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# Multi-entity perspective transportation infrastructure investment decision making

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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 and do not consider 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. The 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.

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## 1. 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. 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 (BTS, 2008). Similarly *expenditures* in operating, maintaining and administering the nation's transportation facilities are over $200 billion annually. Projected federal, state and local highway *revenues* are insufficient to meet estimates of future highway requirements (USDOT, 2006). Lack of capital funds to \meet the infrastructure needs of the country may result in increased private participation in such projects (Roth, 1996).

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 (Yang and Meng, 2000). Thus, the travel cost (in the form of toll charges, travel time and other road-user costs) must be viable to the ultimate end-users. One of the ways to ensure such viability is to minimize inequality in the distribution of services among the user-community.

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

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Hence, in the investment decision making process, the perspectives of the three entities: (1) the private, (2) the public, and (3) the user should be duly considered. The fact that these perspectives are distinctively different makes the decision-making process extremely complex.

A single objective optimization may be used to represent the interest of a specific entity perspective. The optimum solution thus obtained might not be best suited to other entities. A multi-objective optimization (MOO) is the process of simultaneously considering two or more objective functions each with a specific optimization defined. Different solutions of MOO may produce conflicting solutions (trade-offs) among different objectives. Examples of MOO in transportation application include scheduling of trains for single and multiple tracks with varying capacity of trains to platforms (Ghoseiri et al., 2004), vehicle routing and scheduling for hazardous material transportation (Meng et al., 2005), optimal transit network design (Fan and Machemehl, 2006), optimal responsive plans for traffic signal coordination (Abbas and Sharma, 2006), optimum project selection model from portfolio (Doerner et al., 2006; Lee and Kim, 2001; Santhanam and Kyparisis, 1995; Ringuest and Graves, 1989), tradeoff between emission and logistics cost (Seok et al., 2009), bicycling route choice (Ehrgott et al., 2012), and container terminal technologies (Jurgita, 2012). In spite of these examples, the application of MOO in investment decisions is somewhat limited. Thus, there are a number of problems in decision making that are often ignored. These include the need to consider the perspectives of different entities, and to provide a methodology in a multi-objective decision making framework. This paper focuses on the last aspect mentioned above, and the objective of research is

> "*to present a methodology 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*."

## 2. Entity perspectives in investment decision making

Three entities are primarily involved in the decision making process for a typical toll facility. These three are (1) private investor, (2) the public investor and (3) the road user, whose perspectives must be duly considered in the decision making process. Their justification and quantitative formulation in the decision making process can be found in the literature (Mishra et al., 2011) and are summarized below.

### 2.1. 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.

### 2.2. 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 (Wohl and Hendrickson, 1984). There are other social benefits such as improved traffic flow, environmental benefits, higher safety etc., that may be derived from major infrastructure projects. There are conflicting viewpoints regarding the degree to which these social benefits should be considered in investment decisions (Johnson et al., 2007). These are not incorporated in the proposed framework and the classical approach of maximization of consumer surplus was used as the only public benefit from toll and travel time savings.

### 2.3. 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 in the study area 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 (Theil, 1967).

## 3. A framework for multi-entity perspective decision making

A framework for investment decision making in transportation infrastructure with multiple entities is presented in Fig. 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.

### 3.1. Identification of entities in investment decision making

Such investments typically involve different types of decision makers (or investors/users) termed as entities in Fig. 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.

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. An OTG strategy can be looked upon as a mechanism to implement joint ownership projects. These three terms can be defined as follows (Mishra et al., 2011):

- 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.

### 3.2. Multi-objective decision making problem definition

The multi-objective problem definition consists of objective of multiple entities in the transportation investment decision making. MOO approach can be divided into two categories: (1) exact methods and (2) the heuristic method. Few examples of the exact method are the weighted sum method, $\varepsilon$-constraint method, weighted metric method, value function method, and goal programming method (Deb, 2001). The exact method does not use any *a priori* information in estimation of pareto-optimal solution. The approach is applied to a number of MOO problems. Examples include traffic assignment and traffic flow (Lee and