

Article

# Risk Management and Technology: Case Studies of Tsunami Evacuation Drills in Japan

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**Abstract:** Evacuation drills have been developed as part of many risk management programs. However, very few studies have paid attention to the process of evacuation drills. This study employs action research to examine a tsunami risk management strategy called the single-person drill, and applies new technologies in presenting related outcomes presented as multiscreen movies. The drill targets vulnerable people (i.e., older adults), during which a single evacuee moves to a shelter with the aid of a Global Positioning System (GPS) device. Evacuation routes, destination, and duration were used as parameters in an agent-based evacuation simulation shown on movies. The drill has been conducted 58 times in a coastal community (Okitsu, Kochi Prefecture), and 59 multiscreen movies were produced. An analysis of the effectiveness of the drill and related movies was done by collecting both quantitative and qualitative data. Results showed that, with a total of 163 respondents of a semistructured interview, 70.0% of residents were familiar with the drill, and 22.0% wanted to try it. The drill helped elderly people to improve self-efficacy in tsunami risk management, and generated two-way risk communication between experts and participants. This paper contributes new insights into understanding the importance of technology in tsunami risk management.

**Keywords:** evacuation drill; technology; vulnerable people; risk communication

## 1. Introduction

The 2002 World Summit on Sustainable Development warned that the escalation of severe disaster events triggered by natural hazards and related environmental disasters are increasingly posing a substantive threat to sustainable development [1]. Approaches to risk management have become important sustainable development agendas to societies vulnerable to earthquakes, floods, landslides, and tsunamis. An example of one such society would be Japan, where the 2011 Tohoku Earthquake and Tsunami triggered a powerful tsunami and caused 18,483 fatalities, and 401,567 homes totally or partially destroyed [2].

Internationally, in order to provide effective risk management countermeasures, NGOs (non-governmental organizations), community organizations, and government officials have developed and applied multiple methods and guidance [3,4]. In Japan in particular, in order to cope with frequent natural disasters, various evacuation drills have been adopted and conducted as part of risk management programs [5]. However, evacuation drills have not been without their critics. For example, one criticism is that the methods and scenarios used in these drills have become increasingly stereotypical and boring to participants [6]. According to the results of a 2005 survey on earthquake and tsunami risk awareness collected in Japan, the average evacuation drill participation rate was only 19.5% [7]. Similarly, the participation rate in an evacuation drill conducted in Ishinomaki in 2014 was only 7.3%, despite the fact that this city experienced 3968 fatalities due

to drowning in the Tohoku Earthquake and Tsunami [8]. These low participation rates indicate that, on one hand, increased efforts should be made to enhance drill participation, particularly in areas regarded as extremely hazardous. On the other hand, the low participation rates indicate that the traditional tsunami evacuation scenarios are losing their public motivation value, and require urgent transformation.

One such potentially stimulating factor in transforming the effectiveness of evacuation drills is technology. The increasingly sophisticated information technology, such as GIS, Global Positioning Systems (GPS), and Artificial Intelligence (AI) applied in risk management has become evident in the evacuation context [9–11]. New models for predicting evacuation behaviors have been developed using computer simulation systems. These technologies have enabled estimates of the impacts of a given disaster, such as a tsunami, to be constructed, including the potential number of fatalities [12,13]. In these simulation models, the environment and agents of people are typically made to interact simultaneously, and are transformed according to the input of different data sources [12]. Such simulation models provide a platform allowing researchers and research subjects to apply scientific knowledge within a realistic setting. This also helps to create a systematic technological approach to problem solving [9,12]. However, data of agents of people in the simulation is usually estimated according to the average age level, and may thus result in a bias in the simulated outcomes [12]. In addition, most studies used data of past evacuation behaviors, but few have paid attention to the predictive value of evacuation drill data. To investigate the process and effectiveness of an evacuation, it is better to conduct experiments with residents under an assumed stress situation, but this is difficult in practice because there are many uncertainties and risks [14]. The lack of scientific examination of drill data might be one factor that hinders the development of evacuation drills, and thus, stereotypical drills may have lowered participation rates.

