Multi Entity Perspective Transportation Infrastructure Investment Decision Making

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Word Count:
Number of Tables: 8
Number of Figures: 5
Total Count: = 4, 987+ (13 x 250) = 8,237
Date Submitted: November 15, 2013

Submitted for Peer Review and for Compendium of Papers at the Annual Meeting of the Transportation Research Board (TRB) in January 2014

ABSTRACT

Investment in new large transportation infrastructure is capital-intensive and irreversible in nature. Private sector participation in infrastructure investment has gained popularity in recent times because of scarcity of resources at the public sector, and because of the ability of the private sector to build, operate, maintain such facilities, and share future uncertainties. In such cases, there are multiple entities each with different objectives in the project. Traditional techniques used to determine feasibility of such projects often ignore two critical elements. These are the need (1) to identify major entities involved in these projects and their individual objectives, and (2) the importance of analyzing measures of effectiveness of each entity in a multi objective context. A framework is proposed to address these issues along with a set of relaxation policies to reflect the nature and level of participation by the entities. First, the feasibility of each single entity perspective is determined and next, a multi-objective optimization (MOO) is proposed reflecting the perspectives of all entities. The MOO results in pareto optimal solutions to serve as tradeoff between the participation levels of the multiple entities. Analytic Hierarchy Process (AHP) is used as a tool to narrow down number of options for decision makers for further consideration. AHP and MOO are integrated to determine the feasibility of strategies from multi entity perspectives. The framework is examined on the proposed multibillion dollar international river crossing connecting the city of Detroit in the U.S. and the city of Windsor in Canada. This methodology provides a decision making process tool for large-scale transportation infrastructure investment consisting of multiple entities.

INTRODUCTION

Typically, large scale transportation investments are irreversible in nature and require long-term commitment by the public at-large relative to utilization, maintenance, and operation.. A review of national transportation statistics suggests that projected federal, state and local highway *revenues* are insufficient to meet estimates of future highway requirements *(1)*. Lack of capital funds to meet the infrastructure needs of the country may result in increased private participation in such projects *(2)*.

Investment in major transportation infrastructure involving public and private agencies is often a complex process, 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, and with a mission to maximize consumer surplus[1].The private entity, on the other hand, is interested in maximizing profit typically realized through revenue collected for toll facilities. Since the public sector is the eventual the owner of the facility, it must ensure that the facility attracts users and serves the needs of the community *(3)*. Hence, the perspectives of the three entities: (1) the private, (2) the public, and (3) the user should be considered in such investment decision making.

A single objective optimization may not be best suited to represent the interest of multiple entities. A multi-objective optimization (MOO) is the process of simultaneously considering two or more objective functions each with a specific optimization defined. Examples of MOO in transportation application include: scheduling of trains for single and multiple tracks with varying capacity of trains to platforms *(4)*, vehicle routing and scheduling for hazardous material transportation *(5)*, optimal transit network design *(6)*, optimal responsive plans for traffic signal coordination *(7)*, optimum project selection model from portfolio*(8)*, tradeoff between emission and logistics cost *(9)*, bicycling route choice *(10)*, and container terminal technologies *(11)*. In spite of these examples, the application of MOO in investment decisions is somewhat limited. The focus of this paper is on the development of a methodology

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

> "*for investment decision making consisting of multiple-entities with different objectives in a multi-objective framework and to demonstrate the application of the methodology in a real world case study*."

Three entities are primarily involved in decision making process for a typical toll facility. These three are (1) private Investor, (2) the public Investor, (3) the road user, whose perspectives must be duly considered in the decision making process. *(12)*.

Private Investor's Perspective

The objective of the private investor is to maximize profit being the difference between benefit and cost. The revenue generated is a function of demand and toll.

Public Investor's Perspective

The primary objective of the public entity is to maximize consumer surplus, typically measured as the additional monetary value over and above the price paid *(13)*. Other social benefits such as improved traffic flow, environmental benefits, higher safety etc., are not incorporated in the proposed framework because of conflicting viewpoints of experts *(14)*.

Road User's Perspective

The benefits and costs of the project for all Origin Destination (OD) pairs should be reasonably distributed to establish spatial equity which is the objective from road user's view point. A project that results in benefits only for a small fraction of travelers cannot be considered as equitable. Theil's index, one of the commonly used measures of inequality distribution, was used in this research because of its flexible structure *(15).*

A FRAMEWORK FOR MULTI-ENTITY PERSPECTIVE DECISION MAKING

A framework for investment decision making in transportation infrastructure with multiple entities is presented in Figure 1. Multi-entity decision making will identify a single preferred alternative or rank alternatives in a manner that reflects the decision makers' choice. The proposed methodology consists of four steps: (1) identification of entities in investment decision making, (2) multi-objective problem definition, (3) development of experimental design, and (4) choice determination. These are described below.

Identification of entities in investment decision making

Such investments typically involve different types of decision makers (or investors / users) termed as entities in Figure 1. Each entity has a different objective/interest from an investment/operational viewpoint. The proposed approach calls for each entity objective to be optimized initially to ensure that individual interests are satisfied.

