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A Risk Analysis Framework for Toll Road Revenue Forecasts

Gabriel Alejandro Valdez Ceniceros
University of Texas at El Paso, gavaldez@miners.utep.edu

A RISK ANALYSIS FRAMEWORK FOR TOLL ROAD REVENUE FORECASTS

GABRIEL ALEJANDRO VALDEZ CENICEROS

Department of Civil Engineering

APPROVED:

Kelvin Cheu, Ph.D., Chair

Rafael Aldrete, Ph.D.

Carlos Chang, Ph.D.

Patricia D. Witherspoon, Ph.D.
Dean of the Graduate School

DEDICATION

I dedicate this research to my family and friends who gave me their full support throughout this tough period.

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by

GABRIEL ALEJANDRO VALDEZ CENICEROS, BACHELOR OF SCIENCE IN CIVIL ENGINEERING

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CHAPTER 1 : INTRODUCTION

This chapter begins by discussing some of the main problems faced in the U.S. with respect to transportation infrastructure funding. Next, the objective of this research is presented. The step by step methodology in this research is shown at the end of the chapter.

1.1 Background

In the United States, the shortage for traditional public sector funding sources for a safer and more effective highway infrastructure has made it more increasingly difficult for transportation agencies to keep up with the increasing demand. As a consequence, transportation agencies are considering a number of alternatives to raise funds such as charging tolls or cooperating with the private sector to improve the existing highway infrastructure.

One of the most important steps when analyzing the feasibility of a toll road is the traffic forecast process. For the toll road to be both feasible and attractive to private investors, the developing agency must demonstrate with certain confidence that the facility can generate sufficient revenue to cover various costs during its life cycle. However, the uncertainty of the traffic forecast has become apparent across the U.S. as evident in the common overestimation of traffic demand (usually between 25% to 30%) as well as toll revenue. For example, the Polk Parkway toll road (in Florida) and the Sam Houston Tollway (in Texas) only obtained approximately 80% and 65% respectively of the projected revenue in the first year of operation (Kriger, Shiu, & Sasha, 2006). Usually, the traffic forecasting model is a function of several key variables, which include Value of Time (VoT) and toll rate. The incorrect values or assumptions of these variables applied to the model can be critical when determining the traffic volume of a potential toll road. This has a significant impact on the projected revenue and can impose significant financial risk to the responsible party (or parties). Overestimated forecasts have led investors to be concerned about the reliability and accuracy of the current practice, if any, in demand forecasting (Kriger, Shiu, & Sasha, 2006).

1.2 Objective

The objective of this research is to develop a framework to conduct a risk (uncertainty) analysis of revenue for a potential toll road. The risk analysis framework is meant to be flexible in quantifying the risks (uncertainties or variations) of toll road revenue imposed by uncertainty in model inputs. The methodology will be limited to the risk imposed by uncertain model inputs such as the VoT. The proposed framework is then applied to a case study in El Paso, Texas to model a potential toll road in the city to demonstrate its application. It is expected that the findings from this research will benefit transportation agencies or organizations that are involved in the area of toll road revenue forecasting. The proposed risk analysis framework should be flexible enough for analysts to adjust according to their needs or objectives.

1.3 Methodology

In order to conduct this research, a step by step methodology was constructed and is shown in Figure 1.1. The first task consisted of a literature review that covered basic concepts of risk analysis, Public Private Partnership (PPP), and toll road demand forecast accuracy. The second task was to develop a risk analysis framework that could be then applied to a revenue forecast study. In the third and fourth tasks the toll road was coded in the El Paso network to develop different scenarios (i.e. the base year and future years). Finally, in task six, the reliability analysis framework was applied to the case study in order to derive the case study results and recommendations.

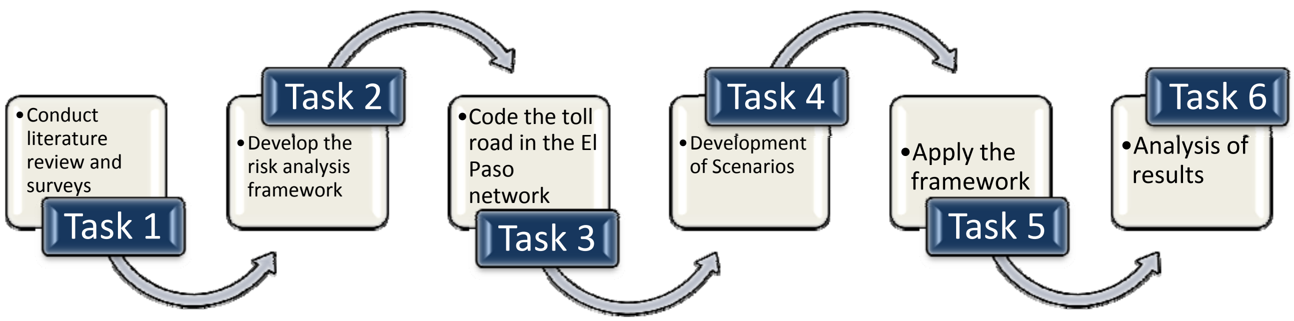

Figure 1.1. Thesis research methodology.

1.4 Thesis Outline

This section provides a brief overview of each of the seven chapters in this thesis.

Chapter 1 provides the background behind this research as well as the objective and methodology.

Chapter 2 describes basic concepts that are related to this research (e.g. risk, value of time, etc.). In addition, the performance of toll roads revenue forecasts and the most common transportation planning software utilized are discussed.

Chapter 3 contains the results from the conducted surveys to several organizations that have experience in the area of toll revenue forecasting.

Chapter 4 presents the risk analysis framework proposed with a short discussion on each of the steps. This chapter concludes with the probability distribution functions and the correlation matrix that were used to model the values of time.

Chapter 5 describes the toll road and its model used in the case study. A description of the traffic network model is provided as well as all of the variables considered for the simulation.

Chapter 6 discussed the fitted probability distributions functions of revenue for the base year, future year 2020, and future year 2030.

Chapter 7 concludes the findings of this research based on the simulation results and fitted revenue distributions. Recommendations are provided to guide readers in the future applications of the proposed risk analysis framework.

CHAPTER 2 : REVIEW OF TOLL ROAD FORECASTING METHODOLOGIES

Chapter 2 defines some of the basic concepts related to this research such as risk, public private partnerships, value for money, stochastic analysis, and the value of time. Next, the performance of toll demand projections in the U.S. is discussed based on reports from Standard & Poor's and the NCHRP Synthesis 364 "Estimating Toll Road Demand Revenue." Finally, a brief description is given on the capabilities of different transportation planning software commonly used for traffic and revenue forecasting.

2.1 Background

In order to achieve the goals of this research a literature review was first conducted to analyze the current state-of-the-practice of toll road demand forecast methodology. The next step was to review the risk assessment methods applied across the U.S. and abroad in toll road demand forecast studies. Both the demand forecast and risk assessment methodologies were obtained by contacting different agencies and consultants who have broad experience in the field. Further investigation was conducted by searching different online databases (such as Transportation Research Board (TRB) papers, Transportation Research Information Services online, etc.) for materials regarding the topics of interest.

2.2 Basic Concepts

2.2.1 Risk

Risk is defined as factors or events with certain probability of occurrence that might compromise the successful completion of a particular project (Irwin, 2007). In addition, the possibilities that involve losses or any undesirable outcome are usually identified as a risk. The risks involved in an infrastructure project (in this research, toll road) can cause different magnitudes of impact depending on what aspect of the project is being affected. The impact can have either moderate or strong consequences but nevertheless is often associated with the expected cost and revenue of the infrastructure project. In the context of this thesis, the term risk refers to the probability that the revenue will fall below a certain value.

2.2.2 Value of Time

The most important behavioral parameter to evaluate a toll road demand is the VoT which is defined as "the marginal rate of substitution of travel time for money in a travelers' indirect utility function" (Brownstone & Small, 2005). The VoT plays a key role in any forecasting process because it represents the monetary value of time as perceived by travelers. The VoT relates how the toll rates influence route choice, that is, the driver's decision to use the tolled facility (including the entry and exit points of the facility) rather than a non-tolled alternate route (Kriger, Shiu, & Sasha, 2006). The estimation of one single value for a specific region can be problematic since every traveler can have a different VoT depending on their trip purpose, income and etc (See Chapter 4-Section 4.3 for further discussion).

2.2.3 Public Private Partnership

A PPP represents an agreement between the government (the public entity) and the private sector to deliver a particular service or asset to the public. The public entity will define what is to be delivered while the private sector collaborates to construct, design, and manage such service or project. The private sector gets the opportunity to earn a financial return over the period of the agreement. This PPP involves appropriate allocation of risks to the entity (public or private) that is best equipped to manage them. In other words, the entity best equipped to manage the risk will be the one that can do it at the least cost and thereby reduce the long-term cost of the project (Burger, Bergvall, & Jacobzone, 2008). For example, the private sector might carry financial (e.g. equity investment or debt) and construction risks within an infrastructure project. However, the public sector might bear risks in the form of political stability or public acceptance. Therefore, the PPP contract must clearly define the risks involved and which entity responsible for each of them. Figure 2.1 shows the different types of methods that can be pursued to introduce new infrastructure ranging from traditional procurement, PPP, and full privatization. The arrow represents the amount of risk being transferred to the private sector (e.g. with concessions being the method with highest degree of risk transfer). The build-own-operate method is not even under consideration in Texas since the state at all times keeps the full legal ownership of the project. This kind of PPP agreement is most commonly used in other countries.

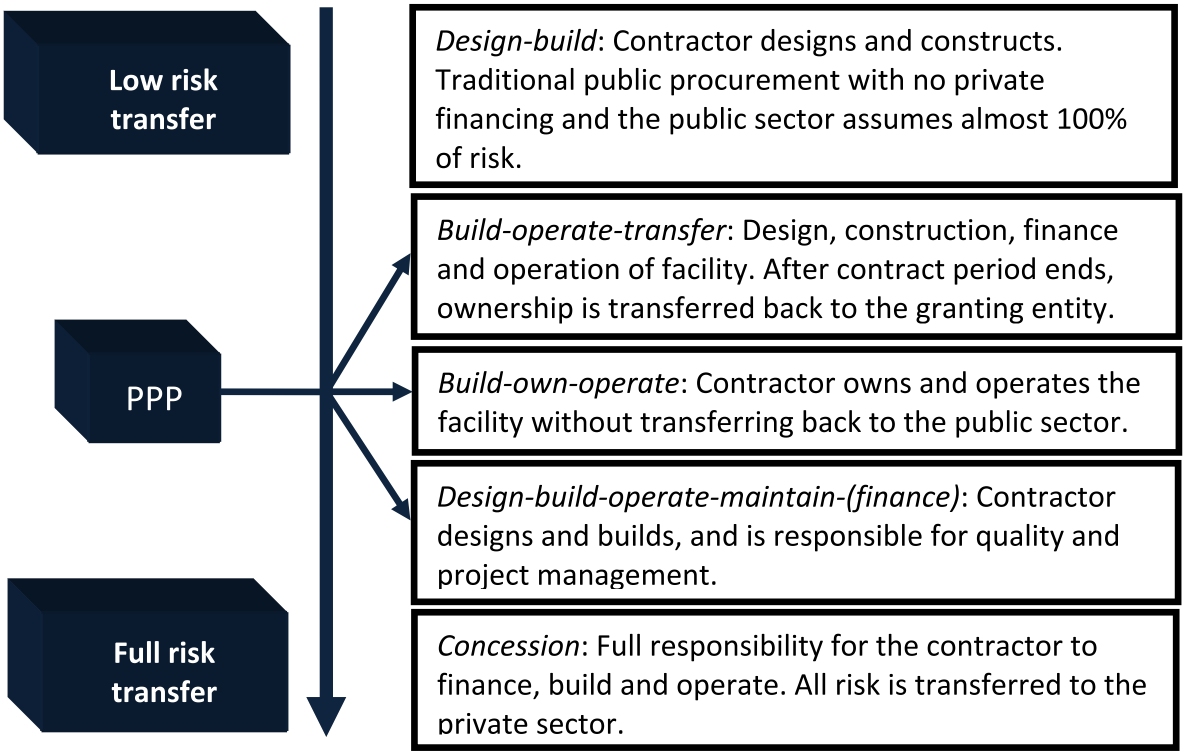

Figure 2.1. Amount of risk shared for different types of contracts (Burger, Bergvall, & Jacobzone, 2008).

2.3 Risks Involved in a Public Private Partnership

One of the main principles of a PPP is that that the risks should be allocated (or shared) between the partners. In other words, the responsibility to bear risk should be distributed so as to maximize total project value and taking into account each party's ability to manipulate a specific risk factor, influence the total project value with respect to the related risk factor, and absorb the risk. This implies that the entity bearing a specific risk will be able to protect against it with minimal cost. However, there are some risks, such as the demand for a toll road, that are not easily managed by either the public or private sector. The uncertainty in the prediction of traffic demand makes such risk difficult to manage properly without having unexpected losses by either entity. Moreover, in most of the toll road projects, the risk of traffic demand is shared between both the public and private entities. The private sector usually bears the risk of the projected demand while as the public sector provides a guarantee (i.e., minimum revenue) to mitigate some of the risk that the private entity is bearing. Furthermore, the government usually carries the legal and political risks associated with the project. Figure 2.2 represents some of the most basic risks that an infrastructure project carries when developed through a PP.

