Research on visualization of evacuation risks during a nuclear disaster

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ABSTRACT

The Fukushima Daiichi nuclear accident revealed significant issues in evacuation planning due to the release of radioactive materials and the mass evacuation of residents. This study aims to develop a simulation-based environment to visualize evacuation risks during nuclear disasters and support the optimization of evacuation plans.

Keywords: Nuclear disaster, Microscopic traffic simulation

I. Background and Objective

In the 2011 Fukushima Daiichi Nuclear Power Plant accident, a wide range of residents were forced to evacuate due to the release of radioactive materials, and confusion spread regarding where and how to evacuate. Many residents expressed concerns such as, "I don't know where to evacuate," and "I'm completely stuck in traffic and can't move." These voices revealed several problems, including inadequate information in evacuation plans and the establishment of unrealistic evacuation routes.

Learning from this experience, prefectures with nuclear power plants, such as Shizuoka and Fukui, are currently revising their evacuation plans and incorporating evacuation simulations that model nuclear disaster scenarios. However, these evaluations are still largely macro in scope, focusing on regional evacuation trends, such as total evacuation time, traffic congestion hotspots, and the overall number of evacuees. This macro-level perspective makes it difficult to understand the real dynamics of individual evacuation behavior—such as whether the designated evacuation routes function as intended, or who faces obstacles and where.

In actual nuclear disasters, mass evacuations often occur simultaneously. Some residents may evacuate along unintended routes due to a lack of understanding, and designated evacuation paths may become unusable due to secondary disasters such as earthquakes, tsunamis, or flooding. Additionally, special consideration must be given to residents with limited mobility, such as the elderly and those with chronic illnesses.

Given these complexities and individual differences, it is difficult to identify the full range of challenges and risks using only a macro-level approach. Key factors to analyze include the traffic situation during evacuation, the availability of evacuation guidance, behavioral differences based on resident characteristics, radiation exposure risks, information transmission delays, and variation in evacuation start times.

Therefore, this study aims to develop a microscale evacuation simulation framework that captures the behavior of individual residents—an approach that can support the verification and enhancement of more realistic and effective nuclear disaster evacuation plans.

II. Research Methodology

II.A. Arrangement of initial conditions

In the actual traffic environment, multiple conditions such as time of day, resident attributes, and geographical factors are intricately intertwined, and have a significant impact on evacuation behavior. Therefore, in this study, it is necessary to systematically organize various elements to be set as initial conditions for simulation implementation.
First, TABLE 1 shows an example of the target resident attributes. This table defines the communities to which residents belong, and describes the main means of transportation in each area, the time of day to start moving, and the time required. In addition, by showing the trend of dwell time in each community, it is possible to set simulation conditions that take into account the distribution of evacuation start times and variations in evacuation behavior.
NEXT, an example of organizing evacuation routes is shown in Figure 1. This makes it easier to visually grasp which route is used when inputting evacuation route information in the simulation tool described later, and by illustrating the main routes in advance, it is easy to compare and analyze the influence of differences in route conditions on the simulation results.

TABLE1. EXAMPLES OF ORGANIZING TARGET RESIDENT ATTRIBUTES

	Going to School/Work	School/Company	Returning from School/Work
Nursery School	Walk / Bicycle / Car	Nursery School	Walk / Bicycle / Car
Required Time	5–10 minutes	8 hours	5–10 minutes
Time	8:00–9:00	9:00–17:00	17:00–18:00
Kindergarten	Walk / Bicycle / Car	Kindergarten	Walk / Bicycle / Car
Required Time	5–10 minutes	5 hours	5–10 minutes
Time	8:00–9:00	9:00–14:00	14:00–15:00

