AN APPROACH TO INCORPORATE UNCERTAINTY AND RISK IN TRANSPORTATION INVESTMENT DECISION MAKING: DETROIT RIVER INTERNATIONAL CROSSING CASE STUDY

By

Sabyasachee Mishra, Ph.D.
Faculty Research Associate
National Center for Smart Growth Research and Education
University of Maryland
College Park, MD 20742
Phone: (301) 405-9424
Email: mishra@umd.edu

Snehamay Khasnabis, Ph.D.
Professor of Civil and Environmental Engineering
Wayne State University
Detroit, MI 48202
Phone: (313) 577-3915
Email: skhas@wayne.edu

Subrat Swain
Graduate Research Assistant
Wayne State University
Detroit, MI 48202
Phone: (313) 598-6742
Email: dx6532@wayne.edu

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ABSTRACT

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 used to evaluate the financial feasibility of such projects are based upon the assumption of deterministic future cash flows that are not subject to any uncertainty and risk. In reality, many of these projects are associated with significant uncertainties and risks stemming from lack of knowledge about future cost and benefit streams. There is a lack of comprehensive literature in addressing uncertainty and risk in transportation investment decision making.

The authors present a framework for addressing uncertainty and risk for large scale transportation investments involving joint participation by the public and private entity. Demand, fare/toll, and demand responsive costs are considered in the uncertainty analysis. A bi-level programming is proposed, where the upper level constitutes the preference of the policy maker, and the lower level determines the user's response to the policy. The uncertainty analysis provides economic feasibility of the transportation project. A set of relaxation policies is proposed to form various Ownership, Tenure, and Governance (OTG) strategies reflecting the nature and level of participation by the public and private entity. 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 combination of both uncertainty and risk reveals insights to the probable outcomes for a transportation infrastructure investment. This methodology can be used as a tool for transportation infrastructure investment decision making process.

Key words: uncertainty, bi-level programming, monte carlo simulation, value at risk, investments

1. INTRODUCTION

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 total gross transportation *investment* by the federal, state and local governments reached $80 billion in the US in the fiscal year 2003 (*1*). 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 insufficient to meet estimates of future highway requirements (*2*). Lack of capital funds to meet the infrastructure needs of the country may result in increased private participation in such projects (*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 the federal, state and local governments.

2. PROBLEM STATEMENT

In traditional economic analysis, future cash flows are assumed to be fully deterministic in nature. Thus, these are not designed to account for any risk and uncertainty involved in the assessment of future returns. In reality, many of these infrastructure projects are associated with significant uncertainties stemming from lack of knowledge about future cost and revenue streams. 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 (*4*).

Current transportation literature does not indicate the availability of a methodology to incorporate risks and uncertainties in transportation investment, though significant research is reported in the fields of economics and financial management. 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 future revenues appear to be high at one end, but 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. 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 large projects, and the advantage of jointly sharing risks and uncertainties, thereby reducing exposure levels to financial losses for both entities. 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 (*5,6*). Joint ownership is generally associated with three terms: Ownership, Tenure and Governance (OTG). 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 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 refers to the status of holding a possession of a project for a specific period, ranging from few days to a number of years. For most joint ownership projects, tenure is likely to coincide with the concession period; however, exception to this general rule may be encountered.
- Governance refers to management, policy and decision making pertaining to an organization with the intent of producing desired results.

The objective of the research is to propose a theoretical framework to incorporate uncertainty and risk from single and multiple entity perspective, and to evaluate the framework with a real world case study.

3. A COMBINED FRAMEWORK FOR UNCERTAINTY AND RISK ANALYSIS

A framework to incorporate the concept of investment decisions under uncertainty and risk is presented in this section. The proposed framework is illustrated in Figure 1 and is categorized into two steps;

- Step 1: Uncertainty Analysis
- Step2: Risk Analysis

<u>Step-1: Uncertainty Analysis</u>

Uncertainty analysis 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 is an examination of the investment policy options recommended by the federal and state levels relating to new transportation projects (*7*). These policy options may represent various combinations of responsibilities of public and private agencies that may vary a wide 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 some understanding of the road users' likely response (lower level) to a given strategy. However, the strategy set by the policy maker can only influence (but not control) the road users' route choice. In other words, policy options and route choice decisions can be represented as a bi-level program, where, the upper level involves policy maker's decision to determine the toll value, while road users are assigned to the proposed facility at the lower level. In the bi-level process, the upper level may be subdivided into three categories (1) Private Investor, (2) Public Investor, (3) Road User. 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 the uncertainty in travel pattern.

