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Original paper

Feedback Process of a Tsunami Evacuation Plan Using Quantitative Data of Drills for Supporting Vulnerable People in a Community

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Abstract To prepare evacuation plans, including an evacuation support system for vulnerable people such as the elderly, injured, pregnant, or other people requiring support during a tsunami evacuation, validating evacuation drills with respect to real-world circumstances using quantitative data is important. This study aims to clarify the importance of using evacuation drill data for evacuation planning. To this end, we measured the movements of residents during an evacuation drill conducted according to a set plan in a community and verified the observed quantitative data. We have been supporting the drills and community disaster management plan (CDMP) in the Shinyo Community of Kobe City since 2008 and hence selected this community for our study. We measured the residents' evacuation time and speed using various transportation modes to transport vulnerable people to safety during the drill and verified the evacuation plan's effectiveness. Quantitative data were verified in the drills and vulnerable people and their supporters, who were measured on this occasion, were evacuated from the tsunami warning area within the estimated tsunami hitting time for Hyogo prefecture of 90 min after the earthquake. Further, using four types of transportation modes—a rollator (wheeled walking aid), transport chair, wheelchair, and cart—yielded conveyance speeds (average of the time taken by a vehicle to traverse the entire evacuation route, excluding wait times at traffic signals) of 1.03, 1.42, 1.50, and 1.27 m/s, respectively. Few days later, the participants provided feedback on the drills in an evaluation meeting and deemed the evacuation plan effective. This study presents a progressive thought process that utilizes the interaction between "planning" and "training" to enable a feasible CDMP to combat disasters.

Key words: Tsunami evacuation plan; Vulnerable people; Drill; Community.

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1. BACKGROUND

To develop an evacuation support system for vulnerable people during disasters, an evacuation plan must be drafted based on the actual circumstances of local communities. Therefore, the mutually dependent processes of "training" and "planning" are essential; the effectiveness of an evacuation plan can be measured by training, and its results will be reflected in the subsequent plan. Herein, we present the results of tsunami evacuation training based on a community disaster management plan (CDMP; Kobe City 2018), created by the Shinyo Community in collaboration with the local government based on the Disaster Countermeasures Basic Act (1961, Amendment 2014) and their influence on the subsequent plan by considering the Shinyo District, Nagata Ward, Kobe City, Japan, as an example.

In the wake of the 2011 Great East Japan Earthquake, 16.1% of the deceased or missing people were observed to be vulnerable people; however, the people who supported those vulnerable people constituted 18.9% of the missing or deceased populace. Therefore, 35% of the missing or deceased people were either vulnerable themselves or related to vulnerable people (Isozaki 2013). Therefore, a considerable number of district welfare commissioners, members of the volunteer fire departments, and others who supported the evacuation became victims along with the vulnerable people.

Another great earthquake is expected to occur in the future, which will originate in the Nankai Trough; the number of deaths is predicted to be ~323,000 in Japan (considering a case in which the Tokai region suffers considerably). Furthermore, ~230,000 of these deaths will be caused by the ensuing tsunami (Cabinet Office 2012). The population of supporters aged under 65 years is decreasing in Japan (National Institute of Population and Social Security Research 2017). In contrast, the population of vulnerable people aged 65 years and above is increasing. In this aging society, considering the increasing number of vulnerable people accompanied by increasing burden on their supporters is important. Therefore, an evacuation support plan must be established as a countermeasure against disasters to rescue vulnerable people (Fire and Disaster Management Agency 2013). Additionally, the total evacuation time required to reduce the danger to human lives belonging to all age groups, including people acting as supporters to vulnerable people, should be understood. The total evacuation time is the sum of the evacuation preparation time and evacuation action time of each group comprising both vulnerable people and their supporter(s); it represents the duration between earthquake occurrence and the completion of evacuation.

Existing studies related to this topic are summarized in the following paragraphs. Liu et al. (2006) demonstrated, in a study involving quantitative data analysis, that the most appropriate evacuation route can be calculated using the spatial temporal geographic information system DiMSIS to minimize the total evacuation time in the case of flood disasters. Using the Shinyo District as an example, they modeled evacuation route selection by considering actual city blocks and performed a computer simulation of the evacuation.

Based on a dynamic control model for evacuation vehicles, a previous study investigated the use of automobiles to reach facilities to support the evacuation of vulnerable people from tsunamis (Urata and Hato 2017). However, that study only used computer simulation with no practical verification. Therefore, the applicability of Urata and Hato's (2017) study to practical scenarios is uncertain.

Another study involving qualitative analysis investigated a five-year project on community-based resilience against environmental disasters, such as floods, droughts, and forest fires in Ghana (Antwi 2014).

Furthermore, local Inclusion Support Centers have conducted a field study on support enhancement for vulnerable people in the disaster area of the Great East Japan Earthquake (Minemoto 2013); a qualitative analysis based on case studies was conducted in that study.

However, to the best of our knowledge, no studies have been conducted thus far in which a plan developed by the residents belonging to a community was verified using the obtained data. Furthermore, no reports are available related to the training of local residents based on experimentally obtained results or related to efforts that contribute to reducing the damage caused by future disasters in the local community.

Compared to Liu et al.'s (2006) work, the novelty of this study is that it was conducted using real data instead of simulated data, e.g., the evacuation training was tested in highly realistic disaster situation by actual residents of a community. In addition, evaluation meetings were conducted with the residents to discuss and mutually reflect on the community disaster management plan (CMDP), district disaster prevention plans, and evacuation drills.

