An Urban Traffic Evacuation Model with Decision-making Capability

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ABSTRACT

Traffic evacuation is one of the most challenging problems in a mega city due to crowded road conditions. This study focuses on developing a traffic evacuation model with decision-making capability. The model basically consists of two modules. The first one is a decision-making support module which runs very fast and provides short-forecast. The second one is a simulation module, which is used for simulating real evacuation process and for overall performance evaluation with vehicle tracking model. The first module can be considered as a "local" module as only partial information, such as traffic information in certain junctions is available. The second module can be considered as a global module which provides traffic directions for junction, and effective using of road-nets. With integration of two modules, overall system optimization may be achieved. Simulation cases are given for model validation and results are satisfied.

Keywords

Decision-making, system optimization, traffic evacuation, information system

INTRODUCTION

Traffic evacuation in many crowded cities is a challenge problem during emergencies. Situation becomes worse due to large scale, time pressure and complex road nets. Much attention was paid on traffic evacuation in emergency management. Most studies focused on the emergency planning and only few studies focused on real-time direction and control. Liu *et al.* (Liu, Ban, Ma and Mirchandani, 2007) proposed a traffic management framework for evacuation used in real-world control, known as MRAC. Liu, Lai and Chang (Liu, Lai and Chang, 2006) developed a two-level optimization model to provide evacuation instructions. Previous researches paid much attention on collecting traffic information and making simulation results fit into real situation. The models did not work well when only partial (local) information is available for optimization. Chiu *et al.* (Chiu, Zheng, Villalobos and Gautam, 2006) built a traffic flow model handling no-notice mass evacuation. Jia and Guo (Jia and Guo, 2012; Jia, 2012) proposed an event-based simulation model with optimization, which was capable of providing directions dynamically.

Effective and dynamical traffic direction and control in junction areas is one of the key issues for evacuation. Solving the junction helps for better traffic distributing to different exits, effective using of road nets, reducing blockages, and eventually reducing overall evacuation time. The problem of junction direction faces several difficulties, one is the local and overall coordination, and another is the assessment of the decision strategy.

In this paper, a traffic evacuation model with decision-making capability is developed, which helps to find key roads and intersections, provides better traffic directions, and achieves overall system optimization. The model basically consists of two modules. The first one is a decision-making support module, which runs very fast and provides short-forecast. The second one is a simulation module, which is used for simulating real evacuation process and for overall performance evaluation with vehicle tracking model. The first module can be considered as a "local" module as only partial information, such as traffic information in certain junctions is available. The second module can be considered as a global module which provides traffic directions for junction, and effective using of road-nets. With the integration of two modules, overall system optimization may be achieved.

MODEL DEVELOPMENT

In this study, two modules are developed: simulation 1 (as module 1) and simulation 2 (as module 2), as shown in Figure 1. Simulation 1 is developed as a decision-making or optimization tool to perform short-forecast simulation for different traffic direction strategies to find better one. A basic strategy or baseline case, which can evacuate target vehicles without considering time constraints, is set as an initial strategy in simulation 1. A series of specific events, such as a large number of vehicles go across an intersection, are set to trigger an optimization algorithm to find better evacuation strategies. Simulation 1 searches all possible strategies and evaluates them in a short period of time after an event is triggered. The obtained results are compared with the result from the basic strategy. If a better one is found, it will then set as a new basic strategy for next time step. As it is a short-forecast simulation, the results from simulation 1 may not be good for overall performance. A validation module, simulation 2, is developed to evaluate the results from simulation 1. Simulation 2 is a detailed vehicle tracking simulation, which is similar to real situation. Simulation 1 can only access local and partial information from simulation 2, similar to sensor data in real world. Traffic directions in junctions are selected as traffic control strategy in this paper. Based on the integrated model, traffic directions can be provided dynamically, and effective using of the road nets and exits are performed, as well as overall strategy performance is assessed. This system can be used for real traffic system optimization and setting the traffic directions in junctions.