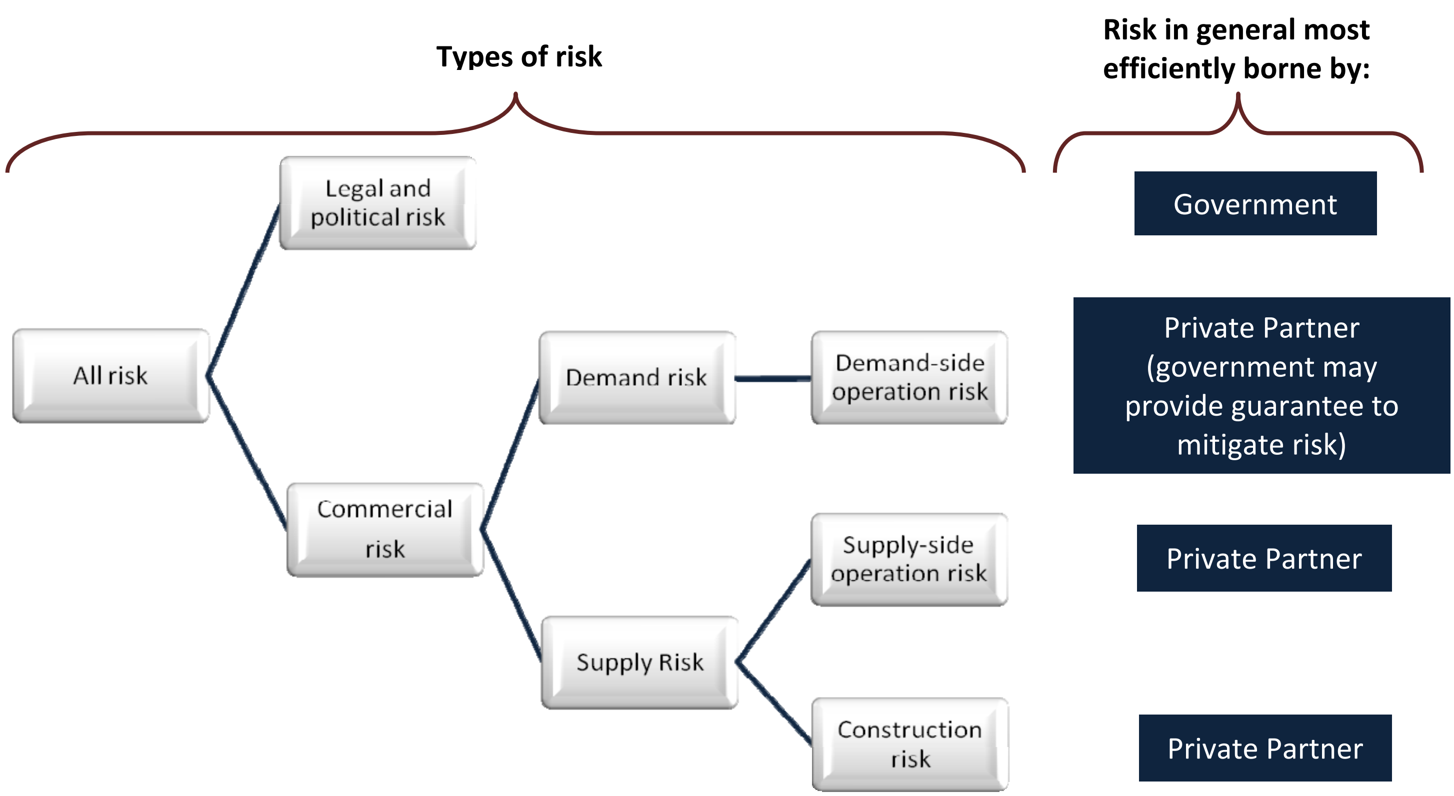

Figure 2.2. General project risks for an infrastructure project developed by a PPP (Burger, Bergvall, & Jacobzone, 2008).

2.3.1 Value for Money

One of the main factors that the government decides to choose a PPP over the traditional procurement method is because it will offer better Value for Money (VfM). By definition VfM is when the maximum expected benefit can be obtained from a particular asset or service within the resources that are available (Burger, Bergvall, & Jacobzone, 2008). Appropriate assessment techniques should be used to analyze if the VfM is better for a PPP than the traditional procurement methods in order to justify the PPP agreement.

A VfM assessment consists of two major elements:

- Monetary comparison. A comparison between the cost of a PPP and a traditional public sector procurement method which is expressed in discounted cash flows over the life of the agreement;
- Non-monetary comparison. These factors include the quality of service or the rate that the project can be completed which is of great value to the government.

Some of the characteristics that could affect the VfM vary depending on what project or sector (transportation, wastewater, structural, etc.) is being considered. However, from a public sector perspective some factors that might increase the VfM in a PPP include the following (European Commission, 2003):

- Appropriate risk transfer
- Generation of additional revenue
- Providing higher quality design, construction, and inspection
- The management skills of the private sector

In order to determine the VfM the scope of the project should be defined in advance. This scope should have realistic projections of the project requirement, cost, and expected revenue. One method that can help to define such scope is to apply value engineering to guarantee that the most cost-effective approach or alternative is being considered. Value engineering is a systematic approach that breaks components of a project into functions where a team of experts identify solutions that can satisfy those functions (USDOT Federal Highway Administration). All this information can then be used to do a comparative analysis between the traditional procurement and PPP to identify which method offers the best VfM (AECOM Consult Team, 2007)

2.4 Valuation Methods

2.4.1 Risk Assessment Tools

Transportation agencies, private consultants, among others, usually utilize special tools to support or perform risk assessment analysis. In order to quantify the risk associated with various factors of an infrastructure project (in this case a toll road), different evaluation methods might be applied. Some of the most common and effective tools used in today's practice is Monte Carlo simulation (stochastic analysis). The importance of having a proper valuation method for contingent liabilities such as guarantees is increasing as governments have learned from past experiences. Measuring the risk exposure is not only about determining maximum possible losses, but also the probability of such losses and the expected value (CASTALIA, 2007). Figure

2.3 depicts a simple three step risk management approach. The following sections give a more thorough explanation of such valuation methods.

Figure 2.3. Risk management approach.

2.4.2 Stochastic Analysis

In an infrastructure project, the estimation of contingent liabilities (or any risk associated with it) will most likely rely on stochastic analysis. The lack of historic data for any given infrastructure project makes the valuation approaches depend mostly on Monte Carlo Simulation (MCS). The MCS can simulate the probability of a particular output variable having a certain value, or the occurrence of an event and estimate the probability distribution. In addition, an expected value can be calculated from the generated distribution. The MCS is a popular technique because it is able to simultaneously take into account the combination of several risk factors (or uncertain inputs). This simulation method permits the user to assess the impact when combining several stochastic variables into the analysis. Figure 2.4 represents an example of output obtained after running a MCS. This simulation produced the probability distribution of guarantee payments. For example, the zero millions pesos bin (or first bar in the chart) have a frequency of 6,000 out of 10,000 iterations (simulation runs). This means that there is a probability of 0.6 that the value of the guarantee will be zero. Following this logic the probability of making between 0 and 10 million pesos is about 0.13 (1,300 out of 10,000 iterations). Such histogram can give the public and private entities a better insight into what to expect from a guarantee and its associated probability of occurrence.

The Monte Carlo simulation assists the policy makers by obtaining quantitative estimates in order to make the appropriate decisions pertaining to an infrastructure project. If no valuation method is applied to estimate the cost of the guarantee the likelihood of imposing pressure on the public budget may increase.

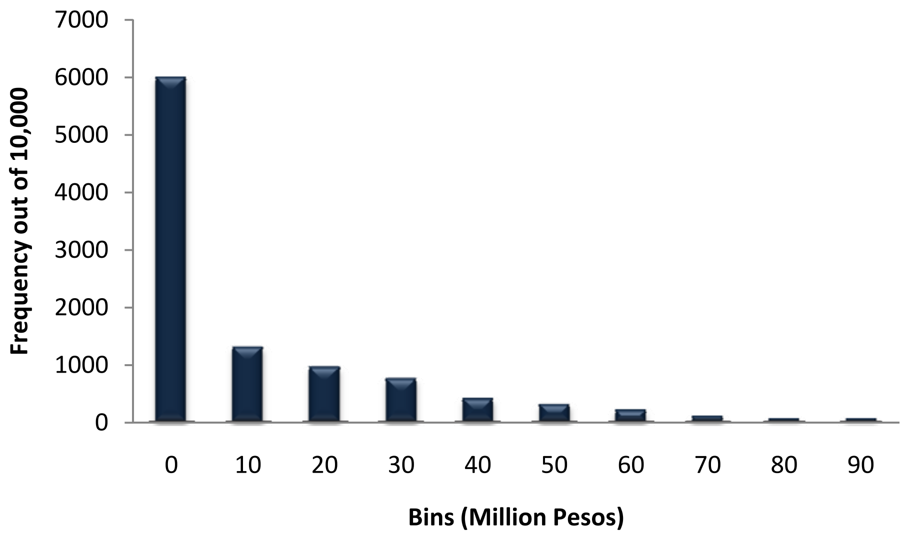

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Figure 2.4. Histogram example of guarantee payments (Irwin, 2007).

2.5 Traffic Demand Forecasts and Over Predictions

2.5.1 Performance of Toll Demand Projections in the U.S.

In 2006, as part of the National Cooperative Highway Research Program (NCHRP), a study was conducted by the TRB on the state of the practice for forecasting demand and revenue for toll roads in the United States. The report "Estimating Toll Road Demand and Revenue" (Kriger, Shiu, & Sasha, 2006) contains a comparison between the projected and actual revenues for different toll facilities across the United States. Table 2.1 shows the actual revenue collected at a specific year (e.g. year 1, year 2, etc) as percentage of what was projected in the study. It is important to note, however, that since there is no universal database that contains revenue forecast studies for toll roads, the NHCRP project team consulted different sources (Kriger, Shiu, & Sasha, 2006). The sources utilized were the following:

- Comparisons of actual and projected revenues that were conducted by different bond rating agencies;
- Traffic and revenue projections from financial offering statements for facilities;
- Financial reports prepared by the government authorities or owners;
- Surveys conducted on practitioners.

Table 2.1 represents the revenue prediction performance of different toll facilities along the first five years of operation. The facilities are listed in order of the opening years from 1986 to 2004. The accuracy of revenue forecasts shows little to no improvement even though modeling techniques are becoming more sophisticated with time. It can be seen that most predictions were overestimated. The actual revenue can go as low as 13% of the predicted revenue. Only a few forecasts have low percentage errors (within 10% difference). The above revenue study for toll roads in the U.S. clearly showed that there is still room for improvement on demand and revenue forecasting. There was also another study conducted that compared traffic forecasts for 104 toll roads from different countries. It was found that the revenue projections ranged from 15% to 150% of the actual performance during the first year of operation (during ramp-up period). Usually, during the first five years of operation the average revenue was approximately 80% of the projected value (Kriger, Shiu, & Sasha, 2006). Traffic forecasting studies have also been conducted by Standard and Poor's (2002). Updates of this initial research were published on the following years (2003, 2004, and 2005) to analyze variability in traffic performance as well as increasing the toll road projects sample size. These studies focus on the first year of operation due to the market risk being the highest at this ramp-up time period (Plantagie & Bain, 2003).

Table 2.1. Comparison between actual and projected revenue as a percentage.

Authority/Facility	Year of Opening	Year 1	2	3	4	5
Florida's Turnpike Enterprise/Saw grass Expressway	1986	17.8%	23.4%	32.0%	37.1%	38.4%
North Texas Tollway Authority/Dallas North Tollway	1986, 1987	73.9%	91.3%	94.7%	99.3%	99.0%
Harris County Toll Road Authority (Texas)/Hardy	1988	29.2%	27.7%	23.8%	22.8%	22.3%
Harris County Toll Road Authority (Texas)/Sam Houston	1988, 1990	64.9%	79.7%	81.0%	83.2%	78.0%
Illinois State Toll Highway Authority/Illinois North South Tollway	1989	94.7%	104.3%	112.5%	116.9%	115.3%
Orlando-Orange Expressway Authority/Central Florida Greenway North Segment	1989	96.8%	85.7%	81.4%	69.6%	77.1%
Orlando-Orange Expressway Authority/Central Florida Greenway South Segment	1990	34.1%	36.2%	36.0%	50.0%	NA
Oklahoma Turnpike Authority/John Kilpatrick	1991	18.0%	26.4%	29.3%	31.4%	34.7%
Oklahoma Turnpike Authority/Creek	1992	49.0%	55.0%	56.8%	59.2%	65.5%
Mid-Bay Bridge Authority (Florida)/Choctawhatchee Bay Bridge	1993	79.8%	95.5%	108.9%	113.2%	116.7%
Orlando-Orange Expressway Authority/Central Florida Greenway Southern Connector	1993	27.5%	36.6%	NA	NA	NA
State Road and Tollway Authority (Georgia)/GA 400	1993	117.0%	133.1%	139.8%	145.8%	141.8%
Florida's Turnpike Enterprise/Veteran's Expressway	1994	50.1%	52.9%	62.5%	65.0%	56.8%
Florida's Turnpike Enterprise/Seminole Expressway	1994	45.6%	58.0%	70.7%	78.4%	70.1%
Transportation Corridor Agencies (California)/Foothill North	1995	86.5%	92.3%	99.3%	NA[1]	NA[1]
Osceola County (Florida)/Osceola County Parkway	1995	13.0%	50.7%	38.5%	40.4%	NA
Toll Road Investment Partnership (Virginia)/Dulles Greenway	1995	20.1%	24.9%	23.6%	25.8%	35.4%
Transportation Corridor Agencies (California)/San Joaquin Hills	1996	31.6%	47.5%	51.5%	52.9%	54.1%

Table 2.1 (Continued). Comparison between actual and projected revenue as a percentage.