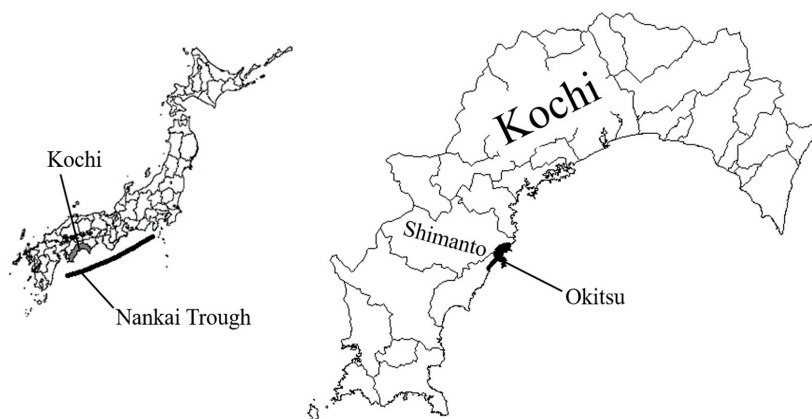
In tsunami risk management, individuals' understanding and management of risk information is typically fraught with challenges. These challenges include limited knowledge of tsunami risk predictions [15], a sense of desperation due to inconceivable hazard predictions [10], and underestimation of protective efficacy [16]. Therefore, criticism of one-way risk information transmission (i.e., experts/officials to the public) and exploration of the implementation of two-way risk communication between experts/officials and the public were carried out [10,17]. Appropriate communication technology in this domain can help to deconstruct complex tasks into smaller ones, making explicit what would otherwise be tacit problem-solving processes [18,19]. For example, if information technology is applied in tsunami simulation, information on tsunami inundation height and tsunami arrival time can be accurately presented in the form of three-dimensional animations [20]. These vivid animations can help people to understand and manage tsunami risk information effectively [21]. Likewise, technology can be designed to model expert thinking and processes [22], and to provide individuals with one-to-one tutoring practice.

However, thus far, few studies have focused on the possibility of integrating information technologies in the process of tsunami evacuation drills. This study addresses these gaps by designing new tsunami evacuation drill procedures and developing new technological tools to help people to understand risk information. Meanwhile, it investigates interactive functions between people and these technological tools, as well as risk communication generated through evacuation drills among participants. We anticipate that the technological tools developed in this study will function as new communication methods to resolve challenges for both information providers (i.e., experts/officials) and users (i.e., the public). In other words, this paper aims to break down rigid boundaries by developing two-way risk communication between experts/officials and the public.

## 2. Materials and Methods

### 2.1. Case Study and Methodology

The study area for this research was Okitsu village, located in the town of Shimanto in Kochi Prefecture, Japan (Figure 1). Okitsu faces three main challenges with regard to tsunami risk management. One is limited access to neighboring communities. Okitsu is surrounded by sea on three sides and mountains on one. There is only one transportation line connecting Okitsu to a nearby community, replete with many sharp bends that make it difficult to maintain this route in heavy rains or earthquakes. A second challenge is the serious risk of Okitsu being hit by a future Nankai Trough tsunami. As the damages caused by the Tohoku Earthquake and Tsunami overwhelmingly exceeded what had been predicted, the project of reviewing predictions of future earthquakes and tsunamis was carried out in regions along the Nankai Trough [23]. For Okitsu, according to the latest disaster prediction report [23], an earthquake of an upper 6 intensity on the JMA (Japan Meteorological Agency) seismic intensity scale would cause a tsunami. Its first wave would arrive at residential areas close to the sea within 15 to 20 min. The predicted tsunami will have a maximum inundation height of 15 m, and a maximum run-up wave height expected to exceed 25 m. In addition, according to historical archives, the village might have experienced earthquakes and subsequent tsunamis along the Nankai Trough about a dozen times in the period of 684 to 2014 [24]. The latest one was Iyonada Earthquake (M6.2), which occurred at 02:06 Tokyo time on 14 March 2014. Its shaking was strongly felt by people in Okitsu, and the shaking misled people into thinking that the predicted Nankai Trough tsunami would come [25]. Therefore, tsunami risk management became an urgent issue in Okitsu. A third challenge is that of the area's aging population. In April 2014, there were 547 households in Okitsu with a total population of 982. Almost half of the population was over the age of 65, and 30.9% was over the age of 75. In short, Okitsu's geographic location and demographic structure have presented challenges to the implementation of tsunami risk management activities.