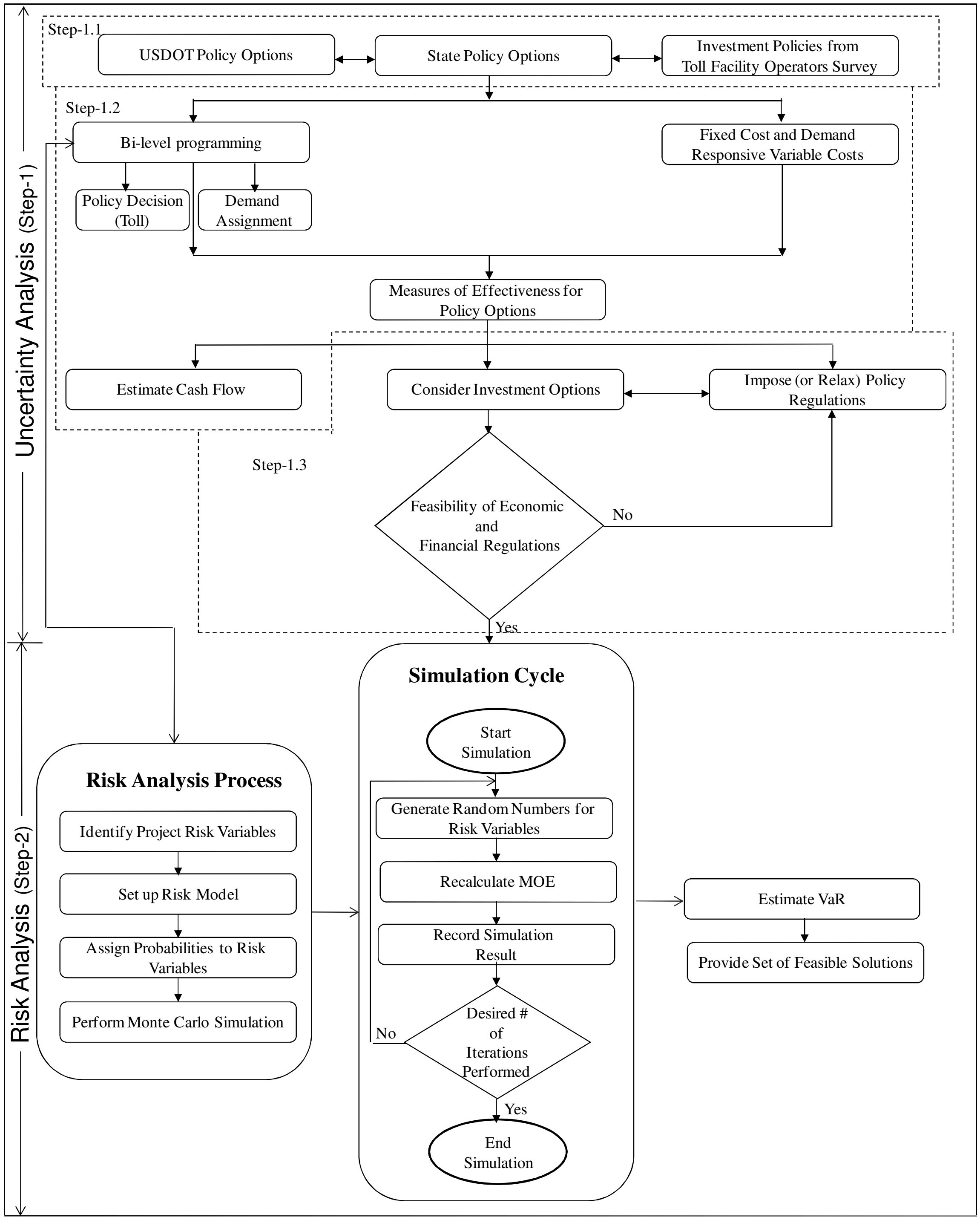

FIGURE 1 Proposed Methodology for Single Entity Uncertainty and Risk Analysis

Various investment options can be considered in step 1.1. Policy regulations such as construction cost subsidy, concession period extension, (or similar relaxation policies) can be considered if necessary. After relaxation of policy regulations, viability of the project can be tested and a set of investment strategies can be examined (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 different investment options 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. This step will enable the decision maker avoid risky policy options, and focus more on these options with modest risk exposure.

