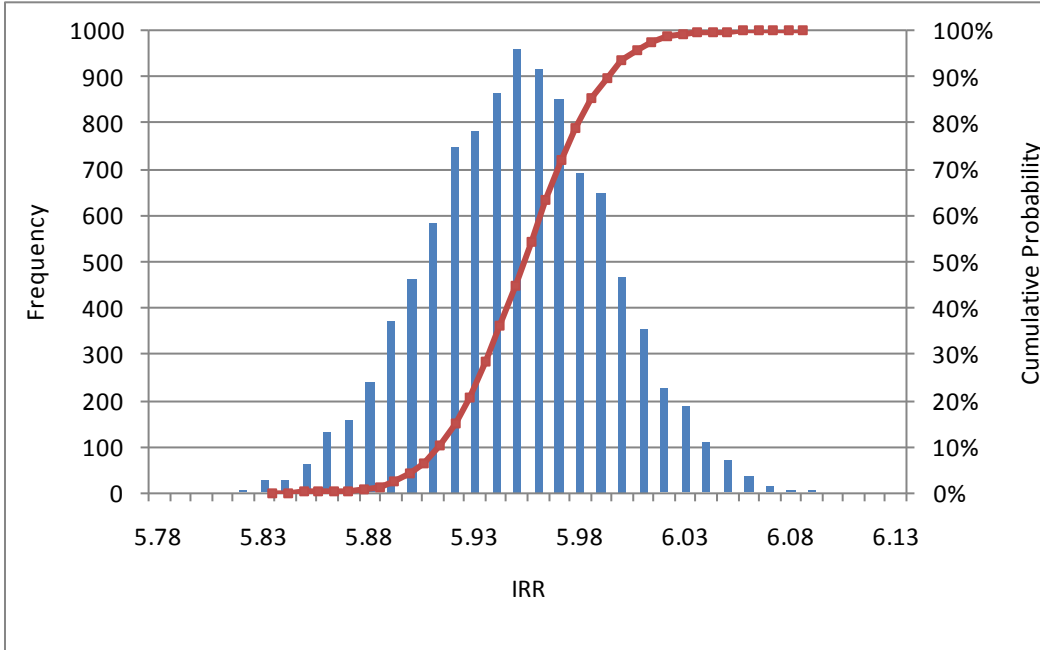
Figure 5.16: Risk Simulation Profile for OTG-2 Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy

Figure 5.17: Risk Simulation Profile for OTG-2 Construction Cost Subsidy

Figure 5.18: Risk Simulation Profile for OTG-3 Construction Cost Subsidy

Figure 5.19: Risk Simulation Profile for OTG-3 Concession Period Extension
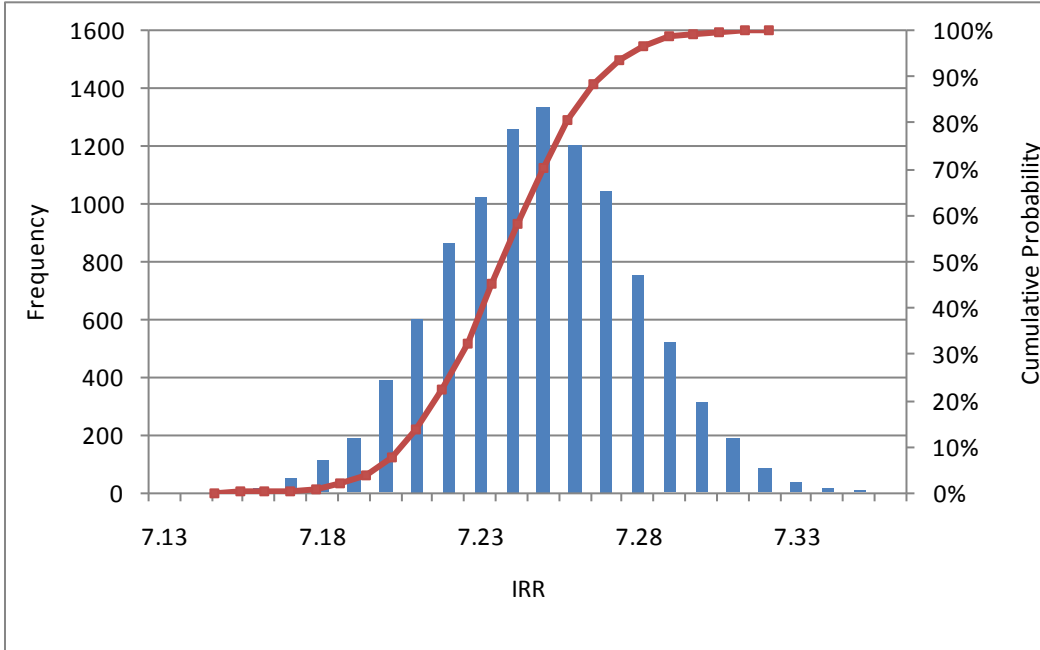
Figure 5.20: Risk Simulation Profile for OTG-3 Construction Cost Subsidy and Concession Period Extension
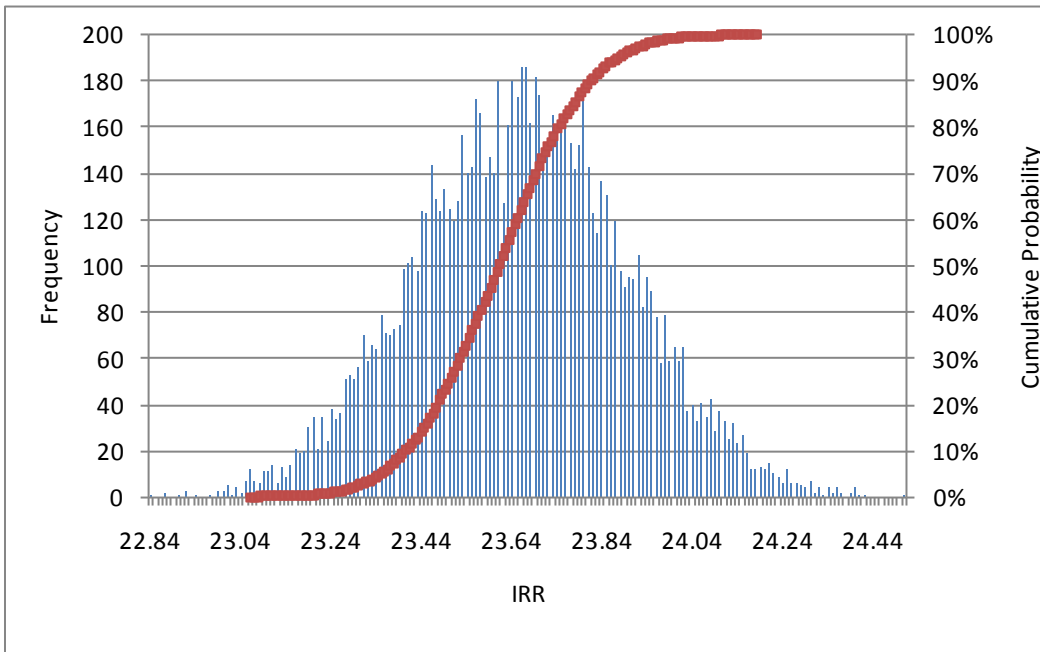
Figure 5.21: Risk Simulation Profile for OTG-4 Construction Cost Subsidy
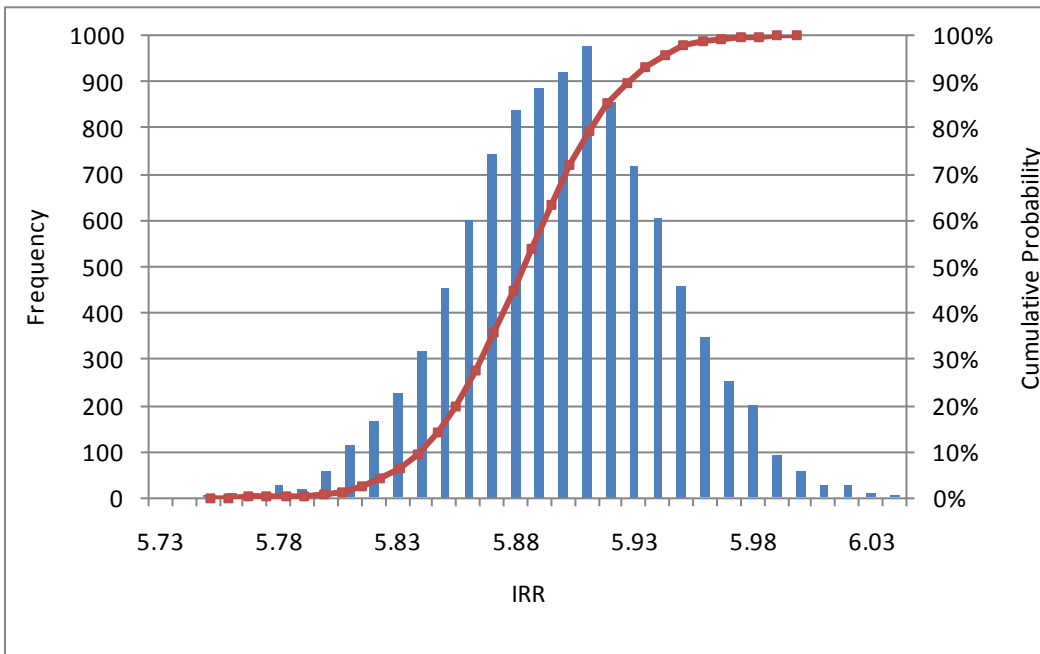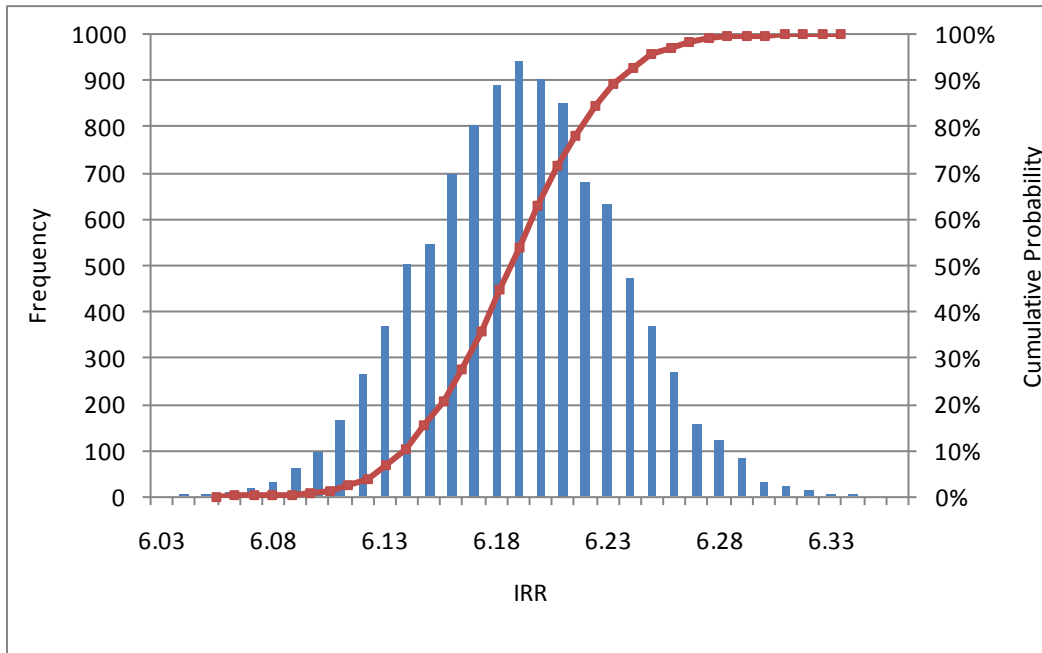
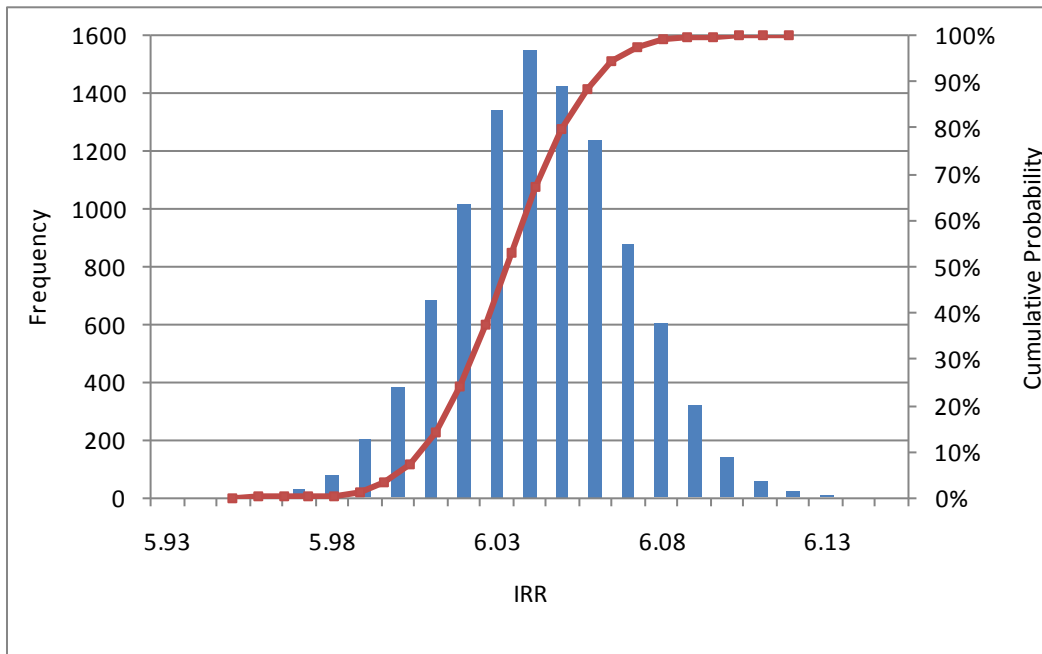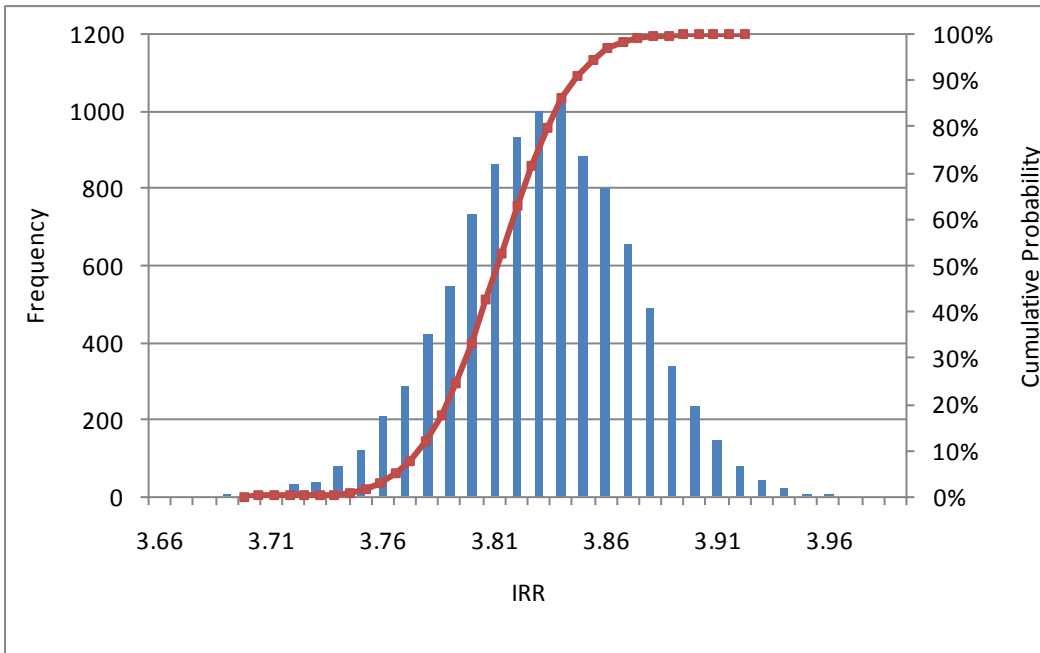Figure 5.22: Risk Simulation Profile for OTG-4 Operation and Maintenance Cost Subsidy
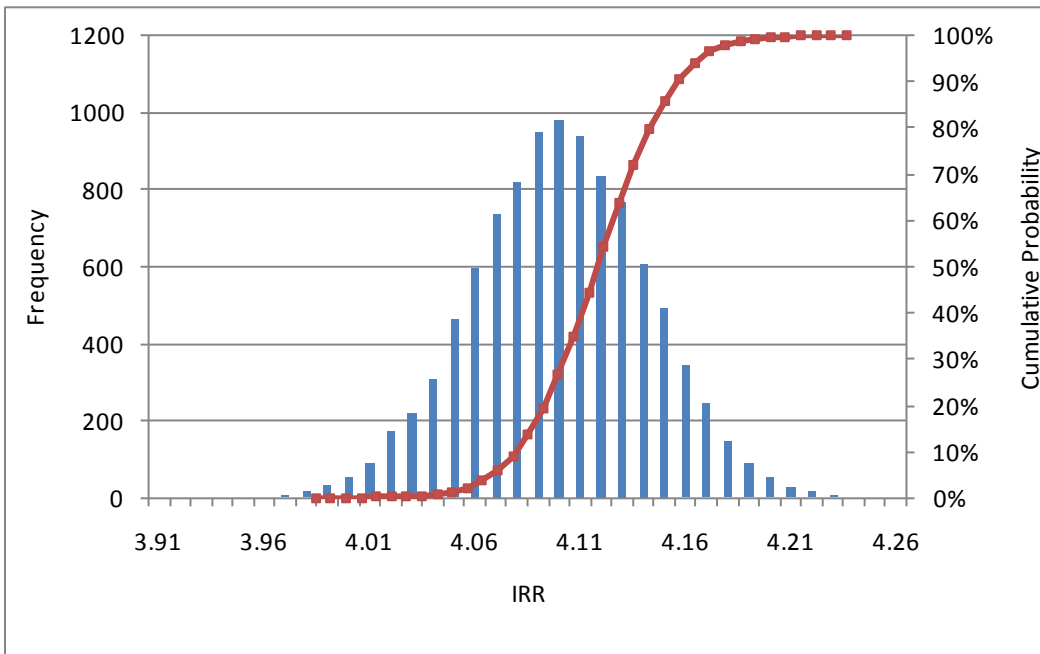
Figure 5.23: Risk Simulation Profile for OTG-4 Public Perspective
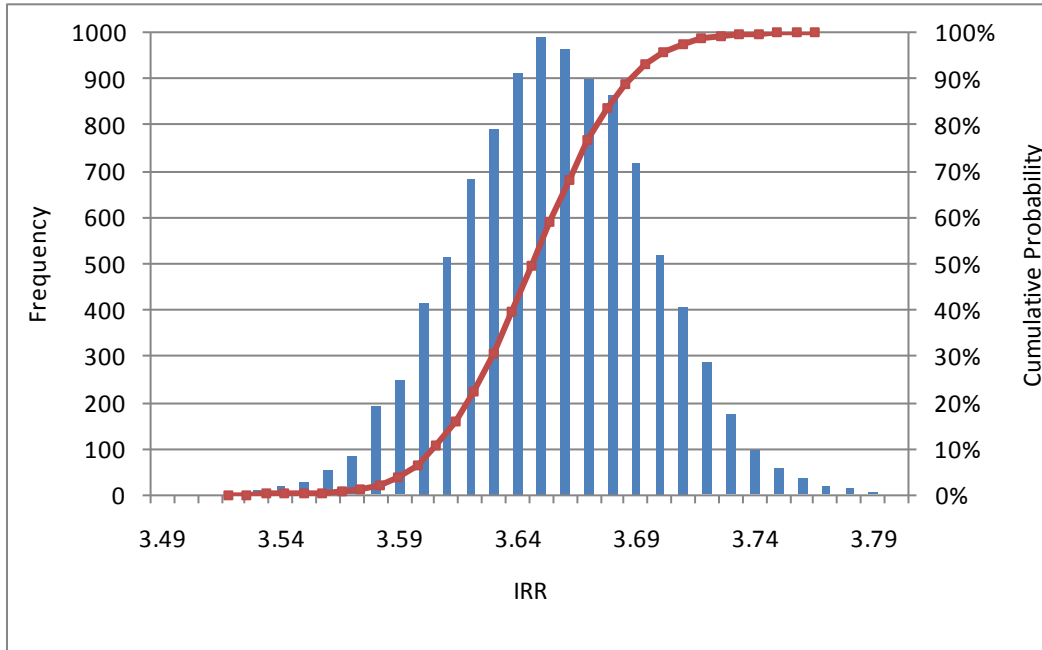
Figure 5.24: Risk Simulation Profile for OTG-5 Public Perspective

