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A dynamic evacuation model for pedestrian–vehicle mixed-flow networks

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ABSTRACT

In urban emergency evacuation, a potentially large number of evacuees may depend either on transit or other modes, or need to walk a long distance, to access their passenger cars. In the process of approaching the designated pick-up points or parking areas for evacuation, the massive number of pedestrians may cause tremendous burden to vehicles in the roadway network. Responsible agencies often need to contend with congestion incurred by massive vehicles emanating from parking garages, evacuation buses generated from bus stops, and the conflicts between evacuees and vehicles at intersections. Hence, an effective plan for such evacuation needs to concurrently address both the multi-modal traffic route assignment and the optimization of network signal controls for mixed traffic flows. This paper presents an integrated model to produce the optimal distribution of vehicle and pedestrian flows, and the responsive network signal plan for massive mixed pedestrian–vehicle flows within the evacuation zone. The proposed model features its effectiveness in accounting for multiple types of evacuation vehicles, the interdependent relations between pedestrian and vehicle flows via some conversion locations, and the inevitable conflicts between intersection turning vehicle and pedestrian flows. An illustrating example concerning an evacuation around the M&T stadium area has been presented, and the results indicate the promising properties of our proposed model, especially on reflecting the complex interactions between vehicle and pedestrian flows and the favorable use of high-occupancy vehicles for evacuation operations.

1. Introduction

Mitigating traffic congestion during emergency evacuation has been evolved as one major task for responsible agencies over the past decades. In congested metropolitan areas, commuters are likely to depend either on transit or other modes for their daily commutes. Thus, during an emergency evacuation evacuees often need to move over some distance to their designated locations, such as parking areas or designated pick-up locations, and the massive number of pedestrians may consequently incur tremendous burden to vehicles in the roadway network (see Fig. 1). The difficulty in modeling urban mixed flow evacuation lies in the complex interrelations between these two types of flows, where the vehicle flows generated from parking garages or transit pick-up stations are dependent of arriving evacuees. The conflicts between these two types of flows also need to be effectively addressed by either law enforcement personnel at intersections or with effective signal control strategies. Besides, the vehicle flows typically consist of both passenger cars and transit vehicles, making the modeling of maximizing the evacuee throughput a complex network optimization issue where transit vehicles shall be preferred.

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Despite the increasing number of studies on either vehicle or pedestrian evacuation, the complex issues associated with urban evacuation, such as coordinating vehicle and pedestrian flows, have not been adequately addressed. Hence, this paper introduces a planning model to coordinate both the pedestrian and vehicle flows in an evacuation network. The contribution of our model lies in yielding the answers to the critical issues concerned by agencies responsible for evacuations such as "do we need to dispatch buses for emergency evacuation or not", "how many buses would be sufficient", "what kind of control should we have to coordinate the intersections when both massive vehicles and pedestrians are present".

The paper is organized as follows: next section reviews the existing traffic flow optimization studies for emergency evacuation. Section 3 presents the formulations of the integrated mixed flow network and its key components. Section 4 details an integer-linear optimization model that accounts for vehicle and pedestrian flows as well as their routing strategies within the evacuation zones. Section 5 demonstrates the model application with an illustrative example of the M&T stadium after the football game. Section 6 summarizes conclusions and future research directions as well as discusses the potential applicability of this model in real-world evacuation scenarios.

2. Literature review

The evacuation modeling has received increasing attention since the Three Mile Island Nuclear Incident in 1979. Due to the vast number of studies that has been carried out, we will only review those related to the network flow optimization in this study. The literature review is divided into three categories: vehicle evacuation, pedestrian evacuation, and mixed-flow evacuation.

2.1. Vehicle evacuation studies

Based on the application focus, the vehicle flow optimization literature for emergency evacuation can be divided into the following categories: demand modeling (Wilmot and Meduri, 2005; Lindell et al., 2005; Fu and Wilmot, 2006; Hasan et al., 2011), staged evacuation (Mitchell and Radwan, 2006; Sbayti and Mahmassani, 2006; Chien and Korikanthimath, 2007; Chen and Zhan, 2006), route choice (Hamacher and Tjandra, 2002; Cova and Johnson, 2003; Chiu and Mirchandani, 2008; Zografos and Androutsopoulos, 2008; Ng and Waller, 2010), contra flow (Theodoulou and Wolshon, 2004; Wolshon et al., 2005; Tuydes and Ziliaskopoulos, 2006; Dixit et al., 2008; Xie and Turnquist, 2011), etc. Most early programs, such as NETVAC (Sheffi et al., 1982) and MASSVAC (Hobeika and Jamei, 1985), were based on the "trial-and-error" method, relying on either the macro- or micro-simulation tools for performance evaluation. To optimize the vehicle flow distribution during the evacuation, Dunn and Newton (1992) and Campos et al. (2000) proposed the use of static network flow models. Hamacher and Tjandra (2002) gave an overview of the mathematical models for various evacuation related issues, focusing especially on modeling dynamic network flows, such as maximum dynamic flows, earliest arrival flows, quickest paths and flows, and continuous dynamic flows. On this regard, Ziliaskopoulos (2000) proposed a model with linear formulations, based on the cell transmission concept to produce the system-optimal dynamic traffic assignment to a single destination. Cova and Johnson

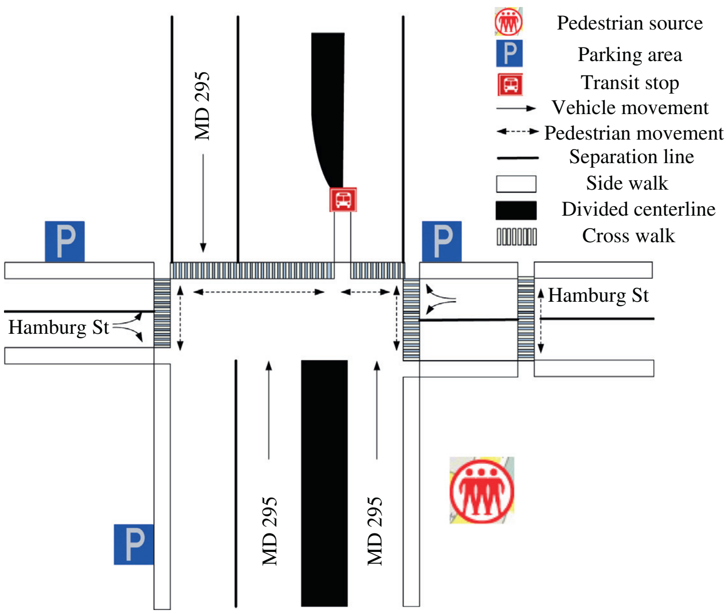

Fig. 1. A graphic illustration of Hamburg street@MD295 near the M&T stadium.