3.1 Decision Tool for Uncertainty Analysis

Sources of uncertainty in the transportation infrastructure investment can arise from future costs and revenues. Bulk of the cost element is from construction cost incurred before the facility is opened to traffic; other future cost elements such as regular and periodic operation and maintenance costs depend on future travel demand. Revenue is directly dependent on travel demand and toll. Uncertainties related to cost and revenue are primarily generated from travel demand.

Investments in major transportation infrastructure are often complex, with a mix of public and private finance, with the respective agencies having different missions and motivations. The public sector may consist of national, state and local agencies with a social welfare perspective. The public and private entities are interested in exploring optimal tolling strategies that may yield different solutions (*8-11*). While the public entity always would like to maximize the consumer surplus[1] (social welfare); the private entity is interested in maximizing profit. Since the public sector will be eventually the owner and operator of the facility; it must ensure that the facility attracts users and serves the needs of the community (*12*). Thus, the optimal toll must be viable to the ultimate end users. Hence, in the investment decision making process, three entities' perspectives should be considered: (1) the private, (2) the public, and (3) the user. Description of objective/perspective of each entity is presented below.

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

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 (*13*).

$$P^n\left(\tau, x\left(\tau,\varepsilon\right)\right) = B^n - C^n \tag{1}$$

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. The revised equation 1 can be represented as:

$$P^n\left(\tau, x\left(\tau,\varepsilon\right)\right) = \sum_{n\in N}\left[\sum_{a\in A}\gamma x_a^n\left(\tau\right)\tau_a^n - C_{a,c}^n - O_a^n\left(x_a^n\right)\right] \tag{2}$$

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:

$$\text{max. } P^n\left(\tau, x\left(\tau,\varepsilon\right)\right) \tag{3}$$

$$\text{subject to: } \tau, x\left(\tau,\varepsilon\right) \geq 0 \tag{4}$$

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

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 (*14*). One can determine whether the extra cost required to improve a facility from two levels. Mathematically,

$$\phi_{rs}^n = \int_0^{q_{rs}^n} q_{rs}^{-1}\left(\omega\right)d\omega - q_{rs}^n\pi_{rs}^n \tag{5}$$

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, $q_{rs}^{-1}\left(\omega\right)$ 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 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 (*12, 13, 15-18*) .

Consumer surplus for an O-D pair *r-s* for an improved case is given by (*15*):

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

$$\sum_{rs} \phi_{rs}^{n} = \sum_{rs} \int_{0}^{q_{rs}^{n}} q_{rs}^{-1}(\omega)\, d\omega - \sum_{rs} q_{rs}^{n} \pi_{rs}^{n} \tag{6}$$

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

$$\sum_{rs} \phi_{rs}^{n} = \frac{\gamma}{\theta} \left[\sum_{rs} \int_{0}^{q_{rs}^{n}} q_{rs}^{-1}(\omega)\, d\omega - \sum_{rs} q_{rs}^{n} \pi_{rs}^{n} \right] \tag{7}$$

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 (*12*,*13*). This can be represented as;

$$\psi^{n}\left(\tau, x(\tau,\varepsilon)\right) = \varphi^{n} - C^{n} \tag{8}$$

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 objective function for consumer surplus maximization can be formulated as:

$$\text{max. } \psi^{n}\left(\tau, x(\tau,\varepsilon)\right) \tag{9}$$

$$\text{subject to: } \tau, x(\tau,\varepsilon) \geq 0 \tag{10}$$

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

<u>*Road User's Perspective*</u>

If the implementation of project only benefits a small section of travelers in the study area, then the distribution will not be called as equitable. Theil's index, one of the commonly used measures of inequality distribution, was used in this study because of its flexible structure (*19*). Theil's index, in its simplest form, can be estimated as (*19*):

$$T_b^n = \sum_r \left(\frac{\sum_s q_{rs}^n}{q^n} \right) . \left(\frac{\sum_s \phi_{rs}^n}{\phi^n} \right) . ln \left(\frac{\sum_s \phi_{rs}^n}{\phi^n} \right) \quad (11)$$

where, q_{rs}^n is the travel demand of OD pair *r-s* in the *n*[th] 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 *n*[th] 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 objective function for user inequality (between groups) minimization can be formulated as:

$$\text{min. } T_b^n \left(\tau, x \left(\tau, \varepsilon \right) \right) \quad (12)$$

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

where, $x\left(\tau,\varepsilon\right)$ 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 (*20*).