Table 5.8: Risk Analysis Summary

OTG Strategy	Relaxation Policy	Mean IRR	95% VaR	90% VaR	95% Relative VaR	90% Relative VaR
OTG-1	No Relaxation	4.66%	4.58%	4.59%	0.08%	0.07%
OTG-2	1. Toll Plaza Cost Subsidy	5.19%	5.10%	5.11%	0.09%	0.08%
	2. Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy	5.95%	5.86%	5.88%	0.08%	0.07%
	3. Construction Cost Subsidy	5.90%	5.81%	5.83%	0.08%	0.07%
OTG3	1. Construction Cost Subsidy	6.19%	6.10%	6.12%	0.09%	0.07%
	2. Concession Period Extension	6.04%	5.99%	6.00%	0.05%	0.04%
	3. Construction Cost Subsidy and Concession Period Extension	7.24%	7.18%	7.19%	0.06%	0.05%
OTG-4	1. Partly Construction Cost by Private Entity	23.66%	23.19%	23.27%	0.46%	0.39%
	2. Operation and Maintenance Cost	3.83%	3.74%	3.76%	0.09%	0.07%
	3. Public Entity	4.10%	4.01%	4.02%	0.08%	0.08%
OTG-5	No Relaxation	3.65%	3.55%	3.59%	0.10%	0.07%

5.7 Sensitivity Analysis

In the preceding section, a detailed analysis of various types of benefits or benefit surrogate (revenue and consumer surplus) for different toll structures for the proposed DRIC was presented. With DRIC included, there will be four river crossings in the region (DRIC, AMB, DWT and BWB), that have the ability to attract trip pertaining to the same trip table for the different horizon years tested. The purpose of the sensitivity analysis presented in this section is to demonstrate if the traffic attracted to the four crossings is affected by the toll structure, and if the resulting changes in DRIC traffic follow reasonable trends. The number of trips assigned to each bridge is a function of the traffic assignment routine, and some critical assumptions. The process and the assumptions are outlined below.

- The traffic assignment process is developed as a TransCAD add in for determining the objective of three entities.

- The toll value (the equivalent value of time) is added to the travel time to determine the composite cost. (One hour of travel time saved was assumed to be equal to eight dollars)

- The composite cost is further used to determine the skim (shortest path).

- The standard Bureau of Public Roads travel time function is used in the equilibrium assignment method.

Table 5-9 shows the fares used in the assignment process for the other three bridges. For the year 2015, the toll structure reflects the current tolls. For succeeding years, a three percent annual increase has been assumed. Also for DWT, (with severe height restrictions for truck traffic), an artificially high toll charge is used to ensure that no truck traffic is assigned on DWT. For, DRIC, these toll strucuture used is already discussed and presented in Table 5.1 (That is reproduced in the section for the sake of continuity).

In Table 5.10, the results of the traffic assignment (Peak hour) and the corresponding traffic volumes on the four crossings are shown, for different toll structures along with the revenue expected from a private prospective. For the other three bridges, the toll structure is held at a constant value. Table 5.10 shows that the traffic volumes on the different bridges vary along with the revenue collected. Essentially, the trends depicted are reasonable, in that, reduced tolls are associated with higher demand and vice-versa, and the maximum revenue for DRIC shown in Table 5.1 is never exceeded. Table 5.10 also shows that the sum total of a crossing volume on the four crossings remain unchanged in a given year; but their distribution among the four crossings changes as the toll structure is changed. The crossing volumes, along with the assumed toll charges are used to estimate the revenue.

In order to test the sensitivity of the model (assignment procedure) to fare changes a number of hypothetical scenarios were tested, only two of which are presented here for the sake of brevity. In Table 5.11, lower toll charges for DRIC (compared to one used in Table 5.10) for the years 2025, 2035, 2045, and 2050 were used, keeping the tolls for the remaining bridges

unchanged. Table 5.11 shows only the analysis from the prospective of the private entity. It shows that lower toll charges for DRIC result in higher volume but lower revenue for the DRIC, with the stipulation that the total crossing volume on all the crossings combined remain unchanged.

A similar experimental analysis is presented in Table 5.12, where the toll charges on DRIC are purposely kept at an inordinately low levels with the other toll charges unchanged. Table 5.12 shows that the low toll charges results in inordinately high volumes on DRIC, with the provision that the sum total of all crossings remain constant for each horizon year. It also shows that inspite of the very high volume level on DRIC, the revenue collected from DRIC is considerably lower than the optimal revenues presented in Table 5.10, thereby supporting the hypothesis, that the revenue is indeed maximized at the optimal toll charges on DRIC.