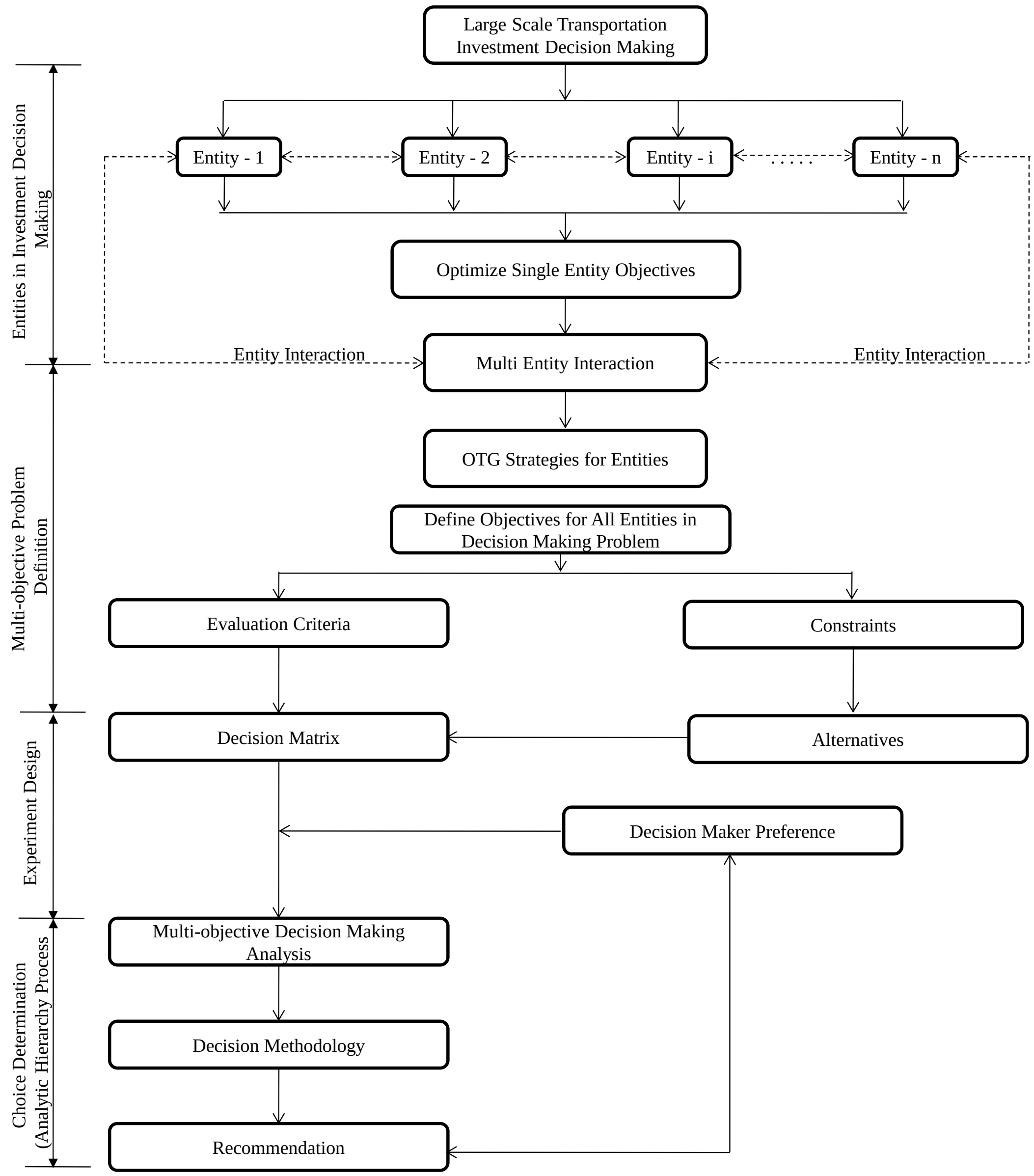

FIGURE 1 Investment Decision Making Framework for Multiple Entities

A multi-objective optimization is needed to incorporate the "merging" of the objectives of all entities. The multi-objective optimization provides a set of optimal solutions as opposed to single optimal solution by analyzing different Ownership-Tenure-Governance (OTG) strategies *(12)*:

- The term "Ownership" has embedded in it, the concept of 'possession' and 'title' related to the property in question.
- "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.
- "Governance" refers to management, policy and decision making pertaining to an organization with the intent of producing desired results.

Each strategy represents specific roles of individual entities involved in the investment process. A methodology is proposed to interface the solution obtained from the multi-objective optimization with the OTG strategies, considering the preferences of each entity involved in the decision making procedure.

Multi-objective Decision Making Problem Definition

The multi-objective problem definition consists of objective of multiple entities in the transportation investment decision making. The mathematical form of the MOO approach used in this paper is as follows:

Maximize

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

Subject to:

$$g_j(y) \geq 0\,, \qquad \forall\, j = 1,2,\dots m. \qquad (2)$$

where,

$F_i = [F_1, F_2, \dots, F_r]$ is the vector of objective functions.

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

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

$g_j$is the j^{th} inequality constraint function

Equation (1) represents maximization of a composite form of objectives of three entities. Please note that when the objective of user is minimization of inequality, this function can be changed to maximization by changing the sign in the optimization function, while preserving the original objective of users. The inequality constraints, $g_j(y)$ include non-negativity values of volume and fare.