**Figure 1.** Map of Okitsu. Source: Produced by the first author using KenMap Version 9.2 software.

Jishu-bosai-soshiki (abbr. Jishubo, a community association for disaster preparedness and rescue activity in Japan) of Okitsu has launched and sustained programs of disaster risk management since 2005. Achievements by the Jishubo and collaborators (i.e., schools, senior clubs) included handmade hazard maps which won first prize in a competition sponsored by the Minister of State for Disaster Prevention. In addition, the capacity of evacuation shelters was expanded, exceeding that which was necessary to cover the whole population of Okitsu [26]. Before the release of the latest disaster prediction report on 31 March 2012, tsunami evacuation shelters in Okitsu consisted of five plazas built on flat ground of 15 m or more in height (i.e., Sakura, Saiho Temple, Todai Line, Tyurei Temple, Honmura), with a total capacity of 1526 people. As of 8 July 2013, tsunami shelters had been expanded

to six plazas and four towers of 15 m or more in height, with a total capacity of 2206 people (see Appendix A).

The current study was conducted based on a 2012 survey of people's attitudes toward tsunami risk management in Okitsu. The survey results showed that, even though Okitsu has enough tsunami shelters to hold all the population, 47.1% of community members requested the construction of additional shelters to aid risk management [27]. However, according to Shimanto town archives, the rate of participation in annual tsunami evacuation drills in Okitsu was about 40% in the period of 2012 to 2014. The rate of drill participation indicated that residents not included in this statistic may never have participated in the drills, and thus, may not have known about the existence of the shelters.

To solve this problem, we employed an action research approach to tsunami risk management. Action research is a social science approach in which, instead of observing the research subjects from the viewpoint of an external observer, the researcher integrates as an engaged participant [28]. Through this method, the researcher aims to facilitate improved local community conditions via collaboration with research subjects [29]. It is for this reason that we applied action research to our study. We proposed a particular type of tsunami evacuation drill, which we termed the "single-person drill". We applied both quantitative and qualitative analysis to examine the effect of single-person drill. Also, we collected qualitative data through our action research and face-to-face interviews. Simple descriptive analysis and qualitative psychological methods were applied as analysis methods.

## 2.2. Action Research on Tsunami Risk Management

To improve public motivation value of tsunami evacuation drills, and to examine drill processes, we conducted the single-person drill in Okitsu. This approach involves four stages (Table 1). The first stage was recruitment of drill participants. Targeted participants were people who could be deemed "vulnerable" [30], that is, those who might have difficulties in the process of a tsunami evacuation. Specifically, primary and secondary school students in Okitsu, and students' grandparents, were invited to participate.

**Table 1.** Implementation process of the single-person drill.

	Activities	Technological Tools
<b>1st stage</b>	Participant recruitment Target participants: students, students' grandparents	/
<b>2nd stage</b>	Implementation and recording Participants: students, adults, government officials, disaster experts	GPS devices, video cameras, stopwatches.
<b>3rd stage</b>	Editing Participants: disaster experts, computer graphics experts	Multiscreen movies
<b>4th stage</b>	Broadcasting Participants: students, adults, government officials, disaster experts, journalists	Multiscreen movies

Notes: GPS, Global Positioning Systems.

The second stage was drill implementation and recording. The technological tools used to record the drills included portable GPS devices, video cameras, and stopwatches. The drill implementation, managed by the local participants, involved decisions regarding operation time and place, and evacuation route and destination. Subsequent recording of the drill was undertaken by supporters, including students, former evacuees who had already conducted their drills, and local government officers. Evacuation scenarios were that a supporter announces "Earthquake!" to signal the occurrence of an earthquake. In evacuation scenarios, movement is impossible for the first 100 s due to strong tremors. During this time, the evacuee takes shelter under a table. After 100 s, a supporter announces, "The earthquake is over. Evacuate immediately," and the evacuee leaves home. Naturally, communication on tsunami risk management frequently occurred between the evacuee and his/her supporters during the recording process. As elderly evacuees had to expend great effort to reach shelters on high ground, supporters provided encouraging messages to them such as: "you should not