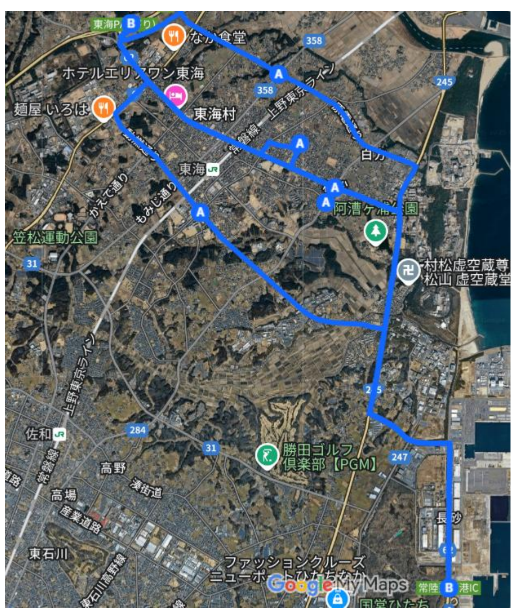

FIGURE1. EXAMPLE OF EVACUATION ROUTE ARRANGEMENT

II.B. Simulation

For the purpose of visualizing evacuation risks, we will develop a simulation construction environment that can reproduce traffic behavior in accordance with reality. In this study, we introduce a microscale approach to traffic simulation in order to accurately capture the flow of vehicles, the location of traffic congestion, and the dwell time in evacuation scenarios. In particular, it is necessary to reflect detailed information about the road infrastructure, such as the timing of traffic light switching, the structure of intersections, and the number of lanes, as well as the driver's driving behavior, such as the following behavior and acceleration and deceleration characteristics of each vehicle. Therefore, as a traffic simulation model, a micro model that can reproduce the behavior of individual vehicles, that is, a follow-up model, is adopted. To construct a specific simulation environment, we will use SUMO, a micro traffic flow simulation software. In addition, the OSM Web Wizard, which is included in SUMO, is used as a method of obtaining road information. This is a software that takes road data from Open Street Map and converts it so that it can be edited on SUMO. Figure 2 shows how the OSM Web Wizard was used, and FIGURE3 shows a diagram of a simulation using it. However, there are parts of the data obtained here that are different from the roads actually used. Therefore, it is necessary to check the number of lanes and the condition of intersections on the actual road on Google Maps and make corrections.

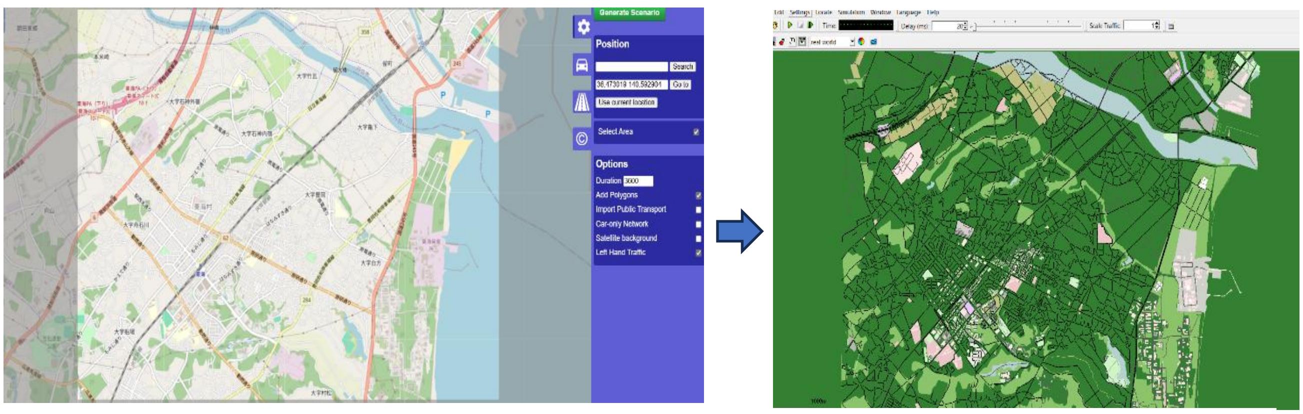

FIGURE2. DIAGRAM OF ROAD DATE OBTAINED USING THE OSM WEB WIZARD

FIGURE3. DIAGRAM OF SIMULATION BASED ON ACQUIRED ROAD DATE

II.C. Evaluation of validity

In this study, we will compare the simulation model with actual traffic data in order to verify the validity of the constructed simulation model. Specifically, as shown in FIGURE4, the "General Traffic Volume Survey Results Web Map" provided by the Ministry of Land, Infrastructure, Transport and Tourism is used to extract the actual measured traffic volume in the target area, the average driving speed for each road section, and the traffic concentration trend by time of day, and to compare it with the simulation results. This comparison evaluates the reproducibility of traffic flow in the simulation and numerically verifies the realism of indicators such as vehicle acceleration, average vehicle speed, and the number of vehicles passing per hour. For example, we will compare in detail whether the speed reduction near a specific intersection or the location of the bottleneck matches the actual data, and improve the accuracy by adjusting and resetting the parameters of the simulation model. In this way, we aim to ensure the reproducibility of evacuation behavior in the virtual environment and consistency with traffic behavior in the real world, and to construct a more reliable evacuation route optimization model.

