**CETRA[2022]** 11-13 May 2022, Pula, Croatia
**7th International Conferenceon Road and Rail Infrastructure**

# BASIC ANALYSIS OF THE NUMBER OF SELF-DRIVING CARS IN USE AND THE TIMING OF THE START OF EVACUATION ASSISTANCE – ASSUMING THE EVACUATION OF VULNERABLE PERSON EVACUATION ACTION IN THE EVENT OF FLOODING

**Yuta Moriwaki[1], Makoto Fujiu[2]**
[1] *Kanazawa University, Division of Geosciences and Civil Engineering, Japan*
[2] *Kanazawa University, Institute of Transdisciplinary Sciences Faculty of Transdisciplinary Sciences, Japan*

## Abstract

In recent years, Japan has been experiencing an increase in human suffering due to the frequent occurrence of large-scale natural disasters that have never been observed before. In particular, there is a lot of damage to vulnerable person, and how to support evacuation of vulnerable person is an issue in the event of a large-scale disaster. Since vulnerable person are often physically or mentally fatigued during disasters, and the number of such people is expected to increase with the aging of the population in Japan, it is important to consider measures to support the rapid and appropriate vulnerable person. In this study, we focused on the use of self-driving cars, which can provide unattended evacuation support while acquiring disaster information, for evacuation support. The purpose of this study is to obtain knowledge on the number of vehicles used to support the evacuation of vulnerable person evacuation action by using automated vehicles in the event of river flooding, the time required for evacuation, and the timing of starting evacuation support considering the number of people affected. In this study, the National Health Insurance database was first used to identify the number of vulnerable person. Next, a simulation of evacuation support for vulnerable person evacuation action using self-driving cars was conducted, assuming that a river flood occurred in Komatsu City, Ishikawa Prefecture. Then, the number of self-driving cars used, the time required for evacuation, and the number of people affected were calculated. As a result, knowledge on the timing of starting support for evacuation of vulnerable person for evacuation action using self-driving cars was obtained during river flooding in Komatsu City.

*Keywords: flood disaster, vulnerable person, self-driving cars, evacuation simulation*

## 1 Introduction

In recent years, Japan has experienced an increase in the number of victims of vulnerable person due to the frequent occurrence of large-scale floods that have not been observed before [1]. One of the reasons for the increase in damage is that vulnerable person are often mentally and physically fatigued in times of disaster, and it takes time for them to choose the timing of evacuation and to select and move to an evacuation site. In Japan, it is expected that the number of vulnerable person will increase as the population ages, while the number of people involved in evacuation support will decrease [2], making it an issue of how to

provide support for the rapid and efficient evacuation of vulnerable person. In this study, we focused on the use of automated vehicles as evacuation support for vulnerable person. By clarifying the effects of using automated vehicles, which can move quickly without the need for manpower, to support the evacuation of vulnerable person, it is possible that this will provide a new solution to the problem of evacuation for vulnerable person.
The purpose of this study was to obtain knowledge on the timing of evacuation support based on the number of vehicles used and the time required for evacuation when evacuation support for vulnerable person was provided using automated vehicles in the event of river flooding.

## 2 Calculation of vulnerable person using KDB data and establishment of target areas

### 2.1 Overview of KDB Data

In this study, the National Health Insurance Database (KDB data) was used to determine the distribution and number of vulnerable person. KDB data is medical big data that contains information on the physical condition of people enrolled in the national health insurance system, including “medical checkups” , “medical care” and “nursing care” for each individual, and is managed by each local government. In this study, the KDB data of Komatsu City, which contains information on care (support) such as “level of care (support) required” in addition to personal attributes such as “age” and “address,” was used to calculate the number of vulnerable person.

### 2.2 Definition of vulnerable person in this study

In this study, it was defined as vulnerable person as “those who need support 1 to those who need care 2”. The reason for this is that we considered people who are not known to the local government as people who should be assisted using automated vehicles. The registration conditions for the list of vulnerable person in Komatsu City are shown in Table 1 [3]. In Komatsu City, people who do not agree to the conditions shown in Table-1 and people who do not meet the registration conditions but need consideration during evacuation may not be able to receive assistance during evacuation and may be caught up in the disaster.

**Table 1** Conditions for registration on the list of vulnerable person in Komatsu City [3]

| **Conditions for registration in the list of people who need support for evacuation** |
|---|
| People over 75 living alone or in households with only people over 75 |
| Physical disability certificate (level 1 or 2) holders with physical, visual, or hearing disabilities |
| Those who have Rehabilitation Certificate A |
| Those who have been certified as requiring nursing care (3 to 5) |
| Persons with Mental Disability Health and Welfare Certificate 1 or 2 |
| Those in need of assistance upon request |

Status of long-term care services by the level of care required, which was obtained by organizing the KDB data for Komatsu City, is shown in Fig. 1. About half of those requiring long-term care 3 or more use facility care services, while those requiring long-term care 2 or less are significantly less likely to use facility care services than those requiring long-term care 3. This suggests that people who require nursing care 2 or less need assistance in their daily lives, but must evacuate on their own when they cannot receive assistance.

