Crowd Simulation Incorporating a Route Choice Model and Similarity Evaluation using Real Large-scale Data

Extended Abstract

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ABSTRACT

Existing literature on crowd modeling focuses on only the decision-making of walking behavior. To construct more practical simulations, we generalize and propose a crowd simulation framework that includes actual crowd movement measurements, route choice model estimation, and crowd simulator construction. In experiments, we measure crowd movements during a firework event where tens of thousands of people moved and prove that the crowd simulation incorporating the route choice model can reproduce the real large-scale crowd movement more accurately.

KEYWORDS

Choice Modeling; Agent-based modeling; Crowd Simulation; Route Choice

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1 INTRODUCTION

To understand crowd movement, modeling and simulation approaches, expressing the crowd movement with a mathematical model, are widely and actively studied. Hoogendoorn et al. define pedestrian behavior at three levels as follows [6]. 1) *Strategic level*: departure time choice and activity planning, 2) *Tactical level*: activity scheduling, destination choice, and route choice, and 3) *Operational level*: obstacle avoidance and interaction with other pedestrians or environment. Existing literature focuses on only an *operational level* and the destination or route is pre-fixed. However, pedestrians, in general, change their routes depending on the situation. Therefore, the decision-making of route choice should also be modeled in order to perform a more practical simulation.

The simulation of crowd movement, including route choice, is being proposed in combination with discrete choice model (DCM) as a route choice model and social force model (SFM) [4, 5] or system dynamics model as a walking model [1–3, 7–9, 12]. The work of Haghani et al. is closest to our goal. They conducted a subject experiment at a sports center, collected data on choice behavior, and used them to estimate the parameters of DCM [2]. They also reported that the crowd simulation in which the estimated DCM and SFM combined can represent the crowd movement as in the experiment, from the perspective of the evacuation time [3]. However, the study is limited to measurement, modeling, and simulation in the imitated environment, and verification in a larger-scale real-world environment is required.

Therefore, this study aims to propose and evaluate a crowd simulation incorporating a route choice model based on real crowd movement data. Our contributions are: 1) generalizing and proposing a crowd simulation framework that includes actual crowd movement measurements, route choice model estimation, and crowd simulator construction, and 2) measuring the crowd movements during a firework event in which tens of thousands of people moved and verifying the similarity of the crowd simulation incorporating the route choice model using the measured real large-scale crowd movement data.

2 SIMULATION FRAMEWORK

In our framework, simulation is performed in the following steps. Measure the crowd dynamics, such as trajectory and number of pedestrians, and calibrate the model based on measured data of crowd movement. Then, a simulator is constructed based on the pedestrian agent model, the map, and other parameters, and run the simulation to output the crowd dynamics. Finally, the simulation is evaluated by comparing the actual crowd movement with the simulation results.

In this study, we focus on the modeling of route choice behavior at the *Tactical level* and in our crowd simulation, the departure time of pedestrian movement is already determined. Pedestrian agents are generated according to pre-defined departure time, then move according to the route choice model and the walking model. We apply DCM as the route choice model. DCM is based on random utility maximization theory [10]. The most basic model is the multinomial logit model (MNL) [10]. Note that in this paper, when we use the term DCM, we mean MNL [1].

3 EXPERIMENT

We verify the similarity of the crowd simulation incorporating the route choice model using large-scale crowd movement at the firework event. People move from the event site to the nearest station as the end of the fireworks display approaches. Security guards are in charge of guiding and controlling the crowd at several points to

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[1]The details of the framework and other experimental evaluations are available at https://arxiv.org/abs/2302.10421.

avoid the risk of congestion and accidents, which occur if many people flow into the station simultaneously. Figure 1 shows the route from the event site to the station and the control points, simulation input and visualization. The dots represent pedestrians, and their color represents the pedestrian's speed. The speed decreases from green to red, and red means that the pedestrian is stationary at zero speed.

3.1 Measurement

We used LiDAR to measure route choice behavior at two junctions and extracted the trajectories. Then, identify the chosen route at the junction from the trajectory data. We extracted a one-step route choice at the two junctions. Additionally, the RGB-Depth cameras were also installed at the station to count the number of pedestrians arriving at the station. The total number of people is 34839.

