Proceedings of the 2023 Winter Simulation Conference
C. G. Corlu, S. R. Hunter, H. Lam, B. S. Onggo, J. Shortle, and B. Biller, eds.

AN AGENT-BASED MODELING TO SIMULATE THE DYNAMICS OF FIRST RESPONDERS AND EVACUEES IN POST-DISASTER SCENARIOS

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ABSTRACT

In the aftermath of a sudden catastrophe, First Responders (FR) strive to promptly reach and rescue victims. Simultaneously, individuals take roads to evacuate the affected region, access medical facilities or shelters, and reunite with their relatives. The escalated traffic congestion significantly hinders critical FR operations. In this study, we construct an Agent-Based Simulation (ABS) model that extends the existing models by incorporating FR agents, their allocated road map, and their interaction with evacuees in the network. Our model investigates individuals' evacuation times as well as FRs' rescue operation performance, provided that a subset of road segments are reserved for the explicit use of FRs. The decision-maker can allocate these segments manually within the simulation interface. Subsequently, the consequences are discovered through the earthquake scenario outputs of the ABS model, casting light on its real-world impact.

1 INTRODUCTION AND OBJECTIVE

The number of natural disasters worldwide has surged tenfold since the 1960s (Institute for Economics & Peace (IEP) 2020). After a sudden-onset disaster, such as an earthquake, individuals strive to take roads to evacuate the affected region, access medical facilities or shelters, and reunite with their relatives. Simultaneously, First Responders (FR) - including search-and-rescue teams, firefighters, policemen, ambulance crews, debris clearance, etc. - rely on the same road infrastructure to quickly reach victims in urgent need during the crucial initial hours following a disaster (referred to as "golden hours"). Naturally, the escalated travel demand yields severe traffic congestion in the road network that disturbs swift FR operations. Delays in reaching the survivors may cause the loss of numerous lives that could have otherwise been saved.

A viable solution to address this critical problem is to reserve a portion of the road network, i.e., specific road segments or lanes, exclusively for the use of FR vehicles. On the bright side, this can expedite response efforts when a disaster strikes. Additionally, the public is informed of the routes available for their evacuation purpose. On the other hand, implementing this strategy necessitates meticulous planning since it can strain the already limited road capacity for evacuees. Furthermore, reserving and announcing road allocations prior to a disaster is difficult, yet imperative. Attempting to communicate and enforce such a strategy amidst the chaos of a disaster, compounded by potential communication breakdowns, would pose an extremely challenging, if not impossible, task. Hence, there exists a trade-off in the proportion of road segments allocated to FRs on an urban road infrastructure.

In this study, our objective is to construct an Agent-Based Simulation (ABS) model that enables decision-makers to reserve road segments for FRs and observe the impacts on FRs' performance as well as individuals' movements. The potential road segments that can be allocated to FRs consist of highways, motorways, and primary roads in the network. After the FR road allocation is made, the model generates earthquake scenarios during which agents evacuate the region. Our ABS model extends the existing models by incorporating FR agents for the first time into the evacuation problem (He 2021). Throughout the scenarios, the interaction of FRs with evacuees, the evacuees' destination/exit node choices, and their route choices to determine the traffic flow in the road network are simulated. Altogether, our model is designed to investigate some performance metrics regarding individuals' evacuation times as well as FRs' rescue operations, provided that a subset of road segments are reserved for the explicit use of FRs.

2 METHODOLOGY AND RESULTS

Three main components to be calibrated in the design of our ABS model are i) road damage simulation, sampled based on the link failure dependency model of Yücel et al. (2018), ii) identification of the spatial distribution of disaster-affected residents by analyzing telecommunication call records of a year-long dataset in Türkiye, and iii) simulation of evacuees' behavior right after the occurrence of a disaster (Lambie et al. 2016), while resorting to the existing traffic models that take into account Bureau of Public Roads (BPR) function in traffic simulation. The scenarios encompass major uncertainties pertinent to the location and extent of inflicted damage, as well as the timing of the disaster (daytime or nighttime, weekday or weekend), influencing variations in travel demand and road network conditions. Also, the unpredictability of FR personnel arrival times to the affected region introduces another layer of uncertainty into the model.

The ABS model is shaped by a realistic case study in Istanbul focusing on a district named Avcilar. Located in the western part of Istanbul along the Marmara Sea coast, Avcılar is highly susceptible to earthquakes, making it a vulnerable area. Also, the simulation interface is designed in the NetLogo simulation environment. NetLogo enables an interactive virtual world, including agents and links, as well as a Geographical Information System (GIS) and Networks (NW) extensions, which best suit our case study (Hashemi and Alesheikh 2010). The agentset includes evacuees who aim to exit the region or drive to medical facilities or their family members. Furthermore, the links symbolize the underlying road infrastructure of the district. Finally, the NetLogo extensions enable us to readily engage with road map layers and employ network-related functions to measure shortest paths, traffic levels, travel durations, etc.

Our preliminary experiments revealed that for every 10% increase in the number of allocated FR road segments within the region, there is an approximate 3% enhancement in the efficiency of rescue operations during the critical golden hours (typically spanning 72 hours). Interestingly, this increase in FR road allocation only results in a modest 0.2% uptick in average evacuation times. With linear behaviors, we observed in the extreme case of full FR road allocation a remarkable 31% reduction in FR rescue times, accompanied by a mere 2% increase in evacuation times. This outcome can be ascribed as FRs must cover multiple neighborhoods, while individuals have the flexibility to evacuate the region through various routes while employing selfish routing strategies. Hence, high levels of FR road allocations are recommended.

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