Experimental Design

An experimental design process represents an intermediate step in multi-objective decision making process to determine the preferences of each entity. The output from MOO is considered as input to the experimental design stage. There are a number of techniques[2] to incorporate multi-objective decision making depending upon how to combine and utilize the data. Analytical Hierarchy Process (AHP) is one of the widely used techniques for analyzing and supporting decisions with multiple and competing alternatives in a multi-objective framework.

AHP allows the decision maker to model complex problems with defined goals, criteria, sub-criteria, and alternatives. AHP is a multi-criteria evaluation tool that can be used to evaluate the relative performances of defined alternatives based on a set of chosen criteria (16).

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

Choice Determination: MOO and AHP Integration

A set of solutions obtained from the MOO is taken as input to formulate a decision matrix (Multi-objective decision making problem definition step in Figure 1). Further, the decision matrix will contain the OTG strategies associated with the alternatives under consideration (Experimental Design step in Figure 1). The objective of designing the decision matrix is to obtain the decision maker's preference to the objective of each entity embedded within each alternative. The preferences of the decision makers are analyzed by AHP (choice determination step in Figure 1) to obtain an OTG strategy- specific solution, with each OTG strategy depicting the roles of the entities involved.

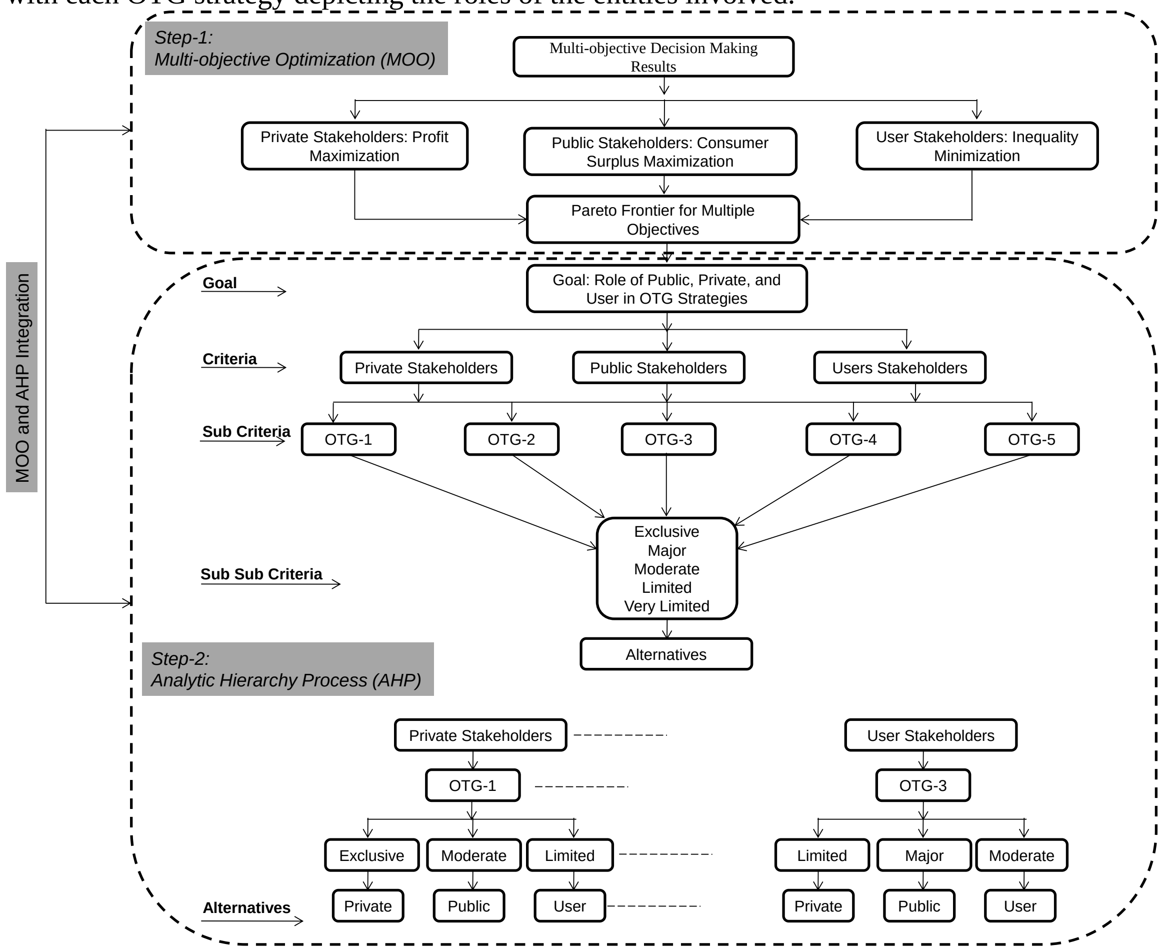

FIGURE 2 Hierarchical System for Multi-objective Decision Making

The proposed AHP model is presented in Figure 2. The AHP model has a number of hierarchies (or subcomponents): (1) goal, (2) criteria, (3) sub-criteria, (4) sub-sub-criteria, (5) alternatives. The goal of the AHP analysis is to determine the role of the each entity in a specific OTG strategy. The process is to collect responses from the corresponding stakeholders involved in the investment decision making. The stakeholder responses for each OTG strategy are considered as the sub-criteria. Further, the OTG strategies are assigned weights (1-10) by the stakeholders with exclusive being the highest weight and very limited being the least weight (sub-sub-criteria). The final subcomponent is the alternatives (public, private, and the user), on how they are associated with each OTG strategy.