Table 5.1: Base Case (Report Data) (Reproduced for convenient reading)

Year	Car-Toll($)	Truck Toll($)	Annual Revenue (Million $)	Annual Consumer Surplus (Million $)	Theil's Inequality Index
2015					
Private Perspective	2.00	14.00	68.54	346.07	0.86
Public Perspective	0.50	4.33	25.78	730.36	0.79
User Perspective	0.25	1.04	7.41	258.62	0.70
2025					
Private Perspective	3.00	15.00	118.22	550.98	0.88
Public Perspective	0.78	5.28	43.65	1091.91	0.81
User Perspective	0.52	2.06	19.53	352.60	0.68
2035					
Private Perspective	4.50	19.00	199.30	681.45	0.88
Public Perspective	1.28	6.75	73.70	1343.04	0.79
User Perspective	0.86	3.35	40.02	464.08	0.72
2045					
Private Perspective	6.00	21.00	281.95	802.24	0.86
Public Perspective	1.75	7.41	105.42	1594.95	0.80
User Perspective	1.26	4.52	68.13	565.78	0.74
2050					
Private Perspective	8.73	22.25	330.63	936.19	0.88
Public Perspective	1.93	7.82	125.19	1664.37	0.72
User Perspective	1.60	5.70	96.22	685.32	0.67

Table 5.9: Car & Truck Toll on AMB, DWT&BWB (Base Case – 3percent Toll increase)

Bridge	Year	Car Toll ($)	Truck Toll ($)
AMB	2015	4.00	20.00
	2025	5.38	26.88
	2035	7.23	36.12
	2045	9.72	48.55
	2050	11.26	56.28
DWT	2015	3.75	5000.00
	2025	5.04	5000.00
	2035	6.77	5000.00
	2045	9.10	5000.00
	2050	10.55	5000.00
BWB	2015	2.00	15.00
	2025	2.69	20.16
	2035	3.61	27.09
	2045	4.85	36.41
	2050	5.63	42.21

Table 5.10: Base Case Summary & Revenue on DRIC, AMB, DWT & BWB:

1	2	3	4	5	6	7		8	9	10		11	12	13	14
Year	DRIC Car-Toll($) (Toll for AMB,DWT and BWB Bridge)	DRIC Truck-Toll($) (Toll for AMB,DWT and BWB Bridge)	Peak Hour Car-Volume					Peak Hour Truck Volume				Annual Revenue (Million $)			
			DRIC	AMB	DWT	BWB	Total	DRIC	AMB	BWB	Total	DRIC	AMB	DWT	BWB
2015															
Private	2 (4,3.75,2)	14 (20,5000[19],15)	1201	1305	1178	824	4509	901	22	371	1294	69	26	20	33
Public	0.5 (4,3.75,2)	4.33 (20,5000,15)	1861	821	1012	814	4509	1090	0	205	1294	26	15	17	21
User	0.25 (4,3.75,2)	1.04 (20,5000,15)	1948	799	950	812	4509	1094	0	201	1295	7	15	16	21
2025															
Private	3 (5.38,5.04,2.69)	15 (26.88,5000,20.16)	1499	1296	1212	919	4926	1428	0	298	1725	118	32	21	29
Public	0.78 (5.38,5.04,2.69)	5.28 (26.88,5000,20.16)	2376	744	906	900	4926	1461	0	266	1727	44	18	16	26
User	0.52 (5.38,5.04,2.69)	2.06 (26.88,5000,20.16)	2431	715	882	898	4926	1464	0	263	1727	20	18	15	26
2035															
Private	4.5 (7.23,6.77,3.61)	19 (36.12,5000,27.09)	2024	995	1274	970	5264	1820	0	355	2175	199	33	22	33
Public	1.28 (7.23,6.77,3.61)	6.75 (36.12,5000,27.09)	2848	615	860	941	5263	1853	0	322	2175	74	20	15	31
User	0.86 (7.23,6.77,3.61)	3.35 (36.12,5000,27.09)	2937	558	830	938	5263	1864	0	311	2176	40	18	14	30
2045															
Private	6 (9.72,9.10,4.85)	21 (48.55,5000,36.41)	2482	916	1287	1031	5716	2234	0	376	2610	282	41	22	35
Public	1.75 (9.72,9.10,4.85)	7.41 (48.55,5000,36.41)	3538	401	792	986	5717	2283	0	327	2610	105	18	14	31
User	1.26 (9.72,9.10,4.85)	4.52 (48.55,5000,36.41)	3622	351	759	984	5717	2294	0	316	2610	68	16	13	31
2050															
Private	8.73 (11.26,10.55,5.63)	22.25 (56.28,5000,42.21)	2113	1299	1477	1029	5917	2428	0	384	2812	331	67	25	36
Public	1.93 (11.26,10.55,5.63)	7.82 (56.28,5000,42.21)	3946	255	752	965	5919	2535	0	277	2812	125	13	13	28
User	1.6 (11.26,10.55,5.63)	5.7 (56.28,5000,42.21)	4027	198	731	963	5919	2569	0	243	2812	96	10	13	25

[19] High truck toll for DWT because of severe height restrictions for truck traffic

Table 5.11 – Summary Sheet 1 (Toll and Revenues of all bridges mentioned in Table 5.9):

1	2	3	4	5	6	7		8	9	10		11	12	13	14
Year	DRIC Car-Toll($) (Toll for AMB,DWT and BWB Bridge)	DRIC Truck-Toll($) (Toll for AMB,DWT and BWB Bridge)	Peak Hour Car-Volume					Peak Hour Truck Volume				Annual Revenue (Million $)			
			DRIC	AMB	DWT	BWB	Total	DRIC	AMB	BWB	Total	DRIC	AMB	DWT	BWB
2015															
Private	2 (4,3.75,2)	15 (20,5000,15)	1201	1305	1178	824	4509	901	22	371	1294	69	26	20	33
2025															
Private	2.69 (6.21,5.82,2.44)	20.16 (31.06,5000,18.28)	2062	852	1091	918	4924	1004	0	722	1725	118	24	29	70
2035															
Private	3.61 (9.65,9.04,2.97)	27.09 (48.23,5000,22.29)	2871	575	852	964	5262	1157	0	1018	2175	190	25	35	117
2045															
Private	4.85 (14.98,14.04,3.62)	36.41 (74.91,5000,27.17)	3975	68	646	1027	5716	1055	0	1554	2610	263	5	41	210
2050															
Private	5.62 (18.67,17.50,4.42)	42.21 (93.35,5000,33.12)	4450	2	463	1002	5917	1061	0	1751	2812	318	0	37	285

Table 5.12 – Summary Sheet 2 (Toll and Revenues of all bridges mentioned in Table 5.9):

1	2	3	4	5	6	7		8	9	10		11	12	13	14
Year	DRIC Car-Toll($) (Toll for AMB,DWT and BWB Bridge)	DRIC Truck-Toll($) (Toll for AMB,DWT and BWB Bridge)	Peak Hour Car-Volume					Peak Hour Truck Volume				Annual Revenue (Million $)			
			DRIC	AMB	DWT	BWB	Total	DRIC	AMB	BWB	Total	DRIC	AMB	DWT	BWB
2015															
Private	0.39 (4,3.75,2)	2.25 (20,5000,15)	1895	813	987	813	4509	1092	0	202	1294	15	15	17	21
2025															
Private	0.66 (6.21,5.82,3.11)	3.47 (31.06,5000,23.29)	2549	643	836	897	4926	1469	0	257	1727	31	18	22	40
2035															
Private	1.05 (9.65,9.04,4.82)	4.06 (48.23,5000,36.18)	3362	292	678	930	5262	1891	0	284	2175	51	13	28	67
2045															
Private	1.26 (14.98,14.04,7.49)	4.52 (74.91,5000,56.18)	4332	4	432	949	5716	2433	0	177	2610	75	0	28	78
2050															
Private	1.93 (18.67,17.50,9.33)	7.82 (93.35,5000,70.01)	4695	0	300	921	5916	2734	0	78	2812	139	0	24	64

5.8 Integration of Uncertainty and Risk

Uncertainty and risk are addressed individually in earlier sections of this chapter. The implications of both uncertainty and risk are important from an investment viewpoint. The purpose of this section is to integrate the concepts of uncertainty and risk for exploring favorable options for the DRIC. For the uncertainty analysis, the IRR is the MOE for all the OTG strategies considered and analyzed. Likewise, for risk analysis, VaR is the MOE for the all the OTG strategies. MOE's for uncertainty and risk analysis are presented in Figure 5.25 to investigate the combined effect of both features on the OTG strategies analyzed. In Figure 5.25, the MOE of uncertainty (IRR) is considered in the X-axis, and MOE of risk (VaR) is considered in the Y-axis.

The most favorable OTG strategy is the one with highest IRR and the least relative VaR, while all favorable OTG strategies should have IRR's greater than the six percent (MARR). Four OTG strategies resulted in IRR of greater than six percent. The highest IRR (23.66 percent) resulted for the OTG-4 strategy for the private entity with construction cost subsidy. For the same OTG strategy, relative VaR is also the highest (0.46 percent, at 95 percent level of confidence), which makes the OTG strategy vulnerable to future risks. From the remaining feasible strategies, the combination of construction cost subsidy and concession period extension strategy (OTG-3) resulted in an IRR of 7.24 percent and a relative VaR is 0.06 percent at 95 percent level of confidence. However, all the OTG3 strategies appear to be feasible with higher IRRs and lower relative VaR.

Figure 5.25: Integration of Uncertainty and Risk

5.9 Summary

The summary of case study and results chapter is as follows:

- The input data for the case study is discussed.

- The optimal values for the single entity perspectives are determined form uncertainty analysis.

- A number of investment OTG strategies are considered for the DRIC considering uncertainty analysis.

- The economic feasibility of OTG strategies are discussed.

- The OTG strategies are further considered for risk analysis.

- VaR for all the OTG strategies are determined.

- An approach for integrating both uncertainty and risk is proposed.

- Favorable OTG strategies are proposed for further consideration from integration of uncertainty and risk analysis.

- The feasibility of OTG strategies discussed in this chapter are for single entity consideration with relaxation of the cost elements or the concession period. In the next chapter OTG strategies from multi entity perspectives are discussed.

CHAPTER 6

MULTI-OBJECTIVE DECISIOIN MAKING

6. 1 Introduction

In the last chapter, single entity perspective results were presented primarily focusing on the private entity. Each single entity perspective results only satisfy the objective of the entity considered. For successful implementation of the infrastructure project, it is imperative that the objectives of each of the three entities are at least partly satisfied. In this chapter, objectives of all the entities are considered in one step in a multi-objective decision making framework.

6.2 Multi-objective Optimization

The proposed multi-objective optimization entails the consideration of the objectives of each of the three entities: private, public, the user; profit maximization, consumer surplus maximization, and inequality minimization. The objectives of three entities are converted to a single objective function, subjected to a set of constraints. A weighted sum approach is adapted to incorporate the objectives of the three entities in a single step. Details of the weighted sum approach were explained in chapter 3 in the section entitled "Multi-objective optimization". A discritization level of 0.1 is considered to make 121^1 combinations of multi-objective solutions.

As discussed earlier, the multi-objective optimization produces a set of solutions as opposed to a single optimum solution. Each realization in the multi- objective optimization is plotted in three two dimensional graphs. A set of pair- wise comparisons among the three entity objectives for the year 2015 is presented in Figure 6.1 through 6.3, in the form of Pareto diagrams.

The pareto diagrams present non-dominated^2 solution points as shown in the connected lines in Figures 6.1 through 6.3. The graphs also contain points which are dominated (the bottom part in Figure 6.1, and the top part in Figure 6.2 and 6.3). The non dominated solution points are connected by a line with two extreme points representing the maximum values of each objective function. The extreme left point on the line in Figure 6.1 represents $25 million of revenue and $720 million of consumer surplus. The extreme right point on the line in Figure 6.1 represents $68 million of revenue and $340 million of consumer surplus. As explained earlier, the multi objective optimization provides a set of solutions in favor of the entities involved. In between the two extreme points of the line in Figure 6.1, there are a number of optimal solutions to consider for the two entities.

In Figure 6.2, pareto optimal solution for profit maximization and inequality minimization is

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[1] The discritization level of 0.1 results in 11 combinations for each entity making 11 x 11 (i.e. 121) combination for three entities.

[2] The non-dominated solution points are the ones those have dominated some of the counterparts of the solution points in the pareto diagram.

presented for the year 2015. The extreme non dominated point on the extreme right (revenue) corresponds to $68 million and 0.85 of Theil's Index. Similarly, the extreme non dominated point on right is the juncture of $7 million of revenue and 0.71 of Theil's index. The pareto frontier in Figure 6.2 consists of other optimal solutions as trade-offs in the objectives between profit maximization and inequality minimization. Similarly, a pareto optimal solution for consumer surplus and Theil's Index is presented in Figure 6.3. The observation of the pareto optimal solutions are similar to that of the Figure 6.2.

