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SIGNIFICANCE OF TRAFFIC LOADING FOR EVACUATION AND PERCOLATION-BASED CONTROL STRATEGIES

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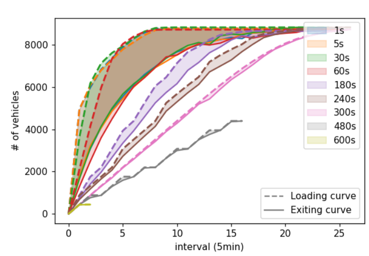
ABSTRACT

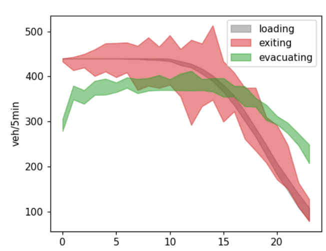
This paper investigates the significance of traffic loading rate for evacuation efficiency through large-scale evacuation simulation on a 20*20 grid network, emphasizing the emergency evacuation of the central 10*10 CBD area. There exists an equilibrium between the loading flow into the CBD and the exiting flow out of the CBD, which simultaneously optimizes evacuation efficiency. Loading can be excessive, over, equilibrium, or under-loaded, with overloading causing widespread jams and potential gridlocks. Using percolation theory, we also proposed several strategies that limit congestion spread to the CBD's edge, achieving equilibrium with optimal evacuee exit rates.

1 INTRODUCTION

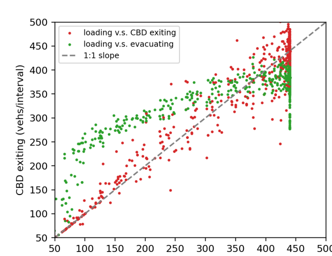
The existing body of evacuation research extensively delves into the topics of travel demand modeling (Feng and Lin 2022) and traffic assignment in evacuation scenarios (Hsu and Peeta 2015), predominantly treating these problems from a planning point of view. Our study takes a unique perspective by focusing on the rapid evacuation of traffic from a Central Business District (CBD) during an emergency, considering that evacuation efficiency can become sensitive to how quickly traffic is loaded onto the network.



(a) CBD exiting rates given varying loading rates



(b) Characteristics of the equilibrium loading: histories from 20 rollouts



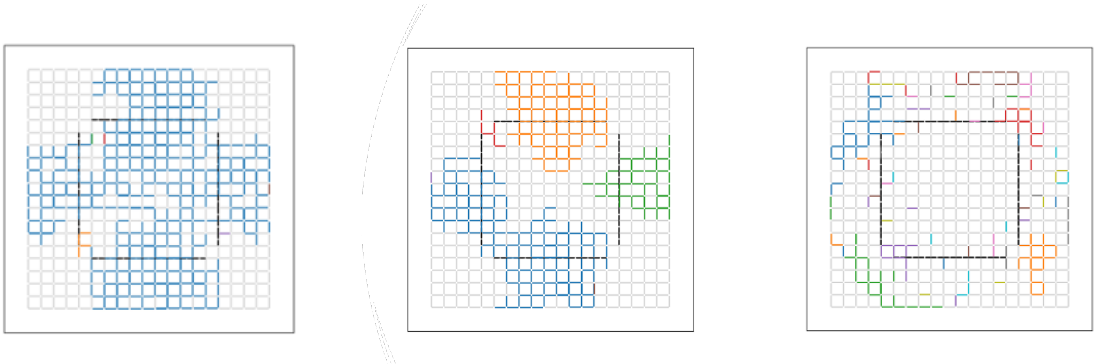
(c) loading/exiting/evacuating scatters

Figure 1: There exists an equilibrium between CBD loading and exiting rate

The loading rate L is implemented by setting a constant time gap τ (seconds) between two successive attempts of insertion of the vehicle into the origin of the trip. The evacuating flow Q_e (veh/h) is defined as the total number of vehicles that have reached shelter destinations per hour or the sum of the arrival flow at exiting links. We also define the exiting flow, Q_x as the rate of vehicles leaving the the danger zone.

2 MAJOR FINDINGS

As shown in Fig.1, we found that there exists an equilibrium between the loading flow into the CBD and the exiting flow out of the CBD, which simultaneously optimizes evacuation efficiency. Loading can be excessive, over, equilibrium, or under-loaded, with overloading causing widespread jams or even gridlocks.



(a) excessive-loading: a giant congested cluster percolates almost the entire network, which includes and originates from the CBD

(b) over-loading: the external congestion cluster spreading back beyond the periphery and encroaching into the CBD

(c) equil-loading: maximum CBD exiting flow requires minimum congestion encroachment from the outside

Figure 2: Percolating congested clusters with different loading rates: congestion is defined using the critical density of Fundamental Diagram, i.e., $k > k_c$. The percolation-based rule for managing the loading is to ensure that the external, spreading congestion cluster barely reaches the periphery of the CBD.

We further investigated the relationship between the percolation pattern and the evacuation efficiency. Fig. 2 plots the size of congestion encroachment into CBD versus the evacuation exit flow under different loading rates. Based on those observations, we proposed the following control strategies: i): The percolation-based rule for managing the loading is to ensure that the external, spreading congestion cluster barely reaches the periphery of the CBD. This approach facilitates an equilibrium state that also delivers the highest exiting rate for evacuating traffic; ii) The size of the percolating congestion cluster emanating from a particular shelter can serve as an effective indicator for traffic engineers to assess the immediacy of increasing the service capacity of that shelter or tackling incidents that have reduced its capacity. Given that multiple shelters often operate concurrently, these indicators from various shelters can be leveraged for comparative purposes; and iii) This percolation-based observation approach also gives us a dynamic region that allows loading with maximum efficiency. When the outside congestion invades the predefined CBD, the fixed region for traffic loading is no longer suitable, which should be replaced by a dynamic zone surrounded by outside congestion clusters.

The method proposed in this paper can easily be transferred from abstract network settings to more realistic urban networks. For example, we applied our percolation analysis method to Nashville, Tennessee, where the code for implementation is shared at https://github.com/QQT77/Eva2023.

REFERENCES

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