Therefore, the objectives of this study are to emphasize the importance of tsunami evacuation drills being conducted from each house or company to the nearest evacuation point, with the residents navigating the streets to reach the closest evacuation point, and investigating various potential scenarios for a district. In this study, the time taken for evacuation (i.e., the speed of evacuation) is measured and verified based on the plan.

Previously, many CDMP or other types of disaster management plans existed, which only showed the assumed tsunami inundation area; however, few plans are available that consider the time taken by the residents (i.e., evacuation speed) to evacuate the affected area. Furthermore, some experiments have previously measured the evacuation time (speed) required for supporting vulnerable people; however, cases where evacuation was successfully implemented with that speed in the community could not be found.

This study not only provides technological approaches involving quantitative data but also investigates sociological influences on evacuation scenarios. Possibly, a pragmatic plan can be developed for verification and interaction with two approaches. The interaction between "planning" and "training" could also improve the CDMP. This is a pioneering caveat of this study.

2. EVACUATION AREA IN THE PRESENT STUDY

Various means can be used to protect human lives from tsunamis (see Figure 1). In the following sections, we describe the evacuation methods and region considered in the present study.

2.1 Ways to avoid tsunami-related hazards

To reduce the damage caused to human life by tsunamis, various types of countermeasures are being developed; these measures include the construction of embankments and the development of a system to transfer groups of people to higher ground in advance (Figure 1(a)). Furthermore, alarm systems are being developed to ensure early awareness.

However, all residential coastlines in Japan cannot be protected using embankments. In a project related to group transport for disaster avoidance, 139 municipalities deemed at risk of tsunami disasters (according to the Act on Special Measures for the Nankai Trough Earthquake) have been designated as “tsunami evacuation special strengthening areas.” Furthermore, the subsidies for such relocation promotion projects have also been increased, although these projects have not been applied by any municipality as of March 2018 (Mainichi Newspapers 2018). Thus, evacuation actions are becoming increasingly necessary for protecting the life of residents.

2.2 Types and means of evacuation and future subjects

With respect to evacuation from tsunamis, evacuation sites can be classified into two categories: evacuation to the upper floors of a building (Figure 1(b), hereafter referred to as “vertical evacuation”) and evacuation to higher ground outside (Figure 1(c), hereafter referred to as “horizontal evacuation”).

In the case of vertical evacuation, elevators may stop functioning in some cases. Therefore, using stairs should be considered as the principal means of evacuation. Evacuees can climb the stairs themselves or with assistance; furthermore, vulnerable people can be carried up the stairs using equipment such as wheelchairs, chairs, or cloth stretchers. For horizontal evacuation, a wide range of outdoor evacuation methods can be used in a city area: independent walking, assisted walking, and transportation using wheelchairs, stretchers, carts, bicycles, or automobiles.

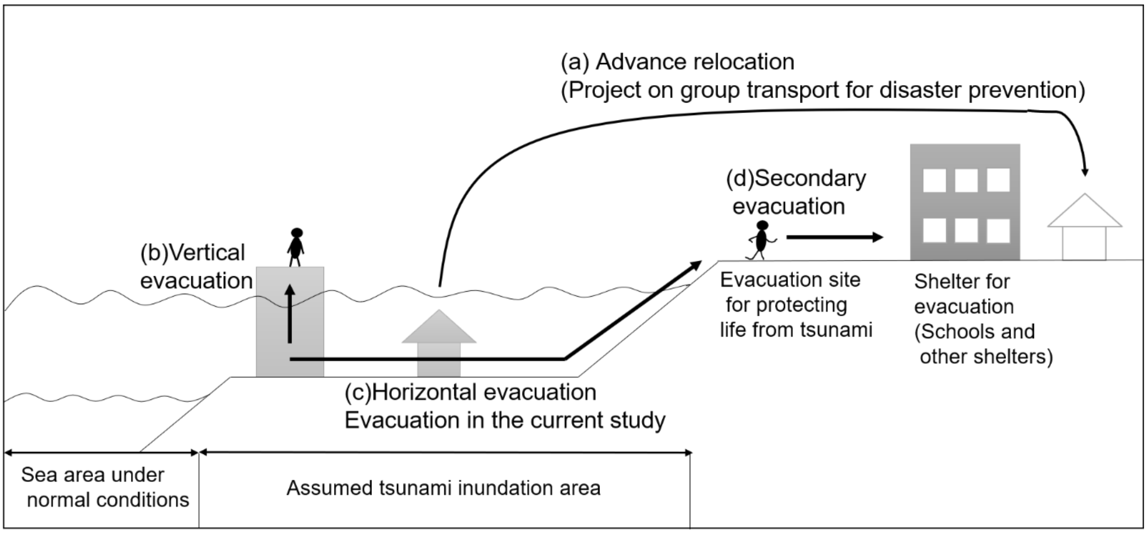

Figure 1. Various means of protecting human life during tsunamis

With regard to vertical evacuation, the possibilities of tsunami fires and isolation within buildings are assumed herein. With regard to horizontal evacuation, congestion of evacuees and a decrease in the evacuation speed owing to a blockage on the evacuation route are assumed because long-distance movement is required during such evacuations.

A common subject in both vertical and horizontal evacuations is that many vulnerable people must be evacuated to higher ground as early as possible with few human and material resources. The present study explores horizontal evacuation.

2.3 Evacuation using automobiles and the risk of traffic congestion

Evacuations can be conducted using either human power or an automobile. Because evacuation using automobiles may cause traffic congestion, herein, we discuss evacuations that utilize human power.

For example, in the 2011 Great East Japan Earthquake, 115 cars (38% of the 303 cars that have been inspected as part of investigations related to evacuations via automobiles) in Ishinomaki City, Miyagi Prefecture, Japan, were stuck in traffic congestion (Yanagihara and Murakami 2013).