   Similar pareto optimal solutions for all the years are presented in Figure 6.4 through 6.15, that provide insights for trade-off analysis. The extent to which the trade-offs can be considered depends upon the preference of decision makers. AHP techniques discussed in Chapter 3 are used to obtain feasible solution based upon multi-objective optimization. Details of AHP procedure are explained in the next section.
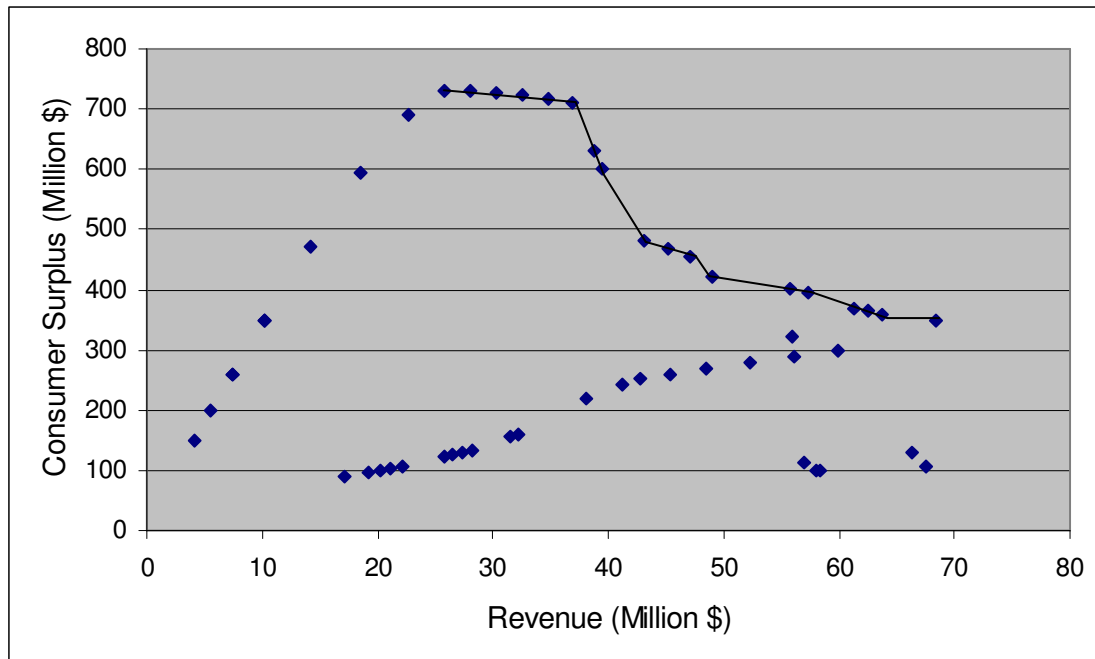

Figure 6.1: Pareto-Optimal Solution for Profit and Consumer Surplus Maximization in 2015.
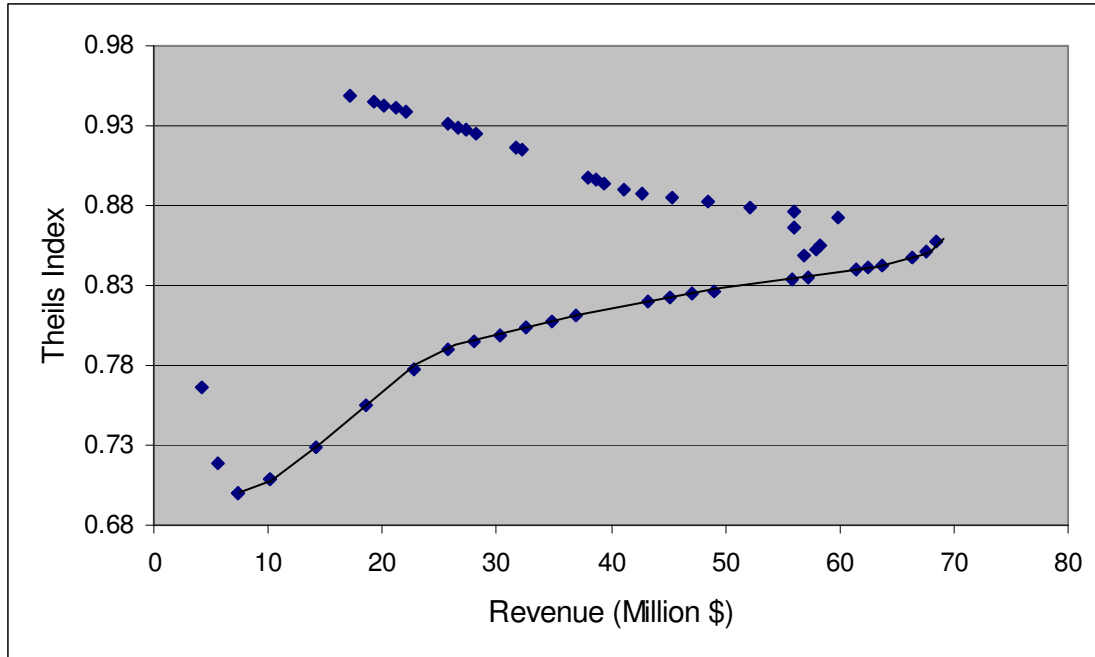
Figure 6.2: Pareto-Optimal Solution for Profit Maximization and Inequality Minimization in 2015.
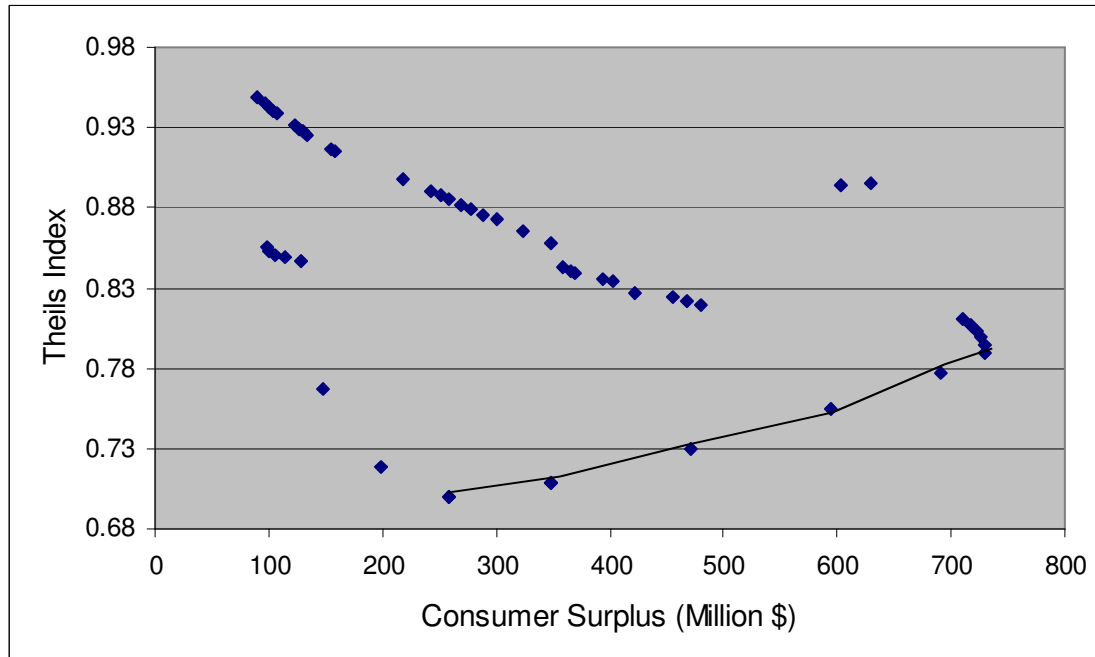

Figure 6.3: Pareto-Optimal Solution for Consumer Surplus Maximization and Inequality Minimization in 2015.
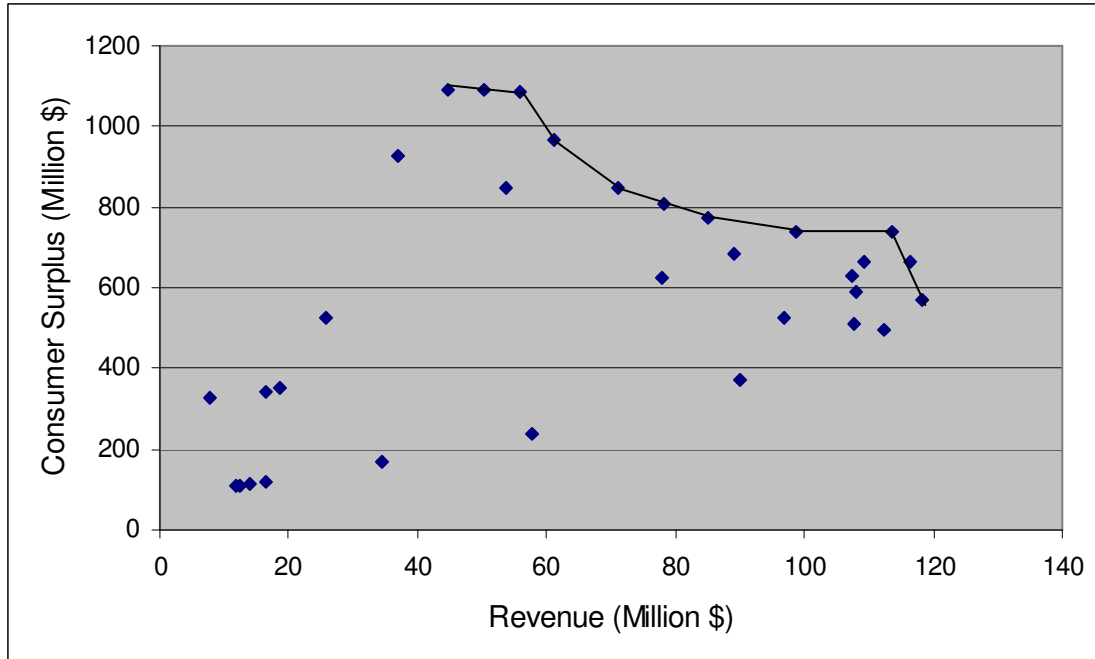
Figure 6.4: Pareto-Optimal Solution for Profit and Consumer Surplus Maximization in 2025.
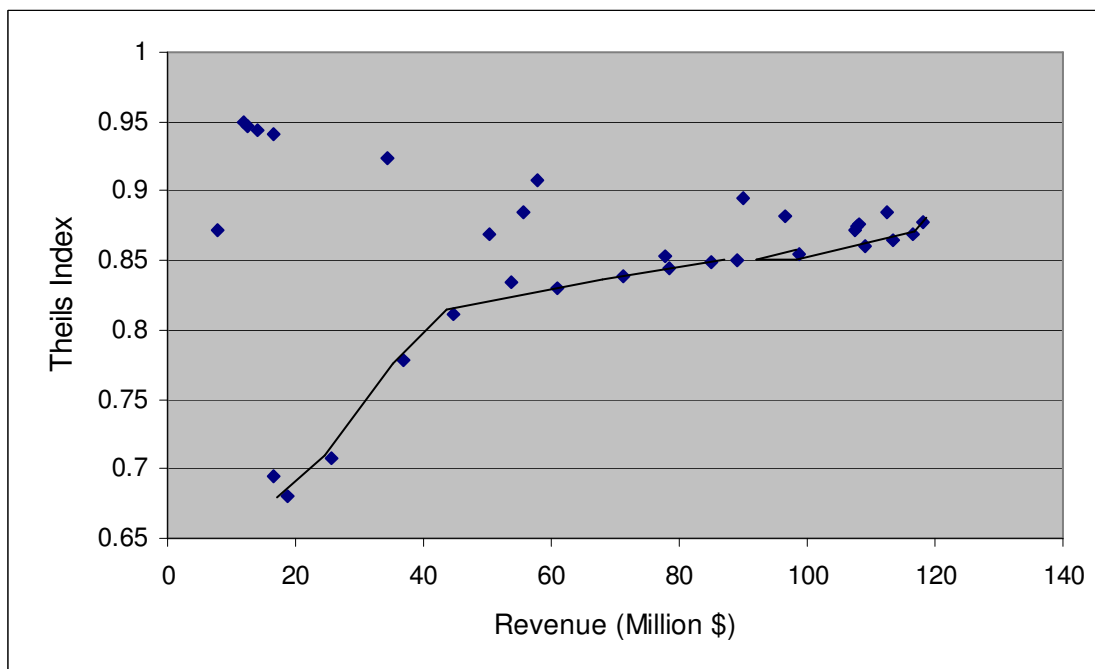

Figure 6.5: Pareto-Optimal Solution for Profit Maximization and Inequality Minimization in 2025.