$$\min_{x \to (\tau,\varepsilon)} \sum_{a \in \left(A - \bar{A}\right)} \int_0^{x_a} t_a\left(w\right) dw + \sum_{a \in \bar{A}} \int_0^{x_a} \left(t_a\left(w\right) + \theta\tau\right) dw - \sum_{rs} \int_0^{q_{rs}} q_{rs}^{-1}\left(w\right) dw \quad (13)$$

subject to:

$$\sum_k f_k^{rs} = q_{rs} \quad (14)$$

$$f_k^{rs} \geq 0 \quad (15)$$

$$q_{rs} \geq 0 \quad (16)$$

$$x_a = \sum_r \sum_s \sum_k f_k^{rs} \delta_{a,k}^{rs} \quad (17)$$

$$\delta_{a,k}^{rs} = \begin{cases} 1 & \text{if link } a \text{ is on path } k \text{ between O-D } r\text{ - }s \\ 0 & \text{Otherwise} \end{cases} \quad (18)$$

The objective function in expression 13 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 14 is a flow conservation constraint to ensure that flow on all paths connecting each OD pair has to equal the trip rate. Expression 15 and 16 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 17 and 18. The minimization problem in expression 13 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 (*20*).

$$q_{rs}^{n} = \tilde{q}_{rs}^{n} \exp\left(-\lambda \pi_{rs}^{n}\right) \tag{19}$$

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, and q_{rs}^{n} is the realized travel demand for year n between the OD pair r-s.

Uncertainty in travel demand random sampling approach is used 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 (*13*).

$$\tilde{q}_{rs}^{n} = \overline{\tilde{q}_{rs}^{n}} + z\sigma_{rs}^{n} \tag{20}$$

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 (*20*):

$$t_{a}^{n}\left(x_{a}^{n}\right) = t_{a}^{0}\left(1 + 0.15\left(\frac{x_{a}^{n}}{G_{a}^{n}}\right)^{4}\right) \tag{21}$$

where, t_{a}^{0} and G_{a} is the free flow travel time and capacity for link *a*.

3.2 Decision Tool for Risk Analysis

Risk is often defined as the probability of occurrence of an undesirable outcome. 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. The MOE thus obtained reflects the effect of risk.

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 inputs is expressed through defining their bounds according to the data points required by the input distributions. Essentially, a MCS risk analysis describes the effect of the volatility of input variables on the simulation output.

Risk can be quantified and measured in different ways (*21*). Value at Risk (VaR) is one of such methods and used in Decision Tool for Risk Analysis. VaR can be defined as the maximum expected loss over a target horizon, with a given level of confidence (*22*). 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 $1-\alpha$ 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.

4. CASE STUDY

A proposed international bridge between the city of Detroit in the US and the city of Windsor in Canada is selected as the case study area. Surface trade between Southwestern Ontario and Southeastern Michigan exceeded 200 billion in 2004 and is expected to increase by twofold by the year 2030 (*23*). 70 percent of trade movement between the US and Canada is by trucks. Approximately 28 percent of surface trading is by trucks for the crossings between Southeast Michigan and Southwest Ontario (*24*). Majority of the trade is for the crossings in the Detroit River area, connecting the city of Detroit in the US 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.

The Central Business Districts (CBDs) of the cities of Detroit and Windsor are currently connected by four crossings: (1) The Ambassador Bridge (AB), (2) The Detroit Windsor Tunnel (DWT), (3) a Rail Tunnel (RT), and (4) The Detroit Windsor Truck Ferry (DWTF). Both AB and DWT across the Detroit River, both built during the late 1920s. AB is a privately owned four-lane suspension structure, while DWT is a two-lane facility with height restriction, jointly owned by the two cities and operated by a private corporation. The Blue Water Bridge (BWB) across the St. Clair River (100 km north of Detroit) that connects Port Huron in the USA with Sarnia in Canada. BWB is a six lane

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

arch structure built in 1938. The bridge was renovated in 1999, and is jointly owned by the two cities. The RT and DWTF, both constructed under the Detroit River, carry cargo between two cities.

The Canada–US–Ontario–Michigan Transportation Partnership Study (Partnership Study) attempted to develop long-term strategies to provide safe and efficient movement of people and goods between Michigan and Ontario (*24*). 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. As a result of number of studies initiated in early 2000's and currently nearing completion, MDOT, in collaboration with the Ontario Ministry of Transportation have identified a bridge known as X-10(B) as the most preferred alternative to built in the vicinity of the Ambassador Bridge (*25*). The alternative has been referred to as the Detroit River International Crossing (DRIC) in the case study. Proposed DRIC and other river crossings are presented in Figure 2.