Kobe City, which is considered in the present study, is located in the Hyogo Prefecture, Japan. Hyogo prefecture contained 2,297,983 private cars at the end of March 2009 (Automobile Inspection & Registration Information Association 2017), whereas Miyagi Prefecture contained 1,164,630 private cars at the end of March 2010 (Automobile Inspection & Registration Information Association 2010). The density of private cars in the Hyogo Prefecture was 273.53879 cars/km^2 (Automobile Inspection & Registration Information Association 2017; Geospatial Information Authority of Japan 2017), whereas that in the Miyagi Prefecture was 169.71893 cars/km^2 (Automobile Inspection & Registration Information Association 2010; Geospatial Information Authority of Japan 2011). Compared with the Miyagi Prefecture, where human life suffered owing to traffic congestion during evacuation by car, the Hyogo Prefecture exhibited a higher number and density of private cars. Therefore, in the present study, we investigated evacuations that utilize human power.

2.4 Time axis and definition of “evacuation” in the present study

The term “evacuation” signifies two meanings when it is approximately classified based on the purpose of evacuation and time axis. The first meaning includes the “evacuation behavior” (Figures 1(b) and (c)) toward the “evacuation site” or “evacuation goal” that protects lives from direct disasters such as fires and tsunamis. The second meaning includes the actual “movement” of affected people (Figure 1(d)) to “shelters” and other such facilities, particularly in the case when a person must spend his/her daily life at the shelter or any place other than home while avoiding secondary damage. From the perspective of the time axis of disaster cycles, such as emergency response, recovery/restoration, disaster mitigation, and disaster prevention, the former meaning of evacuation is limited to the response stage, whereas the latter meaning covers activities ranging from response to recovery/restoration.

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In the present study, we deal with a process through which a community prepares and verifies a horizontal evacuation plan (see Figure 1(c)) in the early response phase that focuses on evacuation behavior to protect lives from potential direct disasters, such as tsunamis and other such events.

2.5 Community disaster management plan (CDMP)

A CDMP is a plan involving the voluntary cooperation of residents or companies in a certain area of a municipality to perform disaster prevention activities based on the Disaster Countermeasures Basic Act. In Japan, CDMPs have been formulated comprehensively and from a long-term perspective at the national level of the Disaster Management Basic Plan; CDMPs have also been formulated by prefectural and municipal governments at the local level of local disaster management plans. In the event of a large-scale disaster that paralyzes the administrative functions of municipalities, protecting oneself and helping others within the community is important. During the Great East Japan Earthquake, people recognized that without a cooperative outlook regarding self-help, mutual-help, and public-help, disaster measures would not be entirely successful. Therefore, following the 2011 Great East Japan Earthquake, a CDMP was added to promote the practice of mutual-help in communities. In the 2013 revision of the Disaster Countermeasures Basic Act, some provisions concerning self-help and mutual help were added (Cabinet Office, 2014). The aim of the CDMP is to improve local disaster prevention capabilities by strengthening mutual help in communities. Internationally, it is considered to be an advanced initiative, and its future scope is attracting attention.

3. METHOD

We initially verified the effectiveness of the evacuation plan by training. We considered the example of Shinyo District, Nagata Ward, Kobe City, as an example. Furthermore, we described the mutual interaction between "planning" and "training," wherein the training results are incorporated in the form of improvements in the subsequent plan.

3.1 Outline of the method

We have been supporting the training and the preparation of CDMP in Shinyo District, Kobe City, Japan, since 2008. In Shinyo District, the Shinyo Disaster Prevention Welfare Community [Shinyo Bokomi (note1)] has been active as a voluntary disaster prevention organization since 1996. It is a voluntary organization that organizes disaster responses among residents. In this district, evacuation training is conducted every year. In 2012, evacuation training was conducted for ~400 kindergarten children; this training was supported by the disaster prevention welfare community. Thereafter, a new subject emerged, related to the means by which vulnerable people, such as kindergarten children, elderly people, and others for whom independent evacuation is difficult, could be evacuated. The district evacuation plan for this area was prepared in 2014 based on community consensus; this plan included a point according to which vulnerable people should be transported used wheelchairs and other such measures.

We initially conducted experiments at the Research Center for Urban Safety and Security, Kobe University, using the transportation means that were included in the CDMP and collected data related to the transportation speed of vulnerable people. In addition, we inspected and verified the effectiveness of this plan by measuring the transportation speed of residents during evacuation training in Shinyo District. The obtained data were evaluated through evaluation meetings, and the evaluated results were reflected in the subsequent plan.

Furthermore, we verified the effectiveness of the evacuation plan according to the four items listed in Table 1.

Table 1. Verified items and benchmarks of the training

Verified Item	Content
A	Can four kinds of apparatus (wheelchair, transport chair, rollator, and cart) be used to support the evacuation of vulnerable people?
B	Is the total evacuation time shorter than the risk-spreading time? Is the t-value: "$t_{hazard\ affect} > t_{total\ evacuation}$"?
C	To support vulnerable people, should we move from a safe area outside an assumed tsunami inundation area to a dangerous location inside the area?
D	After completing the evacuation of the first vulnerable person, should the supporter return to the tsunami inundation assumption area and help to evacuate the second vulnerable person? Is the t-value: "$t_{hazard\ affect} > (t1_{total\ evacuation} + t_{return} + t2_{total\ evacuation})$"?

3.2 Overview of the district

The district where the investigation was conducted can be described as follows. Shinyo District is located in the coastal area of Japan (see Figure 2). During the massive Nankai Trough earthquake that is expected to occur in the Pacific Ocean near Japan in the near future, the tsunami is expected to arrive 90 min after the earthquake strikes and tsunami waves' height is estimated to be ~4 m (note 2) in the district.