Authority/Facility	Year of Opening	Year				
		1	2	3	4	5
North Texas Tollway Authority/George Bush Expressway	1998	152.2%	91.8%	NA	NA	NA
Transportation Corridor Agencies (California)/Foothill Eastern	1999	119.1%	79.0%	79.2%	NA[1]	NA[1]
E-470 Public Highway Authority (Colorado)/E-470	1999	61.8%	59.6%	NA	95.4%[2]	NA[3]
Florida's Turnpike Enterprise/Polk	1999	81.0%	67.5%	NA	NA	NA
Santa Rosa Bay Bridge Authority (Florida)/Garcon Point Bridge	1999	32.6%	54.8%	50.5%	47.1%	48.7%
Connector 2000 Association (South Carolina)/Greenville Connector	2001	29.6%	NA	NA	NA	NA
Pocahontas Parkway Association (Virginia)/Pocahontas Parkway	2002	41.6%[4]	40.4%	50.8%	NA	NA
Northwest Parkway Public Highway Authority (Colorado)/Northwest Parkway	2004	60.5%	56%[5]	NA	NA	NA

Source: (Kriger, Shiu, & Sasha, 2006)
1 For these years, the Transportation Corridor Agencies combined the revenues (earnings) for the two facilities.
(Foothill North and Foothill Eastern). Accordingly, the individual performance for the two facilities cannot be calculated.
2 Data reflect updated traffic and revenue study.
3 Incomplete information (missing November and December).
4 This is approximated owing to construction delays that only allowed the facility to be open for one-quarter of the expected full year.
5 Projected performance for the 2005 fiscal year.

The actual to forecasted revenue ratios (actual revenue as a fraction of predicted revenue) were documented in both 2002 and 2003 analyses (Plantagie & Bain, 2003). Table 2.2 presents the findings for different toll facilities around the world. The results show that majority of the toll facilities did not perform as expected. In other words, the majority of the case studies analyzed had an overestimation of revenue (i.e., the mean of the actual to forecasted ratio was below one).

Table 2.2. Standard & Poor's revenue performance findings from the 2003 publication. (Plantagie & Bain, 2003)

Actual to Forecasted Revenue Ratio		
Properties	2002 Study	2003 Update
Minimum	0.31	0.15
Maximum	1.19	1.51
Mean	0.73	0.74
Number of case studies	32	68

A disaggregate analysis was also conducted by S&P in which the data was separated on whether a specific country had previous toll road experience or none at all. The sample means for both data sets showed a difference on the ratios of actual to forecasted traffic volume with 0.81 for countries with some toll history and 0.58 for those without any experience. Figure 2.5 represents the distributions for the countries with and without tolling experience.

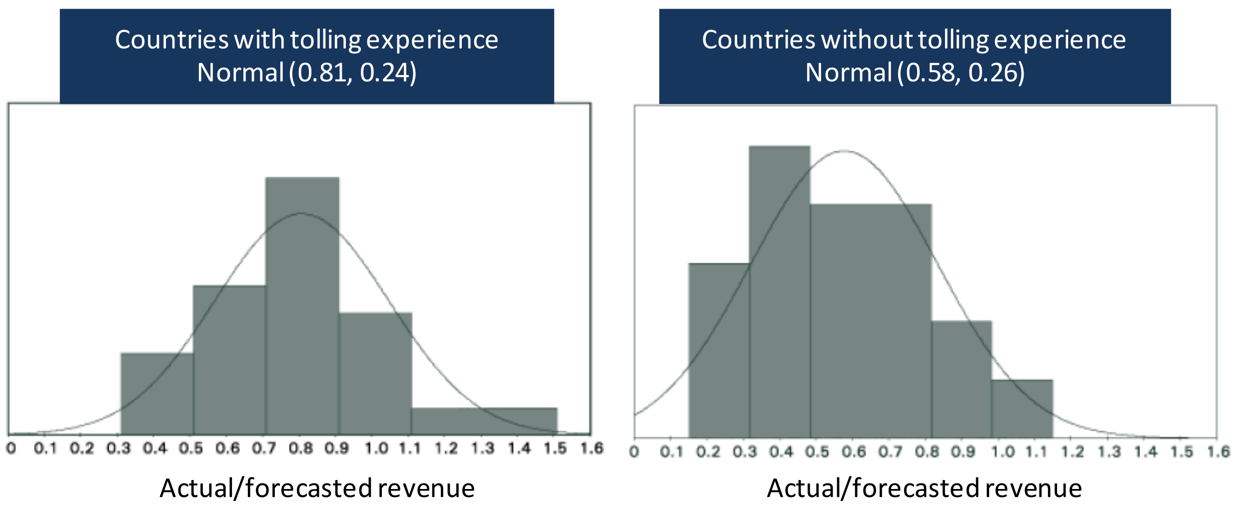

Figure 2.5. Distribution of revenue for countries with and without tolling experience (Plantagie & Bain, 2003).

The low sample mean for those countries with no toll history was most likely due to the slow consumer response when choosing new alternative routes such as a toll road (Bain & Polakovic, 2005). In these countries, toll road demand and revenue forecasts should not only be done carefully, but also with a proper risk analysis framework due to the nature of having higher probability of underperformance (or over estimation). The traffic risk updates from 2004 and 2005 show the same trend in which toll demand forecasts still have an over estimation of about 23%-25% in the first five years of operation (Bain & Polakovic, 2005). Also, the challenge of estimating truck demand in toll roads was only addressed in the most recent publication (Bain & Polakovic, 2005). Even though trucks may occupy a low percentage of the total toll volume, the high roll rate associated with heavy vehicles can significantly contribute to the total revenue. Usually, trucks are charged approximately two to five times of the toll rate for light vehicles.

The S&P traffic risk studies conclude that there is still a lot of optimism bias as well as other factors (e.g. modeling inputs) that contribute to the overestimation of toll road revenue.

2.6 Transportation Planning Software

Transportation analysts often utilize transportation planning software to generate results and compare the network impacts of a new toll road. A critical part of a toll demand and revenue forecast study is therefore the software used in the analysis. However, the results obtained from the model strongly depend on the parameters that are input into the model. Some of the most common transportation planning software are TransCAD, VISUM, and DynusT. For the purpose of this research DynusT was used to model and simulate a network with a potential toll road. However, the analysis framework proposed in this thesis can be applied with any transportation planning software when conductingMCS. The following sub-sections give a brief description of the capabilities (in the context of toll road simulation) of the three transportation planning software.

2.6.1 DynusT

The Dynamic Urban Systems for Transportation (DynusT) is a mesoscopic traffic simulation and assignment tool that provides support for network planning analysis (DynusT Online User's Manual, 2010). Mesoscopic models combine some of the properties from both macroscopic and microscopic models. One of the characteristics of mesoscopic models is that it simulates vehicles individually but also describes their behavior based on macroscopic relationships. In addition, mesoscopic models have the ability to limit the traffic flow to the estimated capacity of a roadway. In other words, the vehicle volume in a link cannot exceed the given capacity as opposed to other software such as TransCAD where the volume to capacity ratio can be greater than one. This feature of DynusT is especially important since volume to capacity ratios greater than one may contribute to the overestimation of toll road volume and revenue. DynusT is capable of modeling value pricing scenarios in which tolls can be time-dependent, distance based, or link based. Different VoTs can be specified for three different vehicle types (i.e. High Occupancy Vehicles (HOV), Low Occupancy Vehicles (LOV), and trucks for a more accurate path decision making. The software uses a time-dependent routing methodology (dynamic traffic assignment or DTA) to capture traveler’s route choice behavior as they traverse from origin to destination. This methodology describes how motorists find their experienced shortest path from origins to destinations taking into account the cost as well as roadway connectivity, capacity, and link traveltime. DynusT has been used for other projects in the context of toll modeling to evaluate high occupancy toll lanes and the impact of advanced traveler information systems to increase toll usage (Abdelghany, Abdelghany, Mahmassani, & Murray, 2000) (Persad, Walton, & Wang, 2006).

2.6.2 TransCAD

TransCAD is a travel demand modeling software that supports the often applied four-step model transportation planning procedure and its variants (Caliper, 2005). The software integrates Geographic Information Systems (GIS) and demand modeling capabilities to provide more geographically accurate models. TransCAD is classified as macroscopic software for modeling large scale networks like large regional metropolitan areas. As opposed to microscopic or mesoscopic models, link travel time is determined as a function of the link's volume to capacity ratio. The user-specified section capacity does not limit the traffic volume, i.e., the volume to capacity ration can be greater than one. Even if vehicles arrive at the section where capacity has been reached, they are still able to pass the link but with a lower speed. TransCAD also offers the option and flexibility to have various VoTs and toll rates for different vehicle classes to simulate toll roads.

2.6.3 VISUM

Similar to TransCAD, VISUM (PTV, 2007) is a macroscopic planning software to aid in the analysis of a region's transportation system. VISUM also allows for the modeling of different VoTs as well as toll rates for different vehicle types. In addition, one can define linear and non-linear road pricing schemes. A linear scheme refers to the road segments where fixed toll rates are charged. On the other hand, a non-linear scheme charges vehicles depending on the time of the day or entry point (of the toll road). In VISUM, it is also possible to allocate different VoT distributions for the different demand class to obtain a more realistic price elasticity behavior.

As mentioned before, DynusT was the software of choice for this research primarily due to its capabilities in mesoscopic modeling that permits individual vehicles route choice (between the tolled and non-tolled links).

CHAPTER 3 : SURVEY

This chapter provides the results from the surveys conducted with various organizations which have been involved in toll revenue forecasting. The feedback obtained from each organization is analyzed and a summary is provided at the end of this chapter.

3.1 Surveys Conducted

To supplement the literature review made in Chapter 2, a survey of eight questions was developed in the context of toll road traffic demand and revenue forecasts. The full survey instrument is included in Appendix A. The survey was sent to a total of 12 organizations which have broad experience in the field of toll road demand forecasting. However, of the 12 surveyed only five of them submitted responses. As part of the survey, the respondents were asked to name the software most commonly used to perform toll road demand forecasts. The results are shown in Table 3.1.

Table 3.1. Software Most Commonly Used to Perform Toll Road Demand Forecasts

Organizations	Planning Software
C&M Associates, Inc (Dallas, Texas)	TransCAD, Cube Voyager, Emme, Transmodeler, Avenue
Whitman, Requardt & Associates, LLP (Baltimore, Maryland)	Cube Voyager (customized toll model)
Wilbur Smith Associates (Columbia, South Carolina)	TransCAD, TRANPLAN, VISSIM, Cube
El Paso Metropolitan Planning Organization (El Paso, Texas)	TransCAD
Walter P Moore (Houston, Texas)	TransCAD, Cube

It can be observed that TransCAD and Cube are very popular among these respondents. Other survey observations were summarized by individual respondents in the following sections.

3.2 C&M Associates, Inc.

C&M Associates, Inc. is a Texas based corporation founded by local investors and Cal y Mayor y Asociados, S.C. that has performed more than 100 Traffic and Revenue (T&R) studies in the U.S. and other countries (C&M Associates, Inc., 2007). Out of the five respondents, C&M Associates, Inc. was the organization that provided a more detailed answer on how they perform a risk analysis for a specific toll road forecast project (see observation number 5). These are the major observations obtained from the survey:

1) The VoT is specified for each vehicle type in the simulation model. However, depending on the project requirement it can also be modeled based on trip purpose or occupancy;
2) In some projects, the VoT is assumed to have a growth rate equivalent to the real per capita income growth;

3) A comparison is often made between the forecasted and the actual traffic (or revenue) of the toll road to analyze its performance over time;
4) A sensitivity analysis is commonly conducted with respect to socioeconomic variables that can affect the toll road demand forecast;
5) For some comprehensive level studies (used to finance projects), a risk analysis is conducted using MCS. The main variables are identified and associated with appropriate probability distribution functions. The values generated from these distributions are then used to run the forecast iteratively to create a risk profile of the outcomes (i.e. in this case the probability distribution of revenue or traffic demand).

No further detail or explanation was provided on the risk analysis methodology applied by C&M Associates which includes MCS and the development of risk profiles.