Figure 6.6: Pareto-Optimal Solution for Consumer Surplus Maximization and Inequality Minimization in 2025.

Figure 6.7: Pareto-Optimal Solution for Profit and Consumer Surplus Maximization in 2035.

Figure 6.8: Pareto-Optimal Solution for Profit Maximization and Inequality Minimization in 2035.
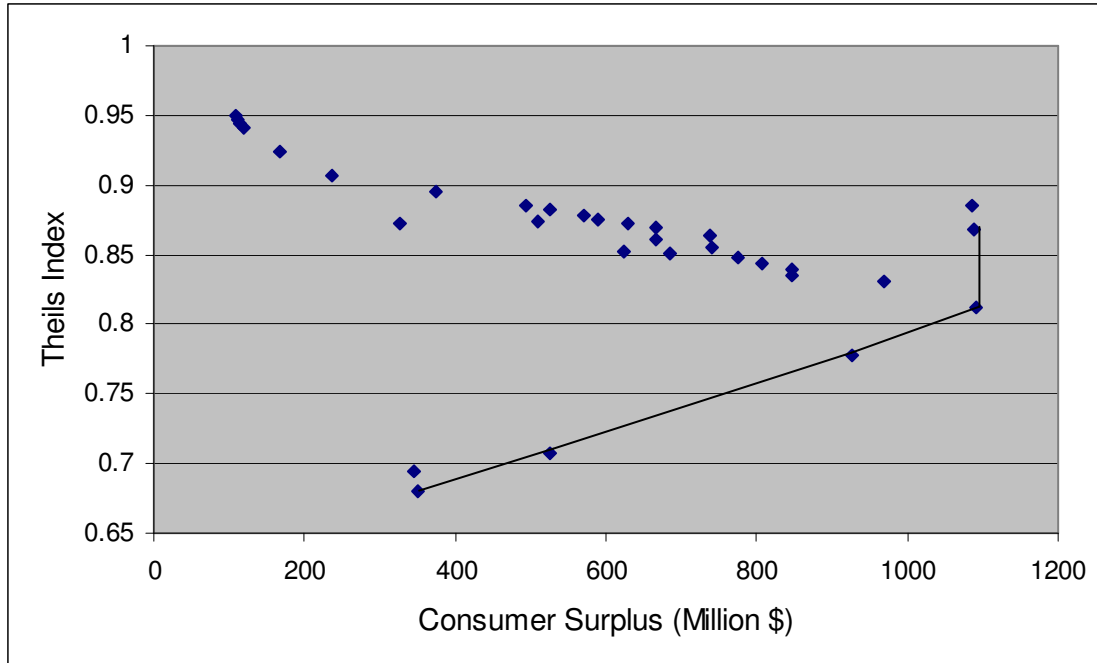

Figure 6.9: Pareto-Optimal Solution for Consumer Surplus Maximization and Inequality Minimization in 2035.

Figure 6.10: Pareto-Optimal Solution for Profit and Consumer Surplus Maximization in 2045.

Figure 6.11: Pareto-Optimal Solution for Profit Maximization and Inequality Minimization in 2045.

Figure 6.12: Pareto-Optimal Solution for Consumer Surplus Maximization and Inequality Minimization in 2045.
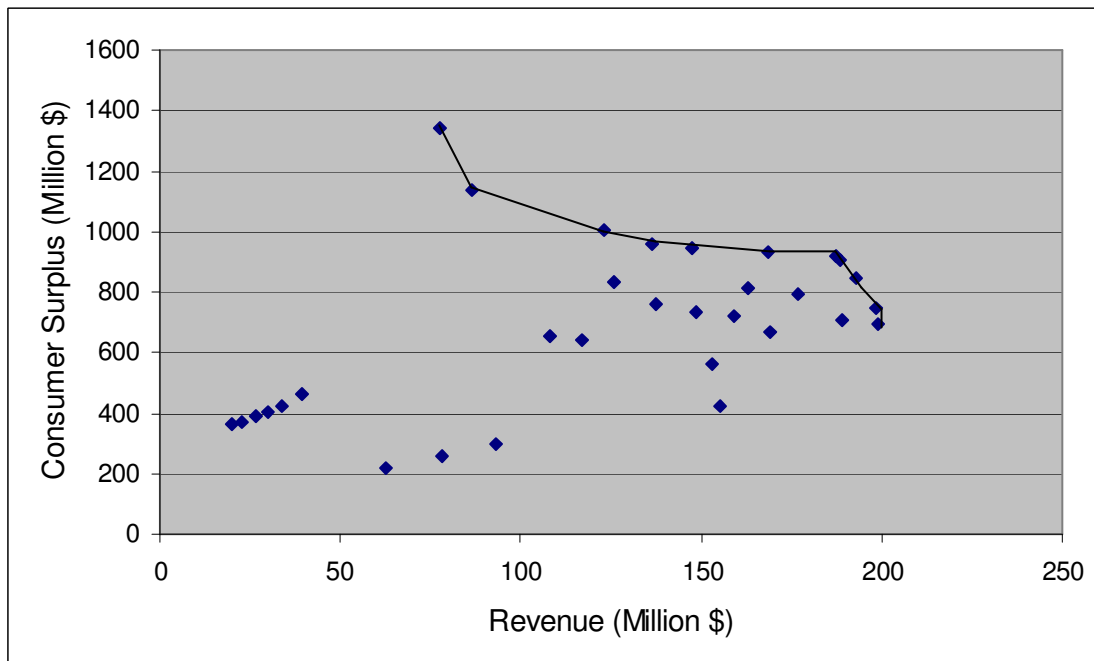

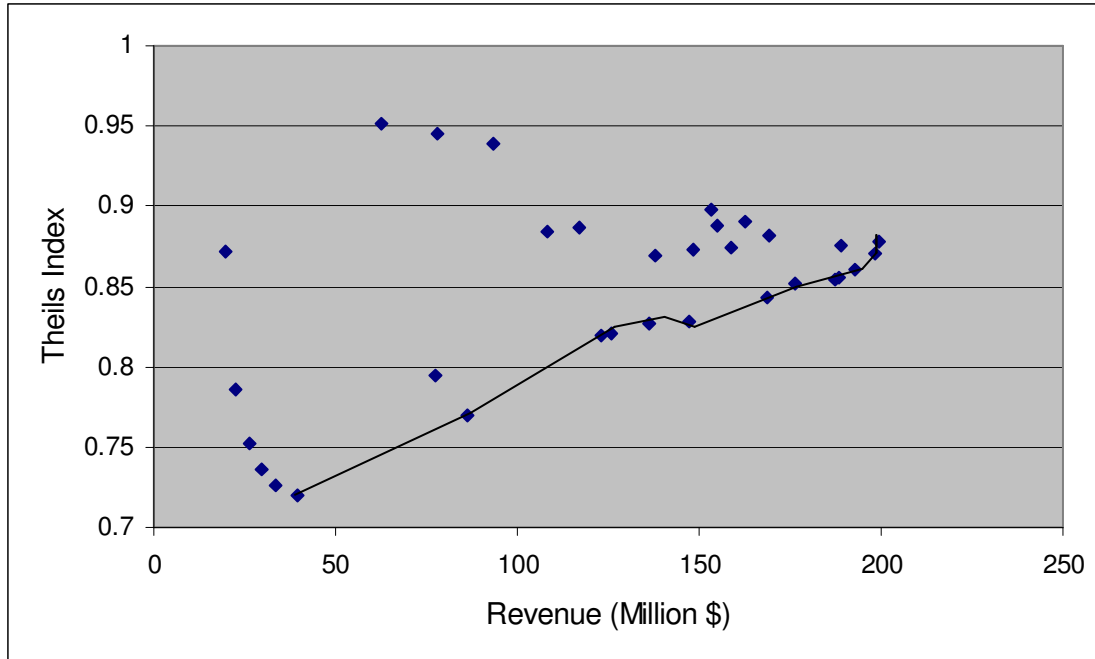Figure 6.13: Pareto-Optimal Solution for Profit and Consumer Surplus Maximization in 2050.