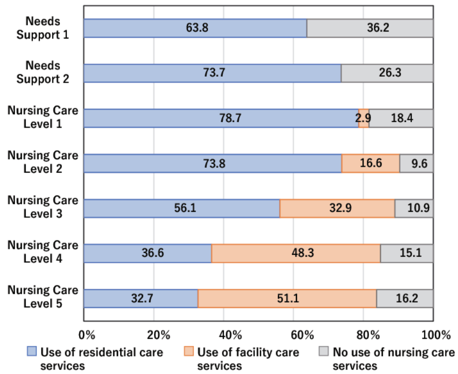


**Figure 1** Status of services used by level of care required

The above suggest that people in Komatsu City who require nursing care 2 or less need to evacuate by themselves if there is no one around them to support them during evacuation, and that they are more likely to suffer damage in the event of a disaster. Therefore, we defined and calculated vulnerable person in this study as those requiring supportive care 2 or less.

## 2.3 Calculation of vulnerable person and selection of target areas

Using the KDB data, the number of vulnerable person as defined in Section 3.2 was calculated. The distribution of vulnerable person in Komatsu City is shown in Figure 2. In the northwestern part of the city, many vulnerable person are located near the river, and it is likely that many people requiring evacuation support in the inundated area will be affected when the Kakehashi River bursts its banks. In this study, four towns facing a river in the northwestern part of Japan, Kamikomatsu-machi (18 persons), Sono-machi (42 persons), Shirae-machi (66 persons), and Kodera-machi (10 persons), were selected as target areas for the evacuation support simulation using an automated vehicle.

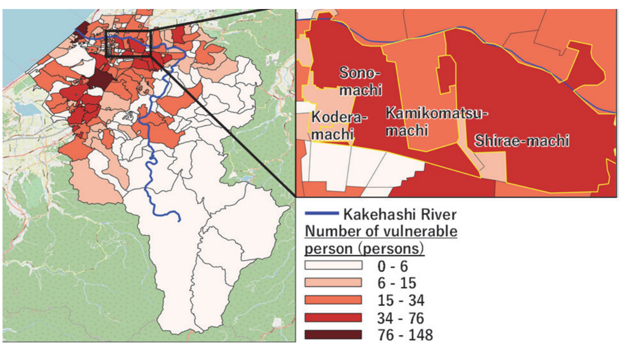


**Figure 2** Distribution of vulnerable person in Komatsu City by town

# 3 Calculation of the number of vulnerable person affected in the target area using the estimated inundation data

The number of disaster victims in the target area was estimated based on the assumption of an external flooding of the Kakehashi River, a first class river flowing through Komatsu City. The extent of inundation in the target area during the 90-minute period after the breach is shown in Figure 3. In the target area, the inundation area expands significantly within 90 minutes of the breach, so people living near the point of the breach do not have much time to wait. In addition, vulnerable person behavior often delay their escape due to lack of information and physical difficulty in vertical evacuation. Based on the above, damage estimation was conducted using data up to 90 minutes after the breach.

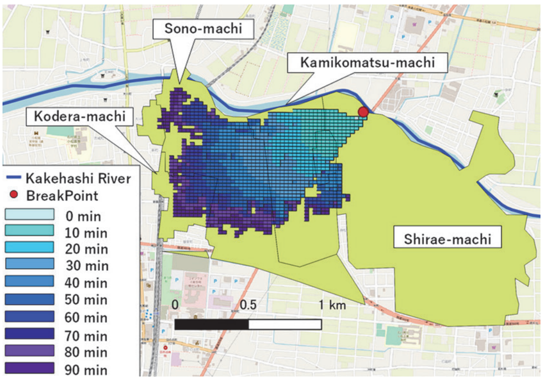


**Figure 3** Inundation area for 90 minutes after the break of the levee

The number of people affected in the target area is calculated in Table 2. For each area, the inundation ratio was calculated from the ratio of area to inundated area, and the number of people affected was calculated by multiplying by the number of evacuees. As a result, the number of affected vulnerable person in the target area was 46, which was the number of persons who should be supported in the simulation.