3.3 Whitman, Requardt & Associates, LLP

Whitman, Requardt & Associates (WR&A) provides various traffic forecasting services that range from statewide travel demand models to project specific models (Whitman, Requardt & Associates, LLP, 2006). WR&A develops traffic forecasts using different techniques such as trend line analysis, diversion curves, and spreadsheet applications. The following observations were obtained from the survey conducted:

1) The VoT is not typically assumed to grow in the future. Other variables considered in the traffic demand forecast are operating costs and toll rates;
2) The actual elasticity versus the predicted elasticity is compared when toll rates are adjusted;

3) A sensitivity analysis is conducted with respect to VoT, toll rate, as well as other demographic variables (however, no further detail was provided);
4) The MCS is not a part of the toll road traffic forecasting methodology.

3.4 Wilbur Smith Associates

Wilbur Smith Associates is a full service transportation and infrastructure consulting firm in planning, design, toll, economic, and construction related services around the world (Wilbur Smith Associates, 2009). The feedback obtained from this entity is as follows:

1) The VoT is adjusted for future years with a compounded growth rate based upon the demographics of the region;
2) A risk assessment is not often conducted for toll traffic and revenue forecast studies;
3) No sensitivity analysis is performed with respect to variables such as the VoT or toll rate;
4) The toll traffic forecast studies conducted did not involve MCS.

3.5 El Paso Metropolitan Organization

The El Paso Metropolitan Planning Organization (EPMPO) is the regional planning and programming agency responsible for working with residents, neighborhood groups, local, state and federal agencies (El Paso Metropolitan Planning Organization, 2010). The most important remarks from its survey response are the following:

1) The EPMPO only has experience on performing forecasts within the El Paso County, Texas, using a generalized cost approach;
2) Only one vehicle type is modeled for a twenty-four hour static traffic assignment;
3) Neither a risk assessment nor sensitivity analysis is conducted for traffic forecast projects;
4) The MCS is not part of the traffic forecast study methodology used by EPMPO.

3.6 Walter P Moore

Walter P Moore (WPM) is a structural, structural diagnostics, civil, traffic and transportation engineering and parking firm in the U.S. (Walter P Moore, 2007). Several toll road forecast projects conducted by this engineering firm include: State-Highway 121 and State Highway 161, both located in Texas. The comments obtained from the survey are presented below:

1) The VoT for every vehicle type is assumed to increase based on the Consumer Price Index (CPI);
2) A risk assessment as well as a sensitivity analysis is developed with respect to the traffic forecast model variables (i.e. VoT, toll rate, etc.);
3) The MCS is applied to traffic forecast and risk analysis.

3.7 Survey Feedback Summary

The five respondents' survey comments were used as a starting point to develop the risk analysis framework provided in the next chapter. A summary of the most relevant remarks obtained are the following:

- The VoT is specified for each vehicle type and assumed to increase according to a relevant demographic or economic variable (e.g. CPI, real per capita income growth);
- One respondent (C&M Associates) develops the probability distribution of revenue from an iteration traffic forecast process by using Monte Carlo simulation;
- Only two of the organizations surveyed use MCS.

CHAPTER 4 : RISK ANALYSIS FRAMEWORK

This chapter presents the risk analysis framework proposed in this research with a short discussion on each of the steps. Next, the importance of the value of the time in this risk analysis framework is explained. This chapter ends with the presentation of the probability distribution functions and the correlation matrix that are used to model the values of time.

4.1 Proposed Framework

The risk analysis framework for toll road demand forecasts was developed based on the literature review in Chapter 2 and survey conducted in Chapter 3. The proposed framework is depicted in Figure 4.1. The first step of the framework involves selecting the transportation planning software to simulate time-dependent pricing. The model inputs that affect the behavior of the tolled and non-tolled vehicles (e.g. toll rate, VoT, etc.) need to be specified in order to conduct the simulation modeling.

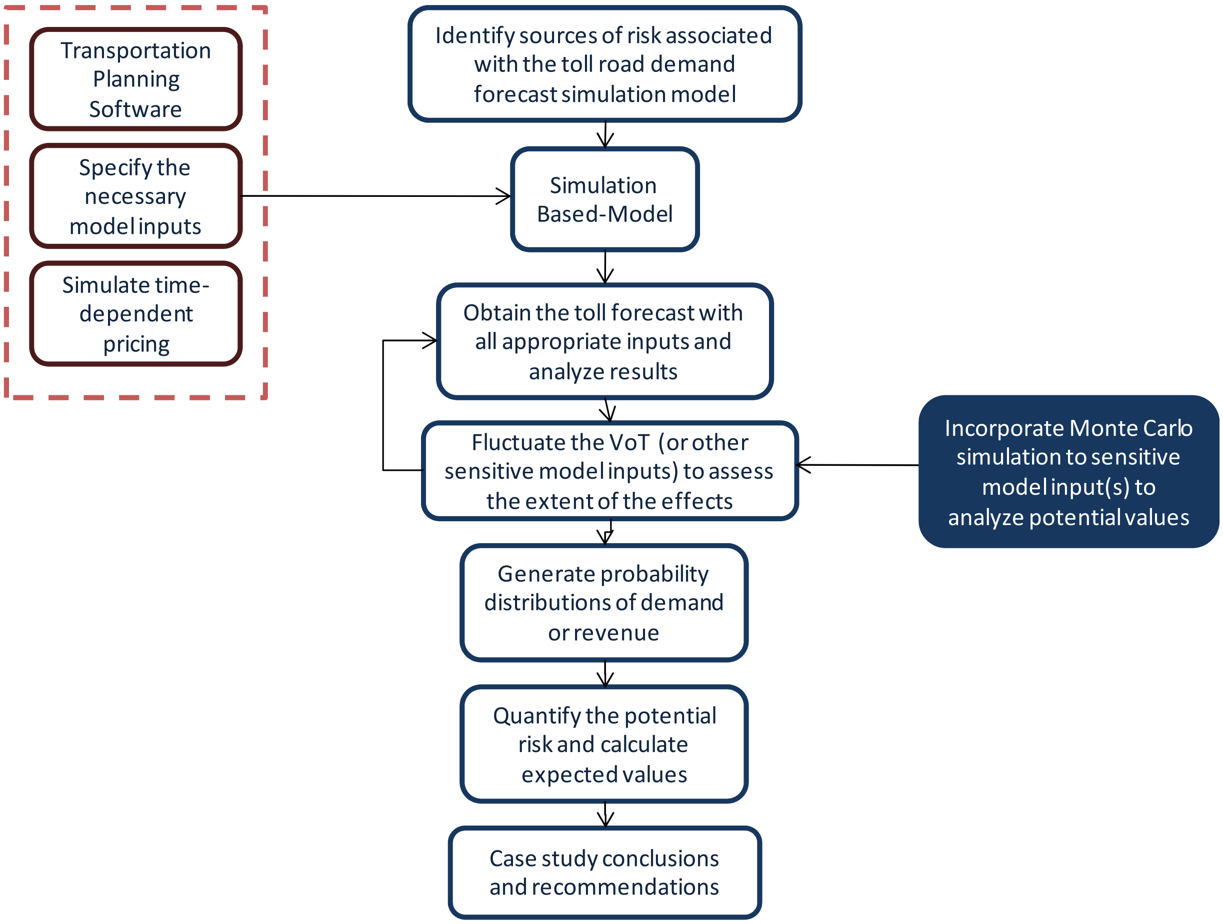

Figure 4.1. Risk analysis framework.

The next step in the framework is to identify the sources of risk (uncertainty) associated with a toll road demand and revenue forecast model. These sources can vary depending on the project or location but variables such as the VoT can impose a significant amount of variation to the toll traffic and revenue forecasts. On the other hand, the toll rate itself might not have so much variability because it usually has a fixed value and escalation rate (i.e. the increase of toll with time). Once the model inputs are specified, the first set of results obtained from the simulation can help to identify any major or minor coding errors. The next step in the framework is to vary the VoT for different vehicle types to assess the extent of their effects on the simulation results (e.g. the traffic volume using the toll road and the total revenue collected). This is achieved by incorporating MCS to vary the VoT of the different vehicle types (each vehicle type's VoT has a certain probability distribution). The MCS is run iteratively to obtain the probability distributions of toll road traffic volume and revenue based on the specified distributions of VoT. This MCS process is repeated for the base year scenario (the first year when the toll road is opened to traffic) as well as the future year scenarios (to forecast the future year's traffic and revenue). The probability distributions of traffic volume and toll revenue are then used in the analysis of risk and subsequent decisions. Note that, the proposed framework primarily concerns with the uncertainties of toll road volume and toll revenue with respected to the uncertainty in VoT. The framework can also be applied to analyze the uncertainty associated with other model inputs, such as land use and trip generation.

4.2 Value of Time Stochastic Analysis

The common methods applied to estimate an average VoT (e.g. based on surveys or income analysis) can carry certain amount of uncertainty in the results. Every person can perceive or value their time in a unique way, making it problematic to estimate just one value for the entire population. One of the steps within the proposed risk analysis framework is to incorporate MCS to assess the sensitivity of the toll road traffic volume and revenue with respect to the VoT. The VoT has to be defined with a probability distribution function based on the data or statistics available. A probability distribution function may be defined for each vehicle type. This probability distribution function is used to generate the VoT values for input into the MCS. The number of VoT values generated is the same as the number of iterations in the MCS. The next step is to run the transportation planning model iteratively for each of the VoT value (or each set of VoT values, for different vehicle types). Each iteration of the model produces a traffic forecast and revenue forecast. After all the iterations have been completed, the data points for the traffic forecasts and revenue forecasts are used to construct their respective probability distributions.

Forecasting revenue for a potential toll road is no exact science, and it can become difficult if many stochastic variables are taken into consideration in the same project. The incorporation of MCS to the most sensitive variables in the toll road demand and revenue forecasts provides a bigger range of revenue possibilities as well as a measure of their probability of occurrence. In addition, the creation of revenue distributions gives the analyst the ability to interpret the results more in depth.

4.3 Value of Time Distributions

A probability distribution was selected to model the uncertainty in the VoT for each type of vehicle. Figure 4.2 shows the VoT distribution for cars. In this figure, the triangular distribution is presented as an example, in the absence of survey data. However, other distributions may be used when survey data is available. In our case, the triangular distribution has a minimum value of $10.50/hr, a most likely value of $14.00/hr (recommended by local transportation agencies), and a maximum value of $17.50/hr. The range of the VoT (i.e. the ±25% of the average VoT) was based on the Standard and Poor's traffic forecasting study's findings (Bain & Polakovic, 2005). The same logic was used to define the VoT distribution for trucks and it is shown in Figure 4.3. The VoT distribution functions for the different vehicle types may not be the same. Other distributions could be applied depending on the data or statistics available for the area of study. Once the two distributions were defined a correlation is incorporated between the two variables before generating the VoT values to be used in the MCS.

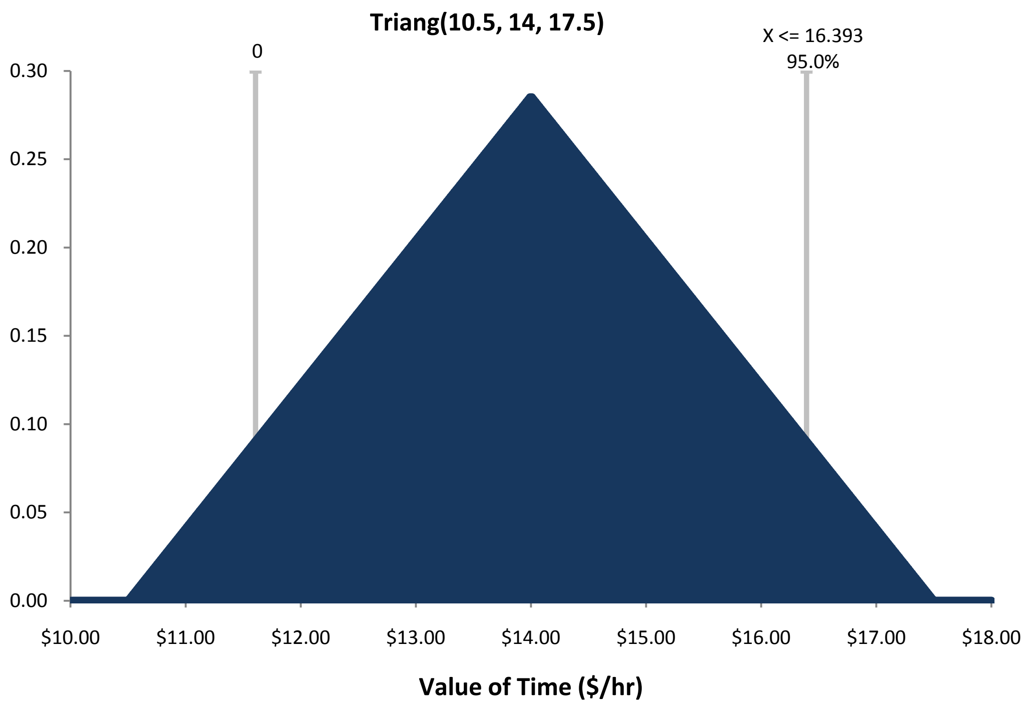

Figure 4.2. Example of a triangular distribution of the VoT for cars.

