Modeling and Simulation of Urban Mass Evacuation during Artillery Attack

(Extended Abstract)

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ABSTRACT

Artillery attacks on an urban area are both critical and realistic in some parts of the world. To diminish damages from the attacks, evacuation should consider complexities in urban geographics and dynamics. If we limit the scope to the evacuation of vehicles and the road topologies, the individual evacuations, as well as the damaged network structure of roads, creates complex congestion dynamics. Using the agent-based model, we performed virtual experiments from the perspectives of bombing and agent parameters, and evaluated evacuation time of each agent. Moreover, in the virtual experiments, we applied real data to generate the road network. The experimental results shows that the evacuation time and the damages are varied with respect to bombing strategy, agent characteristics, and road conditions.

Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**]: Sociology

General Terms

Human Factors

Keywords

Social simulation, Traffic simulation, Agent-based simulation

1. INTRODUCTION

Given that adversarial units are positioned approximately 40 km away from the city boundary of Seoul, the threat of artillery barrage is a nightmarish, yet realistic, scenario for its urban population. To negotiate with this threat and be prepared, we analyze what-if scenarios that involve mass evacuation of the population under attack. The mass evacuation operation requires extensive analyses because of two complexities inherent to the scenarios. First, even under the guidance of evacuation routing by the authorities, the population tends to find its own evacuation routes individually. This adds a complexity because individual movements might create macroscopic bottlenecks at the certain points. Second, the artillery attacks will damage the road topology, which leads changes in the road topology. Moreover, destroyed parts in the road topology would affect to the individual movements.

The agent-based model has been utilized to generate microscopic movements and macroscopic system performance in analyzing [3][7] and evaluating [6] target systems. While those scenarios often focus on how to accurately represent the real-world situation, what-if scenarios predict future situations based on real data. Even in existing mass evacuation models [2], there were few obvious existing works considering dynamic changes in the target system. Our simulation model estimates an efficiency of a mass evacuation with the assumptions of 1) the distributed individual evacuations and 2) the dynamics in the road topology change. With considering these characteristics, our agent-based model can reflect two possible complexities, such as agent's detouring from their evacuation paths and partially destroyed road network, to the evacuation situations. Through the experimental results, we estimated relationships between evacuation time, and bombing strategies and agent characteristics.

2. MODEL DESCRIPTIONS

Our agent-based model is developed using a formal method for agent-based model [1]. By the structure of the formal method, our agent-based model consists of two parts: agent models and environment models. The agent models represent individual vehicles that are participating in the evacuation. Each agent model contains three behavioral models which are 1) job action model for the behaviors of before-attack, 2) evacuation action model for the evacuation, and 3) immovable action model for the agents with devastating damage. In particular, when the evacuation occurs, agents select evacuation paths using A^* algorithm referring the current road velocities as to weights. Moreover, during the evacuation, the evacuation paths can be recalculated on the conditions of the current road velocities. This detouring is

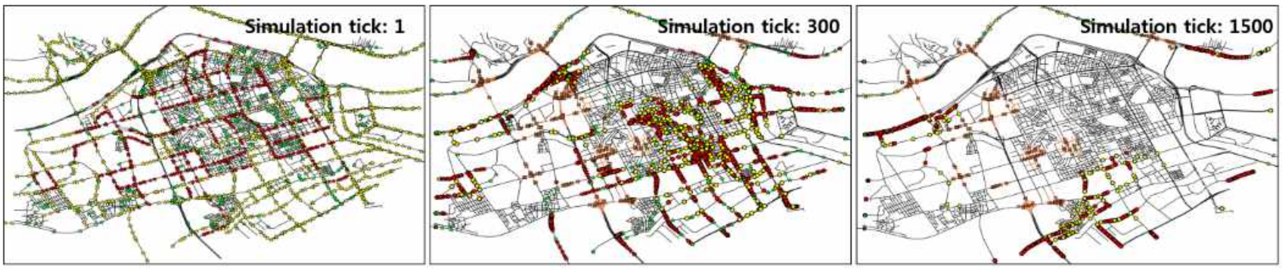

Figure 1: Screenshots from the simulation of the agent-based model at 1 (before the attack), 300, and 1500 (during the evacuation) simulation ticks.

performed with the same algorithm of the first planning.