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*(16).* 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*(17).*

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

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 the 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, MDOT, in collaboration with the Ontario Ministry of Transportation has identified a bridge known as X-10(B) as the most preferred alternative to built in the vicinity of the Ambassador Bridge *(18).* The alternative has been referred to as the Detroit River International Crossing (DRIC) in the case study.

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; and the case study is based on the assumption of a suspension bridge. The planning for the bridge was started in 2004. A part of the planning/design/construction engineering cost is already incurred.. The cost elements used in the study are only for the US part of the bridge. Similarly, all the toll revenue compiled to assess the benefits reflects the fare collected at the Detroit end of the bridge.

Travel Demand Model

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

A 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

[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.

[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).

from the coefficient of variation and the expected demand of the OD matrix. 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. An elastic traffic assignment model and the potential OD matrix for the year 2004 are utilized to determine the assigned volume for cars and trucks. The observed car and truck volumes are obtained from MDOT*(18).* 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 *(19).*

Exclusive Entity Participation

Table 1 represents the results for exclusive entity participation for different horizon years. For the private entity, the objective is profit maximization, where the total cost (capital, operation and maintenance cost) is assumed to be borne by the private entity. Toll values of $2 per car and $14 per truck, derived in an iterative manner to obtain the optimum value of the objective function resulted in annual revenue[5] of $68.54 million in the year 2015. 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.

Similar iterative techniques were used to derive toll values to maximize consumer surplus, and to minimize inequality in distribution of benefits. When the objective of the public entity is considered, the toll is $0.5 per car and $4.33 per truck (year 2015, second row, Table 1) that resulted in an optimal consumer surplus of $730.36 million, considerably higher than the consumer surplus ($347.07 million) estimated 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 (Public Perspective).

Similarly, when the objective of the users is considered (year 2015, third row, Table 1) the 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 same toll values the 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. The highest toll value resulted for profit maximization and the least toll value for minimization of inequity thereby demonstrating that the objectives of the private investor and the users are satisfied. Additionally, the toll value for the public entity perspective resulting in maximization of consumer's surplus is lower than that for the private perspective. Similar trends are observed for the other horizon years during the analysis period presented in Table 1.Increased travel demand in future years resulted in higher toll values, higher revenue and higher consumer surplus in succeeding years. For the Theil's Index that is considered as a minimization function, there are some minor variations between different horizon years, without any specific patterns.

[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.

[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.

TABLE1 Exclusive Entity Participation Results

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

Ownership, Tenure and Governance Strategies

The authors' initial work on the concept of OTG scenarios was presented at the World Conference on Transport Research at the University of California, Berkeley in 2007 *(20)*. Ownership, Tenure and Governance (OTG) may be considered as the three principal components of a joint ownership.

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[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

A number of OTG strategies were considered to reflect varying degrees of participation by the public and the private entity as follows:.

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

A number of relaxation policies are also considered as a part of the OTG strategies and is explained below. The feasibility of OTG strategies are determined by considering the analysis period till2050. A Minimum Attractive Rate of Return of six percent was assumed for the OTG analysis.

OTG-1

For OTG-1, the total capital cost is borne by the private entity with the objective of profit maximization. After construction of the facility, the private entity collects toll, operates and maintains the facility during the concession period. The public entity assumes the responsibility of the project at the end of the concession period.

The cumulative cash flow and IRR for OTG-1are the two MOEs plotted in Figure 3. The negative cost elements during the 2004-2014 period 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 computed as 4.61% over the 35 year concession period. The IRR being less than the MARR (assumed as six percent) lends the project economically infeasible for the strategy (OTG-1).

Other OTG's

The objective of OTG strategy analysis is to assess the fiscal impact of varying levels of joint ownership scenarios on the public and the privateentities.OTG-1 and OTG-5 represent exclusive private and public projects respectively (with no role by the other agency) as the two ends of the joint participation spectrum. OTG-2 and OTG-3 represent various levels of relaxation policies designed to provide higher levels of subsidies (as incentives) to the private agency with all the revenue committed to the agency. OTG-4 is a major public program with minor participation by the private agency both in cost and revenue sharing. Results of this analysis are presentedinTable2 and can be summarized as follows:

Varying degrees of relaxation are proposed in (OTG-2 and OTG-3) to encourage private participation. None of the three relaxation policies within OTG-2 resulted in IRR values higher than the MARR (6%). On the other hand, all of the four relaxation policies within OTG-3 resulted in financially viable solutions with IRR values exceeding the MARR (6%). The exceedingly high IRR (22.97 percent) for OTG-3(d) is caused by a very large construction cost subsidy to the private agency. For major and exclusive public participation (OTG-4 and OTG-5),the project is not financially viable, with none of the IRR values exceeding the 6 percent mark. OTG-4(a) and 4(b) represent small amounts of costs and

[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.

revenue sharing by the private agency with the public agency having the major financial responsibility. OTG-5, on the other hand is exclusive public participation and is not financially viable.