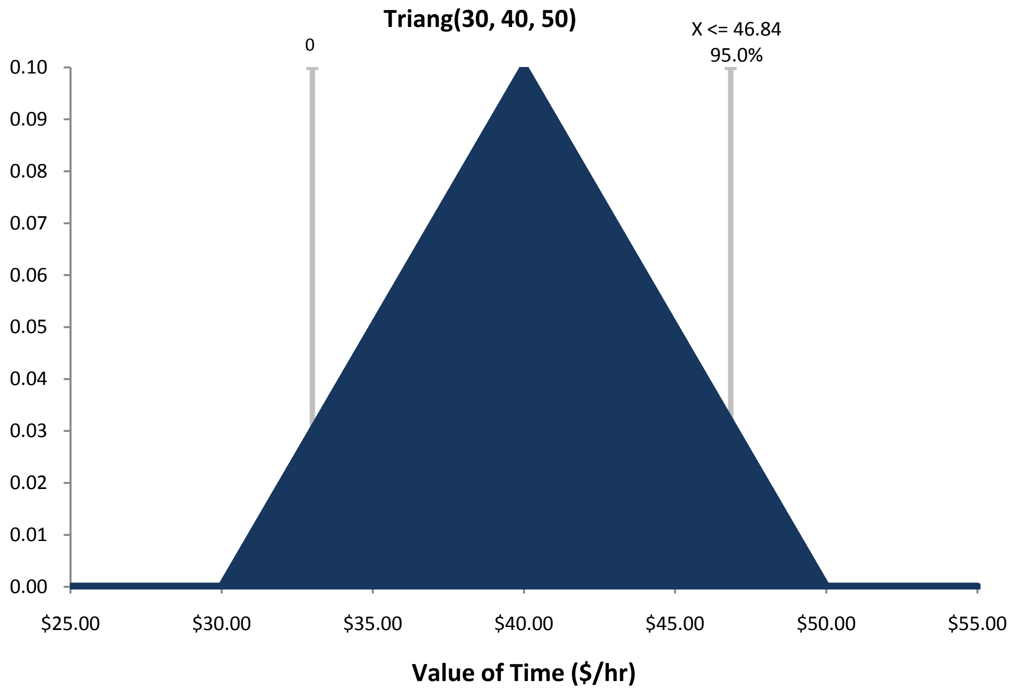

Figure 4.3. Example of a triangular distribution of the VoT for trucks.

Other than specifying the probability distributions of VoTs for different classes of vehicles, one must also consider the correlation between the two variables. The VoT values for the two types of vehicles have a positive correlation. This is because when one VoT distribution returns a relatively "high" value, the second VoT distribution should also return a relatively high value (and vice versa). A correlation matrix (see Table 4.1) is created in order to avoid having a high VoT for cars and a low VoT (or vice versa) for trucks in the same VoT pair which could yield unrealistic results.

Table 4.1. Correlation matrix for two variables.

Value of Time (2x2)	VoT Cars	VoT Trucks
VoT Cars	1	-
VoT Trucks	1	1

The MCS was conducted for hundreds of iterations once the VoT distributions for the different vehicle types and their correlation are defined. The number of iterations depends on the analyst's time budget, computing resources and the run-time of the network modeling software (in this proposed framework, DynusT). The results of MCS and the fitted probability distribution functions of the forecasted revenue are discussed in Chapter 6, using the case study.

4.4 Model Variables Relationship

The VoT and the toll rate specified in the traffic simulation will determine the total revenue and as well as the driving behavior. Trip makers with a higher VoT will perceive that the toll cost has a minimal impact on their trip cost. On the other hand, those with a lower VoT will be more reluctant to use and pay for the toll road. In other words, if the toll road shows a considerable amount of time savings the trip makers with a higher VoT will be likely to use it. The following equation shows this relationship (Smith, Chang, Stockton, & Smith, 2004):

$$Travel\ Time\ Savings\ (hr) * Value\ of\ Time\ \left(\frac{\$}{hr}\right) > Total\ Toll\ Cost$$

The toll rate also influences the driving behavior. However, determining the toll rate that would yield the maximum revenue was not part of the scope of this research. Therefore, only a deterministic value was specified for the toll rate depending on the scenario being modeled.

The simulation software DynusT is based on a congestion responsive tolling scheme algorithm. In essence, the software seeks to maximize throughput (and revenue) while maintaining the operating speed of the tolled link. This is achieved when drivers need to consider between the tolled link and the general purpose lane, but also taking into account the congestion levels and their VoT. In addition, in order for DynusT to activate the pricing calculation it needs to be run with an iterative mode (i.e. to obtain a stable pricing solution). An iteration consists of selecting values for all of the variables including those with uncertainty and calculating an outcome like revenue or VMT (Smith, Chang, Stockton, & Smith, 2004). The number of iterations performed depends on the needs and discretion of the analyst.

CHAPTER 5 : CASE STUDY

This chapter describes the toll road and its model used in the case study. It starts with an overview of the location and specifications of the toll road. A description of the traffic network model is provided as well as all of the variables considered for the simulation. All of the growth rate assumptions for the value of time, the vehicle demand, and the toll rate are discussed in later sections of this chapter.

5.1 Case Study

The El Paso Regional Mobility Authority, Texas, is proposing to add two toll lanes to the Border Highway portion of Loop 375 as part of their 2008 Comprehensive Mobility Plan (2008 CMP). The project extends for approximately nine miles along Loop 375 from U.S. 54 to South Zaragoza Road. The proposed project scope includes rehabilitating the existing two lanes in each direction as well as adding two toll lanes (for a total of six lanes). Figure 5.1 shows the location map of the proposed toll lanes.

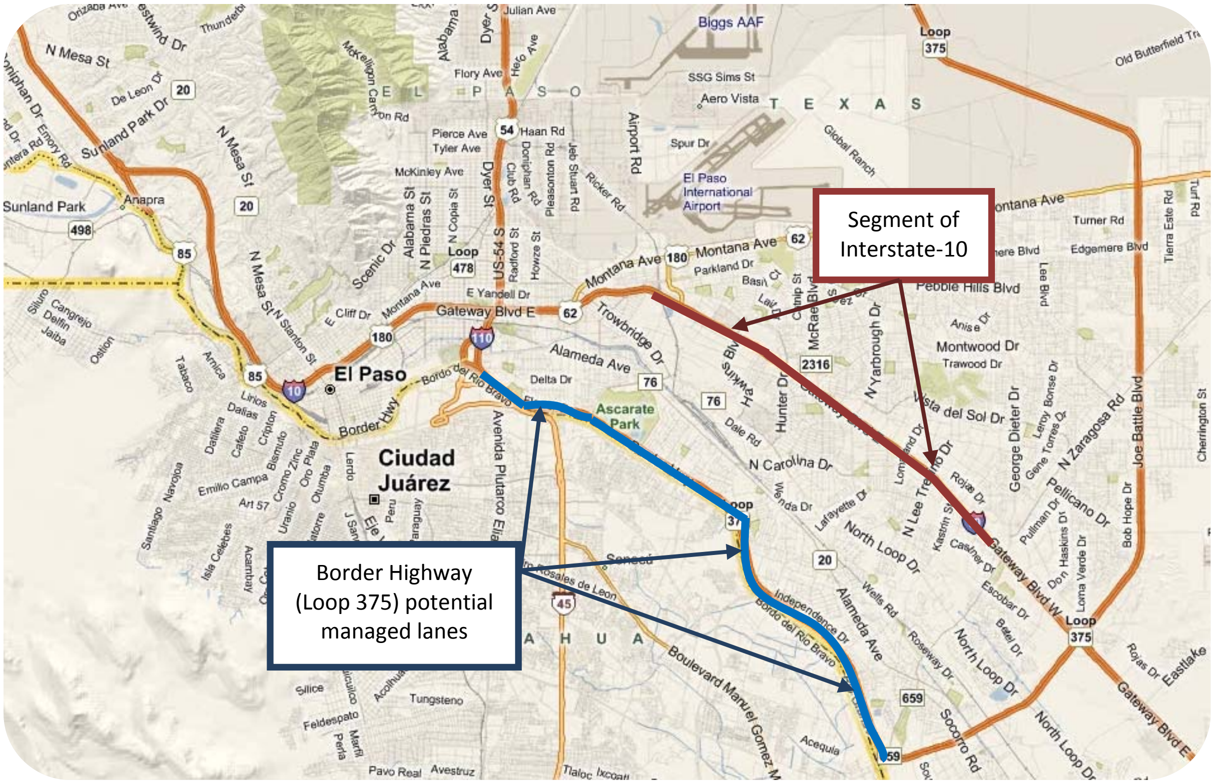

Figure 5.1. Potential managed lanes on the border highway (Loop 375).

5.2 Base Year Model

The first step before conducting MCS was to code the potential express lanes along Loop 375 into the El Paso network in DynusT. This includes, for each travel direction, one toll lane and its four entry/exit points near major interchanges, based on the preliminary design drawings provided by the Texas Department of Transportation El Paso District. Figure 5.2 shows the coded toll lanes portion of the network in DynusT. This model was used as the base year scenario (year 2010) with two Origin-Destination (O-D) matrices for cars and trucks. Because of the long time and demanding computing resources required to run just one DynusT simulation with 24 hour O-D car and truck matrices, only a shorter time period of three hours was simulated. The period selected was from 4 p.m. to 7 p.m. on weekday which appeared to have the most congestion along Loop 375. Average toll rates for both vehicle types were specified according to the year being simulated (i.e. base year or future year). Each DynusT simulation was performed for twenty traffic assignment iterations in order to reach user equilibrium condition (or convergence). The Figures 4.2 and 4.3 shown in the previous chapter represent the variation of the VoT for cars and trucks through triangular probability distributions. Both of these distributions were used for the base year model.

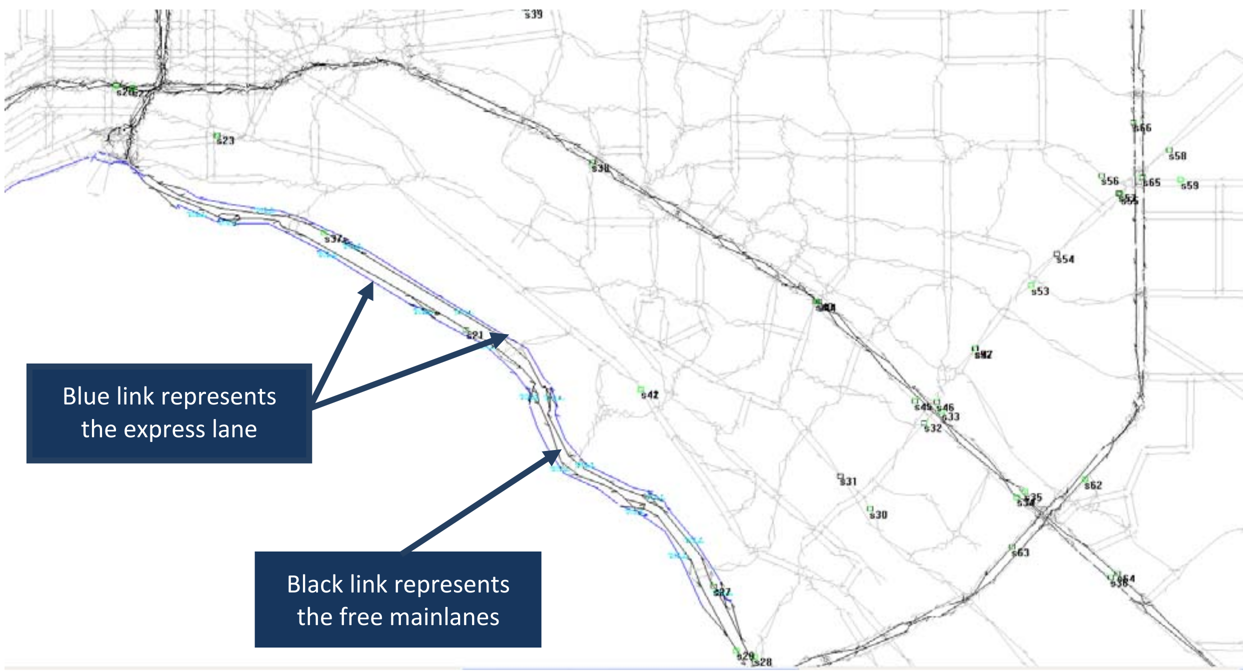

Figure 5.2. Network model utilized to perform simulation with DynusT.

5.3 Growth Rate Assumptions

In this case study, the uncertainties in vehicle demand and toll rates were not considered for MCS because they are deemed more reliable than the VoT. Nevertheless, the O-D matrices, toll rates and VoTs were projected to the future year. The following sub-sections explain in further detail the growth rate assumptions of these three variables.

5.3.1 Value of Time

Prior to the stochastic analysis on the VoT an average value had to be obtained for cars and trucks. For the El Paso region, an average VoT of $14.00 per hour and $40.00 per hour for cars and trucks respectively were recommended by local transportation agencies (i.e. El Paso Metropolitan Planning Organization, and Texas Department of Transportation El Paso District). These numbers were used as the most likely values for the triangle distributions defined for the base year scenario (year 2010). For future years the average VoT values were adjusted by the growth trends of the CPI in the past 12 years. The CPI database was obtained from the Bureau of Labor Statistics website (Bureau of Labor Statistics, 2010). Table 5.1 shows the CPI from 1997 to 2009 for a south urban medium size (i.e. a city with a population between 50,000 and 1.5 million) in which the annual CPI growth rate yields an average value of 2.25%.

