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Integrating mesoscopic dynamic traffic assignment with agent-based travel behavior models for cumulative land development impact analysis

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A R T I C L E I N F O

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A B S T R A C T

A number of approaches have been developed to evaluate the impact of land development on transportation infrastructure. While traditional approaches are either limited to static modeling of traffic performance or lack a strong travel behavior foundation, today's advanced computational technology makes it feasible to model an individual traveler's response to land development. This study integrates dynamic traffic assignment (DTA) with a positive agent-based microsimulation travel behavior model for cumulative land development impact studies. The integrated model not only enhances the behavioral implementation of DTA, but also captures traffic dynamics. It provides an advanced yet practical approach to understanding the impact of a single or series of land development projects on an individual driver's behavior, as well as the aggregated impacts on the demand pattern and time-dependent traffic conditions. A simulation-based optimization (SBO) approach is proposed for the calibration of the modeling system. The SBO calibration approach enhances the transferability of this integrated model to other study areas. Using a case study that focuses on the cumulative land development impact along a congested corridor in Maryland, various regional and local travel behavior changes are discussed to show the capability of this tool for behavior side estimations and the corresponding traffic impacts.

1. Introduction

Sustainable growth is an important topic in urban planning. Along with the development of economy and technologies, urban development may also result in problems such as environmental issues and traffic congestion. Urban development presents a double-edged sword for decision makers. That is to balance the desire for a sustainable urban future with a minimal social and user cost requires comprehensive information and foresight. The performance of transportation, both through accessibility and mobility, is a vital measurement of sustainable growth. Transportation Impact Analysis (TIA) has historically been used to evaluate the interplay between the existing transportation infrastructure and proposed land development projects. TIA can provide a large amount of information to assist with planning activities and policy evaluation, and also make immediate adjustments during long-term plans.

Over the last three decades, there have been many approaches to evaluating the impact of land developments on transportation

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infrastructure (Putman, 1974; Goldner, 1971; Putman, 1983). The ultimate goal of these analyses is to convert land development to transportation demand/supply data for TIA. So far, several traffic analysis models have been proposed to achieve this objective, such as traditional four-step models, advanced four-step models, tour-based models, activity-based models, and even dynamic traffic assignment (DTA). However, there is still room for improvement. The static methods for TIA usually represent traffic as a static phenomenon. Traffic dynamics such as queuing and routing changes are not adequately taken into account. Even though DTA has been used to address this issue, the pursuit of user equilibrium in DTA may not be advanced in depicting how people actually learn about traffic information and make decisions. This is because DTA usually relies on the rational behavior foundation, which assumes that travelers have perfect information on traffic conditions and are able to make optimal decisions.

By integrating DTA with agent-based, positive behavior models, this study seeks to develop a new TIA tool (referred as the "positive model" in this paper) that is capable of capturing both travel demand pattern changes and dynamic traffic conditions. The term "agent" refers to a traveler in the study area; the new TIA predicts every agent's behavior change that results from land developments. The framework of the positive behavior model was developed by Zhang (2007), as part of the SILK theory: Search, Information, Learning, and Knowledge in travel decision-making (Zhang, 2007). The most significant difference between the original DTA and the new, positive model is that the original DTA assumes travelers have perfect information while the positive model is based on subjective belief, knowledge updating, alternative searching, and the decision-making process among travelers (Zhang, 2007). The positive model is capable of forecasting behavior change of heterogeneous travelers due to land developments. This integration work aims to enhance the behavior realism of DTA for TIA while maintaining the capability of DTA in characterizing traffic dynamics. In previous studies (Zhang et al., 2012; Xiong et al., 2015a), a mesoscopic model was developed that integrated a regional land forecasting model with microscopic traffic simulation models for a large region around the Inter-County Connector (ICC) corridor between Montgomery County and Prince George's County in Maryland. However, due to the low support of agent-based modeling, the positive behavior model was only developed and tested for a small area within the study region (Zhang et al., 2012). In this paper, we extend the previous approach to a more behavior-oriented, mesoscopic TIA tool. More specifically, an agent-supporting DTA simulator, DTALite (Zhou and Taylor, 2014), is linked with a regional planning model as a light-weighted tool for time-varying traffic condition analysis. The tool developed in this paper can be widely applicable to planning agencies who have developed a static planning model. Maryland State Highway Administration (SHA) has continuously supported this integrated, agent-based framework for planning and traffic operation applications.

The major contribution of this paper is that it provides a timesaving approach to conducting agent-based TIA. In order to calibrate the integrated TIA, a simulation-based optimization (SBO) approach is developed and tested (Chen et al., 2015; Zhu et al., 2018). For governments or planning agencies who are still using traditional four-step travel demand models, the methodology in this paper can be followed to investigate individual traveler's day-to-day behavior shifts as well as time-dependent traffic condition changes under different scenarios. Compared with activity-based models, the proposed TIA tool captures travelers' knowledge updating and learning process; in addition, it has been shown that the computational time for running the TIA tool is short. The SBO calibration approach enhances the transferability of this tool to other study areas. To summarize, the proposed integrated model captures the interactions between travelers' pre-trip behavior and traffic dynamics; it can be transferred to other study areas by calibrating the behavior parameters utilizing SBO.

The rest of this article is organized as follows: Section 2 presents a comprehensive literature review on the current land development and traffic analysis models. Section 3 introduces the model components required for this TIA tool, i.e., the traditional transportation planning model, DTA model, and agent-based positive behavior model. Section 4 establishes the framework of the proposed tool to approach two significant challenges: how to build a DTA model based on a traditional planning model; and how to integrate a DTA model with an agent-based travel behavior model. The calibration of the integrated TIA tool is discussed in Section 5, which will cover the data, methodology and calibration case study. For demonstrative purposes, the proposed tool is implemented in a real-world land development impact study for Montgomery County, Maryland in Section 6. Finally, conclusions are drawn and future work is proposed in Section 7.

2. Literature review

It is unrealistic to model the change of every relevant aspect of urban areas because they are highly complex entities. Yet, despite the difficulty, researchers have proposed a variety of models forecasting interrelated processes of urban changes (Iacono et al., 2008). Modeling urban changes by examining the interaction between the transportation network improvement, land developments, and locations of economic activities has been a popular way to gauge accessibility. The interaction between spatial patterns of land use and transportation networks is referred to as the transportation-land use "link" (Putman, 1974).

A land development analysis is usually formulated as a bilevel problem. The upper level consists of urban planning and forecasting models, which include: (a) spatial interaction/gravity-based models (Goldner, 1971; Putman, 1974; Putman, 1983); (b) econometric models (Anas, 1982; Wegener, 1982; Martinez, 1992; Hunt and Abraham, 2005); (c) microsimulation models (Waddell, 2000); and (d) agent-based models (Arentze and Timmermans, 2003; Salvini and Miller, 2005; Veldhuisen et al., 2005). The lower-level urban development modeling can be (a) transportation models, such as traditional four-step models, which are also referred to as trip-based models (Boyce et al., 1970); (b) advanced four-step models (Ben-Akiva, 1974; Daganzo, 2014); (c) tour/activity-based models (Koppelman and Pas, 1980; Carpenter and Jones, 1983; Kitamura et al., 1996; Auld et al., 2012); and (d) DTA models (Merchant and Nemhauser, 1978; Janson, 1991; Wu et al., 1998; Zhou and Taylor, 2014).

Spatial interaction models and econometric models are usually linked with four-step models for TIA (Iacono et al., 2008). Most of the studies make an assumption of a static traffic equilibrium condition (Wardrop, 1952; Dafermos and Sparrow, 1969), which is