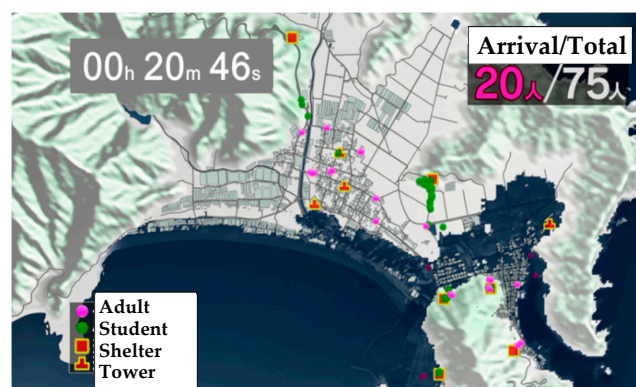
give in to a tsunami,” “you are doing great,” and “do not rely on others, but think of countermeasures for yourself and your family.” At the end of the drill, all evacuees were interviewed about their attitude towards tsunami risk management. The interviews were conducted between the evacuee as the interviewee, and one of his/her supporters as the interviewer.

The third stage was that of editing the captured material. The recording of each evacuee’s drill was summarized into an evacuation animation. In the animation, the participant’s starting place, walking speed, and evacuation duration, and the tsunami movement itself, were synchronized using a timer. The final product was a multiscreen movie composed of four independent frames, which we termed the “Version 1.0 movie” (Figure 2). One frame shows the action of an assumed Nankai Trough tsunami itself, two frames show videos of the evacuee’s movements, and one frame displays the risk communication between the evacuee and his/her supporters.



**Figure 2.** Version 1.0 movie. Copyright: Yamori Laboratory at Kyoto University; Tanisuta Inc.; NHK@Osaka. Translation from Japanese to English was by the first author.

Then, following the accumulation of drill implementation data, the recordings were edited into a further multiscreen movie that we termed the “Version 2.0 movie” (Figure 3). The results of all evacuees’ GPS records were then overlaid on a GIS map on the movie. Similarly, the simulation results of an assumed Nankai Trough tsunami were also overlaid on the GIS map in order to check the rate of successful evacuations. In the Version 2.0 movie, each evacuee was represented by a small dot. A timer on the upper left-hand side of the movie represented the elapsed evacuation time. The upper right-hand side displayed a counter with two numbers separated by a slash. The number on the right represented the total number of drill participants. The number on the left counted how many evacuees successfully arrived at the evacuation facilities. In addition, the time taken by each evacuee to prepare for evacuation could be freely added on by experts, making it possible to calculate the maximum time needed by each person for a successful evacuation.



**Figure 3.** Version 2.0 movie. Copyright: Yamori Laboratory at Kyoto University; Tanisuta Inc.; NHK@Osaka. Translation from Japanese to English was by the first author.



The fourth stage was that of broadcasting the multiscreen movies to residents in a community workshop. All the residents of Okitsu, Shimanto town officers, disaster experts, and journalists were invited to join the workshop. The students who acted as drill supporters were the main reporters demonstrating the achievements and problems of the single-person drill using multiscreen movies. By reflecting on these movies, event participants were able to compare drill behavior with the simulated movement of the assumed tsunami. In addition, specific risks such as the potential depth of inundation of a resident's home were also shown in the virtual scenarios, aiming to encourage residents' greater tsunami risk awareness. Broadcasting events had been organized twice, in which Version 1.0 and Version 2.0 movies were used respectively. During these events, personal concerns, suggestions and requirements for future countermeasures regarding tsunami risk management were presented and discussed. Related problems and scientific advice provided by experts were also summarized in report format and submitted to Shimanto town government.

### 3. Results

#### 3.1. Data of Single-Person Drill Implementation

The single-person drill in Okitsu was originally conducted on 26 June 2012. Results are shown in Table 2. By the end of 2014, the drill involving adult residents had been implemented 55 times. Each adult evacuee did one drill. Therefore, 55 separate Version 1.0 movies were made for each adult evacuee. In addition, one integrated Version 2.0 movie was made according to evacuation data of both adult drills and student drills.