Table 5.1. Consumer price index percent change for a south urban city.

Year	Annual	Percent Change
1997	101.20	
1998	102.30	1.09%
1999	104.20	1.86%
2000	107.40	3.07%
2001	109.60	2.05%
2002	110.80	1.09%
2003	113.10	2.08%
2004	116.20	2.74%
2005	120.00	3.27%
2006	123.90	3.25%
2007	127.42	2.84%
2008	132.62	4.08%
2009	132.07	-0.41%
	Average	2.25%

The 2.25% value was used to adjust the most likely value of the VoT's triangular distributions for the future year. Table 5.2 shows the VoT results after adjusting it for the scenarios in years 2020 and 2030.

Table 5.2. VoT adjusted based on the growth in CPI

	2010	2020	2030
Vehicle Type	**Value of Time ($ per hour)**		
Cars	14.0	17.5	21.8
Trucks	40.0	50.0	62.4

5.3.2 Vehicle Demand

The O-D matrix for cars was adjusted for the future year scenarios according to the total population growth rate in El Paso County. The population data was collected from the UTEP's

Border Region Modeling Project (Fullerton, 2010) which includes major economic indicators, demographic information, and employment. Table 5.3 shows the average annual percent change in population obtained from 1997 to 2008. The average yield a result of one percent change per year.

Table 5.3. El Paso population and annual percent change.

Year	Population (in thousands)	Percent Change
1997	665.066	
1998	671.250	0.93%
1999	675.397	0.62%
2000	681.026	0.83%
2001	685.035	0.59%
2002	689.213	0.61%
2003	695.376	0.89%
2004	703.437	1.16%
2005	709.992	0.93%
2006	722.458	1.76%
2007	729.969	1.04%
2008	742.062	1.66%
	Average	1.00%

`

The O-D matrix for trucks was adjusted from 2010 to the future years based on the truck traffic growth prediction for the next 23 years, as reported in the El Paso Regional Growth Management Plan (El Paso Regional Growth Management Plan, 2006). The generated truck trips estimation was conducted with socioeconomic data from El Paso and the results from the report are shown in Table 5.4 (El Paso Regional Growth Management Plan, 2006). For this case study, the truck demand was adjusted by 1.3% per year.

Table 5.4. Truck traffic growth by classification.

Truck Type	Year 2005	Year 2030	Change	% Change	% Annual
Light Trucks	100,819	140,791	39,972	40	1.3
Medium Trucks	39,618	54,896	15,278	39	1.3
Heavy Trucks	11,739	16,267	4,528	39	1.3
Total Production	152,716	211,954	59,778	39	**1.3**

5.3.3 Toll Rate

The toll rate for the base year (2010) was specified as $0.16 per mile and $0.48 per mile for cars and trucks respectively. The escalation for the toll rate was assumed to be 3% per year (based on other common toll cost escalation practices in Texas). Toll roads like the Dallas North Tollway or the George Bush Turnpike (which passes through three Texas counties Dallas, Collin, and Denton) have similar toll rate increments (NTTA, 2010). The future toll rates were computed and are shown in Table 5.5.

Table 5.5. Toll rate adjustments for future scenarios.

	Base Case	Scenario 2	Scenario 3
Vehicle Type	**2010**	**2020**	**2030**
Cars	$0.16/mile	$0.22/mile	$0.29/mile
Trucks	$0.48/mile	$0.65/mile	$0.87/mile

CHAPTER 6 : SIMULATION RESULTS

The chapter starts by describing the output that was obtained from all the traffic simulations. The next section describes the distribution fitting process of the revenue data. The fitted probability distributions functions of revenue for the base year, future year 2020, and future year 2030 are discussed in further detail.

6.1 Traffic Simulation and Monte Carlo Specifications

One of the challenges faced in this research was to run hundreds of simulations using DynusT. Because of the large size of the network, the simulation requires a large random access memory (RAM) and a high speed computer processor unit (CPU). All the traffic simulations were conducted in a desktop personal computer with a dual core CPU and 4 GB of RAM. The run time for each simulation (with three hours of afternoon peak traffic demand) was approximately four to five hours. However, DynusT is capable of taking advantage of a more advanced CPU's such as a quad-core equipped unit that should reduce the simulation time considerably. The revenue shown in the results section represents only what was generated during the three hours of demand (i.e. afternoon peak period on a weekday). Table 6.1 shows an example of a revenue output file (for base year 2010) from DynusT. The first column of the table specifies the toll link from which the results belong to. The vehicle miles traveled (VMT) are presented two columns: the first one pertains to cars and the second one pertains to trucks. The volume is given in total vehicles that passed through the link during the three hours of simulation. The revenue is on the last column of the table and it represents the amount of dollars obtained per link and per vehicle type. An example of how the revenue is computed for each toll link included in the traffic network is shown below:

Car revenue for Link 82 → 110 (highlighted in gray, See Table 6.1)

$$Revenue\ (\$) = (VMT's) * (Toll\ Rate) * (Link\ Segment\ Lenght\ in\ miles)$$

$$Revenue(\$) = (2685.6\ miles\ traveled) * (0.16\ cents/mile) * (2.6329\ miles)$$

$$Revenue\ (\$) = \mathbf{1131.4}$$

Table 6.1. Example of a revenue output from DynusT.

Link (from Node - to Node)		Link Length (miles)	Vehicle Miles Traveled		Volume (veh)		Toll Revenue ($)	
			Cars	Trucks	Cars	Trucks	Cars	Trucks
41->	94	0.23	0.5	0	2	0	0	0
82->	110	2.63	2685.6	347.6	1020	132	1131.4	439.2
84->	123	0.20	160.1	35.2	795	175	5.2	3.4
86->	89	0.27	0.5	0.5	2	2	0	0.1
94->	108	1.48	379.5	28.2	256	19	90	20
110->	113	0.27	42.8	5.4	158	20	1.9	0.7
113->	40	1.86	657.1	145.6	352	78	196.3	130.5
77->	37	1.25	1857.7	439.1	1485	351	371.8	263.6
89->	41	1.07	1077.8	158	1003	147	185.3	81.5
115->	117	0.25	18.7	4.3	74	17	0.8	0.5
117->	119	2.13	2909	454.6	1363	213	993.4	465.7
119->	121	0.35	252.6	48.2	708	135	14.4	8.3
123->	124	1.58	1734.4	308.3	1097	195	438.8	234
124->	77	0.36	246.7	61	679	168	14.3	10.6
108->	82	0.24	51.7	4.4	210	18	2	0.5
121->	84	1.31	2589.6	447.5	1979	342	542.2	281.1
127->	115	0.47	518.2	69.9	1105	149	38.9	15.7
Total VMT			**17740.4**		Total Revenue ($)		**5982.1**	

For each year of interest, MCS was performed for 100 iterations, with each iteration corresponding to one VoT pair for cars and trucks. The revenue is presented as the best fit PDF as well as the cumulative distribution function (CDF). Also, the most important parameters such as the mean, mode, median, and standard deviation are given for each fitted distribution. However, the volume traveling through the toll road is not analyzed in depth because of the difficulty in post processing the volume or VMT traveled in the toll facility. The toll lanes along loop 375 have four entry/exit points in each direction making the volume not a good representation of the usage. The VMT gives a better perspective of the toll usage road since the toll rate is based on a cost per mile basis.

6.2 Distribution Fitting

The simulation results from the iterative process of the Border Highway (Loop 375) case study helped to develop the revenue distributions for each of the three scenarios for years 2010, 2020 and 2030 respectively. In order to do so, @Risk 4.5 for Excel (Palisade, 2005) was used to fit the output data to obtain a probability density function (PDF) of revenue. Continuous PDF were tested since revenue is not restricted to discrete (or integer) values. The goodness of fits was based on the Chi-square statistic (Palisade, 2005). Several possible distributions (e.g. Normal, Log Normal, and Weibull) were fitted and the one that produced the best results in the Chi-square test was selected. For the purpose of demonstration, a 95th percentile was chosen to show the amount of revenue collected.

The Beta General distribution was chosen as the best fit distribution for the revenue data for two scenarios (base year and future year 2030). Section 6.3 explains in further detail the parameters of a Beta General distribution and its versatility to fit different types of data.

6.3 The Beta General Distribution

The Beta distribution has been widely used because of its versatility in modeling a variety of uncertainties including those that are constrained by minimum and maximum values. It is often used for risk analysis in the fields of finance, marketing, and engineering systems simulation, among others (Moitra, 1990). This Beta General distribution consists of four parameters which are represented byBeta General (*α1, α2, minimum, maximum*)

The *α1* and *α2* are the shape parameters of the distribution followed by the range between the minimum and the maximum value. For example, a Beta General (2, 3, 0, 5) means that it has shape parameters 2 and 3 with a minimum value of 0 and a maximum value of 5 (See Figure 6.1).

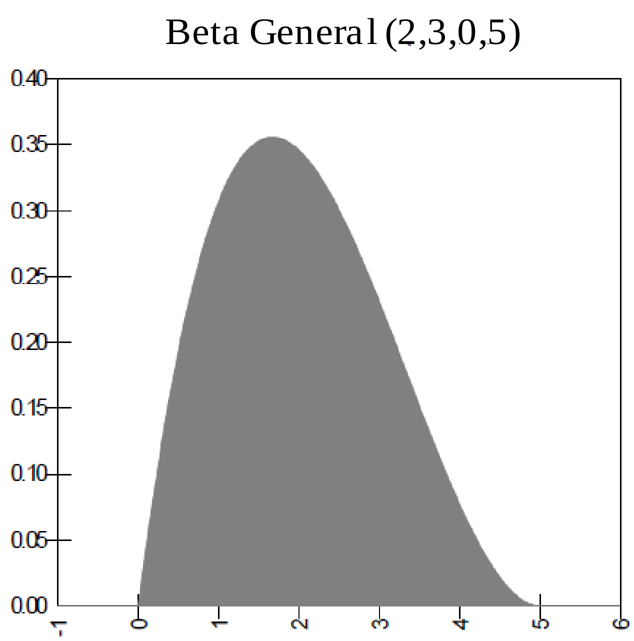

Figure 6.1. Example of a beta general distribution function.

6.4 Simulation Results

6.4.1 Base Year 2010

The first output data set to analyze was the base year scenario with three hours of afternoon peak traffic as previously mentioned in Chapter 5. The PDF of the best fitted distribution considered for this scenario is shown in Figure 6.2. This distribution showed the lowest Chi-square statistic out of all the possible PDF fitted. It is evident that the distribution skews to the left. Most of the revenue falls in the range of $5,000 to $8,000. On the other hand, revenue under $5,000 has a lower frequency of occurrence. In terms of VMT, the $5,000 of revenue corresponds to 14,183 VMT's (both directions combined, passenger cars equivalent). Out of the total VMT's, 12,410 correspond to car miles traveled and 1773.2 to truck miles traveled.

In addition, the CDF was also plotted and is shown in Figure 6.3. The cumulative plot indicates that there is a 95% confidence that the revenue collected during the p.m. peak hour will be between $3,565 and $8,586. In other words, there is only a 5% probability that the revenue will be lower than $3565. The following table shows the VMTs that yield the revenue range with a 95% confidence interval. All of the numbers represent the miles traveled in both directions.

Table 6.2. Base year range of vehicle miles traveled (95% Confidence).

Limit	Revenue Generated	Vehicle Miles Traveled		
		Cars	**Trucks**	**Total**
Lower	$3,565	9,371	1,400	10,771
Upper	$8,586	22,193	3,666	25,859

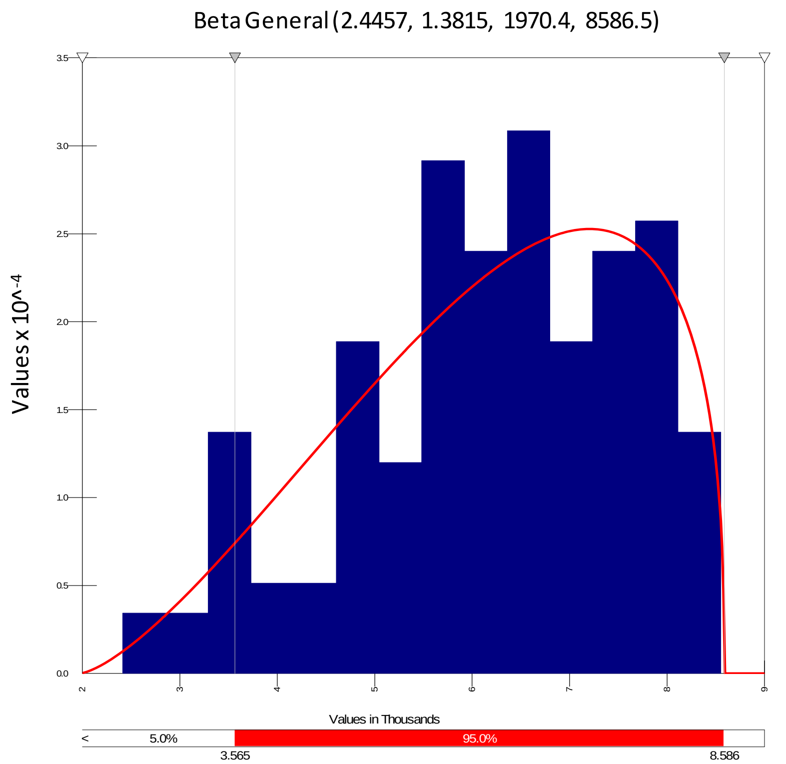

Figure 6.2. Probability density function of revenue for the base case scenario.