In summary, the OTG strategies representing different joint ownership scenarios generate varying returns ranging from a low of 4.61 percent to a high of 22.97 percent to the private agency, and from 3.27 percent to 3.69 percent for the public agency. With an assumed MARR of 6 percent, all the four options within OTG-3 are found financially viable for the private agency. Unfortunately, none of the two options in OTG-4, and the single option in OTG-5 is financially viable for the public agency.

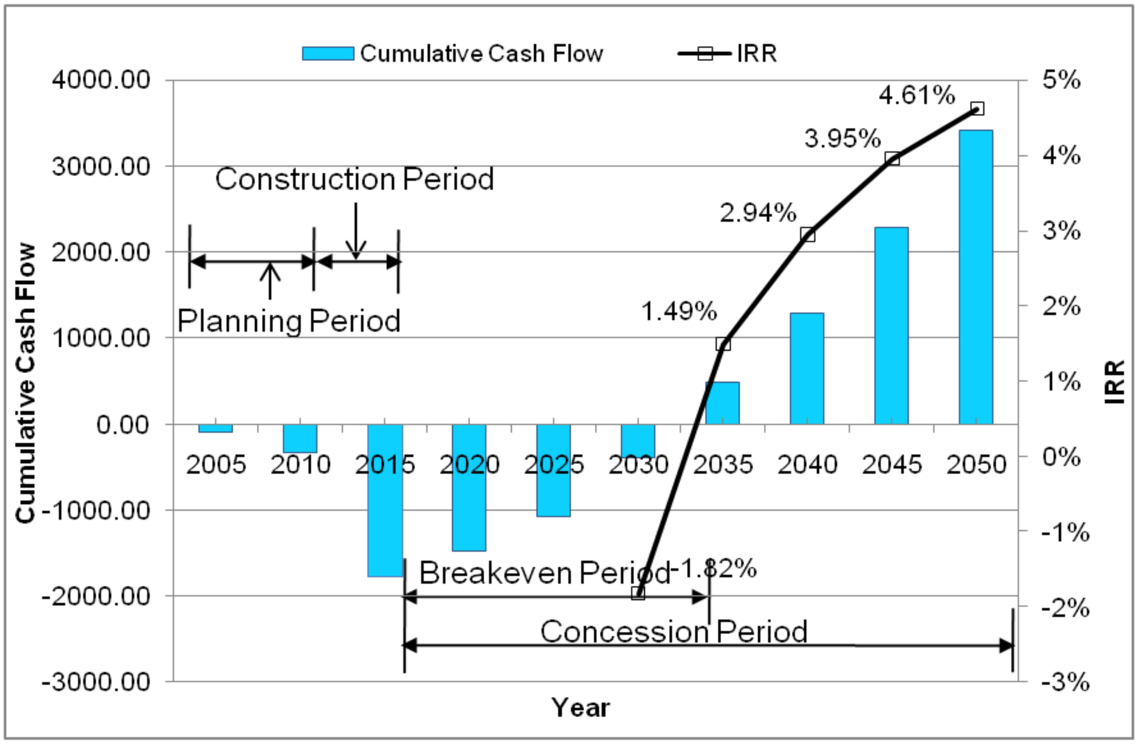

FIGURE 3 Cumulative Cash Flow and IRR: Exclusive Private Participation (OTG-1)
(Note: There is no IRR value till the end of 2025 as the cost is much higher than the benefit received. The IRR at the end of 2030 is -1.82)

Multi-objective optimization

The proposed multi-objective optimization is an attempt to incorporate the objective of three entities in an equitable manner in the decision making process: private, public, and user. The objectives of three entities: profit maximization, consumer surplus maximization, and inequality minimization are to be converted to a single objective function, subjected to a set of constraints.

Pareto-optimal solutions for a combination of all entities taken two at a time are presented in Figure 4 in six sub-graphs for the year 2015. A number of solution points which dominated others are connected by a line and are called as non-dominated solutions. Each point on the non-dominated solution is different from the other when the weight of one objective is different from the other in the MOO analysis. As the pareto optimality suggests, no objective can be made better off without making another

TABLE 2 OTG Strategies, Relaxation Policies and IRR's

OTG Strategy	Explanation	Relaxation Policy	Entity Objective	IRR (%) (Private)	IRR (%) (Public)
OTG-1	Exclusive Private Participation	1. No Relaxation	Profit Maximization	4.61	
OTG-2	Major Private Participation	2(a). Toll Plaza Cost Subsidy 2(b). Toll Plaza, Interchange, and Inspection Plaza Cost Subsidy 2(c). Construction Cost Subsidy	Profit Maximization	5.14 5.89 5.84	
OTG-3	Moderate Private Participation	3(a). Construction Cost Subsidy 3(b). Concession Period Extension 3(c). Construction Cost Subsidy and Concession Period Extension	Profit Maximization	6.13 6.01 7.20	
OTG-4	Major Public Participation	4(a). Partly Construction Cost by Private Entity 4(b) Operation and Maintenance Cost – Public Entity 4(c). Construction Cost Subsidy-Public Entity	Consumer Surplus Maximization	22.97*	3.27** 3.69** 3.95**
OTG-5	Exclusive Public Participation	No Relaxation	Consumer Surplus Maximization		3.51**

Note: *: IRR for private entity; **: 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.