Table 2 lists the population, number of households, and aging rate (percentage of people over 65 years of age in the total population) in Shinyo District. The aging rate is provided in Table 2 because the majority of vulnerable people are elderly. Regional age statistics are also provided in Table 2; however, no statistics on vulnerable people were available.

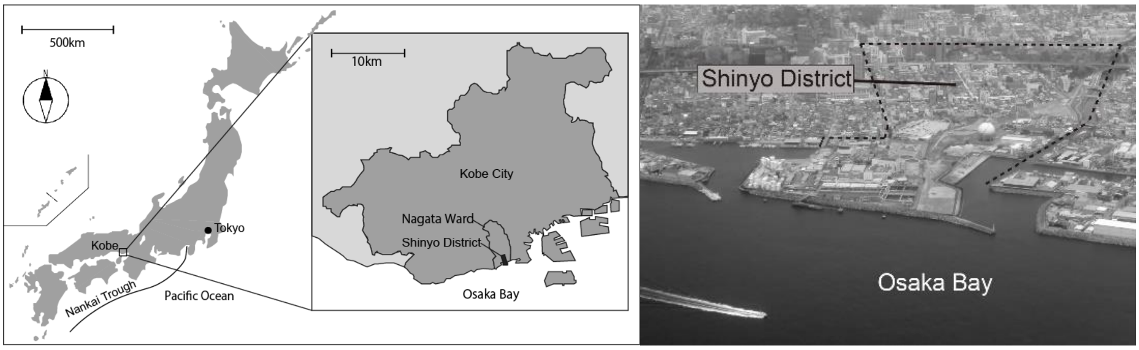

Figure 2. Location (left) and aerial photograph (right) of Shinyo District (Source: Ohtsu and Hokugo 2017).

Table 2. Housing situation in Shinyo District

	Shinyo District	Whole country
Population	5,896 (a)	
Number of households	3,036 (b)	
Average number of persons in a household (people)	1.94 (a/b)	2.51
Aging rate (%)	30.7	23.0 (FY2010)

"Comprehensive Survey of Living Conditions (FY2013)" by the Ministry of Health, Labour, and Welfare
Number of households and age (5-year step) per municipality in Kobe City (Census)
Results of the FY 2010 census (as of October 1, 2010)

3.3 Plan outline and preparation process

The CDMP describes the procedures of Bokomi activities for organizing disaster responses. With regard to the time axis of the disaster cycle, the activity flow at the community was observed to focus on the "prevention" and "response" phases. In the present study, we focus on the planning and data reflection of "evacuation support for vulnerable people in case of a tsunami" in the initial phase of "response."

Table 3 presents the details of the meetings on CDMP preparation and training evaluation in Shinyo District. Three meetings were held on CDMP preparation, and the related summary report was completed in December 2014. This report, comprising 23 pages, first describes fundamental information such as the standards for establishing the Bokomi headquarters, the activity policy, and the resources for disaster prevention (materials and cooperative offices). Subsequently, the report provides a checklist-type action manual that describes disaster-specific actions, including those for earthquakes, tsunamis, storms, and floods. Finally, it describes "advance activity instructions," which simplify the evacuation process on the day of an actual disaster. Horizontal evacuation during a tsunami is mostly described on pages 9–11 and 18–23.

With regard to the meetings related to CDMP preparation of the Shinyo Bokomi, the following three points were considered noteworthy:

(1) A member of a fire department took charge as the facilitator. However, the facilitators in each group were not consultants but volunteer firefighters, who formed the core of the disaster prevention effort in the district (Figure 3). Because the plan was prepared for large-scale disasters in which public assistance was impossible, the discussion was

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limited to what could be performed by the people who would be working in the district during a disaster.

(2) The meeting attendees were members of 19 self-governing associations in Shinyo District that participated in the Bokomi, including the following committees: The consumer committee council, youth development council, women's association, parent–teacher association, children's board, elderly association, fraternity visit group, probation board, shopping street associations, markets, hospital boards, volunteer fire departments, and the Parishioner's Board of the Nagara Shrine. Because people from various organizations that were active in the district participate in the Bokomi, the CDMP could be easily extended to the community.

(3) Even if a plan was completed, it would not be effective unless the public was notified. In the case of the Shinyo Bokomi, 23-page booklets describing the plan were distributed to ~3,000 households in the district.

Figure 3. Member of the volunteer fire department (center) taking charge as the facilitator of the group.

Table 3. List of meetings on CDMP preparation and training evaluation.

	1st meeting on CDMP preparation	2nd meeting on CDMP preparation	3rd meeting on CDMP preparation	Evaluation meeting 2015	Evaluation meeting 2016
Date	29-Aug-14	25-Sep-14	22-Oct-14	3-Mar-15	21-Feb-16
Place	Shinyo Elementary School Library	Shinyo Elementary School Library	Shinyo Elementary School Library	Shinyo District Welfare Center	Shinyo District Welfare Center
Sponsorship	Shinyo Bokomi	Shinyo Bokomi	Shinyo Bokomi	Shinyo Bokomi	Shinyo Bokomi
Attendance	Total: 50 people Bokomi: 29 people (including 19 residents' associations) Elementary school: 2 people (principal and vice-principal) Volunteer fire corps: 11 people Fire Bureau: 6 people Ward Office: 2 people	No data	Total: 47 people Bokomi: 26 people (including 19 residents' associations) Elementary school: 2 people (principal and vice-principal) Volunteer fire corps: 11 people Fire Bureau: 6 people Ward Office: 2 people	Total: 15 people Bokomi: 11 people Fire Bureau: 1 person Kobe University: 3 people	Total: 29 people Bokomi: 24 people Fire Bureau: 1 person Kobe University: 4 people
Facilitator	Total: Fire Bureau Group: Volunteer fire corps	Total: Fire Bureau Group: Volunteer fire corps	Total: Fire Bureau Group: Volunteer fire corps	Kobe University	Kobe University
Main content	・Information sharing with regard to previous disasters in the district ・Information sharing regarding the outline of the plan ・Preparation of the basis for the plan	・Distributing the activities' time between self-help and mutual assistance ・Revision of the basis for the plan	・Selection of actions that can or cannot be supported by the Bokomi ・Determination of the plan	Items A–D in Table 1 were verified.	Items A–D in Table 1 were verified.

