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An agent-based multimodal simulation model for capacity planning of a cross-border transit facility

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ABSTRACT

Cross-border transit facilities constitute major public investment, and thus must serve the long-term needs of the communities, such as providing access to schools and businesses, contributing to a shared regional culture and lifestyle, fostering international trade, and supporting jobs for the region's residents. Numerous studies have been conducted to evaluate the economic implications of vehicular flow delays at border crossings, however none of the studies focused on assessing cross-border flow of bus passengers and pedestrians. Since pedestrians are considered to be autonomous, intelligent, and perceptive, it is a challenging task to predict pedestrian movement and behavior in comparison to vehicular flows which follow a specific set of traffic rules. This paper presents a multiagent based multimodal simulation model to evaluate the capacity and performance of a cross-border transit facility. The significance of this research is the use of dynamic mode choice functionality in the model, which allows an individual person to make instantaneous choices between available modes of transportation. The scope of interest of the paper is limited to simulating access interface, circulation areas, ancillary and processing facilities. The developed model was calibrated to ensure realistic performance, and validated against specific performance criteria such as throughput per processing facility. In order to demonstrate the applicability of the developed simulation model, capacity and operational planning of a pedestrian transit facility was performed. The relative performance of alternative design or configuration was evaluated using the level of service criteria. Lastly, the effectiveness of each proposed capacity or operational improvement strategy was compared to the "do-nothing" scenario.

1. Introduction

Cross-border transit facilities constitute major public investment, and thus must serve the long-term needs of the communities, such as providing access to schools and businesses, contributing to a shared regional culture and lifestyle, fostering international trade, and supporting jobs for the region's residents. However, unexpected increase in traffic volumes, driven by growing population and economy, can compromise the performance of the transit facility. Trip times and costs for travelers will increase in addition to congestion along critical access routes across all modes of transportation due to burgeoning travel demand. Past literature has extensively documented various studies conducted to estimate vehicular delays and the use of advanced technologies to reduce processing time at border crossings. For example, a microsimulation based

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approach has been proposed to quantify the effects of priority crossing programs and queue jump lanes for U.S. bound border crossing vehicular traffic (Brijmohan and Khan, 2011). Spinning Network (SPN) method was employed to forecast hourly traffic volumes at the international border crossing between U.S. and Canada (Lin et al., 2014). Haughton and Isotupa (2012) developed a discrete event simulation model to evaluate impacts of smoothing of incoming freight trucks on the performance of a border crossing facility between U.S. and Canada.

Similarly, an analytical model is proposed to appraise road vehicle processing capacities with respect to improvements in service booth layout, such as tandem, staggered, and branch, at a border crossing (Gu et al., 2012). Paselk and Mannering (1994) proposed a methodology based on the use of duration models to estimate vehicular delays at U.S./Canadian border crossing. Turnquist and Rawls (2010) assessed economic costs of commodity flow disruptions at border crossing facilities between U.S. and Canada. Nozick et al. (1998) and employed discrete event simulation model to quantify the performance gains achieved through the application of advanced technologies. Cetin and List (2004) proposed to consider correlations among the service times at inspection facilities in order to evaluate performance of border crossing operations. Aside from the aforementioned literature, numerous studies have been conducted for capacity planning and to evaluate economic implications of vehicular flow delays at border crossings (Roberts et al., 2014; Brogan and Ahern, 2012; TTI, 2012; FHWA, 2012; Villalobos et al., 2010; Chaires et al., 1999).

Interestingly, none of the preceding studies focused on assessing cross-border flow of bus passengers and pedestrians. Since pedestrians are considered to be autonomous, intelligent, and perceptive, it becomes challenging to predict pedestrian movement and behavior in comparison to vehicular flows which follow a specific set of traffic rules. Consequently, it is becoming increasingly difficult to capture the complete range of crowd behaviors in one single model, which have led to quite sophisticated mathematical expressions that are relatively hard to calibrate. Multiagent based models offers an approach to simulate pedestrians as agents who can (i) interact with each other, (ii) learn from their experiences, and (iii) adapt to their environment. The key strength of the agent based modeling approach is the fact that one can combine basic behaviors to create complex patterns of behaviors. This paper proposes a simulation approach that models cross-border trips made by people over multiple modes using multiagent systems. The significance of this research is the provision of dynamic mode choice functionality in the model, which allows a traveler to make instantaneous choices between available modes of transportation. The scope of interest of the paper is limited to simulating access interface, circulation areas, ancillary and processing facilities at the cross-border transit facility. The remainder of the paper is organized as follows. Section 2 provides an overview of the proposed multiagent based multimodal simulation model. Section 3 describes the characteristics, calibration, and validation procedure of the proposed model for the cross-border transit facility. Finally, the model is used to perform capacity and operational planning of the transit facility in section 4.

2. Multiagent based multimodal simulation model

Simulation models are usually classified as macroscopic, mesoscopic, and microscopic, of discrete or continuous time and space, of event or time based transition. Most macroscopic models are based on traffic flow theory, queuing theory, fluid or continuum mechanics, and represent traffic as a time varying value of flow for each lane. Mesoscopic models, though less precise in the representation of traffic behavior in comparison to microscopic models, are developed to create a balance between computational constraints in real-time applications and realism of macroscopic simulation properties. These models are known to describe traffic flow dynamics in aggregate form, such as by using probability distribution functions. Since this research focuses on pedestrian and vehicular movement at a microscopic level, the remainder of this section will only discuss microsimulation models in the context of route choice.

Historically, pedestrian simulation models have been classified as Cellular Automata (CA) models, and social force models. In Cellular Automata model, pedestrians move on a grid of cells, with each cell represented by a state determined based on a predefined set of rules, and a transition matrix that updates the cell states successively (Nagel and Schreckenberg, 1992; Antonini et al., 2006; Davidich et al., 2013). These models are known to be completely discrete in space, time, and state. Though efficient and easy to implement, Cellular Automata based models are limited by the grid size, used to discretize space, and fail to incorporate autonomous pedestrian behaviors (Andersen et al., 2005). Social force model assumes that individuals are subject to social forces that are a measure of their internal motivation to act (Helbing and Molnar, 1995). These forces are computed using a set of mathematical expressions, which can be extended to include a number of behaviors (Bandini et al., 2014; Zeng et al., 2014). However, it is becoming increasingly difficult to capture the complete range of crowd behaviors in one single model, which has led to quite sophisticated mathematical expressions that are relatively hard to calibrate. Another drawback of these models is their inability to incorporate human intelligence given the process of decision making cannot be easily represented in the form of mathematical expressions.

With the advent of artificial intelligence, multiagent simulation models have become popular which treat pedestrians as fully autonomous agents with cognitive and learning abilities (Bonabeau, 2002). In this model, each agent is generally expected to (i) pursue a static target, (ii) influence other agents in its walking behavior and interact with the environment, (iii) avoid stationary obstacles and other agents, (iv) maintain speed and distance relative to other agents, (v) be able to change velocity and direction, and (vi) give way and stop. Various multiagent based models that simulate pedestrian motion behavior have been reported in the literature (Dijkstra and Timmermans, 2002; Teknomo, 2006; Gaud et al., 2008; Wang et al., 2014). Although these models differ by their type and application, the general concept remains to simulate behaviors