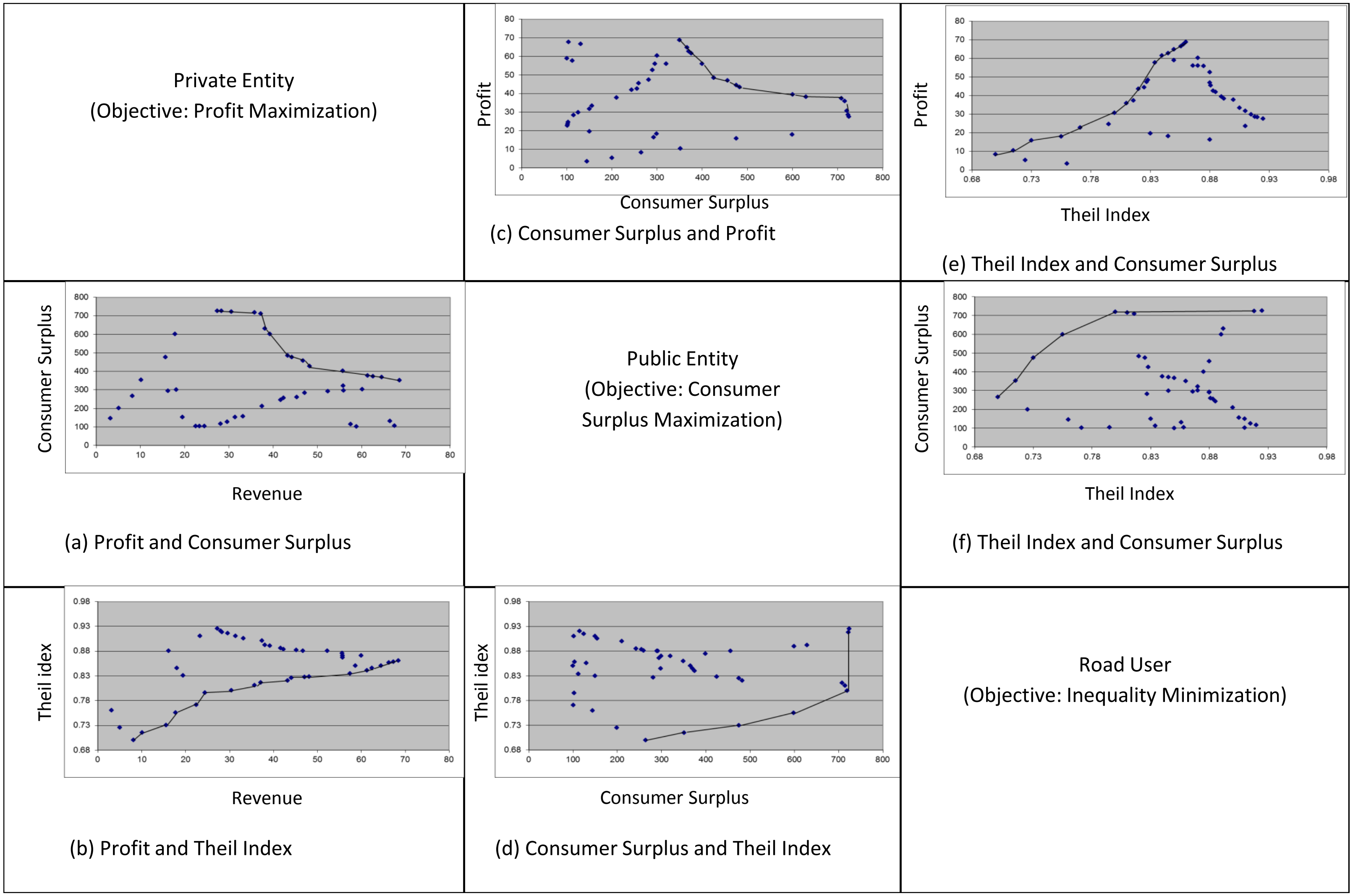

FIGURE 4 MOO Solution for All Entities

objective worse off. Points not joined by a line represent dominated solutions and should not be considered for decision making.

For example, when profit maximization and consumer surplus maximization is considered, the non-dominated solution points are connected by a line with two extreme points representing the maximum values of each objective function. The extreme left point on the line in Figure 4 (a) represents $25 million of revenue and $720 million of consumer surplus. The extreme right point on the line in Figure 4 (a) represents $68 million of revenue and $340 million of consumer surplus.. In between two extreme points of the line in Figure 4 (a) there are a number of optimal solutions to consider for the two entities.

When profit maximization and inequality minimization are considered as two objectives, the extreme non dominated point on the extreme right corresponds to $68 million of revenue and 0.85 of Theil's Index (Figure 4 (b)). Similarly, the extreme non dominated point on extreme left is the juncture of $7 million of revenue and 0.71 of Theil's index. The Pareto-frontier[17] in Figure 4(b) consists of other optimal solutions as trade off in the objectives between profit maximization and inequality minimization. Similarly, the pareto frontier for other combination of objectives can be found from Figure 4 (c) through Figure 4(f).