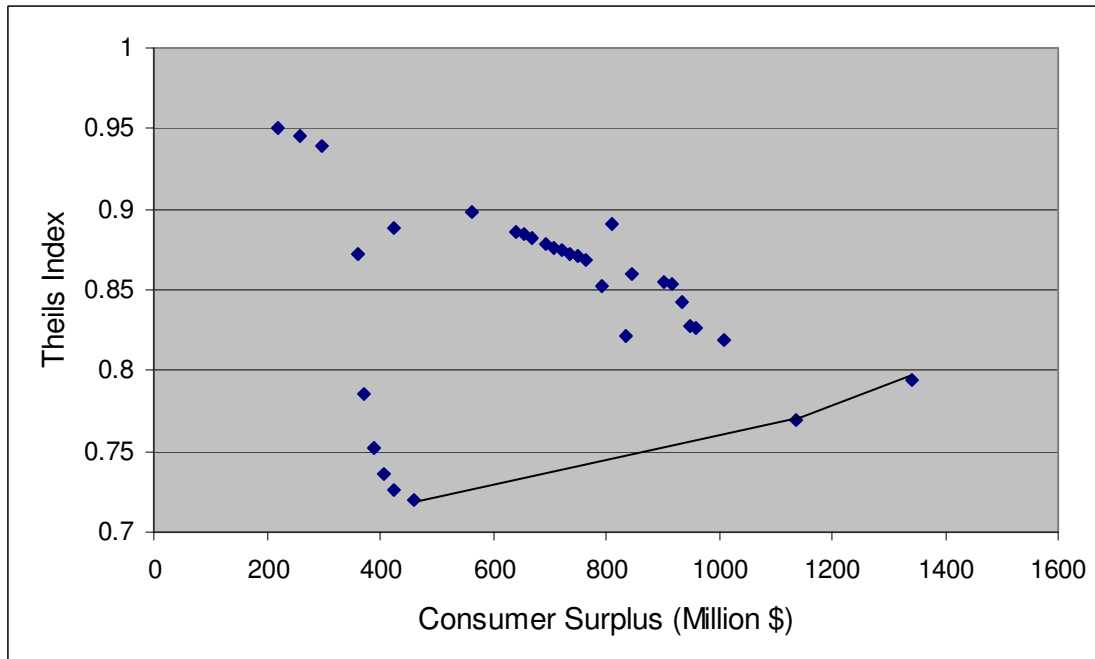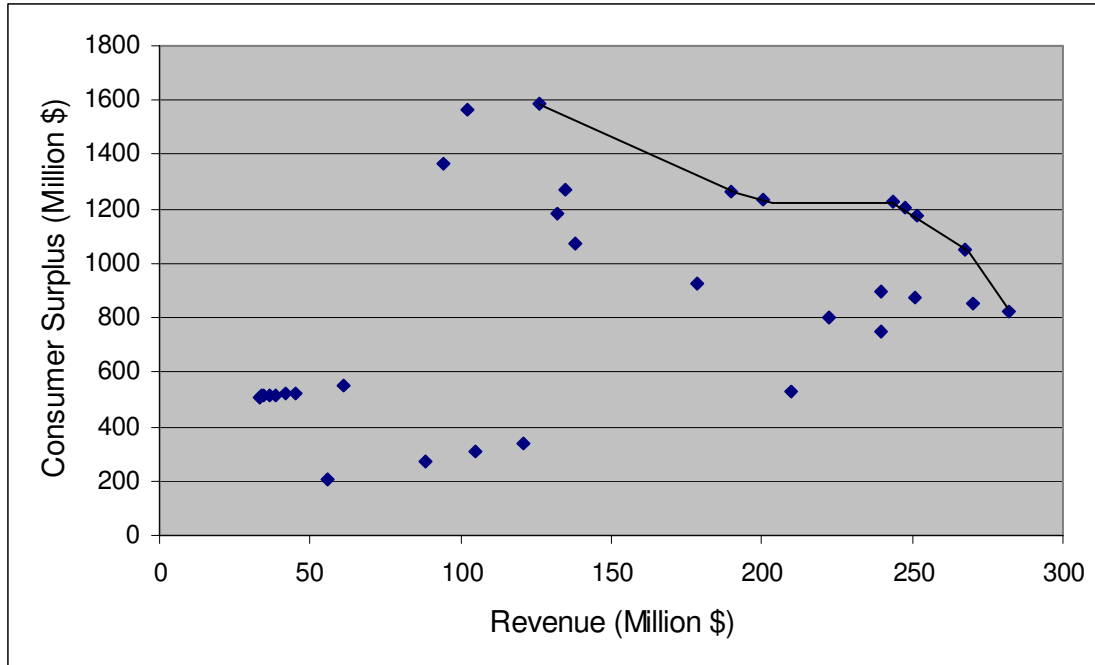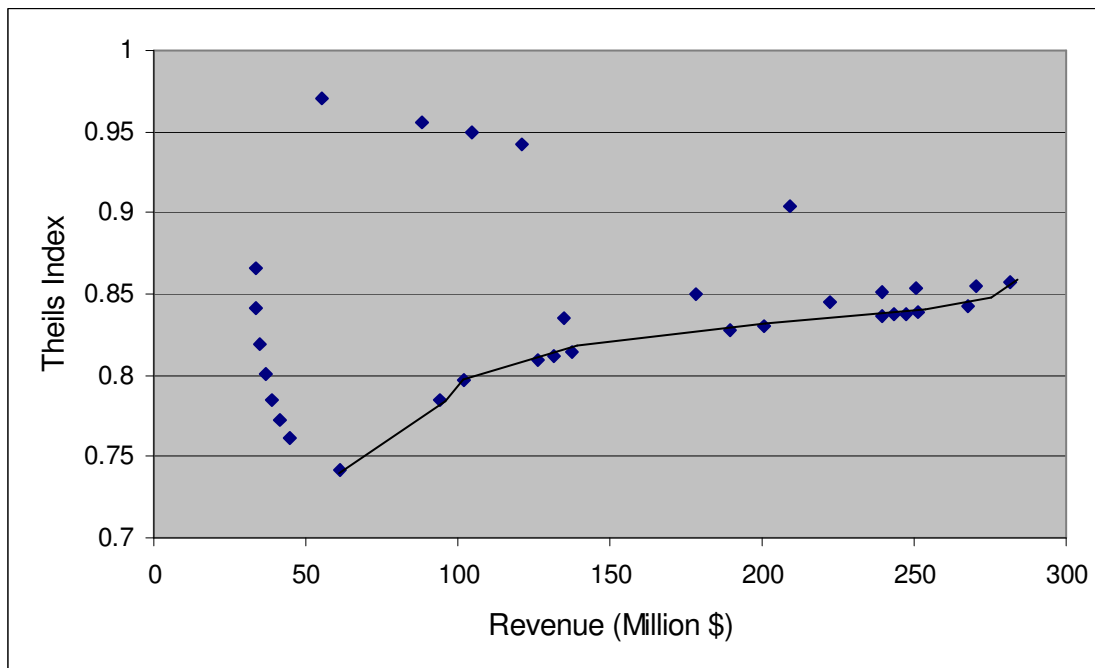Figure 6.14: Pareto-Optimal Solution for Profit Maximization and Inequality Minimization in 2050.
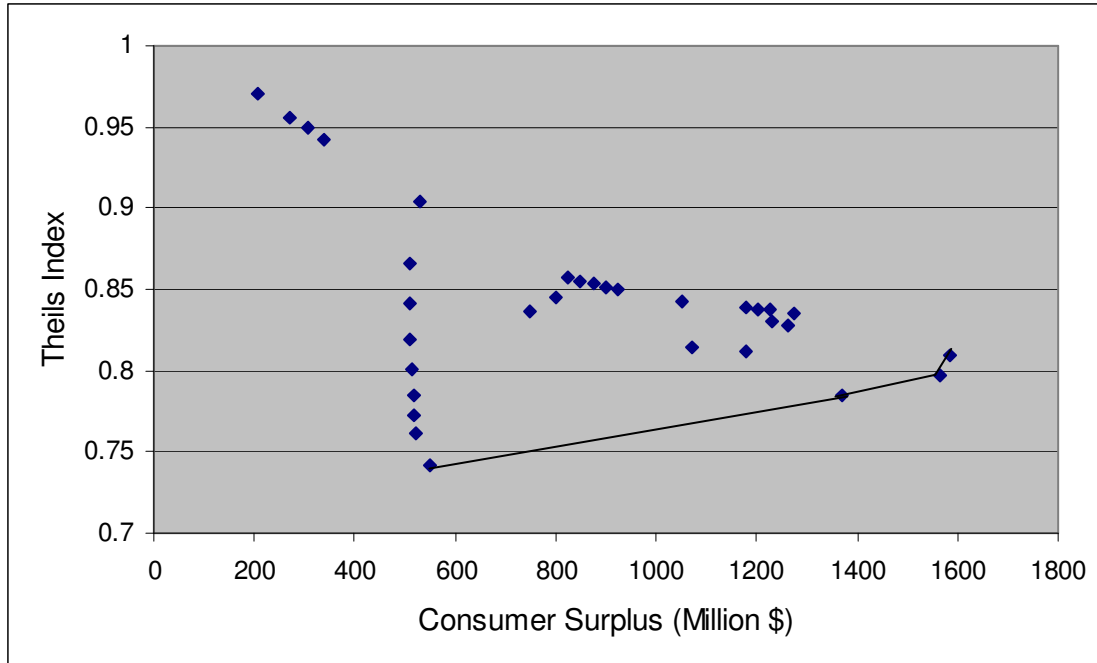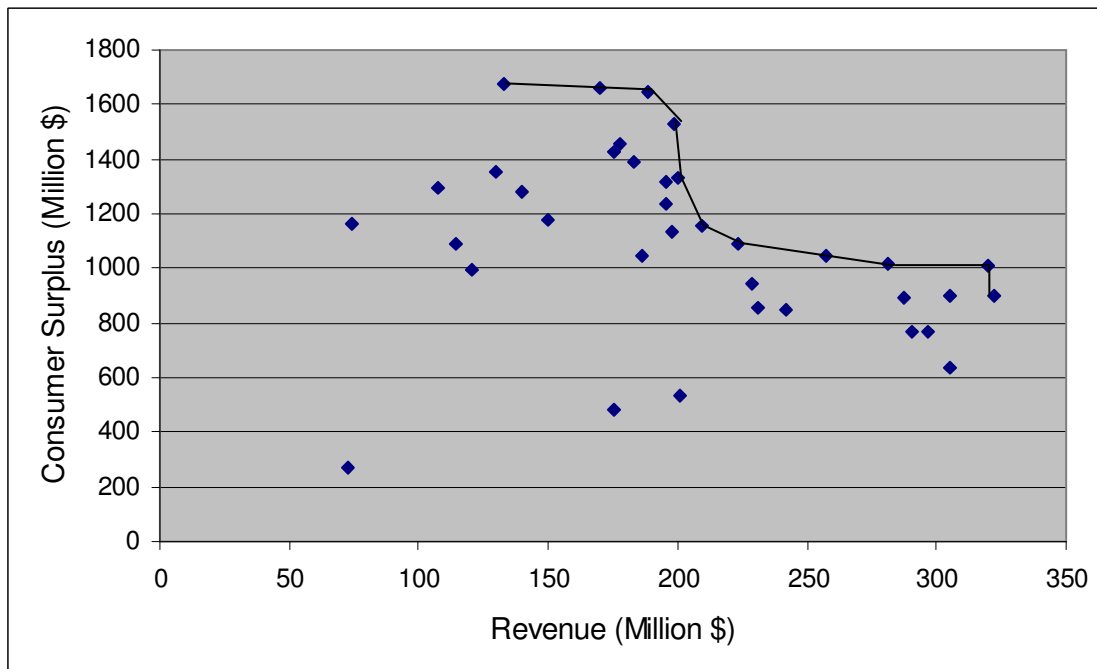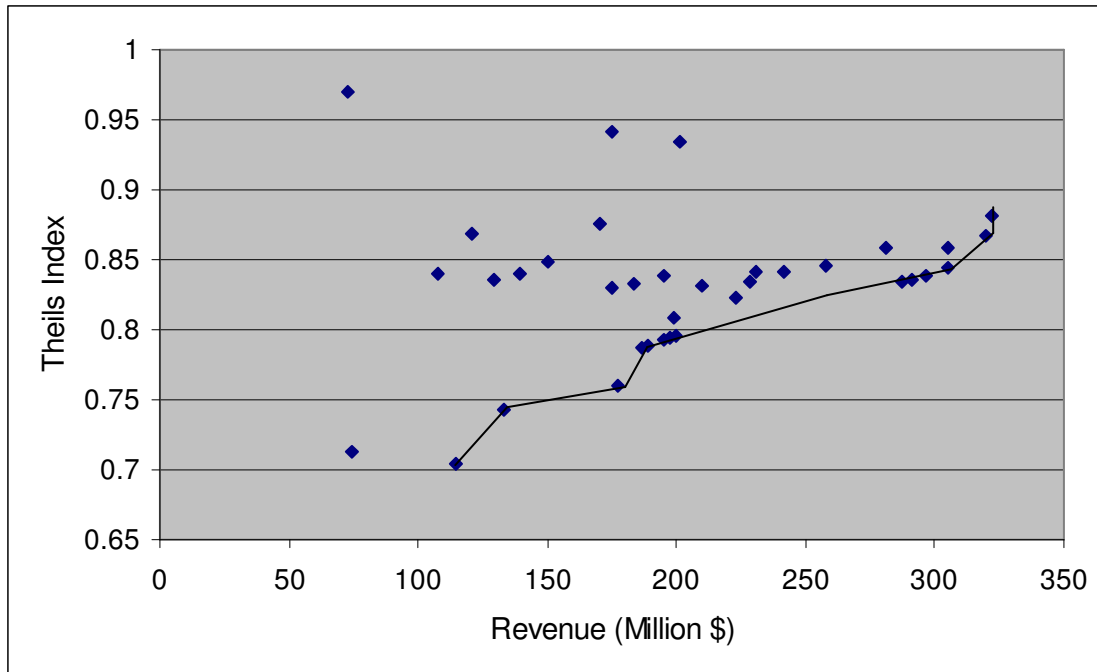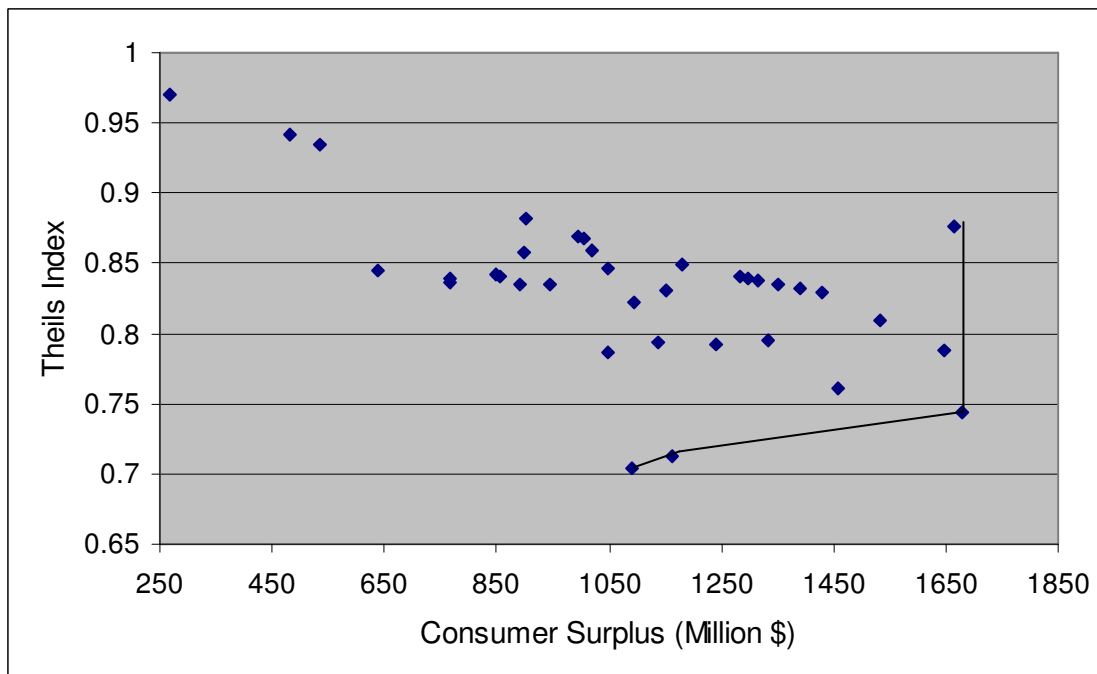

Figure 6.15: Pareto-Optimal Solution for Consumer Surplus Maximization and Inequality Minimization in 2050.

6.3 From Pareto-Optimal to Feasible Solution

The multi-objective optimization approach resulted in pareto-optimal solutions as a trade-off between the entity perspectives. How the trade-off will be accepted is a decision making process that may enlist the opinions of involved entities. From a transportation investment viewpoint, the decision makers are the stakeholders (say public, private, and user). The task of narrowing down the solution space from the pareto-optimal options was accomplished by AHP.