5. RESULTS

Two types of bridges are proposed for X-10(B); (1) suspension bridge, and (2) cable-stay bridge. The costs of the bridges along with associated infrastructures, are $1809 million and $1814 million respectively. In the case study it is assumed that a suspension bridge will be built. The cost components, are shown in Table 1. The planning for the bridge was started in 2004. A part of the planning/design/construction engineering cost is already incurred. The construction is expected to be complete in 2014, and the bridge will be open to traffic in 2015. The cost elements shown in Table 1 are only for the US part of the bridge. By the same token, all the toll revenue compiled to assess the benefits reflect the fare collected at the Detroit end of the bridge.

5.1 Travel Demand Uncertainty

The Origin-Destination (O-D) matrices (1510*1510) for the study area are obtained from MDOT for the years 2015, 2025, and 2035. There are a total of 960 Traffic Analysis Zones (TAZ) in the Detroit (US) side of the border and 527 TAZs in the Windsor (Canada) side of the border. Including 23 external TAZs, the study area consists of a total of 1510 TAZs. 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[3] of 0.15 is considered to incorporate variance in travel demand.

[3]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.

FIGURE 2 Network of Study Area

The potential[4] OD matrix was not available. The base and horizon year projected OD matrices were increased by ten percent to obtain the potential OD. The standard deviation of the OD matrix is obtained from the coefficient of variation and the expected demand of the OD matrix.

TABLE 1 Cost Components for DRIC *(25)*

Investment Type	Cost (Million $)
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 (5%)	$40
Planning/Design/Construction Engineering	
Final Design and Permits (10%)	$80
Construction Engineering (10%)	$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

Solution Approach for Demand Uncertainty

A Monte Carlo Simulation (MCS) 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 20). From the distribution of OD matrix, the median matrix was chosen for further analysis. However, one can use any percentile from the distributed OD matrix. This procedure was followed for all the horizon years. The resulting OD matrix from MCS contains the variation in travel pattern and incorporates the uncertainty in travel demand, which is used in the elastic traffic assignment procedure.

The proposed traffic assignment model is calibrated for the base year 2004. Actual toll values for 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 and the potential OD matrix for the year 2004 is utilized to

[4] 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).

determine the assigned volume for cars and trucks. The observed car and truck volumes are obtained from MDOT (*22*). The relative closeness of assigned and observed volume at the respective crossings demonstrates the calibration of the model. Results of the calibration are not presented in the paper for the sake of brevity. The details of calibration of the model are discussed in the project report (*26*).

5.2 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 the three entities from investment viewpoint are different, as discussed earlier. 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 (*27*). A GISDK 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 (*20*).

5.3 Base Case

The base case scenario refers to exclusive entity participation. Table 2 represents the results for the base case scenario. The results of the base case are presented 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 (capital, operation and maintenance cost) will be borne by the private entity. As explained earlier, 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. The toll values are obtained in an iterative manner with directional search to obtain the optimum value of the objective function for profit maximization, consumer surplus maximization and inequality minimization. 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.

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 2) that resulted in an optimal consumer surplus of $730.36 million, which is higher than the estimated consumer

[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 as the monetary benefit obtained by the toll/fare collection only.

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 value of $0.5 car and $4.33 for truck is estimated to be $25.78 million and 0.79 respectively.

TABLE 2 Base Case Entity Objective Results (*25*)

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

[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 2) the optimal toll values obtained are $0.25 per car and $ 1.04 per truck, resulting in a Theil'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 $7.41 and $258.62 million respectively.

Three distinct toll values are obtained for three different entities each of which results in optimum value for the three objective functions defined in equation 3, 9, and 12. The highest toll value resulted for the profit maximization and the least toll value for the Theil's Index, thereby demonstrating that the 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 2. Increased travel demand in future 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. The Theil's Index is considered as a minimization function and based on the distribution of trips among the TAZs in the study area.

5.4 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 (*28*). 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. Ownership, Tenure and Governance (OTG) are the three principal components of a joint ownership.

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 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 in the project report (*26*). The feasibility of OTG strategies are determined by considering the analysis period till 2050.

OTG-1

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 IRR are the two MOEs plotted in Figure 3. The negative cost elements for 2004-2014 represent the planning and construction of the facility. When the facility is opened to traffic, the cumulative negative value of cash flow decreases, as the toll charges are collected and the break even period occurs in the year 2034. The Internal Rate of Return (IRR)[16] for OTG-1 strategy is 4.61% over the 35 years of concession period. The Minimum Attractive Rate of Return (MARR)[17] was assumed to be 6%. The IRR being less than the MARR lends the project economically infeasible for the strategy (OTG-1) tested.