From Pareto-Optimal to Feasible Solution

MOO resulted in Pareto-optimal solutions as a trade-off between the entity perspectives. How the trade-off will be accepted is a decision making process that may enlist the opinions of involved entities or the stakeholders in this case (public, private, and user). The task of narrowing down the solution space from the Pareto-optimal options was accomplished by AHP. A questionnaire survey was conducted among a select group of experienced professionals to include their preferences in terms of the five OTG strategies identified earlier(Table 3).

The survey participants were asked to respond to the question of relative importance of the role of each entity for a specific OTG strategy on a scale from 1-10 in such a manner that the total score for each OTG strategy (sum of scores in one row) is equal to 10. The respondents are asked to assign scores for all OTG strategies.

Results of the AHP Analysis

The survey responses are considered in AHP analysis. The relative importance of the three entities for each OTG strategy expressed in percentage, as obtained from the AHP analysis is presented in Table 4. For each OTG strategy the sum of degree of involvement for three entities is 100 percent. For example, in the case of OTG-1 (exclusive private involvement), AHP analysis resulted in 68.1% of private, 14.0% of public, and 17.9% of user involvement. Similarly for OTG-5 (exclusive public involvement), the AHP analysis resulted in 7.2% of private, 75.8% public, and 17.0% of user involvement.

[17]The Pareto frontier is the set of choices that are Pareto efficient and non-dominant.

TABLE 3 Proposed OTG Strategies

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

Note:
[1]Concession Period- The time period during the service life of a project when the private entity is allowed to collect revenue to regain its earlier committed investment. The concession period often termed as “tenure” and may vary depending upon specific ownership type. The ownership of the facility is expected to revert back to the public entity at the end of the concession period.
[2] Governance: Relates to the management, policy and decision making for the general area of responsibility. The public entity is assumed to have full governance rights through the project life because it is the ultimate owner of the facility.
[3] Project Life- The time period from the start day till the facility is considered no longer beneficial for service.

TABLE 4 Results of the AHP analysis

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

Integration of Multi-objective Optimization and AHP

The perception of the relative importance of three entities for each OTG strategy can now be integrated with the Pareto-optimal solutions. The relative importance of the OTG's as perceived by the three entities is reflected in the respective cells of Table 5. To determine the objective of each OTG strategy, two distinctions are made: (1) the objective of an OTG strategy is determined by the entity (private or public) which received the highest percentage of relative importance, and (2) the objective of the selected entity will receive the consideration of the users. For OTG-1 the tradeoff can be chosen as 68.1% of private, 14.0% of public, and 17.9% of user participation. The objective of OTG-1 is profit maximization as the private entity received highest relative importance (68.1%) from the AHP results. Even though OTG-1 maximization relates to exclusive private participation, the private entity will receive 86% of revenue (i.e. 68.1% plus 17.9% in OTG-1, Table 4). The maximum revenue for the year 2015 is 68 million (Figure 4).

The tradeoff threshold value of revenue for the private entity is $58.94 (i.e. 0.86 x $68 million) million (Table 5). The corresponding consumer surplus can be obtained from Figure 5 by drawing an imaginary vertical line from the X-axis value of $58.94 million to the intersection of the Pareto-frontier and then drawing a horizontal line to the Y-axis to obtain the consumer surplus. The threshold value of consumer surplus is $401.12 (Table 5) million for corresponding revenue of $58.94 million for OTG-1. Similarly, the threshold value of Theil's Index for corresponding revenue of $58.94 million is obtained as 0.84 (Table 5) from the Figure 3. For OTG-2 and OTG-3 the objective remains as profit maximization and similar procedure can be followed to obtain the threshold values. The threshold values for all OTG strategies are presented in Table 5.For OTG-4 and OTG-5 the objective is consumer surplus maximization as the public entity received the highest relative importance. For example for OTG-5, the public entity will receive 92.8% (i.e. 75.8% plus 17% in OTG-5, Table 5) of consumer surplus. The maximum value of consumer surplus for the year 2015 is $720 million (Figure 4). The threshold value of consumer surplus for the OTG-5 for year 2015 is $677.78 million (i.e. 0.928 x $720 million) (Table 5). The corresponding revenue can be obtained by drawing an imaginary line from the Y-axis value $677.8 million to the intersection of the Pareto-frontier and then drawing a vertical line to X-axis to obtain the threshold revenue of $34 million. Similarly from Figure 3 the corresponding threshold of Theil's Index can be obtained as 0.80 (Table 5). The revenue is maximum for OTG-1 as the objective is profit maximization and the private entity had the highest relative importance among all OTG strategies. The threshold revenue amount decreases as the private entity relative importance is reduced. The effect of reducing revenue can be observed for the year 2015 in the Table 5 (Column 1) from OTG-1 to OTG-5 as $58.94, $52.22, $44.48, $38, and $34 million respectively. On the contrary, the consumer surplus increases as the relative importance of the public entity increases from OTG-1 through OTG-5. For the year 2015 in Table 5 (Column 2), the increase in consumer surplus from OTG-1 through OTG-5 can be observed as $401.12, $420.64, $480, $583.55, and $677.78 million respectively. The revenue and consumer surplus increases as the relative importance of the respective entities increases across the OTG strategies. From the user perspective, there does not appear any trend in the Theil's Index. But the effect of the users is considered in the private and public entity perspectives in all the OTG strategies. The car and truck toll values for each set of threshold value for particular year is presented in the last two columns of Table 5.