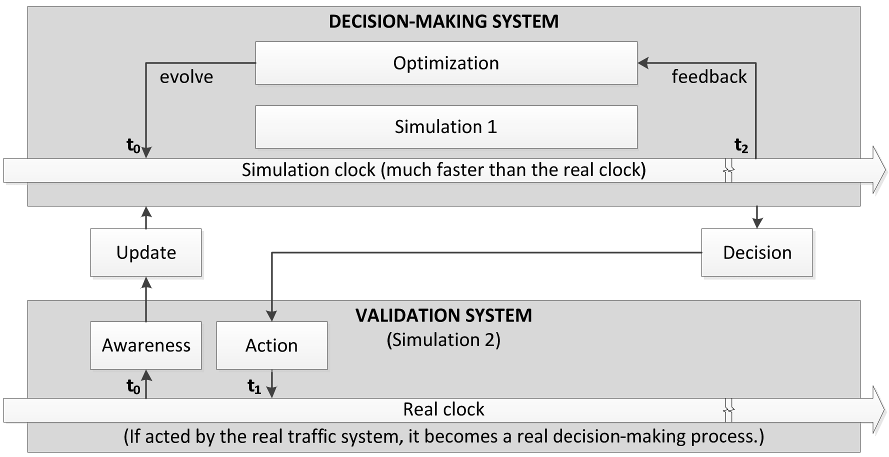

Figure 1: Decision-making Validation Model in Traffic Evacuation

WORK PROCESS

The detailed work process is as follows. Assuming that overall situation is partially known, when an event occurs in real world (at time t_0), information collected by guiders and sensors will be imported to validation module (simulation 2) as virtual awareness information and updated to the decision-making system as initial condition. Initial situation will then be simulated and evolved in decision-making module (simulation 1) until time t_2. Taking the probability into account, simulation 1 may repeat the simulation tasks to obtain a statistical result. Every possible strategy should be simulated and compared with each other until the best strategy in a short period of time is determined. After receiving the optimized strategy, simulation 2 will then perform strategy validation and performance assessment. The guiders in junction will be asked to implement the new strategy. It is worth to mention that the decision should be implemented at time t_1 since the optimization cannot be completed in a short time due to the heavy computing load.

In practice, the most important thing is to determine initial condition in two simulation modules. Simulation 1 should run fast enough to complete the optimization step. There is no time requirement for computing in simulation 2, but detailed event changes should be taken into consideration at every moment. Two modules are developed based on the method of queue theory and the car-following model. Simulation 2 is designed by combing the standard Bureau of Public Roads formula (BPR, 1964) with a collision avoidance model (CA model) (Kometani and Sasaki, 1959; Brackstone and McDonald, 1999). Specifying a vehicle which is running in a given road network, if there is no obstacle or other vehicle in front of it, the speed of vehicle can be computed by the BPR formula:

$$v(x_a) = \frac{v_a^0}{1 + 0.15\left(\frac{x_a}{G_a}\right)^4}, a \in A,$$

where v_a^0 is the free travel speed and G_a is the capacity on road a. When the vehicle arrives at an intersection or meets another vehicle, the speed will change and can be computed by the CA model:

$$\Delta x(t - 0.5) = 0.00028\left(-v_{n-1}^2(t - 0.5) + v_n^2(t)\right) + 0.585v_n(t) + 4.1,$$

where v_n is the speed of vehicle n, v_{n-1} is the speed of the closest vehicle in front of it, and Δx is the distance between them.

Simulation 1 assumes that vehicles travel with a speed given by the BPR model on the roads, stop at the crossing and wait in queues. In this way, simulations can be described as the queue theory. Note that the collision avoidance model is eliminated in simulation 1, in order to remove the difference among individuals and fasten the speed of simulation.

Both simulation 1 and simulation 2 follow the rule of self-evacuation, which is determined by a time-greed model. The work process is listed as follows:

1) Move forward to an intersection.

2) Figure out the length l_i which represents the shortest distance from each direction i to an exit.

3) Calculate the average speed v_i at each direction by the BPR model.

4) Use t_k ($t_k = l_k / v_k$) as an evaluation variable to select an optimal direction.

5) Go back to step 1 until vehicles arrive at an exit.