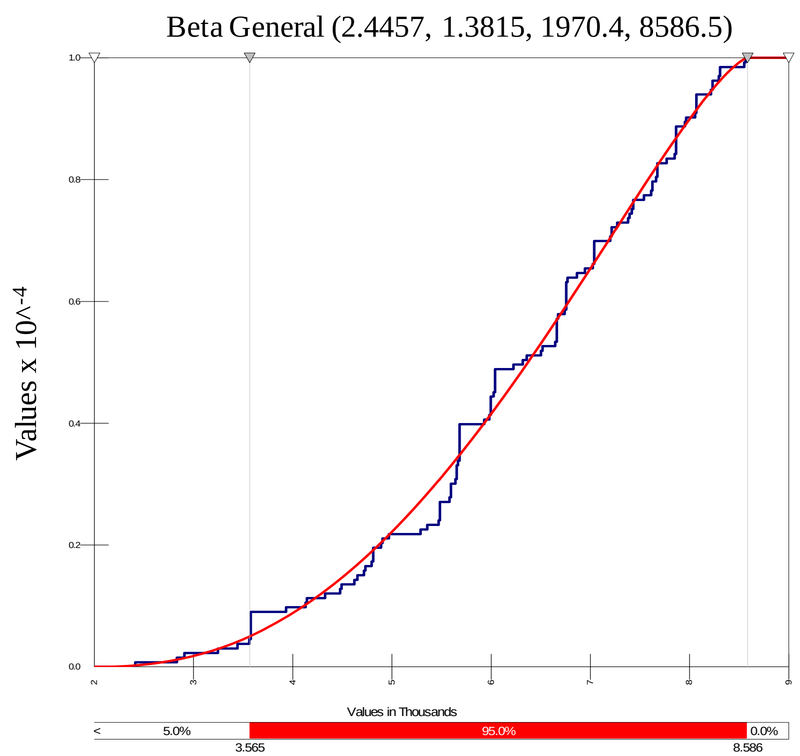

Figure 6.3. Cumulative distribution function of revenue for the base case scenario.

The properties from the fitted Beta General distribution are shown in Table 6.3. The standard deviation is rather large due to the skewness of fitted distribution.

Table 6.3. Beta General distribution properties for the 2010 scenario.

2010 - Distribution Properties	
Mean	$6,198.30
Mode	$7,205.20
Median	$6,371.90
Std. Deviation	$1,446.30

6.4.2 Future Year 2020

The next scenario was to forecast the toll road revenue obtained in 2020, having adjusted for the growths in VoTs, the toll rates, and the O-D matrices accordingly. The revenue data and the fitted PDF obtained from the MCS are shown in Figure 6.4. The results show that the Normal distribution gives the best fit as opposed to a Beta General distribution like in the base year scenario.

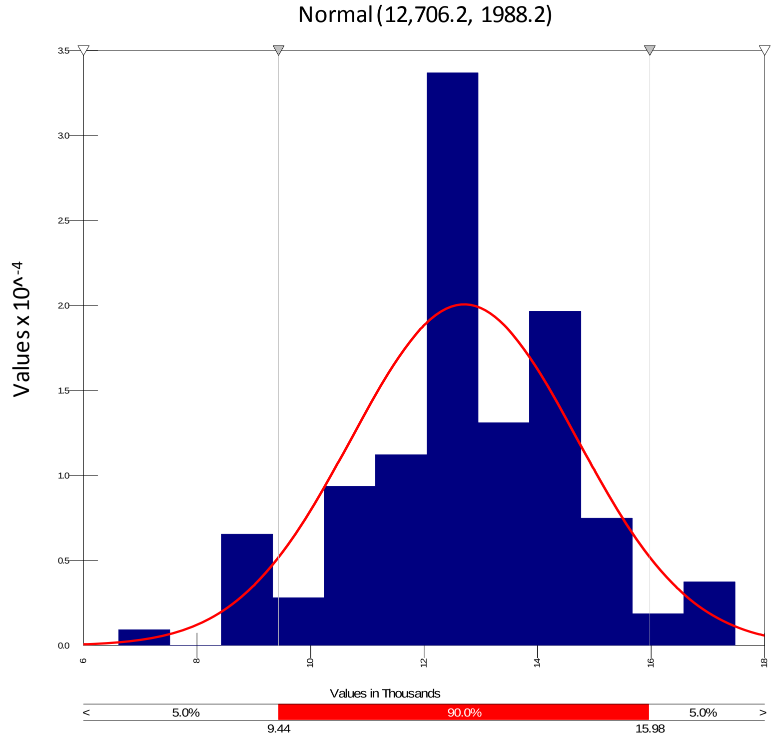

Figure 6.4. Density distribution function of revenue for the 2020 scenario.

The normal distribution had the lowest Chi-square value among the various fitted distributions. The CDF for the 2020 scenario is shown in Figure 6.5. It indicates that there is a 0.05 probability that the revenue could be lower than $9,440. In other words, there is a 95% probability that the revenue will be between $9,440 and $17,480. Table 6.4 shows the range of VMTs that generated this revenue and it accounts for all the vehicles traveling in both directions.

Table 6.4. Future year 2020 range of vehicle miles traveled (95% Confidence).

Limit	Revenue Generated	Vehicle Miles Traveled		
		Cars	**Trucks**	**Total**
Lower	$9,440	18,103	3,011	21,114
Upper	$17,480	30,258	4,761	35,019

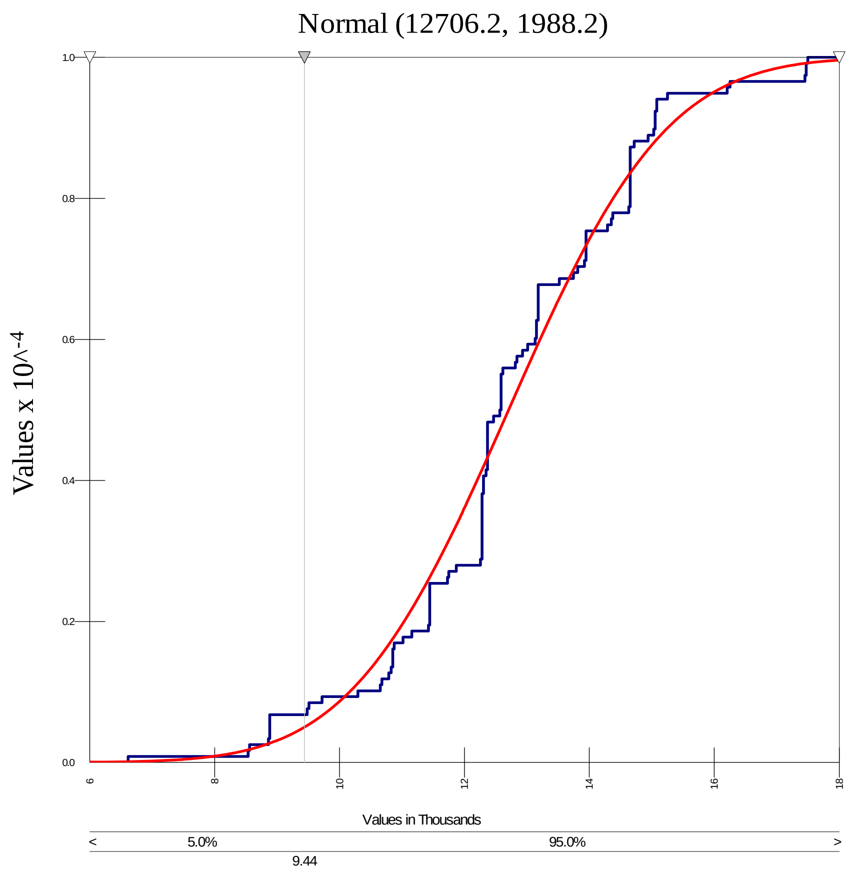

Figure 6.5. Cumulative distribution of revenue for the 2020 scenario.

The mean, mode, and the median are all shown in Table 6.5. These three statistics has the same value of $12,706. In addition, the standard deviation has a value of $1,988.

Table 6.5. Normal distribution properties for the 2020 scenario.

2020 - Distribution Properties	
Mean	$12,706.20
Mode	$12,706.20
Median	$12,706.20
Std. Deviation	$1,988.20

6.4.3 Future Year 2030

The last MCS performed was for the year 2030. The revenue values, when fitted to a Beta General distribution, showed the lowest Chi-square statistic. The Beta General PDF in Figure 6.6 shows skewness to the right, meaning that there is a relatively low probability of having revenue near the maximum value of the distribution. Like the other scenarios, the CDF was plotted and it is shown in Figure 6.7. Based on the fitted CDF, there is only a 5% probability that the revenue will fall under $21,230 for the three hours of demand simulated. This means that there is a 95% probability that the revenue generated will fall between $21,230 and $48,420.

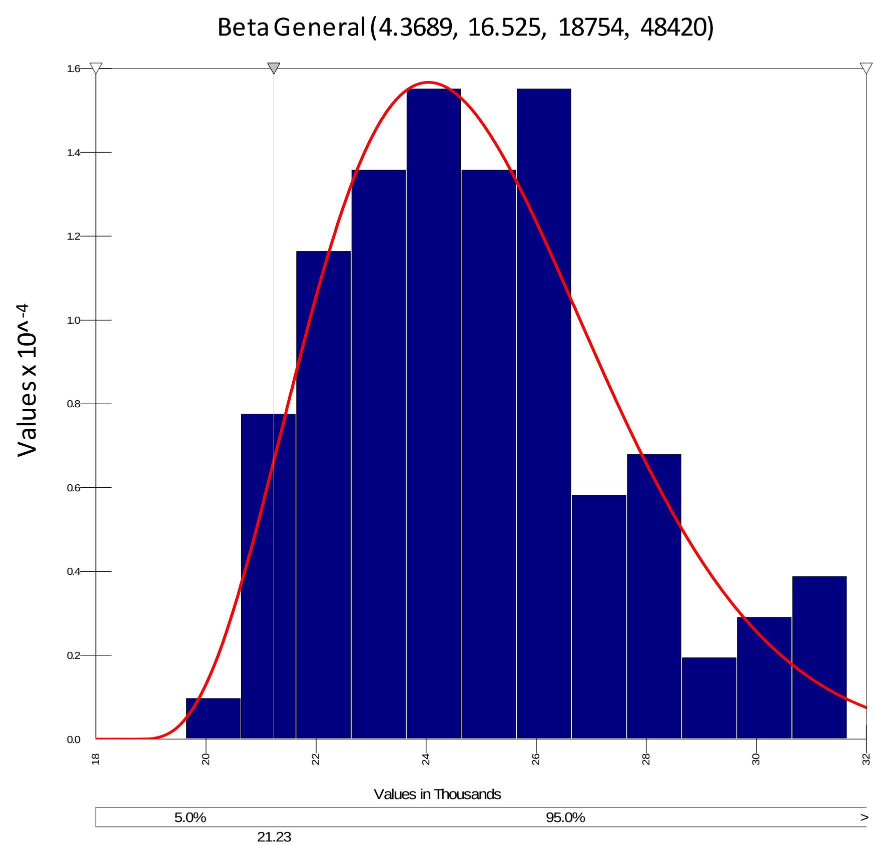

Figure 6.6. Density distribution function of revenue for the 2020 scenario.

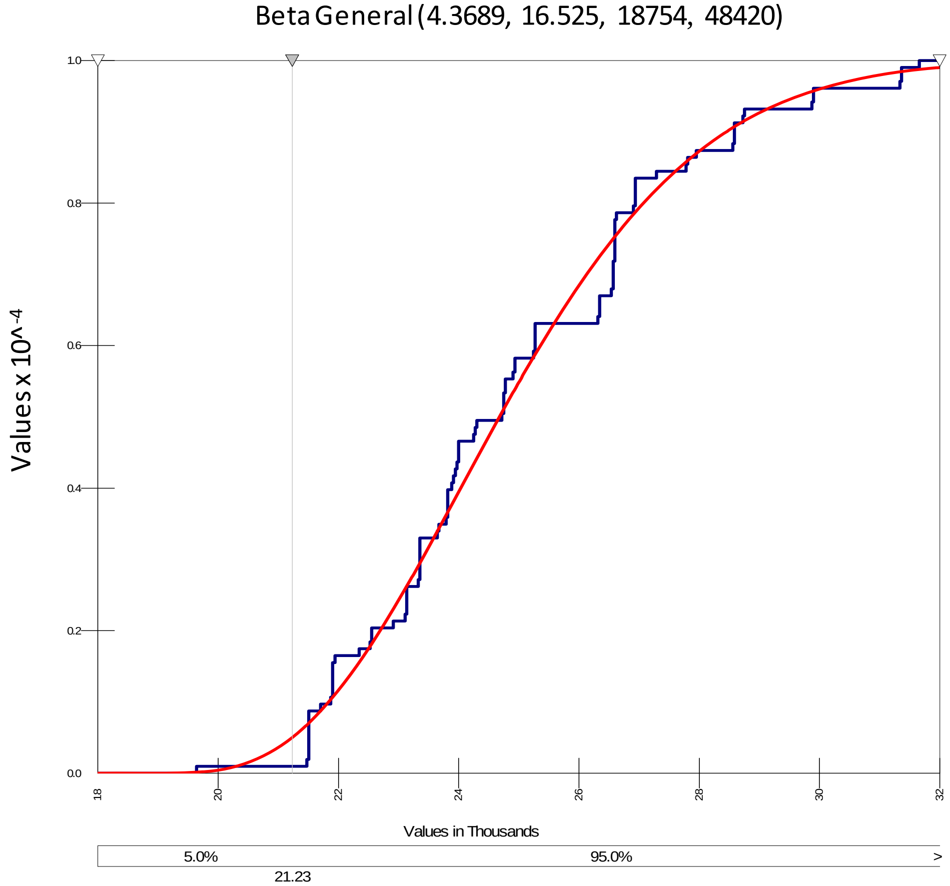

Figure 6.7. Cumulative distribution of revenue for the 2020 scenario.

