論文の内容要旨

論文題目: Enhancements and applications of a scalable multi-agent based large urban area evacuation simulator with emphasis on the use of cars
(スケーラブルなマルチエージェント大都市域避難行動シミュレータの自動車の考慮に重点をおいた拡張と適用)

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This work presents the enhancements of a scalable multi-agent based large urban area evacuation simulator, with the aim of quantitatively evaluating mixed mode evacuations with cars and pedestrians. This dissertation introduces a mathematical framework to provide a language and notation necessary to explain the multi-agent system and the enhancements required to evaluate mixed mode evacuations; provides an overview on the design of agents and environment and the enhancements; introduces the concept of basic translational interactions and provides means to automatically calibrate them based on field observations; and finally demonstrates the ability to perform quantitative evaluations of mixed mode evacuations evaluating different evacuation strategies and countermeasures. The design and implementation of the multi-agent system, verification and validation of the necessary components, and demonstrative applications are presented.

During the 2011 Great East Japan Earthquake and Tsunami, many residents living in coastal areas used cars to evacuate, reportedly producing congestion. This experience has drawn the attention to the use of cars for tsunami triggered evacuations with the aim to identify means to benefit from the use of cars, especially to evacuate people in need. There have been discussions on the implementation of countermeasures and evacuation strategies in mixed mode evacuations, but currently there is no way to make detailed quantitative measures of the outcome of such measures.

Existing studies on the use of cars are limited to traffic flow studies in highways and main roads, where vehicles have no or little interaction with pedestrians. No research articles are found on the use of cars in narrow roads of densely populated residential areas, where the interaction among pedestrians and vehicles can slow each other down producing significant impacts on the evacuation throughput. The lack of research on this issue can be attributed to the limitations in common evacuation simulation software such as the use of simplified models for large areas (one dimensional networks or queues) or the software considering details in the simulation not being able to scale to large urban areas.

In order to address these limitations a multi-agent system based mass evacuation simulation software is enhanced to include the detailed interactions among evacuees. This simulator can accommodate sub-meter detailed model of environment and utilizes high performance computing to simulate large urban areas. Different types of agents with various interaction models are introduced with the aim to model the heterogeneity of crowds and the different modes of evacuation.

For the basic interaction, the avoidance of collisions, a collision avoidance scheme, ORCA, is enhanced and adapted to reproduce field observations. For the special case of car-pedestrian interactions, field observations are performed in

order to collect quantitative data necessary for validating the implemented interaction model. Pedestrian-pedestrian interaction is validated by comparing the simulation results to the field observations by Mori and Tsukaguchi, and Weidmann's summary of field observations. Car-car interaction is validated by comparing the simulation results with Lincoln tunnel observations, and the car-pedestrian interactions are validated by comparing the simulation results with observations collected by the author.

Evacuees' collision avoidance behaviors change according to many factors like culture, age, time of the day, etc., and can be reproduced by adjusting several parameters in the implemented algorithms. A calibration tool, enhanced with parallel computing capabilities, is implemented to automate the identification of these parameters according to given observation data.

In order to support the agents' interaction models, the use of vertical shelters and multi-storey buildings, an extended hybrid environment model consisting of a high resolution grid and topological graphs is introduced. Also, tools are implemented to automate the construction of the hybrid environment from GIS data.

Finally, demonstrative applications of the software highlighting the need of detailed modeling and its potential in finding means to benefit from the usage of cars in mixed mode evacuations are presented. Strategies and countermeasures such as the restriction of the car usage for people in need, widening of roads and the use of different evacuation schedules are evaluated and quantified. It is found that the best throughput after 40 minutes of evacuation is provided by restricting the usage of cars to people in need with a vehicle usage of 25%
percent of the population. Moreover, the initial throughput of the evacuation can be improved by persuading people evacuating using vehicles to start the evacuation earlier, providing a boost on the initial throughput of more than 10% within the first 20min of the evacuation. Additionally the effect of the car-pedestrians interactions and the effect of the model of intersections are quantified amounting to about 5% and 4% respectively for the base demonstration scenario. Furthermore, the number of Monte-Carlo simulations necessary to provide robustness to the results in this scenario are evaluated. It is found that for the base scenario Monte-Carlo simulations drawing 600 samples are necessary to provide a converged characterization of the distribution of the results.