3.4 Outline of training

Table 4 presents an outline of the training and experiment that are the objects of this study, in terms of the interaction between the feedback process and planning. Following a request by the Shinyo Disaster Prevention Welfare Community, which intends to formulate a plan, Kobe

University, which has conducted evacuation research for a long time, began to cooperate with them to verify the effectiveness of the evacuation plan.

Table 4. Training and experiments related to the investigation.

No.	1	2	3
Schedule	5 days between December 18, 2014, and May 1, 2015.	17-Jan-15	17-Jan-16
Title	Measurement by experiment	Measurement in training	Measurement in training
Place	Experimental course at the Kobe University	Shinyo District	Shinyo District
Inspected item (refer to Table 1)	A	A, B, C, D	A, B, C, D
Data	Data1	Data2	Data3

4. RESULTS: REFLECTION ON THE PLAN AND TRAINING

Figure 4 displays a flowchart that reflects both the plan and training for the CDMP that was completed in 2014.

Bokomi members deemed the improved plan to be comprehensive while considering both quantitative and qualitative data, based on whether the verification items listed in Table were available. Here, quantitative data refers to the data obtained in the experiment or training such as evacuation speed or time. Qualitative data refers to the feedback provided by the participants at the meeting.

4.1 Verification Data 1

The evacuation speed data obtained in the experiment (refer to entry No. 1 in Table 4 and Table 6) and the data demonstrating the potential transportation of vulnerable people in the same experiment are collectively referred to as Data 1 in this study. These results were presented to the residents at the meeting on CDMP preparation, and Data 1 were discussed and verified.

Experiments were conducted to determine whether vulnerable people could be transported using three vehicles (i.e., wheelchair, transport chair, or rollator) listed as transport means in the CDMP. Experimental results revealed that all three vehicles could be used; furthermore, we obtained data related to their speeds.

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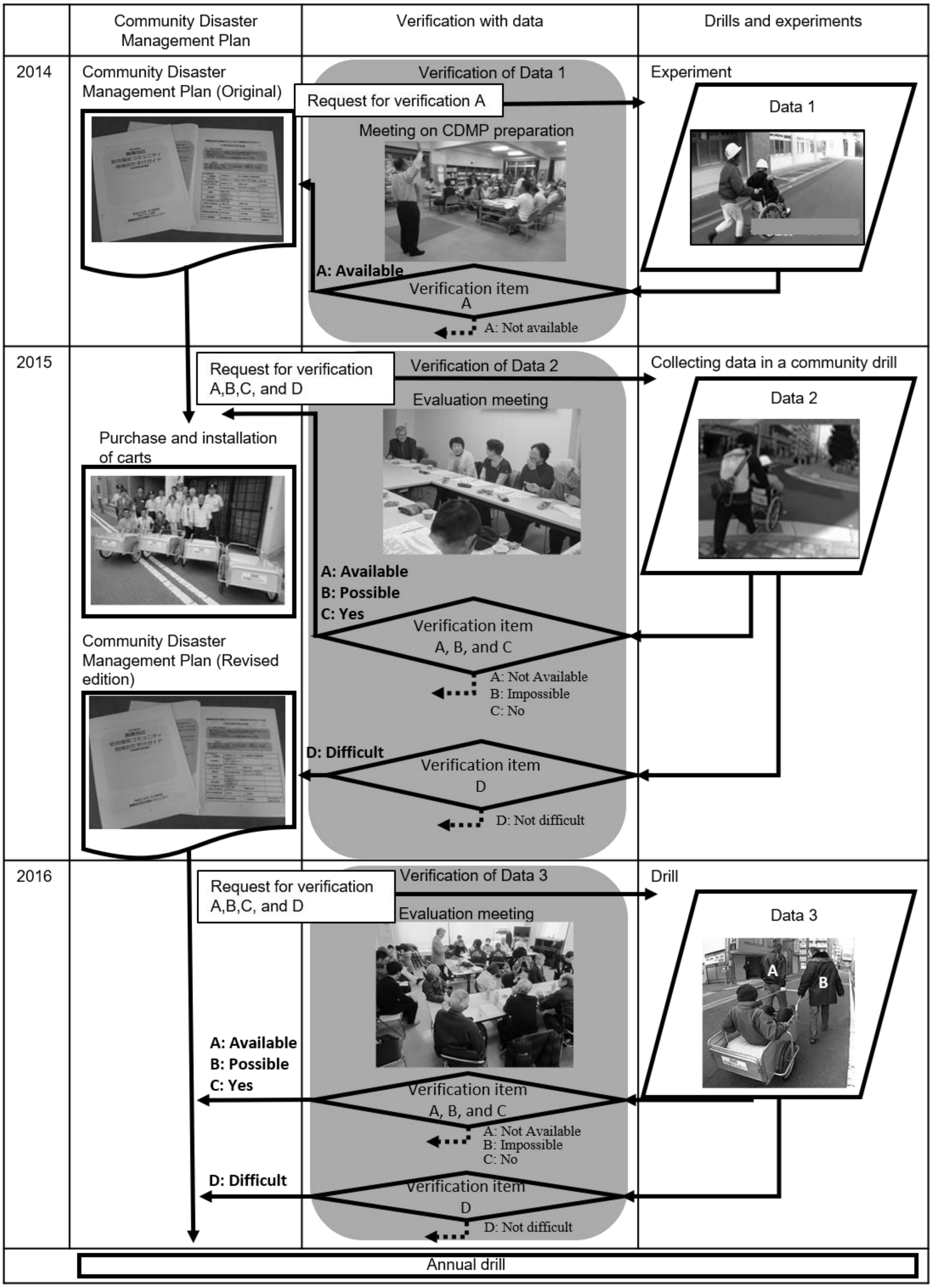