**Table 2** Calculation results of the number of people affected

| | Kodera-machi | Kamikomatsu-machi | Sono-machi | Shirae-machi |
|---|---|---|---|---|
| Population (persons) | 458 | 452 | 909 | 2377 |
| Flooded area [m²] | 80625 | 273125 | 403125 | 108125 |
| Town area [m²] | 119640 | 462338 | 734694 | 1239628 |
| Flooding rate [%] | 67.3899 | 59.0683 | 54.8698 | 8.72238 |
| Number of vulnerable person (persons) | 10 | 18 | 42 | 66 |
| Number of people affected (persons) | 7 | 10 | 23 | 6 |
| Total number of people affected (persons) | 46 | | | |

# 4 Simulation on evacuation assistance using automated vehicles

## 4.1 Calculation conditions and scenarios for simulations

An example of the placement of each agent in the initial state is shown in Figure 4. The location of the evacuation shelters was assumed to be outside the inundation area and within a short distance. The starting locations for the automated vehicles were the Komatsu City Fire Department Headquarters and public assembly facilities in the target area. For the initial allocation of vulnerable person, 46 persons were randomly selected from among the nodes belonging to the inundation area that spread every 10 minutes.

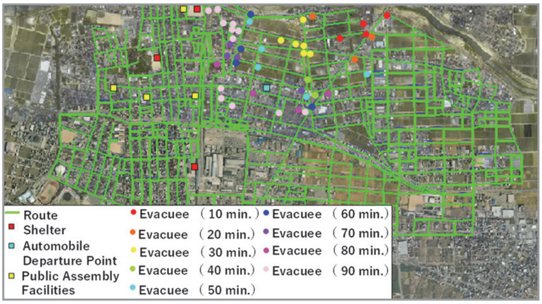


**Figure 4** Example of each agent's placement

The conditions for evacuation simulation are shown in Table 3. Simulations were conducted until all vulnerable person arrived at the evacuation shelter. The speed of the automated vehicle was set at 24 km/h, calculated from the average 12-hour daytime average travel speed [4] along the Komatsu-Tsurugi Line on National Route 305. For the selection of evacuation routes, it was decided to select routes in which the order of distance from vehicles was closer to vulnerable person with shorter inundation time and the roads within the inundation area were inaccessible. The A* (A-star) algorithm, one of the shortest path search methods, was also used. The capacity of the automated vehicle was set to five passengers.

**Table 3** Conditions for evacuation simulation

| Condition Item | Details |
|---|---|
| Shelter | Evacuation shelters located in close proximity outside of the flood zone |
| Evacuation start time | 0 second (At the start of the simulation) |
| Simulation time | Until everyone has been evacuated |
| Number of evacuees | 46 people |
| Location of evacuees | On the node that is flooded every flooding time (Randomly selected) |
| Departure point for automated vehicles | Fire stations and public assembly facilities located in the target area |
| Speed of Automated Vehicles | 24 km/h (2015 National Road and Street Traffic Conditions Survey) |
| Number of simulations | 10 times |
| Selecting evacuation routes | • Order of proximity to vehicles among evacuees with shorter inundation times<br>• Roads within the flooded area are impassable |
| Max. number of passengers | 5 people |
| Number of Vehicles | From 1 to 5 units |

In the simulation scenario, automated vehicle goes to an evacuee, takes the evacuee for a ride, and then heads to a shelter. In the simulation, it was assumed that there is a 13 % probability that some evacuees are not ready to evacuate, taking into account the fact that some evacuees do not intend to evacuate. The probability of the number of people who do not intend to evacuate was calculated using the percentage of those who selected "I don't think it is necessary to evacuate" in the "Resident Awareness Questionnaire on Flood Disaster"[5] conducted by the Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism.

In addition, the time required for boarding the vehicle, the time required to call for evacuation to those who do not intend to evacuate, and the time required for those who do not intend to evacuate to prepare for evacuation were set as the time spent when the automated vehicle arrives at vulnerable person. In order to account for the variation in time spent, each time was calculated probabilistically using a Poisson distribution with a mean of 180 seconds for the time taken to board and call out, and a Poisson distribution with a mean of 600 seconds for the time taken to prepare for the ride.

## 4.2 Simulation results

Change in the number of automated vehicles in use and the time required is shown in Figure 5. According to Figure 5, the time required for the use of two vehicles was reduced by about 43.9 %, 55.8 %, 67.5 %, and 70.6 %, when three, four, and five vehicles were used, respectively, based on the time required when one vehicle was used. The highest reduction in time required was observed when the number of automated vehicles used was varied from 1 to 2. When the number of automated vehicles used was increased from 4 to 5, the reduction in time required was about 9 %, the smallest change.