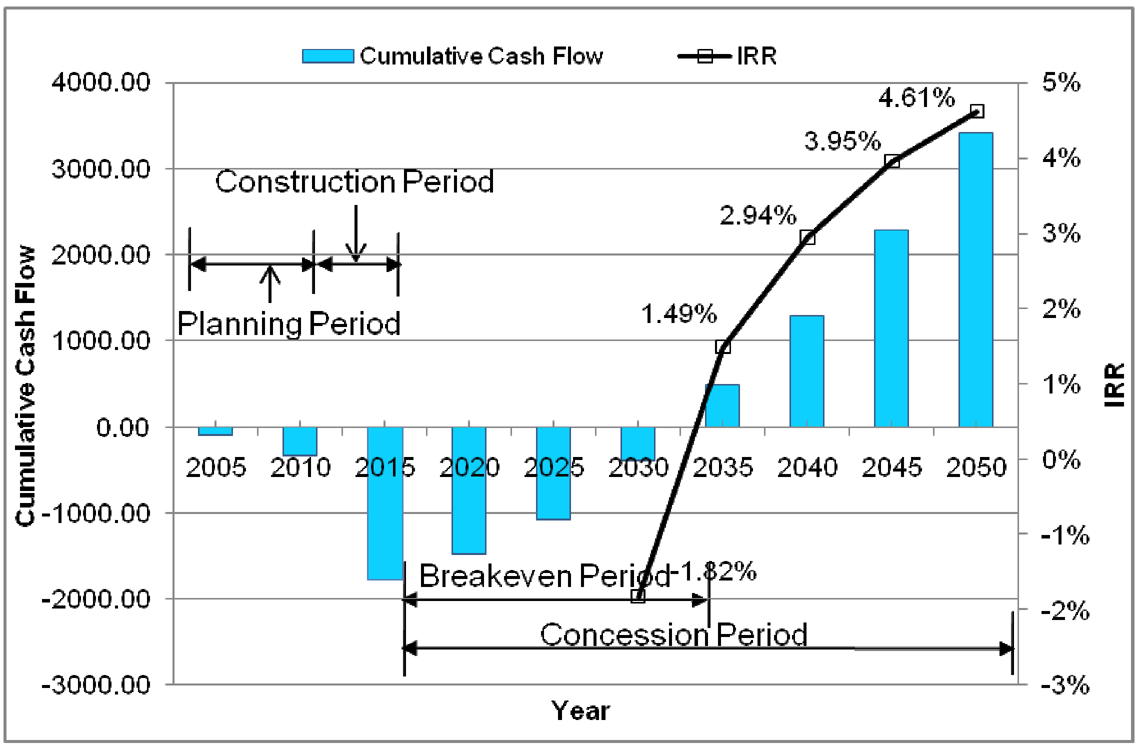

FIGURE 5 Cumulative Cash Flow and IRR: Exclusive Private Participation (OTG-1)
(Note: There is no IRR value till the end of 2025 as the cost is much higher than the benefit received. The IRR at the end of 2030 is -1.82)

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[16] 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.

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

Other OTG's

A complete description of the four other OTG's is provided in the project report (*26*). Essentially, the transition from OTG-1 to OTG-4 is marked by higher levels of subsidy to the private entity either by reduced cost, or by extension of concession period. These relaxation policies adopted to encourage private participation will obviously reflect on higher financial responsibility for the public sector. OTG-5, by contrast, represents a completely public undertaking, encompassing all financial, management, operational and maintenance responsibilities.

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 3, 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.

5.5 Risk Analysis

The OTG strategies are further considered in the risk analysis. Feasible options from the relaxation polices are subjected to 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 random toll values automaticaly choose the ridership resulting from elastic traffic assignment, and the corresponding operation and maintenance cost. For each random toll value, and the appropriate ridership, operation and maintenance cost changes, the IRR value is estimated. 10, 000 such iterations are performed, and the corresponding IRR's are recorded. The distribution of al realization of IRR is plotted in Figure 4.