AHP is a tool that can be utilized to include the preferences/interests of multiple decision makers/stakeholders. Details of AHP are explained in chapter 3. A questionnaire survey was conducted among a select group of knowledgeable professionals to incorporate their preferences in terms of five OTG strategies identified earlier. The OTG strategies as proposed in the questionnaire survey are presented in Table 6.1. The survey participants were asked to respond to questions of relative importance of the role of each entity for a specific OTG strategy with a scale from 1-10. The scale (as proposed in survey questionnaire) for three entities for each OTG strategy is presented in Table 6.2. The respondents were asked to assign weights from 0-10 in such a manner that the total score for each OTG strategy (sum of scores in one row) is equal to 10. The survey instrument used is presented in Appendix B. The summary of the survey data is presented based on 12 responses in Table 6.3.

Table 6.1: Proposed OTG Strategies

Ownership Type	Responsibilities / Privileges
Exclusive Private Involvement	**Private**: Responsible for **all** capital, operation-maintenance cost and for toll collection for a designated concession period[3] **Public**: Responsible for complete governance[4] through the project life[5]
Major Private Involvement	**Private**: Responsible for **major** capital, operation-maintenance cost and for toll collection for a designated concession period **Public**: Responsible for minimum capital, operation-maintenance cost, and complete governance through the project life
Moderate Private Involvement	**Private**: Responsible for **moderate** capital, operation-maintenance cost and for toll collection for a designated concession period **Public**: Responsible for moderate capital, operation-maintenance cost, and complete governance through the project life
Major Public Involvement	**Private**: Responsible for minimum capital, operation-maintenance cost and for toll collection for a designated concession period **Public**: Responsible for **major** capital investment and complete governance through the project life
Exclusive Public Involvement	**Private:** No private involvement **Public**: Responsible for **all** capital investment, full toll collection, and complete governance through the project life

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[3] Concession Period- The time period during the service life of a project when the private entity is allowed to collect revenue to regain its earlier committed investment. The concession period often termed as "tenure" and may vary depending upon specific ownership type. The ownership of the facility is expected to revert back to the public entity at the end of the concession period.

[4] Governance: Relates to the management, policy and decision making for the general area of responsibility. The public entity is assumed to have full governance rights through the project life because it is the ultimate owner of the facility.

[5] Project Life- The time period from the start day till the facility is considered no longer beneficial for service.

Table 6.2: Scores for Entities

Type of Joint Ownership	Scores (1 – 10)			Total
	Private	*Public*	*User*	Score*
Exclusive Private Involvement (OTG1)				10
Major Private Involvement (OTG2)				10
Moderate Private Involvement (OTG3)				10
Major Public Involvement (OTG4)				10
Exclusive Public Involvement (OTG5)				10

Note: *: Total score must be equal to 10

Table 6.3: Summary of Survey Results

Type of Joint Ownership	Private				Public				User			
	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.	Max.	Min.	Mean	Std. Dev.
OTG1	10	4	6.750	1.603	2	0	1.417	0.669	5	0	1.833	1.337
OTG2	8	4	5.333	1.435	3	2	2.583	0.515	4	0	2.083	1.311
OTG3	6	2	3.833	1.467	5	3	3.750	0.866	4	0	2.417	1.240
OTG4	4	1	2.250	1.215	7	4	5.417	0.996	3	0	2.333	0.888
OTG5	3	0	0.417	0.900	10	5	7.000	1.595	4	0	2.583	1.379

The survey responses are considered in AHP analysis. The proposed AHP model is presented in Figure 6.16. Figure 6.16a presents a system level hierarchy and Figure 6.16b presents a stakeholder specific hierarchy. The AHP model has a number of hierarchies (or subcomponents): (1) goal, (2) criteria, (3) sub-criteria, (4) sub- sub-criteria, (5) alternatives. The goal of the AHP analysis is to determine the role of the each entity in a specific OTG strategy. The criterion is to collect responses from the corresponding stakeholders involved in the investment decision making. The stakeholder responses for each OTG strategy are considered as the sub-criteria. Further, the OTG strategies are assigned weights (0-10) by the stakeholders with exclusive being the highest weight and very limited being the least weight (sub-sub-criteria). The final subcomponent is the alternatives (public, private, and the user), on how they are associated with each OTG strategy. The proposed AHP model is analyzed using the procedure explained in chapter 3.
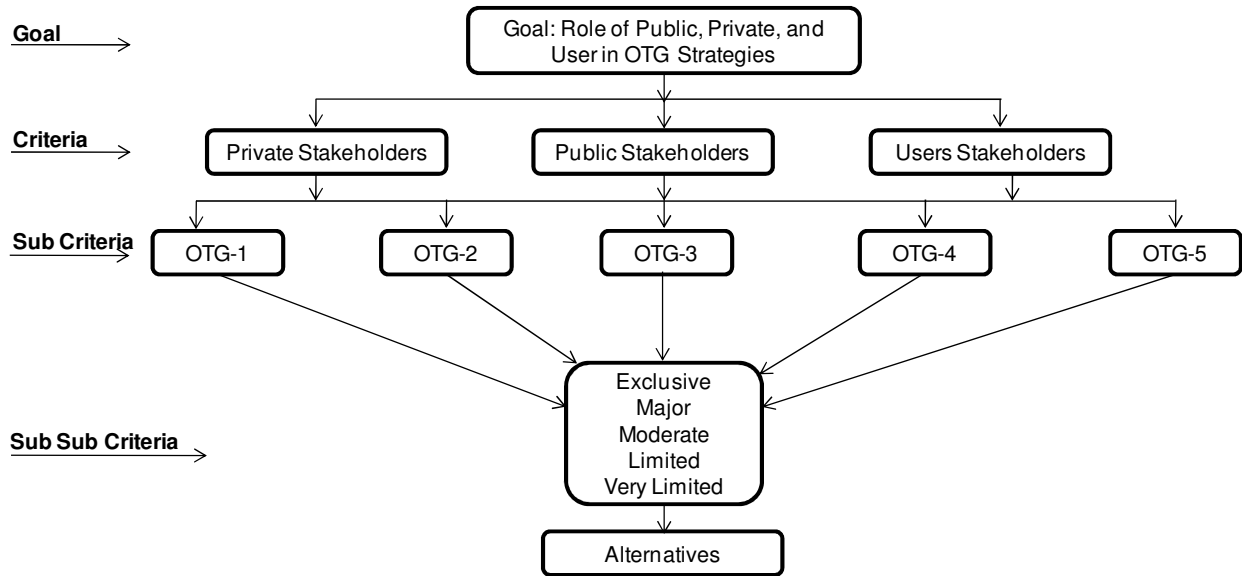
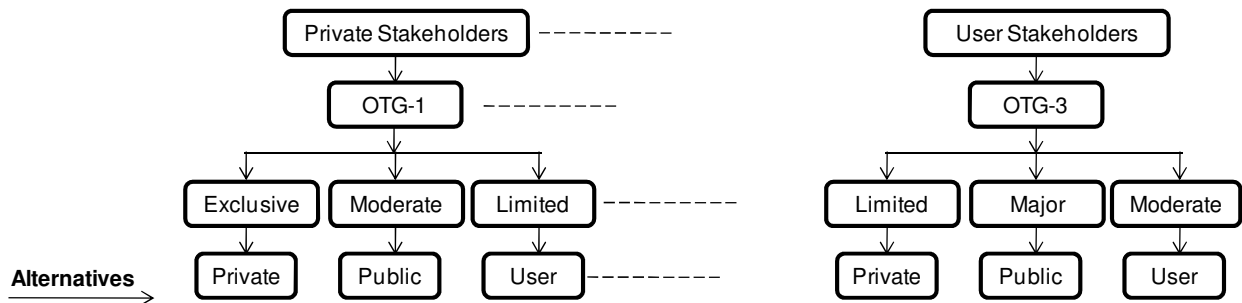Figure 6.16 a: System level Hierarchy for Multi-objective Decision Making

Figure 6.16 b: Stakeholder Specific Hierarchy for Multi-objective Decision Making

6.4 Results of the AHP Analysis

The relative importance of the three entities for each OTG strategy expressed in percentage is presented in Table 6.4. For each OTG strategy the sum of degree of involvement for three entities is 100 percent. For example, in the case of OTG-1 (exclusive private involvement), AHP analysis resulted in 68.1% of private, 14.0% of public, and 17.9% of user involvement. Similarly for OTG-5 (exclusive public involvement), AHP analysis resulted in 7.2% of private, 75.8% public, and 17.0% of user involvement.

Table 6.4: Results of the AHP analysis

Strategy ⟍ Entity	OTG-1 (%)	OTG-2 (%)	OTG-3 (%)	OTG-4 (%)	OTG-5 (%)
Private	68.1	56.8	43.5	20.1	7.2
Public	14.0	23.9	35.1	58.4	75.8
User	17.9	19.4	21.4	21.5	17.0

6.5. Integration of Multi-objective Optimization and AHP

The relative importance of three entities for each OTG strategy can be integrated with the pareto-optimal solutions obtained from the multi- objective optimization. Each OTG structure in Table 6.4 consists of relative importance of entities. To determine the objective of each OTG strategy two distinctions are made: (1) the objective of an OTG strategy is determined by the entity (private or public) which received the highest percentage of relative importance (2) the objective of the selected entity will receive the consideration of the users.

For OTG-1, the trade off can be chosen as 68.1% of private, 14.0% of public, and 17.9% of user participation. The objective of OTG-1 is profit maximization as the private entity received highest relative importance (68.1%) from the AHP results. Even though OTG-1 relates to exclusive private participation, the private entity will receive 86% of revenue (i.e. 68.1% plus 17.9% in OTG-1, Table 6.4). The maximum revenue for the year 2015 is 68 million (Figure 6.1). The trade off threshold in revenue for the private entity is $58.94 (i.e. 0.86 x $68 million) million (Table 6.5). The corresponding consumer surplus can be obtained from Figure 6.1 by drawing an imaginary vertical line from the X-axis value of $58.94 million to the intersection of the pareto frontier and then drawing a horizontal line to the Y-axis to obtain the consumer surplus. The threshold value of consumer surplus is $401.12 million (Table 6.5) for corresponding revenue of $58.94 million for OTG-1. Similarly the threshold value of Theil's Index for corresponding revenue of $58.94 million obtained as 0.84 (Table 6.5) from the Figure 6.2. For OTG-2 and OTG-3, the objective remains profit maximization and a similar procedure can be followed to obtain the threshold values. The

threshold values for all OTG strategies are presented in Table 6.5.

For OTG-4 and OTG-5 the objective is consumer surplus maximization as the public entity received the highest relative importance. For example, for OTG-5, the public entity will be the beneficiary, and receive 92.8% (i.e. 75.8% plus 17% in OTG-5, Table 6.4) of consumer surplus. The maximum value of consumer surplus for the year 2015 is $720 million (Figure 6.1). The threshold value of consumer surplus for the OTG-5 for year 2015 is $677.78 million (i.e. 0.928 x $720 million) (Table 6.5). The corresponding revenue can be obtained by drawing an imaginary line from the Y-axis value $677.8 million to the intersection of the pareto frontier and then drawing a vertical line to X-axis to obtain the threshold revenue of $34 million. Similarly from Figure 6.3 the corresponding threshold of Theil's Index can be obtained as 0.80 (Table 6.5). The revenue is maximum for OTG-1, as the objective is profit maximization and the private entity had highest relative importance among all OTG strategies.

The threshold revenue amount decreases as the relative importance of the private entity is reduced. The effect of reducing revenue can be observed for the year 2015 in Table 6.5 from OTG-1 to OTG-5 as $58.94, $52.22, $44.48, $38, and $34 million respectively. On the other hand, contrary, the consumer surplus increases as the relative importance of the public entity increases from OTG-1 through OTG-5. For the year 2015 in Table 6.5, consumer surplus increase from OTG-1 through OTG-5 are $401.12, $420.64, $480, $583.55, and $677.78 million respectively. The revenue and consumer surplus increase as the relative importance of the respective entities increases across the OTG strategies. From the user perspective, there does not appear any trend in the Theil's Index. But the effect of the users is considered in the private and public entity perspectives in all the OTG strategies. The car and truck toll values for each set of threshold value for particular year is presented in the last two columns of Table 6.5. Each set of three trade-off values of the objectives (for a particular OTG strategy and for a particular year) obtained from MOO and AHP analysis, are function of the car and truck toll values. Specific toll[6] values are estimated once the trade-off objectives were known.

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[6] Each point on the pareto optimal curve represent a specific toll value (the third dimension not presented in the figures) satisfying two objectives. Once the trade off is established, the two objective values are used to determine the toll values.