The following table shows the VMTs that yield the revenue range with a 95% confidence.

Table 6.6. Future year 2030 range of vehicle miles traveled (95% Confidence).

Limit	Revenue Generated	Vehicle Miles Traveled		
		Cars	**Trucks**	**Total**
Lower	$21,230	27,700	4,553	32,253
Upper	$31,661	42,445	5,835	48,280

In addition, the properties of the Beta General distribution for the 2030 forecast are shown in Table 6.7. The standard deviation has a value of $2,578 which is almost as twice as high as the year 2010 forecast. However, it is noted that the year 2030 forecast it is expected to be higher.

Table 6.7. Beta general distribution properties for the 2030 scenario.

2030 - Distribution Properties	
Mean	$24,957.00
Mode	$24,044.00
Median	$24,679.00
Std. Deviation	$2,578.40

The Beta General appears to be a very flexible distribution for the revenue forecasts conducted. The revenue behavior of two scenarios (i.e. base year and year 2030) was best represented by such distribution. However, as previously mentioned the year 2020 revenue forecast distribution was not represented by a Beta General distribution but with a Normal distribution. The reason for this change was because the revenue data obtained from the MCS follow a bell shape (symmetrical and peak in the mid-value).

CHAPTER 7 : CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the findings of this research based on the simulation results and fitted revenue distributions. Recommendations are provided to guide readers in the future applications of the proposed risk analysis framework.

7.1 Conclusions

The risk analysis framework developed for this research (presented in Chapter 4) was based on the literature review and surveys conducted. The first step of the framework is the selection of the transportation planning software to simulate time dependent pricing. The necessary model inputs need to be specified that can affect route choice behavior. The next step is to identify the sources of risk associated with a toll road demand and revenue forecast model (e.g. VoT, toll rate). Once the traffic network model is ready, the first set of results can help identify any major or minor coding errors. Then, MCS is run iteratively based on specified distributions (e.g. normal, triangular) for the most sensitive model inputs in order to obtain the probability distributions of toll road traffic or revenue. This MCS process is conducted for the base and future year scenarios. The probability distribution functions are then used to quantify the risk and make decisions accordingly.

The risk analysis framework was implemented to a potential toll road (Loop 375) in El Paso County. The probability distribution functions for revenue were obtained for each scenario and were used to quantify the risk in both revenue figures and VMT. In addition, the most important properties (e.g. mean, media, etc) of each fitted distribution were tabulated.

After analyzing the results, it appears that the Beta General distribution provides the flexibility (due to its shape parameters) to fit the forecasted toll revenue data. In addition, for this case study, quantifying the VMT provided a better understanding about the toll facility usage as opposed to a total vehicle count. However, this might differ depending on the toll facility being studied. If for example, a toll road has only one entry point and one exit point then the vehicle volume can also be helpful to show the demand.

This risk analysis framework is expected to benefit transportation agencies that conduct toll road revenue forecasting. The framework should provide the analyst with a basic approach on how to develop probability distribution functions of revenue with respect to uncertainty in model variables.

7.2 Recommendations

The PDF obtained from the results of each forecast year represents the variation in revenue. However, only 100 simulations were modeled with DynusT for each year of the forecast. More iterations in the MCS (i.e., more VoT values) should provide more accurate results (in terms of the value of the distribution parameters). In addition, the model inputs selected for MCS are not limited to the VoT.

These revenue distributions were only performed with a three hour demand on a typical weekday to demonstrate the process on how to apply the risk analysis framework developed. The application of this framework is not limited to such and could be done to estimate annual revenue by using the appropriate demand periods and annual growth rate factors. The revenue analysis performed in the previous sections show the 5th or 95th percentile to demonstrate the possibility use of the fitted distribution in quantifying the risk, and its associated revenue. However, the percentile value selected for analysis is at the discretion of the analyst conducting the revenue forecast.

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APPENDIX A

Feedback obtained from the different consulting agencies surveyed.

C&M Associates, Inc.

1. Can you mention a few toll road forecast projects that your organization has conducted in the U.S.?

   Please see the attached file (e.g. S.H. 121, SH 161, I-75 Managed Lanes among others).

2. What software is often utilized by your organization to perform toll road traffic demand forecasts? If more than one, please specify.

   Travel demand modeling software: Transcad, Cube Voyager, Emme. Mesoscopic simulation software: Transmodeler, Avenue. Microscopic simulation software: Vissim, Corsim. Excel.

3. Which time periods are modelled to perform the forecast?

   Opening years for all phases and a number of future years.

4. Are different vehicle types specified in the model and does each vehicle type have a unique value of time?

   Yes to both. Depending on the project different type of users are also modeled based on trip purpose, occupancy, etc.

5. Is the value of time for a specific vehicle type assumed to grow in the future? If yes, could you briefly explain the assumptions behind the growth rate? If not, why not.

   For some projects it may be warranted and the main driver is real per capita income growth.

6. Do you routinely conduct an assessment of the reliability of your toll road traffic forecast studies?

   Yes, we are periodically comparing forecasted traffic and revenue vs. observed.

7. A toll road traffic demand forecast might be sensitive to model variables such as value of time or toll rate. Do you routinely carry out a sensitivity analysis for such variables in your traffic demand forecast studies?

   Yes, these two variables always at the very minimum. Many others may be analysed such as socioeconomic growth assumptions.

8. If Monte Carlo Simulation is part of the traffic forecast study, can you shortly discuss how was it utilized?

   For comprehensive level studies that are used to finance projects many times a Risk Analysis is conducted utilizing Monte Carlo simulations. The main variables identified to affect the forecast in the sensitivity analysis are utilized through an appropiate distribution and a model created to represent the forecast is run iteratively to create a distribution of outcomes. The risk profile obtained is just as good as the distribution of the identified variables and the model created.

Whitman, Requardt & Associates, LLP

1. Can you mention a few toll road forecast projects that your organization has conducted in the U.S.?

   Indian River Bridge, Sussex County, DE. US 301, New Castle County, DE. I-95 Toll Plaza, New Castle County, DE.

2. What software is often utilized by your organization to perform toll road traffic demand forecasts? If more than one, please specify.

   Cube Voyager (customized toll model).

3. Which time periods are modelled to perform the forecast?

   AM, MIDDAY, PM, Off-Peak.

4. Are different vehicle types specified in the model and does each vehicle type have a unique value of time?

   Yes. We model both trucks and cars.

5. Is the value of time for a specific vehicle type assumed to grow in the future? If yes, could you briefly explain the assumptions behind the growth rate? If not, why not.

   Not typically. Value of time is only one variable related to economics. Other variables that must be considered would be operating costs, parking costs, differing value of wait time, and toll costs. We can't just change one variable to account for future growth without changing them all, if we change them all by the same amount then why bother changing them at all?

6. Do you routinely conduct an assessment of the reliability of your toll road traffic forecast studies?

When possible. For example when our client adjusts toll rates or policy significantly we are beginning to track actual elasticity versus predicted elasticity. This will help refine the model over time.

7. A toll road traffic demand forecast might be sensitive to model variables such as value of time or toll rate. Do you routinely carry out a sensitivity analysis for such variables in your traffic demand forecast studies?

   Yes. We also believe that other demographic variables, other than simply time, are equally important when modeling toll usage. The statistics play this out.

8. If Monte Carlo Simulation is part of the traffic forecast study, can you shortly discuss how was it utilized?

   We don't use Monte Carlo Simulation for this purpose.

Wilbur Smith Associates

1. Can you mention a few toll road forecast projects that your organization has conducted in the U.S.?

   El Paso, Loop 375 Cesar Chavez from US 54 to S. Zaragoza Road. Many in Dallas Ft. Worth Region.

2. What software is often utilized by your organization to perform toll road traffic demand forecasts? If more than one, please specify.

   TransCAD, TRANPLAN, VISSIM, Cube, Ms Office, GisDK, C++, Visual Basic.

3. Which time periods are modelled to perform the forecast?

   Peak (2 to 5) and Offpeak (1 to 2).

4. Are different vehicle types specified in the model and does each vehicle type have a unique value of time?

   Yes and Yes.

5. Is the value of time for a specific vehicle type assumed to grow in the future? If yes, could you briefly explain the assumptions behind the growth rate? If not, why not.

   Yes, Compounded growth, rate depends upon the demographic of the region.

6. Do you routinely conduct an assessment of the reliability of your toll road traffic forecast studies?

   No.

7. A toll road traffic demand forecast might be sensitive to model variables such as value of time or toll rate. Do you routinely carry out a sensitivity analysis for such variables in your traffic demand forecast studies?

   No.

8. If Monte Carlo Simulation is part of the traffic forecast study, can you shortly discuss how was it utilized?

   Risk Analysis, Sensitivity Analysis: Change in T&R for the change in different T&R forecast factors.

El Paso Metropolitan Organization

1. Can you mention a few toll road forecast projects that your organization has conducted in the U.S.?

   Only in El Paso, and for the time being using Generalized Cost approach directly on assignment (very simplistic tool in TrasnCAD software).

2. What software is often utilized by your organization to perform toll road traffic demand forecasts? If more than one, please specify.

   TransCAD tools only.

3. Which time periods are modelled to perform the forecast?

   24-hr assignment.

4. Are different vehicle types specified in the model and does each vehicle type have a unique value of time?

   Only one vehicle type.

5. Is the value of time for a specific vehicle type assumed to grow in the future? If yes, could you briefly explain the assumptions behind the growth rate? If not, why not.

   No.

6. Do you routinely conduct an assessment of the reliability of your toll road traffic forecast studies?

   No.

7. A toll road traffic demand forecast might be sensitive to model variables such as value of time or toll rate. Do you routinely carry out a sensitivity analysis for such variables in your traffic demand forecast studies?

   Not for the time being.

8. If Monte Carlo Simulation is part of the traffic forecast study, can you shortly discuss how was it utilized?

   No Monte Carlo simulation.

Walter P Moore

1. Can you mention a few toll road forecast projects that your organization has conducted in the U.S.?

   SH 121, SH 161, North Tarrant Toll Road.

2. What software is often utilized by your organization to perform toll road traffic demand forecasts? If more than one, please specify.

   TransCAD, Cube.

3. Which time periods are modelled to perform the forecast?

   AM/MD/PM/NT.

4. Are different vehicle types specified in the model and does each vehicle type have a unique value of time?

   Yes, they do.

5. Is the value of time for a specific vehicle type assumed to grow in the future? If yes, could you briefly explain the assumptions behind the growth rate? If not, why not.

   VoT is expected to grow for every type of vehicle based on CPI.

6. Do you routinely conduct an assessment of the reliability of your toll road traffic forecast studies?

Yes.

7. A toll road traffic demand forecast might be sensitive to model variables such as value of time or toll rate. Do you routinely carry out a sensitivity analysis for such variables in your traffic demand forecast studies?

   Yes, we do.

8. If Monte Carlo Simulation is part of the traffic forecast study, can you shortly discuss how was it utilized?

   Monte Carlo is used for the risk assessment.

CURRICULUM VITA

Gabriel A. Valdéz was born in the city of Juarez, Chihuahua in which he graduated from the “El Chamizal” High School. He started his education at The University of Texas at El Paso (UTEP) in the fall of 2003 and received the J&Y Janacek Scholarship while pursuing a bachelor’s degree in Civil Engineering. In 2005, he started working as a research assistant at the Laboratory of Advance Dynamic Transportation and Urban Systems under the guidance of Dr. Yi-Chang Chiu. Later on, in 2006 he continued working as a research assistant but now under the supervision of Dr. Kelvin Cheu for the Border Intermodal Gateway Laboratory until his graduation in the spring of 2008. He received the Andrew D. Jones award for outstanding student as well as the best senior design project award. In the summer of 2008 Gabriel started his graduate program in transportation while working at the Texas Transportation Institute. Throughout his graduate study period he was awarded with the Eisenhower Fellowship and gave a presentation at Washington, D.C. In 2009, he was part of the UTEP team that was selected as a project finalist of the Mondialogo Engineering Award by Daimler and UNESCO.

Permanent Address: Parque de las Flores 7860

C.P. 32440, Cd. Juárez, Chihuahua, México