TABLE 3 OTG Strategies, Relaxation Policies and IRR's

OTG Strategy	Explanation	Relaxation Policy	Entity Objective	IRR (percent)
OTG-1	Exclusive Private Participation	No Relaxation	Profit Maximization	4.61
OTG-2	Major Private Participation	1. Toll Plaza Cost Subsidy 2. Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy 3. Construction Cost Subsidy	Profit Maximization	5.14 5.89 5.84
OTG-3	Moderate Private Participation	1. Construction Cost Subsidy 2. Concession Period Extension 3. Construction Cost Subsidy and Concession Period Extension	Profit Maximization	6.13 6.01 7.20
OTG-4	Major Public Participation	1. Partly Construction Cost by Private Entity 2. Operation and Maintenance Cost – Public Entity 3. Construction Cost Subsidy-Public Entity	Consumer Surplus Maximization	22.97* 3.69** 3.95**
OTG-5	Exclusive Public Participation	No Relaxation	Consumer Surplus Max.	3.51**

Note: *: Private entity is only responsible for a part of the construction cost and receives all the benefits throughout the concession period. Lesser investment and higher return for the private entity has resulted in relatively larger IRR. This OTG strategy is considered as an attractive option for the private entity.

**: IRR for the public entity (the remainder of the IRR are for the private entity).

Procedure for Obtaining VaR

Figure 4 shows the mean value of IRR on the X-axis, the frequency on primary Y-axis, and the probabilities on secondary Y-axis for OTG-3 concession period extension. The mean IRR of the distribution is 6.04%. 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%. To determine the 95th percentile IRR, an imaginary horizontal line can be drawn from the 5% 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 95th percentile IRR to be 5.99%. The VaR for OTG-3 concession period extension is 5.99%. In other words, the maximum expected loss (or the lower level) in IRR can be 5.99%.

The 95th percentile relative VaR is the difference between the mean IRR and 95th percentile IRR, i.e. 6.04%-5.99% = 0.05%.The 95th percentile relative VaR suggests that the maximum loss in IRR at 95 percentile level of confidence can not exceed 0.05% for the OTG-3 concession period extension strategy. Similarly 90th percentile VaR can be determined. The 95th and 90th percentile absolute and relative VaR is determined for all the strategies, and presented in Table 4.

