Mathematical modeling and numerical analysis of “Car abandonment” during tsunami evacuation

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During tsunami evacuations, many people use cars as their means of escape. In the Great East Japan Earthquake, over 40% of evacuees reached their initial evacuation point on foot, while over 50% used cars. Among those who evacuated by car, the most reported issue was traffic congestion. In some areas, gridlock occurred, where vehicles were completely immobilized due to severe traffic jams.

Despite these challenges, when asked about their preferred evacuation method for future tsunamis, around 50% of respondents said they would evacuate on foot, while approximately 45% indicated they would use cars. While this shows a slight decrease in the number of people choosing to use cars, a significant portion of people still prefer to evacuate by car. However, some people who evacuated by car succeeded in surviving. Therefore, the best approach is decreasing the number of deaths without reducing car usage.

Previous studies, such as those by H. Wang et al.(2016) and Z. Wang and G. Jia(2021), have proposed "car abandonment" as a future prospect. However, this has not yet been implemented. Most researches was concluded that reducing the number of people evacuating by car was the best way to save most people.

Our study focused on "car abandonment". The goal and purpose of this research was to investigate whether abandoning cars during tsunami evacuations can reduce deaths. In this study, we defined "car abandonment" as the act of evacuees initially using a car to evacuate but switching to walking at some point during the evacuation. The number of deaths was defined as the total number of people present within the inundated area at the time the tsunami strikes.

For this purpose, we adopted a macroscopic model instead of a microscopic one. Specifically, we constructed a mathematical model based on the advection equation that expresses "car abandonment".

To solve the model, we used Python. We employed the first-order upwind difference method for discretization.

Under the initial conditions and assumptions of this study, when the maximum speed of cars was 14 km/hour or less, "car abandonment" reduced the number of deaths. When the maximum speed of cars was 15 km/hour or more, car abandonment increased the number of deaths. It was also revealed that the drop-off point with the lowest number of deaths and those with the highest number of deaths varied depending on the maximum speed of cars. Additionally, we investigated the effects of the parameter representing ease of abandoning cars. If it was too easy to abandon cars, a larger number of slow-moving pedestrians would be on evacuation routes, so which increased deaths. On the other hand, if it was too difficult to

abandon cars, traffic congestion would worsen, and this reduced vehicle speed and increased the number of deaths. Therefore, it is important to determine an optimal level for this parameter based on the specific conditions of each situation.

Finally, the model was applied to Higashimatsushima City in Miyagi Prefecture to evaluate the effectiveness of abandoning cars. As a result, unlike the initial simulations under simplified conditions, it became clear that abandoning vehicles reduces the number of deaths regardless of the maximum speed of the vehicles, both during the day and at night.