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Public transportation adoption requires a paradigm shift in urban development structure

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ABSTRACT

Urban passenger transportation in the U.S. has been heavily dependent on car modes, mainly due to prevailing trends in urban development. However, transportation mode choice studies are currently limited to micro-level and regional-level boundaries, lacking of presenting a complete picture of the issues and the root causes associated with urban passenger transportation choices in the U.S. To this end, further analysis from a system perspective is required to investigate the interdependencies among system parameters more thoroughly, thus revealing the underlying mechanisms contributing or causing the low public transportation use in the U.S. Hence, system dynamics modeling approach is utilized to capture complex causal relationships among the critical system parameters affecting public transportation ridership in the U.S. as well as to identify possible policy areas to improve public transportation ridership rates. Considering the high degree of uncertainties inherent to the problem, multivariate sensitivity analysis is utilized to explore the effectiveness of existing and possible policy implications up to the year 2050 in the terms of their potential to increase transit ridership and locating critical parameters that influences the most on mode choice and emission rates. Transportation mode choice behavior is projected to change slightly and reach up to a maximum of 7.25% of public transportation ridership until 2050. Analysis results reveal that the effects of trip length and rate are by far the most influential factors. Both parameters are 99% sensitive compared to all other factors including the effects of fuel tax policies, federal funds for public transportation, use of alternative green bus technologies, increasing private vehicle occupancy rates, etc. on negative environmental, economic, and social impacts of transportation. This finding highlights how important urban structures are to secure the future of public transportation in the U.S. as the existing urban structures and the shared-idea in the minds of the society about how urban transportation should be (the prevailing paradigm) are the root causes of excessive trip generation and increasing average trip lengths. Thus a paradigm-shift, a radical change in the shared-idea in the minds of the society about existing urban structures, is needed.

1. Introduction

Urbanization in the U.S. has been rapidly increasing since World War II, but sustainable urban development was not considered as an applicable concept with respect to smart growth initiatives until Clean Air Act Amendments declaration (Bento et al., 2005). Therefore, urban passenger transportation in the U.S. has since become greatly dependent on private vehicle use, as demonstrated consistently by the results of the National Household Travel Surveys (NHTS) (1990, 1995, 2001, and 2009) for U.S. households (Santos et al., 2011). For instance, the average number of vehicle ownership per household increased from 1.77 in 1990 to 1.86 in 2009, and 23% of the surveyed households owned 3 or more vehicles in 2009 (Santos et al., 2011). As a result of this car mode dependency, the level of motorization is significantly higher on average in the U.S. compared to the average motorization of Europe (EU27), where there are 477 light-duty vehicles (2 axles - 4 tires) for every one thousand people in Europe, whereas the corresponding number for the U.S. is 763 light-duty vehicles for every one thousand people (European Commission, 2011). Moreover, the high dependency on private vehicles in the U.S. has significant

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environmental impacts, such as greenhouse gas (GHG), and conventional air pollutant (CO, NO_x, SO_x, PM_{10}, $PM_{2.5}$, and VOC) emissions (Onat et al., 2015, 2014b). In addition to the climate change impacts of these emissions, their impacts on society can be measured in terms of externalities, which accounts for human health impacts, timber loss, and other relevant factors (Muller and Mendelsohn, 2007, 2006), which are specifically quantified for light-, medium-, and heavy-duty vehicle operations (Ercan et al., 2015; Michalek et al., 2011; Sen et al., 2017; Zhao et al., 2016a, 2016b).