Table 6.5: OTG Strategy and Threshold Values for Revenue, Consumer Surplus, and Theil's Index

Strategy	Year	Threshold Value			Toll	
		Revenue (Million$)	Consumer Surplus (Million$)	Theil's's Index	Car ($)	Truck ($)
OTG-1	2015	58.94	401.12	0.84	1.35	9.81
	2025	101.66	748.25	0.85	2.00	10.66
	2035	171.39	950.54	0.84	3.40	14.80
	2045	242.47	1,202.63	0.83	4.30	15.62
	2050	277.53	1,054.87	0.83	5.60	16.08
OTG-2	2015	52.22	420.64	0.83	1.25	9.17
	2025	90.07	770.00	0.84	1.70	9.36
	2035	151.86	980.00	0.82	2.70	12.12
	2045	214.84	1,240.15	0.82	3.70	13.73
	2050	245.90	1,100.00	0.82	4.55	14.20
OTG-3	2015	44.48	480.00	0.81	0.95	7.23
	2025	76.71	810.00	0.83	1.40	8.06
	2035	129.34	1,010.00	0.81	2.30	10.60
	2045	182.98	1,260.00	0.81	3.10	11.83
	2050	209.43	1,180.00	0.80	3.60	12.34
OTG-4	2015	38.00	583.55	0.80	0.85	6.59
	2025	62.00	872.43	0.82	1.15	6.98
	2035	101.00	1,073.09	0.82	1.75	8.50
	2045	164.00	1,274.37	0.82	2.80	10.88
	2050	181.00	1,340.26	0.78	3.00	11.39
OTG-5	2015	34.00	677.78	0.80	0.70	5.62
	2025	58.00	1,013.29	0.81	1.05	6.54
	2035	76.00	1,246.34	0.81	1.35	6.97
	2045	142.00	1,480.12	0.81	2.50	9.93
	2050	164.00	1,556.65	0.76	2.70	10.45

6.6 Feasibility Analysis from AHP Results

The threshold values of revenue and consumer surplus resulting from the integration of MOO and AHP analysis are further considered to determine the IRR for each OTG strategy (Table 6.6). In Table 6.6, IRR_m and IRR_s are defined as the multi-objective rate of return and single objective rate of return respectively. The IRR for OTG1 is 3.73%. The corresponding IRR for the single entity (IRR_S, as determined inChapter 5, Table 5.7) is 4.61%.

Table 6.6: IRR for OTG Strategies

OTG Strategy	Relaxation Policy	IRR_m (%)	IRR_S (%)
OTG-1	No Relaxation	3.73	4.61
OTG-2			
	Toll Plaza Cost Subsidy	3.58	5.14
	Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy	4.30	5.89
	Construction Cost Subsidy (50%)	4.26	5.84
OTG-3			
	Construction Cost Subsidy (60%)	2.87	6.13
	Concession Period Extension (27 years)	4.36	6.01
	Construction Cost Subsidy and Concession Period Extension	6.13	7.20
OTG-4			
	Partly Construction Cost by Private Entity	17.47	22.97
	Operation and Maintenance Cost-Public	1.97	3.69
	Construction Cost Subsidy-Public	2.12	
OTG-5	No Relaxation	1.17	3.51

The reduction in IRR is attributable to the trade off in the objectives of both private and public entities. The IRR_m (for multi-objective solutions) is lower but the consumer surplus for OTG1 for multiple entities is higher than that of the single entity. Similarly t h e IRR for all OTG strategies are determined and presented in Table 6.6. Two OTG strategies

resulted in IRR_m higher than the MARR of 6%: (1) OTG3 construction cost subsidy and concession period extension and (2) OTG4 partly construction cost by private entity.

6.7 Summary

- The MOO resulted in pareto optimal solutions as a trade-off between multiple entities. As opposed to a single optimal solution, the MOO offers a number of non dominated solutions represented in the pareto frontier to be considered by the multiple entities.

- The preferences of multiple entities are embedded in the form of OTG strategies and the relative importance of the entities is determined in the form of a multi objective decision making questionnaire survey.

- The survey was conducted among knowledgeable transportation professionals who were asked to respond to a questionnaire with relative importance of entities involved in each OTG strategy. The survey responses are analyzed in AHP and the resulting relative importances were determined.

- The AHP results were integrated with the pareto optimal solutions obtained from MOO analysis, and corresponding trade off optimal values were determined for each OTG strategy.

- The feasibility of each OTG strategy is determined from multi entity perspectives and the results were compared to those of the single entity.

- The multi entity OTG strategy feasibility analysis results demonstrated trade off in the objective of the major participant entity in a OTG strategy, when compared to the results of the corresponding single entity perspectives.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7. 1 Conslusions

The primary objective of this study is to develop a framework for large scale transportation infrastructure investment decisions that incorporates the concept of uncertainties and risks. Additionally, a set of strategies representing various combinations of private-public participation, resulting in different levels of Ownership, Tenure and Governance (OTG) scenarios are to be identified, and incorporated into the proposed framework. Lastly, demonstration of the proposed framework is also presented in a case study. The summary of the study is described as follows:

- The implication of the terms "uncertainty" and "risk" in transportation investment decisions are discussed relative to the current literature and the state of practice. Often these two terms are used synonymously but their implications from investment viewpoint are somewhat different.

- Infrastructure investment decisions require estimation of future costs and benefits. In reality, the future costs and benefits are associated with uncertainty and risk. The sources of uncertainty and risk are different. From investment view point, the sources of uncertainty include demand, fare (toll) and the associated future costs. Risk is a consequence of uncertainty, and the impact of risk can be determined after the measures of uncertainty are assessed.

- The entities often involved in large-scale infrastructure investment decision are enlisted as: private, public, and user each with different set of objectives and expectations; profit maximization, consumer surplus maximization and inequality minimization, respectively.

- A procedure for single entity uncertainty analysis is presented as a bi-level process. The upper level consists of the entity under consideration, while the lower level represents an elastic traffic assignment problem. The output of uncertainty analysis is designed to serve as input to risk analysis. VaR is considered as the MOE for risk analysis and determined using MCS technique.

- The objective of each entity, when subjected to uncertainty, should be considered in assessing the optimal demand and toll estimates. The feasibility of the investment can be determined by considering measures such as IRR, NPV, etc. Further, risk consequences of the MOE should be determined.

- If the single entity uncertainty analysis does not result in feasible solutions, relaxation policies can be proposed. Relaxation policies may include extension of the concession period and financial support from the other entities involved in the decision making process, leading to the formulation of a set of OTG strategies. Further, the feasibility of OTG strategies can be determined using IRR as the MOE.

- Multi entity perspectives may result in a number of favorable solutions which can be considered as trade-off between the entities. As the objective of each entity is different, multi entity solutions may need to be evaluated by the decision makers. The design of a survey instrument can enable the decision makers to relate the importance of each entity in a particular OTG strategy.

- The methodology is evaluated on the proposed DRIC project in Southeast Michigan, through the use of existing socioeconomic, zone, and network data. Entity-specific optimal toll and ridership are determined from the uncertainty analysis. For the analysis period, the feasibility of the project is determined from each entity perspective.

- A set of joint OTG scenarios are created considering the multi entity operation of the transportation facilities. For some OTG strategies, relaxation policies are proposed to ensure feasibility of the project. The IRR is considered as the measure of feasibility of uncertainty analysis for OTG strategies. VaR is determined for each OTG strategy. A methodology for integrating uncertainty and risk is proposed.

- A single objective optimization is imperative from a specific entity perspective. The optimum solution thus obtained might not be best suited to other entities. A multi-objective optimization (MOO), the process of simultaneously considering two or more objective functions each with a specific optimization defined is proposed considering the perspectives of all three entities.

- The MOO resulted in a set of pareto optimal solutions, that provide a basis for trade-offs between single entity objectives. To determine the feasible solution from MOO results, a survey instrument was designed to incorporate the relative importance of entities within each OTG strategy.

- The survey was conducted among a select group of knowledgeable professionals in the states of Michigan and Ohio to include their preferences in terms of the OTG strategies. The survey results were analyzed using AHP and the relative importance of three entities with respect to each OTG strategy.

- The feasibility of OTG strategies from multi entity perspective is tested by integrating the Pareto optimal solutions from MOO analysis and the relative importance of entities from AHP analysis. The feasibility of OTG strategies from single and multi entity perspectives are compared. The proposed framework for uncertainty and risk with single and multi entity perspective can serve as a tool for large scale transportation infrastructure investment decision making.

- Multi entity OTG strategies when compared with single entity strategies appear to produce lower MOEs. The reduction in MOEs can be attributed to the trade-offs between multiple entities. Single and multi entity results provide a menu of solutions for the entities to consider for investment decisions.

7.2 Recommendation

- For this study with a large study area, it was computationally not feasible to analyze uncertainty in conjunction with the elastic traffic assignment model. Future studies should address the issue of simultaneous incorporation of uncertainty and elastic traffic assignment.

- The consideration of OTG strategies was incorporated in the case study as an exogenous entity. Future studies can explore incorporating OTG strategies as a part of a broader methodology as a tri-level process.

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<u>APPENDIX A</u>

Questionnaire Survey

Multi-Objective Decision Making Transportation Infrastructure Survey

This survey is designed to assess the importance of the roles of various entities involved in joint ownership of transportation infrastructure projects, sometimes referred to as Public Private Partnership (PPP) projects. PPP primarily involves three entities (public, private, and user), each with a different objective. A brief description of each entity and its objective is presented in Table 1.

Table 1: Entities and Objectives

Entity	Objective	Brief Description
Private	Maximize Profit	Profit is the difference between the revenue and cost
Public	Maximize Social Welfare	Social welfare is the savings in total travel cost
User	Maximize Equity	Equity is the uniformity in distribution of benefits among users

Background

This survey pertains to a USDOT sponsored study through the University of Toledo being conducted at Wayne State University. The purpose of the study is to develop a method for testing alternate ownership, tenure, and governance strategies for transportation infrastructure projects. The method is to be applied to the proposed Detroit-Windsor River crossing as a demonstration exercise. As a part of this study, we would like to explore the method of Multi-Objective Decision Making, where each entity will receive some consideration in the policy decisions on PPP projects. In Table 2, five generic types of PPP projects are presented, with an explanation of the responsibilities of each of the two primary entities.

Table 2: Types of PPP

Ownership Type	Responsibilities / Privileges
Exclusive Private Involvement	*Private*: Responsible for **all** capital, operation-maintenance cost and for toll collection for a designated concession period[1] *Public*: Responsible for complete governance[2] through the project life[3]
Major Private Involvement	*Private*: Responsible for **major** capital, operation-maintenance cost and for toll collection for a designated concession period *Public*: Responsible for minimum capital, operation-maintenance cost, and complete governance through the project life
Moderate Private Involvement	*Private*: Responsible for **moderate** capital, operation-maintenance cost and for toll collection for a designated concession period *Public*: Responsible for moderate capital, operation-maintenance cost, and complete governance through the project life
Major Public Involvement	*Private*: Responsible for minimum capital, operation-maintenance cost and for toll collection for a designated concession period *Public*: Responsible for **major** capital investment and complete governance through the project life
Exclusive Public Involvement	*Private:* No private involvement *Public*: Responsible for **all** capital investment, full toll collection, and complete governance through the project life

Note:

[1]**Concession Period**- The time period during the service life of a project when the private entity is allowed to collect revenue to regain its earlier committed investment. The concession period often termed as "tenure" and may vary depending upon specific ownership type. The ownership of the facility is expected to revert back to the public entity at the end of the concession period.

[2] Governance: Relates to the management, policy and decision making for the general area of responsibility. The public entity is assumed to have full governance rights through the project life because it is the ultimate owner of the facility.

[3] **Project Life**- The time period from the start day till the facility is considered no longer beneficial for service

The Survey

Now we request you to turn to the survey for your perception of the relative importance of the roles of each of the three entities (public, private, and user) for each of the ownership type. In responding to the questionnaire, please assign your score (on a scale of 1 to 10), with higher values reflecting greater importance of the relative roles of the three entities. Total score for each row must be equal to 10.

Optional: Your affiliation: Public   Private   User

(Note: This is only for information on the relative distribution the responses among three entities)

You assigned scores should reflect your perception of the relative importance of the roles of the three entities for the specific ownership type identified in each row (and explained in Table 2), for a total score of 10 as shown in the last column of Table 3.

Thanks for your participation in the survey.

Table 3: Scores for Entities

Type of Joint Ownership	Scores (1 – 10)			Total Score*
	Private	*Public*	*User*	
Exclusive Private Involvement				10
Major Private Involvement				10
Moderate Private Involvement				10
Major Public Involvement				10
Exclusive Public Involvement				10

Note: *: Total score must be equal to 10