3.2 Modeling

We describe a method for modeling route choice behavior. Note that we assume that the pedestrian makes a route choice only once at a junction. The factors we considered are:

- **DIST**ance of the decision-maker from the junction to the station (DIST);
- **GUIDE**ance of the route (GUIDE);
- **ATT**raction of the route, such as stall (ATT);

Here, we define that the route closer to the station is Route 1, and the other route is Route 2 at each junction. The distance to the station on each route at each junction is one of the factors. In addition, the presence or absence of route guidance at a junction is also considered a factor related to route choice. If there is an guidance, set it to 1, otherwise 0. And we assume that the attraction of the route is influenced by the presence or absence of food stalls. If there is a stall on the route, it is set to 1, otherwise 0.

Based on the above, the determinant term of the utility function in the case of the firework event is as follows:

$$V_{ij} = ASC_j + \beta_{DIST} DIST_{ij} + \beta_{GUIDE} GUIDE_{ij} + \beta_{ATT} ATT_{ij} \quad (1)$$

where j is Route 1 or Route 2 and $ASC_{Route1} = 0$.

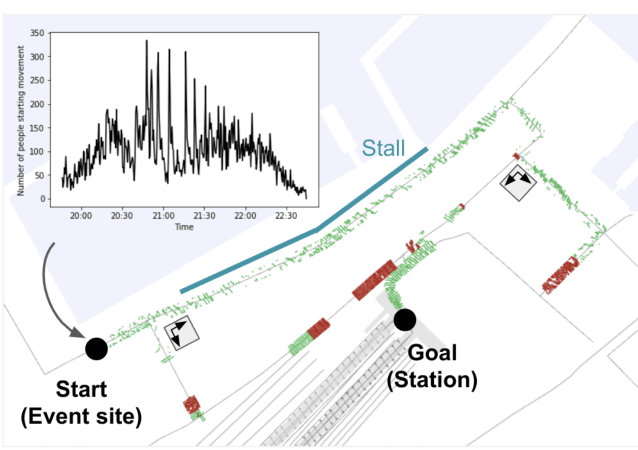

Figure 1: Crowd simulation the target area

Table 1: Estimation result of DCM in the firework event

β_{DIST}	β_{GUIDE}	β_{ATT}	ASC_{Route2}	Accuracy
-9.76	1.26	0.021	2.929	70.7 [%]

Table 2: The performance of the crowd simulation

	MAE	RMSE	Computation time
Follow	69.5	91.4	6 min 21 s
DCM	54.0 (0.31)	77.2 (0.33)	7 min 12 s

Table 1 lists the estimated parameters of DCM and the prediction accuracy. The following can be deduced from the estimated parameters. First, pedestrians are less likely to choose a route with a long distance. Second, pedestrians tend to choose guided routes and routes with stalls.

3.3 Simulation

We test whether a large-scale crowd simulation consisting of the estimated DCM and SFM can represent crowd movement during the firework event. In the simulation, agents are generated at the starting point according to the distribution as shown in Figure 1. Then, pedestrian agents select a route at two junctions according to DCM, and walk on the route according to SFM. Guidance at junctions and stops is performed as the actual measured operation in the simulation. At the station, trains operate according to the actual timetable. The capacity of the trains is fixed, and pedestrians who cannot board a train wait at the station until the next train arrives.

We use CrowdWalk, a multi-agent pedestrian simulator, as a base simulator [11]. CrowdWalk uses SFM as a walking model of pedestrian agents. The default parameters of SFM of CrowdWalk are used in this experiment. The default route choice of agents in CrowdWalk is SP. Therefore, we extend the functionality of CrowdWalk to allow for utility calculation and DCM-based route choice.

We evaluate the similarity of the simulation by the number of people arriving at the station at each time point. The evaluation index is MAE (Mean Absolute Error) and RMSE (Root Mean Square Error) of the real data and simulation results. For comparison, the similarity of a simulation in which the pedestrian perfectly follows the guidance is also calculated. In the case of using DCM as the route choice model, the pedestrian's route choice is stochastic, so the simulation is run 50 times.

Table 2 lists the performance of the crowd simulation. The value for DCM represents the average and standard deviations of each metric. It can be seen that the use of DCM improves the similarity compared to Follow case, which did not consider pedestrians' decision-making. Compared to Follow, the use of DCM improved the error by 22.3% for MAE and 15.6% for RMSE. In addition, the computation time of the simulation with DCM is 1.13 times longer than Follow, which does not model route choice, but this is acceptable for improving similarity.

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