Figure 4. Verification of the plan and training. Verification items: A. Can the equipment be made available? B. Is the total evacuation time shorter than 90 min? C. Is the evacuation direction accurate? D. Is it possible to for a supporter to evacuate a second vulnerable person? Participants in each meeting judged the feasibility of each verification item.

Table 5. Items that were investigated and their results

	Verification 1	Verification 2	Verification 3	Reflection in the CDMP
Verification item A Availability of apparatus	Available	Available	Available	The support provided for the transportation of vulnerable people who use wheelchairs, transport chairs, rollators, and carts is described.
Verification item B Can the total evacuation time be within the risk-spreading time? Is the t value " t hazard affect ＞ t Total Evacuation"?	–	Possible	Possible	Confirming that the evacuation of vulnerable people who participated in the training was completed within the risk-spreading time.
Verification item C Is the direction of supporters "from inside of the tsunami inundation assumption area to the outside of the area"?	–	Yes	Yes	Describing "If there are residents who try to return to the seaside, we should call them to inform them to remain on the mountain side from the JR line."
Verification item D Second support	–	Difficult	Difficult	

Specifically, in the first CDMP preparation meeting, held in August 2014, the inclusion of transportation support using wheelchairs and rollators in the CDMP was discussed. In the following paragraphs, we present the outline of our experiments conducted in December 2014 (Ohtsu et al. 2016). We conducted the transportation experiment on an experimental course at Kobe University. The average speeds of a wheelchair, transport chair, and rollator were observed to be 1.87, 1.58, and 1.18 m/s, respectively. Results revealed that the abovementioned vehicles could be used for transportation during evacuation. Table 6 shows the average speed for each vehicle.

Based on these results, we confirmed that the guideline, "transportation support for vulnerable people is conducted using apparatuses with wheels, such as wheelchairs and rollators," should be included in the CDMP. The CDMP for Shinyo District was completed in December 2014.

Table 6. Average velocity of each vehicle.

Instrument	**Rollator**	**Transport chair**	**Wheelchair**
Distance(m)	1000	1000	1000
Average velocity(m/s)	1.18	1.58	1.87

(Based on Ohtsu et al. 2016)

4.2 Verification 2

The transportation speed data for vulnerable people using three types of vehicles by residents, and the evacuation time data in an actual urban area, which were obtained in the evacuation drill (refer to entry No.2 in Tables 4 and 7 and to Figure 5) conducted by the voluntary disaster prevention organization are collectively referred to as Data 2 in this study.

With the verification of Data 2 and the knowledge of the evacuation speed and evacuation time in an actual urban area, it can be judged whether incorporating the use of the abovementioned vehicles in the CDMP is appropriate. Furthermore, Data 2 becomes a criterion for determining whether the next vulnerable person can be rescued. Verification of Data 2 was conducted at the post-training evaluation meeting.

We conducted evacuation transport training using three types of vehicles in Shinyo District and measured their respective transportation times. Using all three vehicles, transportation was completed within the risk-spreading time. Additionally, we confirmed that evacuation transport is possible in a community using the abovementioned vehicles. Supporters outside the tsunami inundation assumption area did not enter the inundated area, which would have been opposite to the evacuation movement. Furthermore, providing transportation support to a second vulnerable person was revealed to be difficult because of time limitations.

At the stage described in Section 4.1, a problem was observed: was the evacuation complete if the training for the community residents was conducted along the actual evacuation route (place)? Accordingly, we conducted evacuation training wherein the evacuation speed on the experimental course was verified in the actual community.

During the evaluation meeting post training in 2015, the average transportation speeds were reported to be 1.50, 1.42, and 1.03 m/s for the wheelchair, transport chair, and rollator, respectively (Table 7). Thus, the evacuation of all of the participants in this training (vulnerable people: 5, supporting people: 6) could be completed before the tsunami arrival time (Ohtsu and Hokugo 2017). Figure 5 shows an evacuation diagram in this training that shows the estimated tsunami first wave superimposed on a diagram that shows the distance to the evacuation site and the passage of time. The estimated first tsunami wave (b) in the figure does not intersect with the movement line of any subjects (a), indicating that evacuation was completed in this training before the arrival of the tsunami.

Table 7. Evacuation velocity, time, and distance.