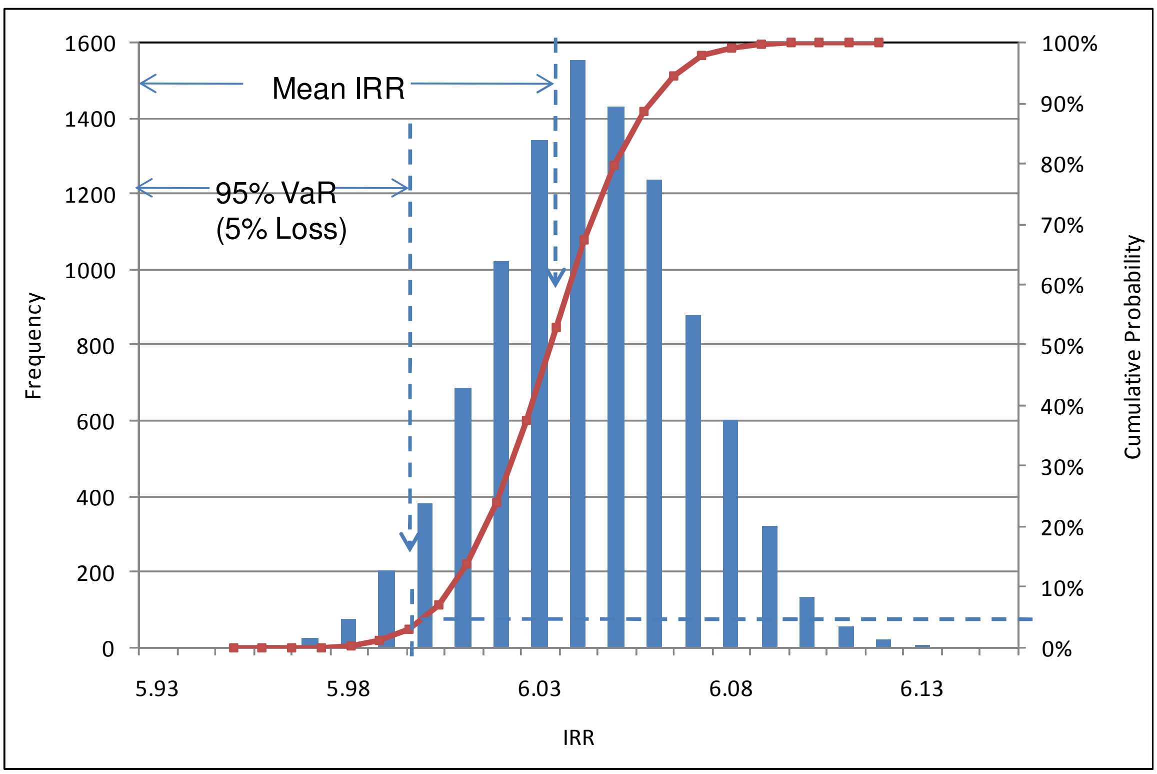

FIGURE 4 Value at Risk for OTG-3 Concession Period Extension

TABLE 4 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%

6. INTEGRATION OF UNCERTAINTY AND RISK

Uncertainty and risk are addressed individually in the earlier sections of this chapter. The implications of both uncertainty and risk are important from investment viewpoint. The purpose of this section is to integrate uncertainty and risk for exploring favorable options for the DRIC project. For the uncertainty analysis, IRR is the MOE for all the OTG strategies considered and analyzed. Likewise, for risk analysis, the VaR is the MOE for all the OTG strategies. MOE's of both uncertainty and risk analysis are presented in Figure 5 to investigate the combined effect of both features on the OTG strategies analyzed. In Figure 5, the MOE of uncertainty (IRR) is considered in the X-axis, and MOE of risk (VaR) is considered in the Y-axis.

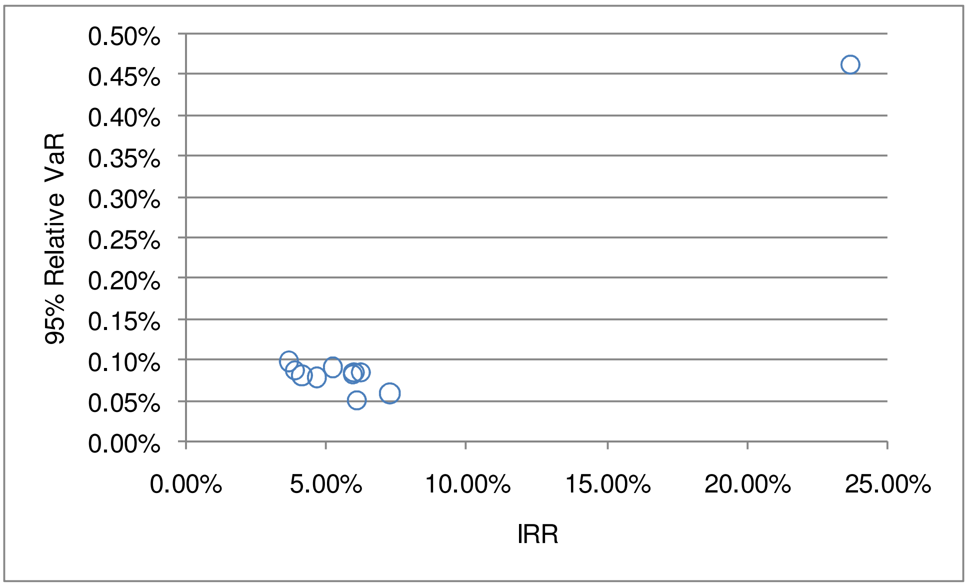

FIGURE 5 Integration of Uncertainty and Risk (Note: The outlier in the graph represents higher IRR and VaR)

The favorable OTG strategy is the one with higher IRR and lesser relative VaR. One the other hand the favorable OTG strategy should have IRR greater than the six percent of MARR. Four OTG strategies resulted in IRR of greater than six percent. The highest IRR (22.97%) 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%, 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% and a relative VaR is 0.06% at 95 percent level of confidence. However, all the OTG-3 strategies appear to be feasible with higher IRRs and lower relative VaR.

7. CONCLUSION

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; and apply the framework in a real world case study to augment the decision making process. 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. IRR and VaR are considered as the MOE's for uncertainty and risk analysis respectively and determined using MCS technique. The objective of each entity, when subjected to uncertainty, is considered in assessing the optimal demand and toll estimates.

If the single entity uncertainty analysis does not result in feasible solutions, relaxation policies are 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. 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. It is observed that projects producing higher IRR are also associated with higher VaR. The integration of uncertainty and risk allows the decision maker to choose from a set of alternative investment strategies of a project to minimize uncertainty and risk. The framework is applied to study the investment decision making of DRIC connecting US, and Canada; a project in the planning stage for over ten years. Results of the case study indicate that the framework presented is viable; however additional research is needed to integrate the perspectives of all the entities into a multi-objective framework. As another future task, the effect of changes in the toll structure of the competing bridges on DRIC can be incorporated into the uncertainty and risk analysis framework.

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