Vehicles execute this process with probability (w.p.) p_s. Drivers, who do not follow the greedy model, will select a new direction randomly.

In addition, when the vehicles arrive at a crossing where a guider is dispatched and direcion is provided, drivers are required to make decisions on whether they will follow the instruction given by the guider w.p. p_g or not. They can refuse the instruction and keep their own decision based on a preset parameter related to driver's behaviors. Table 1 shows the similarities and differences between simulation 1 and simulation 2.

	Simulation 1 (Optimization)	Simulation 2 (Validation)
Movement	BPR model	BPR model
Behavior on Roads	N/A	Car-following model
Behavior at Interjections	Queue model	Car-following model
Execution repeatedly	Yes	No
Display	No	Yes
Self-evacuation	Time-greed & probability model	Time-greed & probability model
Accept suggestions	With probability	With probability

Table 1: Similarity and Difference Between Simulation 1 and Simulation 2

CASE STUDY

This paper conducts a case study on traffic evacuation. Figure 2(a) shows a traffic evacuation case in an urban area with heavy traffic. The area is about 80 square kilometers and contains 454 intersections, 616 roads, 811 blocks and 22,477 buildings. There are about 1.02 million people living in this area with 320,000 private vehicles in total. All of vehicles are going to be evacuated to 8 exits, which are marked as red boxes in Figure 2(a). 5 guiders are dispatched, which will provide directions from the integrated model at several key intersections, which are marked as blue circles in Figure 2(a).

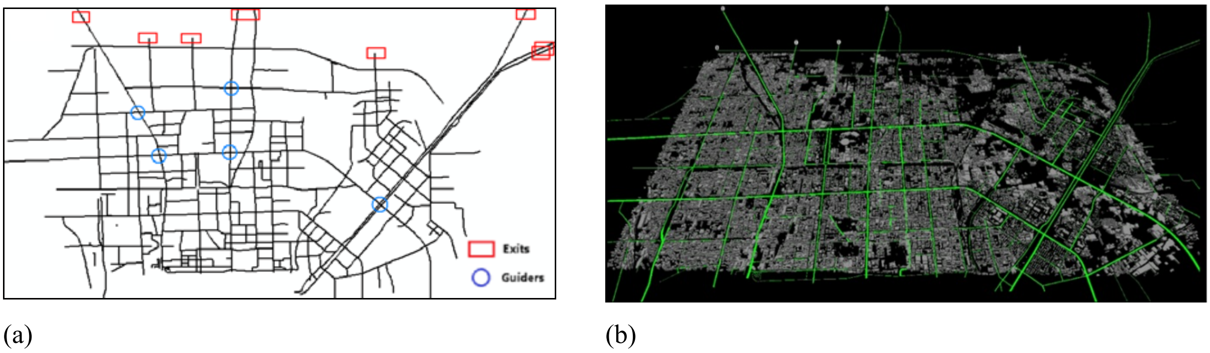

Figure 2: Roadmap of Numerical Experiments and Display of the Validation System

Two simulation cases are given: 1) no guider (evacuation without validation/feedback control); 2) five guiders are dispatched and drivers' movements are instructed by the optimized strategy, which is computed by simulation 1 and validated by simulation 2. At the first condition, drivers' movements are controlled by self-evacuation rules developed in the Jia and Guo's model. At the second condition, the evacuation process is initially simulated by simulation 2 using initial condition as input. Figure 2(b) presents the initial state of simulation. All vehicles are subject to the following rules in simulation: When vehicles are on roads or at the intersections where no guider is assigned, the drivers will make their decisions based on a self-evacuation model. When vehicles pass the intersections where the guiders give the direction to the drivers, drivers will decide whether they will follow the direction based on a preset parameter related to psychological consideration. The instruction is based on a basic strategy calculated by the shortest pass algorithm and optimized by the decision-making system after every 500 vehicles passing the intersections. In the decision-making step, information gathered by sensors will be input to decision-making process, such as average speed of vehicles on each road and queue length at each intersection.