Instrument	Rollator		Transport chair		Wheelchair		Cart		
Subject number	①	②	③	④	⑤	⑥	⑦	⑧	⑨
Distance(m)	952.0	1400.5	976.0	1202.4	1582.4	1165.4	1119.8	1049.3	1207.9
Evacuation time	18m04s	27m58s	11m46s	17m28s	19m35s	16m15s	18m55s	21m20s	15m17s
Average velocity except stop(m/s)*	1.15	1.08	1.47	1.36	1.43	1.55	1.26	1.23	1.40
Total average velocity(m/s)	0.88	0.83	1.38	1.15	1.35	1.20	0.99	0.82	1.32
Boarding average velocity(m/s)	1.03		1.42		1.50		1.27		

*Average velocity of empty vehicles and occupied vehicles over entire evacuation route

(Based on Ohtsu and Hokugo 2017)

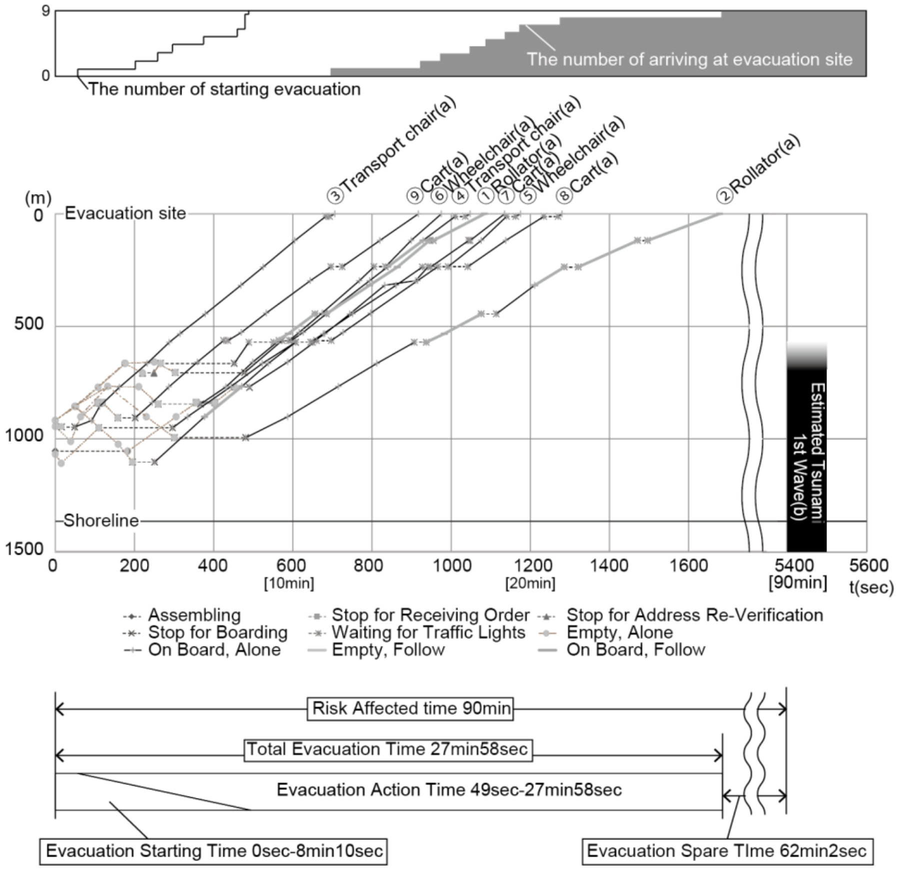

Figure 5. Evacuation diagram (Source: Ohtsu and Hokugo 2017).

Simultaneously, it was also established that, after transporting a vulnerable person, the supporter should not re-enter the assumed tsunami inundation area because a second evacuation could not be completed within 90 min, which is the interval between an earthquake and the arrival of the tsunami. Therefore, we confirmed that the transportation support should be limited to a single evacuation. Thus, the importance of the role of a "time-keeper group" (note 3) that stops a person from attempting to return to the seaside for a second attempt at providing support was reconfirmed.

In the evaluation meeting, an opinion was put forward that claimed "vulnerable people who can maintain a sitting position should be transported using a wheelchair. However, it is difficult to transport those who cannot sit in a chair, such as the elderly or disabled people, or those who are injured in the earthquake. To transport these people quickly, we need equipment such as carts, in addition to wheelchairs, and rollators."

4.3 Verification 3

The data on transportation speed and evacuation time for vulnerable people by cart, which was measured in the evacuation training conducted in 2016 (refer to entry No.3 in Tables 4 and 7 and to Figure 5), are collectively referred to as Data 3 in this study.

By verifying Data 3 and knowing the evacuation speed and evacuation time in an actual urban area, it is possible to judge whether incorporating the use of the transport vehicles in the evacuation plan is appropriate. Furthermore, Data 3 becomes a criterion for determining whether the next vulnerable person can be rescued. Verification of Data 3 was conducted at the evaluation meeting after training.

In the CDMP, the description stating that “a cart is used as an apparatus to transport vulnerable people” was added. In the evacuation training during the subsequent fiscal year, we verified the evacuation time when using a cart. We confirmed that evacuation using a cart can be completed before the arrival of a tsunami, and no movement of supporters from outside the assumed tsunami inundation area to the inside was required. Furthermore, we confirmed transportation support could not be provided for a second vulnerable person when using a cart.

Based on the opinion described in Section 4.3, the Shinyo Community bought four carts using a subsidy provided by the Kobe City Fire Bureau on June 16, 2015. Three of the carts were stored at a cooperative company in the community. The Bokomi and the cooperative companies signed an agreement according to which the executives and employees of the company became supporters who would transport vulnerable people during tsunami evacuation. The Shinyo Community added the details of this agreement to the CDMP in December 2015. Thus, verifying the feasibility of transportation using a cart became necessary. Therefore, we used carts to conduct evacuation transport training in the community on January 17, 2016 and verified the availability of carts (Ohtsu and Hokugo 2017). The employees of the cooperative companies actively participated in this training. The evacuation time, evacuation speed, and evacuation diagram obtained in the training are shown in Table 7 and Figure 5.