**Table 2.** Single-person drill implementation data.

Time period	Adult Drills		Student Drills	
	June 2012 to December 2014	10 July 2012	29 January 2013	12 November 2013
Number of drills	55	1	1	1
Number of evacuees	55	43	40	46
Gender	M = 17 (30.9%) F = 38 (69.1%)		/	
Age	24 to 96 years (SD = 14.20)		6 to 15 years (SD = 2.49)	
	Age distributions: 20s (3.6%), 30s (0%), 40s (1.8%), 50s (5.5%), 60s (30.9%), 70s (21.8%), 80s (30.9%), 90s (5.5%)		1st to 6th grade = 103 (79.8%) 7th to 9th grade = 26 (20.2%)	
Number of movies	55 + 1		3 + 1	
Time required for each drill	Drill preparation: several days Drill itself: >30 min		Drill preparation: several days Drill itself: about 1 h	

Regarding the gender distribution of participants, Table 2 showed that there were 17 (30.9%) adult males and 38 (69.1%) adult females. The age of the adult evacuees ranged from 24 to 96 years old (SD = 14.20). As the primary targeted participants were those who could be considered vulnerable, we did not place particular emphasis on recruiting participants among young adults. Thus, only 10.9% of participants were aged 20 to 59. The majority of the participants were elderly adults in their 60s (30.9%), 70s (21.8%), and 80s (30.9%). It also came as some surprise to learn that 5.5% of participants who completed the drill were in their 90s.

Regarding the time it took for adults to complete their drills, each evacuee took at least 30 min in the second stage—that of implementation and recording—and, in some cases, evacuees took as long as four hours. This wide range in implementation times was mainly due to the interviews that took place after each evacuation. Generally, evacuees who indicated a high level of interest in participating in local events were willing to spend more time doing the interviews. Taking stage one—that of recruitment—into consideration, each single-person drill took several days to complete, in total. This resulted in comparatively few adult participants in the drills overall.

As children have been deemed “vulnerable” in disasters [30], school students in Okitsu were also invited to perform the single-person drill. Due to the sharply aging tendency of Okitsu’s population, the total number of students from primary and secondary schools did not exceed 50. The student drills were practiced three times in groups. The recording of each student’s drill was made with GPS devices, including the student’s departure location and destination, and evacuation routes and duration. Three separate Version 2.0 movies were produced. Primary school students did 103 (79.8%) person-times of single-person drills, and secondary school students did 26 (20.2%) person-times of the drills. Students’ ages ranged from six to 15 years old (SD = 2.49). After each drill, experts conducted interviews with the students to understand the concrete difficulties they had experienced during the drill. Not counting preparation time, such as that taken to receive instructions on how to use GPS devices, each student drill took almost an hour to be completed.

Given the prediction that Okitsu would be hit by a tsunami 15 to 20 min following an assumed Nankai Trough earthquake, evacuation duration should be a crucial concern for community members. According to the tsunami movements simulated in this research on the multiscreen movies, all of the evacuees in the drill successfully fled to shelters. The rate of successful evacuation thus reached 100%. The multiscreen movies were also useful for highlighting the maximum preparation time prior to evacuation. For example, when 15 min were added on to the movies to allow for evacuees preparing emergency kits, or urging others to evacuate, the rate of successful evacuation decreased to 88%.

3.2. Snowball Effect among Drill Participants

To attract older adults to do the single-person drill, we asked people who had conducted the drill to recommend at least one candidate. Through the method of recommendation, about 27 participants were involved in a snowball effect relationship (Figure 4). This indicated that nearly half (27 out of 55) of the adult participants were persuaded to do a single-person drill by previous evacuees. For example, 65-year-old Hatsu recommended at least seven residents to take part in the drill. Tama, 85 years old, recommended Y.S. (79), who further persuaded four people to perform the drill. Mitsu, who was 63 years old, rescued Yoshi (80) and Tsuta (83) in the drill performance. T.K. (70) rescued E. Ko (94) in the drill, and also recommended M. Ta (65).