Figure 3 shows the comparison of above two cases: the left column of pictures represents the situation without guider; the right column of pictures represents the situation that five guiders are assigned. Obviously, traffic evacuation is improved with guiders. Comparing Figure 3(c) and Figure 3(f), it is found that near 96,000 cars (30% of total number) are waiting to be evacuated in case 1 while the cars are completely evacuated in case 2.

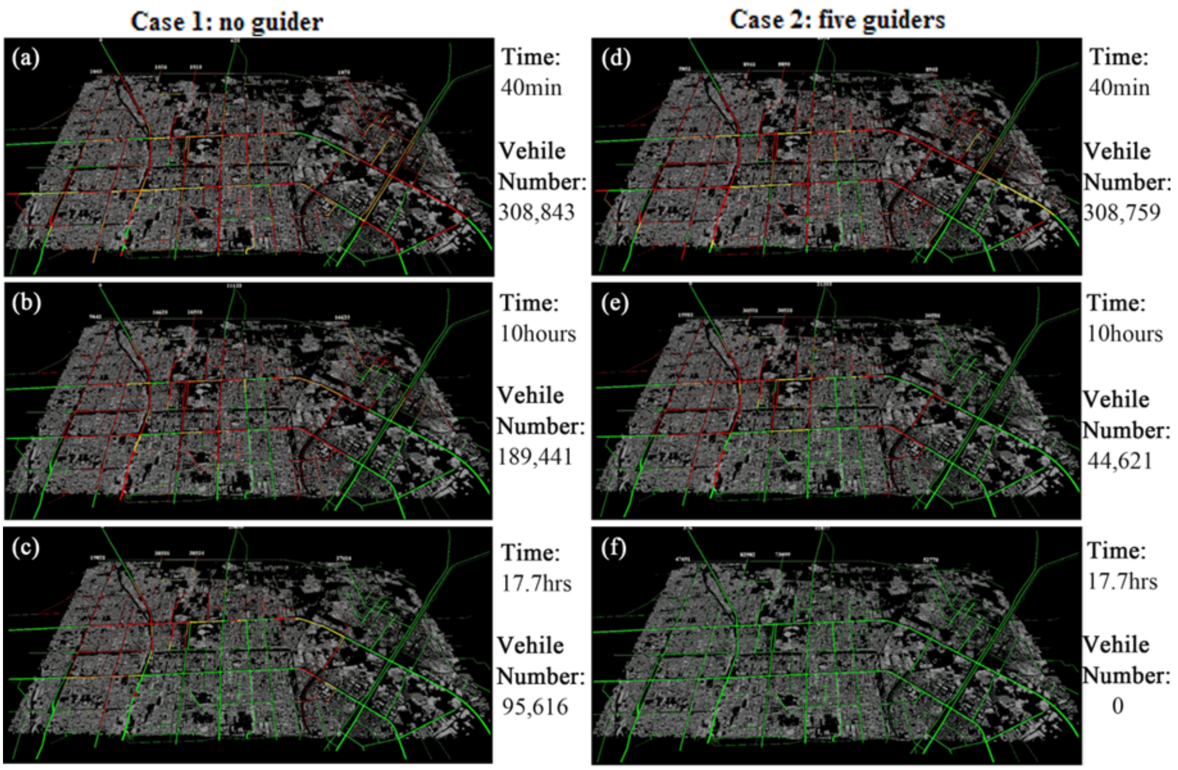

Figure 3: A Demonstration of Decision-making Process for Transportation Evacuation

CONCLUSION

A traffic evacuation model is developed with decision-making capability, which helps to make decisions for traffic evacuation in emergencies when road information and drivers' behaviors are partly known. Two simulation modules are designed for strategy optimization and performance evaluation, which shows better performance on reflecting the real situation and making effective evacuation strategy compared with traditional evacuation models. In the last part, numerical experiments are conducted to evaluate the model's performance on making optimized strategy in traffic evacuation. The results show that current model provides a satisfied performance on decision-making and finding the better strategy.

For the future work, we will pay more attention on psychological effects on traffic evacuation during emergency and make further improvement on model validation, such as developing the behavior analysis module or add more validation rules.

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