Since then, the Shinyo Community has been conducting evacuation training in January every year. If necessary, we intend to modify the contents of the CDMP.

5. DISCUSSION

In the present study, we dealt with tsunami evacuation training in the Shinyo District, Nagata Ward, Kobe City, based on the CDMP and examples for reconsidering the training based on the obtained results.

5.1 Summary of results

We used training to verify the effectiveness of the evacuation plan in Shinyo District. The following results were obtained, which were reflected in the subsequent plan.

A. Four types of vehicles (wheelchairs, transport chairs, rollators, and carts) can be used for transporting vulnerable people.
B. The total evacuation time was within the risk-spreading time.
C. While supporting vulnerable people, supporters did not move in the direction opposite to that of the evacuation, i.e., from outside the assumed tsunami inundation area to inside the area.
D. After transporting the first vulnerable person to the evacuation location, the supporter could not return to the assumed tsunami inundation area to transport a second vulnerable person because of time limitations.

E. Based on the verifications performed using the obtained data, the effectiveness of the CDMP was confirmed.

5.2 Uncertainties of the present study and future subjects

To use the present results for disaster responses, the following points can be cited as uncertainties that need to be overcome in the future.

Throughout the current research, we verified the effectiveness of the evacuation plan through training sessions and experiments. However, verifying whether a plan is applicable to real disasters is difficult. Although we attempted to simulate training conditions that were as close as possible to real disasters, the following uncertainties still remain.

First, with regard to human uncertainty, a time difference was observed between the training time and real evacuation. This difference stemmed from the difference in age and physical strength between the subjects who participated in the training/experiments and real supporters during a real disaster.

A supporter could possibly become a vulnerable person because of an injury. There is a risk that the designated supporters may not always be available when they are needed; for example, the supporter could be absent because of business or travel reasons. Additionally, we have to recognize that the number of employees who can operate carts and act as supporters decreases at night and on holidays, which could disrupt the flow of the evacuation plan.

Subsequently, with regard to the geographical uncertainty related to the selection of the evacuation route, it may become difficult to cross National Route No. 2 with five lanes in one direction (10 lanes in total). This is because the traffic signals may not be functioning owing to blackouts. Furthermore, the evacuation route may be blocked because of the collapse of houses/walls or damage to road surfaces. In addition, in case of an actual disaster, unexpected obstacles and failures may occur, unlike planned evacuation.

With regard to a situation in which both human and geographical uncertainties are combined, the rate of evacuation could stall. Furthermore, the evacuation speed may reduce depending on the density of pedestrian traffic passing through the railway viaduct. We should consider whether the preceding evacuees will hinder subsequent evacuees if their progress stalls.

5.3 Comparison with previous studies

Murakami et al. (2013) surveyed 324 cases of evacuation behavior from a tsunami including their travel means in the Yuriage community, Miyagi Prefecture, Japan, after the Great East Japan Earthquake, 2011. They distributed 1,135 questionnaires, collecting feedback from 324 household (response rate: 29%). For future work, we must consider using questionnaires to understand the relation between risk perception and evacuation behavior of citizens.

According to Tsuchiya et al. (2002), the speed of a person who operates a wheelchair by himself/herself is ~0.8 m/s. However, the speed that was considered in the present study is that of a vulnerable person in a wheelchair pushed by a supporter. In case of real evacuation from a tsunami, both self-operating and supported wheelchair movements may be involved. Therefore, the speed of a self-operating wheelchair will be included in future works.

The present methods, "reflecting the data in the next plan" and "verifying the plan by the data," can also be applied to other districts that plan to prepare or complete a CDMP. Finally, we believe that our study mitigates damage to human life caused by tsunami disasters, thereby making a considerable scientific contribution. In our previous research, the training and experimental data were not reflected in the plan. Therefore, this research is an improvement over our previous study in that it makes the evacuation plan more effective and practical for the considered region.

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Note 1: Bokomi

Organizations for community-based disaster risk reduction, which are led by the citizens and supported by the Kobe City Fire Bureau.

A voluntary disaster prevention organization aiming to provide assistance was found in the Kobe City in 1996 following the Great Hanshin-Awaji Earthquake of 1995. There are 191 Bokomis in the city, and the activity range of a Bokomi is within the district community of an elementary school with a population of several thousand to ten thousand people each. At times, it is written as "Bokomi," whereas it is translated at times as "Kobe city disaster-safe welfare community."

"Disaster Prevention Welfare Community," Homepage of Kobe City, http://www.city.kobe.lg.jp/safety/fire/bokomi/(referenced on July 16, 2018).

Note 2: Tsunami height

Tsunami height is different from inundation depth. The tsunami height is the difference between the normal tide level and the height the sea level rises owing to the tsunami. Inundation depth is the height from the ground to the mark of the tsunami. In the community disaster prevention plan created by the Shinyo Community, the degree of risk does not differ depending on the inundation depth. In the tsunami inundation area, evacuating uniformly is necessary to avoid human damage.

Note 3: Time-Keeper Group

In the 2nd meeting on CDMP preparation, there was a discussion with regard to whether a supporter who finished transporting one vulnerable person to the evacuation location should return to the assumed tsunami inundation area to transport a second vulnerable person. During the 2011 Great East Japan Earthquake Disaster, more than 200 volunteer fire corps members and district welfare commissioners who assisted the evacuation of vulnerable people were killed. Therefore, it was decided that a supporter should not attempt to transport vulnerable people twice because it was dangerous. To avoid such dangers, CDMP stated that the residents who finished evacuation should play the role of a "time-keeper group" to stop the supporters from returning to the assumed tsunami inundation area.