The environment models represent the structure of road network, which is a geospatially distributed set of road models. The road models collectively create a link from one road model to another. Using the structure of the road network, agent models decide the evacuation paths considering the current road velocities. Hence, each road model should compute its current velocity during the simulation by equation (1) which is related with maximum speed ($velocity_{max_i}$), density (the number of agents, $agent_i$, over the area of the road, $area_i$), and coefficient (α, for relaxing assumptions of road conditions) of the road:

$$velocity_{cur_i} = \frac{velocity_{max_i}}{(\alpha_i \times \frac{agent_i}{area_i} + 1)} \quad (1)$$

If an agent comes in or goes out from a road, the road model updates its current velocity using equation (1). When the attack occurs, parts of the road network are destroyed with respect to the bombing point, and the agents would plan the evacuation path through the damaged road network.

3. VIRTUAL EXPERIMENTS

Virtual experiments are performed on Gangnam region in Seoul, South Korea. The road network model of Gangnam region is established using GIS data from OpenStreetMap. On the target region, we designed virtual experiments considering bombing points and detouring probability. The bombing points are selected by random, network-based, and knowledge-based methods. In the network-based method, degree centrality [5] and betweenness centrality [4] in the road network are selected, and in the knowledge-based method, popular and crowded places in Gangnam region are selected. The detouring probability of an agent represents a probability of modifying evacuation paths considering the current road conditions. When the detouring probability is larger, agents would change their evacuation paths more frequently. In all the virtual experiment cases, we fixed the number of bombings as 16 rounds to Gangnam region and repeated each experiment for 30 times. Through the virtual experiments, we measured evacuation time of each agent. The evacuation time means a duration from starting evacuation to arriving at one of the evacuation points. Figure 1 illustrates the screenshots from the virtual experiments at 1, 300, and 1500 simulation ticks.

Figure 2 summarizes the results of the virtual experiments. Left of figure 2 shows the average of the evacuation time on various bombing points. Placing bombing points based on the degree centrality strategy shows more leverage

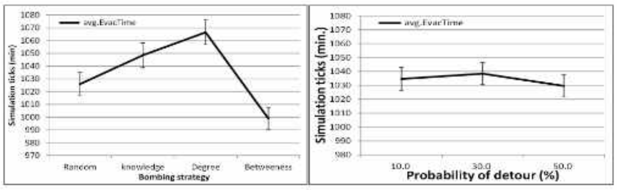

Figure 2: Average of evacuation time from varying bombing points (left) and probability of detour (right) scenarios

on delaying the evacuation time than any other bombing strategies. On the other hand, bombing locations with high betweenness centrality show even worse efficiency in delaying the evacuation time than random bombing. This result states that delaying the evacuation time can not be achieved by bombing points, while it needs to consider more information, such as dynamics of agent movement and geospatial information. The changes in the detouring probabilities do not change much of the evacuation performance, although it is for reducing evacuation time by the individuals. From the visualization of the simulation, we identified that most agents had limited perception in congestion situations on the overall road topology; therefore, the detouring did not facilitate the evacuation, which calls upon global information sharing in a real-life situation.

4. CONCLUSIONS

For analyzing the efficiency of urban mass evacuation during bombing attacks, we developed agent-based model which consists of vehicle agents and road network. Moreover, our model shows the dynamics of road network, such as destroyed road and road velocity and utilizes real road network to our model for increasing reliability of experimental results. Through the virtual experiments, we estimated relationships between evacuation time, and bombing strategy and detour probability, which shows that this research can be an infrastructure for various analyses of evacuation in more complex situations. However, our simulation model lacks of the validation for evacuation situation, but such data about mass evacuations are rarely obtainable. Currently, our best effort is to calibrate the agent distribution and the coefficients of the road segment models, which would require further sophistication to generate real-world traffic. Finally, our virtual experiment design should be extended to cover more parameters of the threat scenarios.

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