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A framework for evaluating the dynamic impacts of a congestion pricing policy for a transportation socioeconomic system

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ABSTRACT

This paper provides a modeling framework based on the system dynamics approach by which policy makers can understand the dynamic and complex nature of traffic congestion within a transportation socioeconomic system representation of a metropolitan area. This framework offers policy makers an assessment platform that focuses on the short- and long-term system behaviors arising from an area-wide congestion pricing policy along with other congestion mitigation policies. Since only a few cities in the world have implemented congestion pricing and several are about to do so, a framework that helps policy makers to understand the impacts of congestion pricing is currently quite relevant. Within this framework, improved bus and metro capacities contribute to the supply dynamics which in turn affect the travel demand of individuals and their choice of different transportation modes. Work travel and social networking activities are assumed to generate additional travel demand dynamics that are affected by travelers' perception of the level of service of the different transportation modes, their perception of the congestion level, and the associated traveling costs. It is assumed that the, population, tourism and employment growth are exogenous factors that affect demand. Furthermore, this paper builds on a previously formulated approach where fuzzy logic concepts are used to represent linguistic variables assumed to describe consumer perceptions about transportation conditions.

1. Introduction and research context

Population growth and urbanization have increased traffic congestion in many parts of the world. An increasing number of US highways and roads experience overwhelming traffic congestion problems, even though most Interstate physical and safety conditions have been improved. According to a report by the Texas Transportation Institute (TTI), based on congestion trends for 439 selected areas from 1982 to 2007, traffic congestion is costing Americans $87.2 billion (in constant 2007 dollars) in wasted time and fuel annually (Schrank and Lomax, 2009). Many metropolitan areas in the world including but not limited to London, Paris, Stockholm, Tokyo, and Beijing are experiencing serious traffic congestion that causes significant economic losses. Nevertheless, interventions such as congestion pricing have been taken to counter congestion. One key challenge is to evaluate the impacts of an intervention within a specific metropolitan area before and after it is implemented.

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The objective of this paper is to provide a modeling framework based on the system dynamics (SD) approach by which policy makers can understand the dynamic and complex nature of traffic congestion within a *transportation socioeconomic system* (TSES) representation of a metropolitan area. This framework offers policy makers an assessment platform that focuses on the short- and long-term system behaviors arising from an area-wide[2] congestion pricing policy along with other demand–based transportation policies. This can lead to the understanding of the dynamic long-term behavior of key variables in the TSES with and without a congestion pricing policy being implemented. Since only a few cities in the world have implemented congestion pricing and several are about to do so, a framework that helps policy makers to understand impacts of congestion pricing is currently very relevant.

For illustration purposes, in this research framework, congestion pricing can be complemented with the funding of public transportation (metro, bus, etc.) from the revenues that accrue from the implementation of congestion pricing implementation. The framework allows for the evaluation of this strategy whether the decision makers decide to do this or not. Funding of public transportation modes can potentially changes users' perceptions of the level of service associated with these modes and their social networking activities[3] that induce the mobility of people living around a metropolitan area. Additionally, in this framework, we consider how users' perceptions with respect to the congestion level, traveling cost, and level of service of mass transit can affect the switching behavior of travelers among different transportation modes.

The structure of this framework is well grounded in the literature and practices of congestion pricing found in London (Transport for London, 2008) and Stockholm (Special issue on Stockholm Congestion Charging Trial, Transportation Research Part A, 2009). Consequently, this framework incorporates important subsystems and components for a system dynamics model that can be simulated on a computer. With the availability of pertinent data, one can run simulation models once they are formulated and analyze the impacts of a traffic congestion pricing policy in the TSES. Although we have incorporated some specific features and evaluated one set of policies, our framework can be easily adapted to include other aspects and evaluate alternative policies. Furthermore, the framework can be used to generate more than one simulation model. This will be depend in part on the input afforded by the decision makers that potentially would use the model and the availability of the existing data for existing congestion pricing schemes.

The primary motivation for using the SD approach is that we need to represent multiple and concurrent interactions among variables that are incorporated in multiple feedback loops. This approach allows one to easily understand and interpret these interactions. It should be noted that we are not suggesting that alternative modeling approaches could not be considered instead. However, we are using the SD approach to provide a framework that is reasonable for practitioners/decision makers to use (Sterman, 2001).

Furthermore, one of the key strengths of the SD modeling paradigm is its ability to describe the dynamics of systems that evolve continuously and with time lags or delays. This is important for our framework since we assume that we need to study the impact of congestion pricing over many years and that key delays (e.g., delays associated with changing perceptions of consumers, with additions to existing infrastructure, etc.) manifest themselves over years. Finally, in the SD modeling paradigm we assume that some key relationships are non-linear (Sterman, 2001) (e.g., the relationship of the congestion on roads and travel comfort of metro with the attractiveness of each mode respectively). This is important for our framework since if we do not consider these non-linear relationships we are potentially ignoring the basic physics of systems and/or the non-linear interaction of multiple factors that are part of decision making.

In the literature, one can identify many examples where the SD paradigm has been useful with respect to many applications starting with settling legal disputes (Cooper, 1980; Stephens et al., 2005), project management (Lyneis and Ford, 2007) and public health (Sterman, 2006). While a number of researchers have used the SD approach to evaluate different transportation policies, there is very little research that evaluates the dynamics associated with the impacts of a congestion pricing policy on the TSES within a pricing area.

From a methodological perspective, we are also suggesting that the linguistic or qualitative representation of perceptions can be formulated with fuzzy logic and incorporated in the SD modeling paradigm. This idea builds on the work of Liu et al. (forthcoming) and on the existing literature. For example, research on travel mode choice indicates that perceptions and information about alternative modes of transportation are important issues to consider. Misperceptions act as a major barrier for mode choice and information about cost, duration, comfort and convenience can lead to the consideration of alternatives (Kenyon and Lyons, 2003). Handy et al. (2005), report that car users in the US often lack information about other modes of transportation. Rose and Ampt (2001) have a similar finding for Australia. Using data from Amsterdam, van Exel and Rietveld (2010) report that distorted perceptions play a significant role in people's decision to use cars. Kingham et al. (2001) also find that concerns about travel time are a major obstacle in getting people to switch from cars to alternative transportation modes. It has also been suggested that for perceptions about quality of service does affect the decision to use mass transit (Tyrinopoulos and Antoniou, 2008; see also Friman and Fellesson, 2009). Note that in our framework perceptions about both cars and mass transit are important.

Teodorović (1999) provides numerous examples in transportation that constitute perceptions and where fuzzy logic can be used to represent these perceptions. He states the human operators, dispatchers, drivers and passengers use perceptions represented as linguistic information to make decisions, for example, choosing a route because there is considerable

[2] Since the framework is grounded on the London congestion pricing scheme and this scheme is an area-based pricing policy, we use the term area-based pricing policy throughout this paper.

[3] Social networking activities refer to any activities such as entertaining, meeting friends at outside establishments, etc. that typically generate mobility.