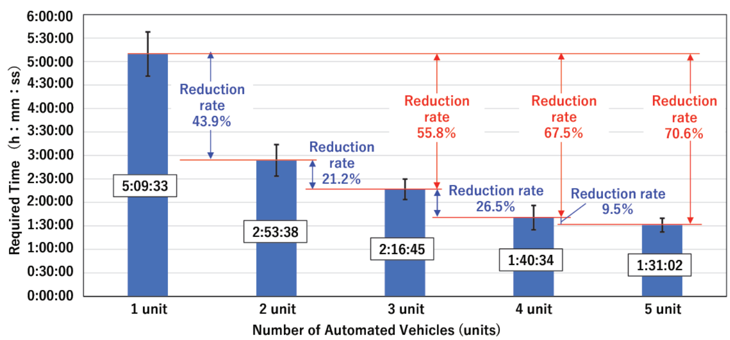


**Figure 5** Changes in the number of automated vehicles in use and the time required

## 4.3 Number of automated vehicles in use and changes in departure timing

The departure timing of the automated vehicles was calculated as the time when the evacuation could be completed without causing a single victim. Therefore, because the timing of departure is too early when evacuees are affected by the disaster, the starting time for evacuation assistance was set to a certain time before the break of the levee rather than at the time of the break. The interval before a certain time from the levee break was set to 30 minutes. Simulations were performed 10 times for each set start time, and the number of times the evacuation was completed without causing damage to any person was calculated as a percentage. The departure timing was calculated as the time when evacuation was completed without causing any damage in all 10 times.

Departure timing by the number of automated vehicles in use is shown in Figure 6. According to Figure 6, the departure time to complete the evacuation without causing any victims is 5 hours and 30 minutes before the breakout when the number of automated vehicles used is 1, while it is 1 hour before the breakout when the number of automated vehicles used is 5.

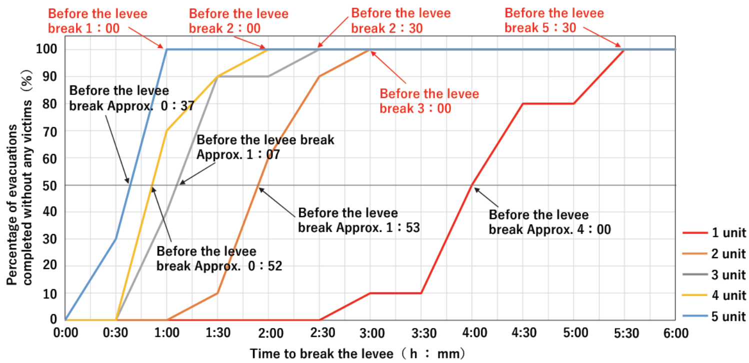


**Figure 6** Number of automated vehicles in use and timing of departure

## 5 Conclusions

In this study, evacuation simulation using an automated vehicle was conducted to obtain knowledge on the timing of departure when an automated vehicle is used to support the evacuation of vulnerable person in the event of river flooding, and the time required for the evacuation was examined.

As for the relationship between the number of automated vehicles and the time required for evacuation, the time required for evacuation decreased as the number of automated vehicles increased. The highest rate of decrease in time required was obtained when the number of vehicles used was changed from one to two, at approximately 43.9 %.

As for the departure timing of the automated vehicles, it was obtained that increasing the number of automated vehicles in use would reduce the time required before the start of breaking the levee in the river. When the number of vehicles used was one, evacuation support had to be started five hours before the levee began to break, but when five vehicles were used, evacuation support could be started one hour before the levee began to break and all the subjects could still be evacuated.

As a future issue, the simulations in this study set the travel speed of the automated vehicles at a constant 24 km/h and did not take into account road congestion or the specific behavior of the automated vehicles. Therefore, it is necessary to consider the speed-related behavior of automated vehicles and use accurate speeds during left-right turns and congestion. In the same simulation, the probability of not intending to evacuate was set at 13 %, but it is necessary to obtain more accurate information through questionnaires, etc., because the results may differ as to whether or not a person would ride in an automated vehicle at the time of evacuation.

## References


[1] Japanese Government Public Relations Online, Protect your community from floods, such as river floods and storm surges, "Flood Prevention", https://www.gov-online.go.jp/useful/article/201507/1.html, 25.02.2022.

[2] Cabinet Office, Impact of Population Decline and Increase in Number of People in Need of Assistance on Large-Scale Disaster Preparedness, https://www.soumu.go.jp/main_content/000578734.pdf, 25.02.2022.

[3] Komatsu City Website, Komatsu City List of vulnerable person, https://www.city.komatsu.lg.jp/kenko_fukushi/11/5447.html, 26.02.2022.

[4] National Road and Street Traffic Conditions Survey, https://www.mlit.go.jp/road/census/h27/, 27.02.2022.

[5] Ministry of Land, Infrastructure, Transport and Tourism. Kanto Regional Development Bureau, Survey on Residents' Awareness of Flood Disaster Prevention, https://www.ktr.mlit.go.jp/ktr_content/content/000716660.pdf, 27.02.2022.