Each set of three tradeoff values of the objectives (for a particular OTG strategy and for a particular year) obtained from MOO and AHP analysis, are functions of the car and truck toll values. Specific toll values are estimated once the tradeoff objectives were known. The profit and Theil index obtained from MOO is lesser than the single objectives (shown in Table 1) for all OTG strategies, but the consumer surplus is higher.

TABLE 5OTG Strategy and Threshold Values for Revenue, Consumer Surplus, and Theil's Index

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

Feasibility Analysis from AHP Results

The threshold values of revenue and consumer surplus resulting from the integration of MOO and AHP analysis are used to determine the IRR for each OTG strategy (referred as IRR_m in Table 6). The IRR_m for OTG1 is 3.73%. The corresponding IRR_s for the single entity (as determined in Table 3) is 4.61%. The reduction in IRR is attributable to the trade off in the objectives of both private and public entities. The IRR_m is lower but the consumer surplus for OTG1 for multiple entities is higher than that of the single entity. Similarly IRR values for all OTG strategies are determined and presented in Table 6. Two OTG strategies resulted in IRR_m higher than the MARR of 6%: (1) OTG3 (c) construction cost subsidy and concession period extension, and (2) OTG4 (a) partly construction cost by private entity.

TABLE 6 IRR for OTG Strategies

OTG Strategy	Relaxation Policy	IRR_m (%)	IRR_s (%)
OTG-1	No Relaxation	3.73	4.61
OTG-2	Toll Plaza Cost Subsidy	3.58	5.14
	Toll Plaza, Interchange, and Inspection Plaza Cost	4.30	5.89
	Construction Cost Subsidy (50%)	4.26	5.84
OTG-3	Construction Cost Subsidy (60%)	2.87	6.13
	Concession Period Extension (27 years)	4.36	6.01
	Construction Cost Subsidy and Concession Period	6.13	7.20
OTG-4	Partly Construction Cost by Private Entity	17.47	22.97
	Operation and Maintenance Cost-Public	1.97	3.69
	Construction Cost Subsidy-Public	2.12	3.95
OTG-5	No Relaxation	1.17	3.51

CONCLUSION

The primary goal of this paper is to develop a framework for large scale transportation infrastructure investment that incorporates the following: (1) determine the entities involved in decision making and their individual objectives, and (2) combine the objective of all entities, and (3) apply the framework in a real world case study to augment the decision making process.. A MOO procedure is proposed, which attempts to incorporate the objective of all the entities involved in the decision making process. 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 analysis for OTG strategies.

The MOO process when applied on a case study resulted in Pareto-optimal solutions as a tradeoff between multiple entities. As opposed to a single optimal solution, the MOO offers a number of non-dominated solutions represented in the Pareto-frontier to be considered by the multiple entities. The preferences of multiple entities are embedded in the form of OTG strategies and the relative importance of the entities is determined in the form of a multi objective decision making through a questionnaire survey. The survey was conducted among transportation professionals and stakeholders who were asked to respond to the questionnaire with relative importance of entities involved in each OTG strategy. The survey responses are analyzed in AHP and the relative importance was determined. The AHP results were integrated with the Pareto-optimal solutions obtained from MOO analysis and corresponding trade off optimal values were determined for each OTG strategy. The feasibility of each OTG strategy is determined from multi entity perspectives and the results were compared to that of the single entity.

The MOO framework may be used by transportation and financing professionals involved in infrastructure investment decisions. Such professionals include: engineers/planners/economists, investment and cost analysts involved both in private and public financing of infrastructure projects. Typically, economic analysis of infrastructure projects is based upon the assumption of single entities and in reality there are multiple entities involved each with different set of objectives. 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 expand on the proposed research to incorporate additional entities, and more uncertain variable in the multi-objective framework.

To what extent, if at all, the proposed framework can be transferred to other problems involving investment decisions, is in its simplest form, a matter of extrapolation, or a matter of future research in more complex forms in the opinion of the authors.. The computational requirement would clearly increase with the size and the dimension of the problem. For non-transportation issues encompassing multiple entities and multiple strategies involving stakeholders with conflicting viewpoints, additional research may be needed to test the extent to which the proposed framework can be applied as a tool for such investment decision. At the very minimum, the authors feel that the proposed framework will need some "fine tuning" to meet the demand of the specific problem. The authors recommend additional research to explore the transferability of the proposed approach.

ACKNOWLEDGEMENT

This research was supported by the U.S. Department of Transportation (USDOT) through its University Transportation Center (UTC) program. The authors would like to thank the USDOT and the University of Toledo for supporting this research through the UTC program, and Wayne State University (WSU) for providing crucial matching support. The authors would like to acknowledge the assistance of Michigan Department of Transportation (MDOT) and Southeast Michigan Council of Governments (SEMCOG) for their assistance during the course of the study. The comments and opinions expressed in this report are entirely those of the authors, and do not necessarily reflect the programs and policies of any of the agencies mentioned above.

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