As Litman (1999) argues, sustainable transportation measures are not limited to mobility measures where most transportation studies account for. Sustainable transportation needs to be considered in more holistic perspective so social, health, environmental, and economic impacts of high car dependency as transportation mode choice can be presented (Onat et al., 2016a, 2016c) The U.S. society has very limited experience with transit-oriented and healthy communities, which cause more resistance on changes from behavior or habits of living (Litman, 1999). Litman and Burwell's (2006) later study also underlines that in order to achieve sustainable transportation goals, holistic approach suggests institutional reforms, land use (built environment) changes, and economic incentives as opposed to individual technological (vehicle oriented) solutions of myopic perspective. The shared-idea in the minds of the society about how urban transportation should be (prevailing paradigm) played very important role on the development of today's urban structures using vast amount of land and requiring excessive trip lengths to meet basic needs, employee commuting, etc. In addition to these macro level literature, some of the survey based studies also presented overlaying results as they pointed out the abnormalities in the existing paradigm. Rajamani et al. (2003) stated that even non-commute type travels tend to be significantly sensitive to urban form. Their study concludes that high residential density favors walking and transit modes for non-work travels. Similarly, Zhang (2004) emphasized that travel time and monetary cost related influences on mode choice is independent from land use related influences. Besides urban infrastructure and demographic information, transportation mode choice is a matter of decision making by individuals and this decision is affected by psychological behavioral and emotional models. Bamberg and Schmidt (2010) and Carrus et al. (2008) found similar results that previous behavior tends to influence later behavior for transportation mode choice since it is no longer a decision making but a habit of the person. The question is how are these actions become habits over the past decades of urban development in the U.S. There is a shared idea in the society's mind about how urban structures and transportation should be, which can be realized by looking at historical trends in urban structures and minimal increase in public transportation ridership. Despite the increased federal funds and investments in public transportation, the shared-idea, unstated assumptions, perceptions push right up against the accepted idea of “urban structure”, which constitutes the society's paradigm. At what degree these external factors (exogenous factors) are effective on the transportation mode choice is one of the critical questions to be answered in this research. Overarching goal of the systematic approach taken in this research is to reveal the underlying mechanisms feeding the current paradigm of the society and provide a complete picture of the problem.

The American Public Transportation Association (APTA) reported a record for transit ridership by the year 2014, when it reached its highest ridership levels in 58 years (American Public Transportation Association, 2015, 2014). However, transportation mode share percentage statistics indicate that transit ridership in the U.S. is still relatively very low compared to private vehicle use. Nevertheless, to yield any significant reductions in transportation-related impacts, a greater shift in commute/travel mode from private vehicle to transit should also be encouraged. In this regard, transportation mode choice is being widely studied in current literature with different discrete event simulation methods (Meixell and Norbis, 2008). However, these simulation studies are mostly limited due to their reliance on micro-level data, resulting in a lack of any complete picture of the overall U.S. transportation system, as well as a failure to properly account for the inherent interdependencies among important parameters within the system. In fact, transportation mode choice shares in the U.S. as a whole are influenced, directly or indirectly, by many separate entities that are connected via complex feedback relationships, through which these parameters simultaneously affect each other (Bhat, 1998, 1997; Eluru et al., 2012; Xiong et al., 2015). Furthermore, as the system boundary expands and new interconnections are introduced, the resulting degree of uncertainty in any analysis of the system will dramatically increase, compromising a policy maker's ability to develop more effective future transportation policies to increase adoption of public transportation. Along with the same lines, this research aims to answer following research questions:

- What is the current state of public transportation ridership, and what are the expected trends for ridership, private vehicle use, carbon emissions, and transportation-related externalities on a midterm and long-term basis, given the deep uncertainties inherent in these trends?
- How effective are current and planned public transportation policies for increasing public transportation ridership, and what are the root cause(s) of inefficiencies in these public transportation policies?
- What are the most critical parameters (policy leverage points) influencing private vehicle use, public transportation ridership, transportation-related externalities (health costs of air pollutants and greenhouse gases), and carbon emissions?

To answer these research questions, a comprehensive System Dynamics (SD) model is developed to model and test the U.S. public transportation system.

2. Methods and materials

SD has been utilized in many research areas (policymaking, sustainable development, etc.) ever since its introduction by Jay Forrester in 1969 (Abbas and Bell, 1994; Fong et al., 2009; Forrester, 1969; Haghani et al., 2002; Han and Hayashi, 2008; Laurenti et al., 2014; Onat et al., 2014a; Shen et al., 2009; Shepherd, 2014). Moreover, predicting or simulating the behavior of society as a whole in terms of transportation mode choice requires robust analysis, which may connect many different factors influencing such decision via complex relationships and feedback mechanisms (Alirezaei et al., 2016a; Struben and Sterman, 2008). SD method is capable of doing such robust analysis and it has been utilized for some transportation mode choice models and these models provide a crucial perspective for selecting regional study boundaries (Fong et al., 2009; Han and Hayashi, 2008; Shen et al., 2009; Wang et al., 2008). In addition, a recent transportation mode choice study has been published that also used the SD method with respect to the U.S. as a whole, thus using a similar system boundary that is being considered in this research (Ercan et al., 2016).

A dynamic modeling approach will allow this study to identify the feedback mechanisms of the U.S. transportation mode choice as an independent system, particularly those that divide the total number of trips made into those using private vehicles and those using public transit, depending on society's preference. Instead of

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