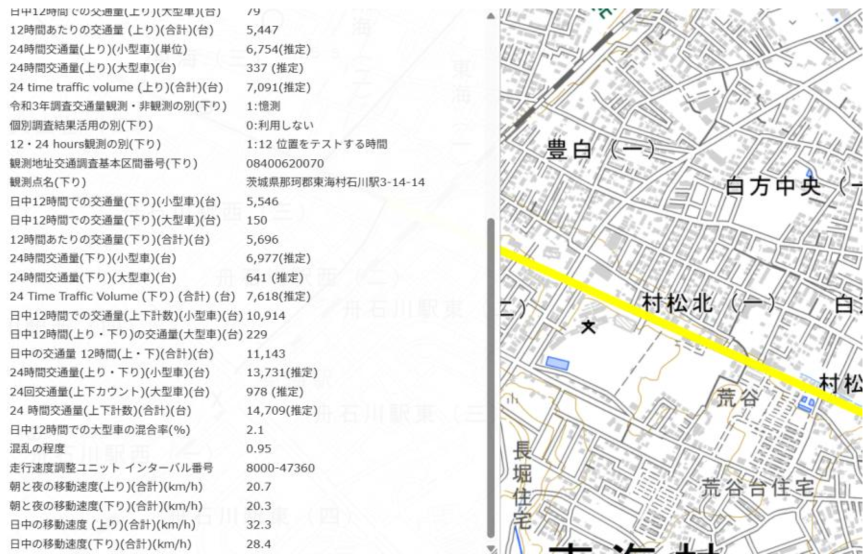

FIGURE4. IMAGE OF THE GENERAL TRAFFIC VOLUME SURVEY RESULTS WEB MAP [3]

II.D. Evaluation of output simulation results

In the constructed simulation environment, evacuation behavior is reproduced under the initial conditions set, and the results are quantitatively evaluated. In particular, the distribution of the time spent by each vehicle on the evacuation route, the location of traffic congestion and its duration, etc., are the main evaluation indicators. By analyzing based on these indicators, it is possible to identify bottleneck sections where vehicles are likely to occur on evacuation routes and points where the risk of radiation exposure is relatively high due to traffic congestion.

II.E. Reconstruction of simulation

For reconstructing the simulation, it is necessary to clarify what specific factors will be analyzed from the previous simulation results and what kind of results are expected as an analysis of the results, and then reconstruct the simulation. For example, the simulation results show that traffic congestion occurs on a specific road, which has a significant impact on evacuation time. First, we will extract the various causes that cause traffic congestion. From the extracted causes, set a goal for which cause to reconstruct the simulation, and if it is to focus on traffic congestion at an intersection, reconstruct the simulation when the time of switching signals is changed for the intersection part. At this time, the extent to which the signal switching time is changed is determined after predicting the value expected to shorten traffic congestion and evacuation time from the previous simulation result. After that, a simulation is performed to analyze the extent to which traffic congestion and evacuation time have changed due to changes in the time when traffic lights change. The results are re-analyzed and simulations are built for multiple scenarios.

III. Future Works and Conclusion

This study developed a microscopic traffic simulation framework to realistically reproduce and analyze evacuation behavior during a nuclear disaster. The framework enables the detailed modeling of individual vehicle behaviors such as acceleration, deceleration, and headway control, as well as the prioritization of emergency vehicles and the identification of bottleneck locations. Insights from the microscopic simulation help visualize the temporal and spatial disparities in evacuation behavior, offering valuable input for macro-level evacuation planning. This contributes to realistic and effective improvements, such as optimizing traffic signal control and strengthening countermeasures in high-risk areas. In the future, to more accurately reflect real-world evacuation behavior, we plan to gradually construct multiple scenarios that consider complex conditions such as variations in evacuation start times, road closures, U-turns, and emergency vehicle priority. Through the analysis of these scenarios, we aim to identify the key factors that cause bottlenecks—such as where and how long traffic congestion occurs—and contribute to optimizing

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