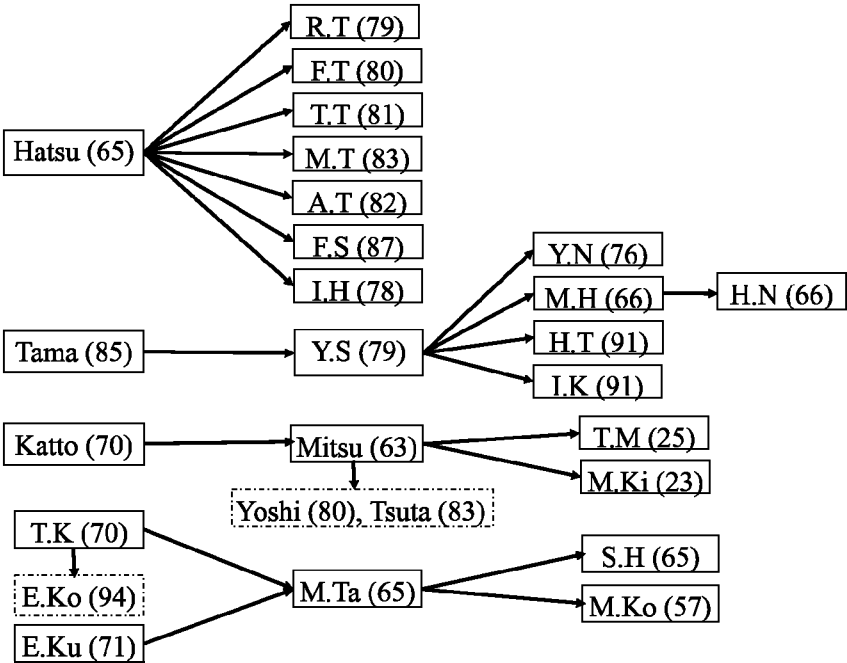


Figure 4. Snowball effect among drill participants.

### 3.3. Community Recognition of the Single-Person Drill

To analyze the degree of community recognition of the single-person drill and to recruit more drill candidates, a questionnaire survey was conducted from 28 January 2013 to 2 April 2013, about six months after the drill was launched. The survey was conducted face to face, using semistructured interviews. The interviewers were adult evacuees themselves. This survey investigated demographic items (name, gender, age, and address), questions of tsunami evacuation (start location, destination, transportation means, and evacuation duration), and attitude to the single-person drill. Questions regarding the single-person drill were that, “do you know about the single-person drill”, and “do you want to do a single-person drill?”

A total of 163 community members responded to the survey. The gender distribution consisted of 41.1% males and 58.9% females (Table 3). Respondents’ ages ranged from 24 to 96 years old ( $SD = 16.6$ ). Similar to the age distribution of adult evacuees, community members in their 60s (25.8%), 70s (17.2%), and 80s (23.3%) were the main respondents. In terms of the level of community recognition of the drill, 70.0% of the respondents reported being familiar with it, while 30.0% were not. In addition, 22.0% of respondents wanted to do a single-person drill.

**Table 3.** Survey results of community recognition of the single-person drill (N = 163).

Survey time period	28 January 2013 to 2 April 2013
Gender	M = 67 (41.1%) F = 96 (58.9%)
Age	24 to 96 years ( $SD = 16.6$ ) Distribution: 20s (6.1%), 30s (7.4%), 40s (9.2%), 50s (12.3%), 60s (25.8%), 70s (17.2%), 80s (23.3%), 90s (2.5%)
Do you know about the single-person drill?	Yes = 114 (70.0%) No = 49 (30.0%)
Do you want to do a single-person drill?	Yes = 36 (22.0%) No = 127 (77.0%)

## 4. Discussion

From a risk management perspective, hazard vulnerabilities must be identified and the vulnerable empowered to address the root causes of these vulnerabilities. The single-person drill proposed in this study follows such concepts of stimulating people’s ability to cope with tsunami disasters. In this section, we will discuss the theoretical and practical significance of the action research of the single-person drill.

### 4.1. Improving Self-Efficacy

The 2012 risk prediction reports stated that there would be a Nankai Trough tsunami that will impact Okitsu [23]. The magnitude and scale of the risk prediction discouraged community members, especially older adults, from undertaking tsunami risk management measures. At the recruiting stage for participants in our study, we frequently heard negative opinions. For example, “I’m already old. I would rather be swept away with my house in a tsunami,” “given that tsunami predictions are so serious, I’ve started to believe that it is meaningless to undertake further preparations for tsunami risk.” This was a major reason given by elderly adults for their rejection of the single-person drill, which also made participant recruitment quite difficult. Different from answering questionnaire surveys, the single-person drill requires participants to actively respond regardless of the cold and the heat. From a traditional psychological perspective, elderly people tend to lack motivation in terms of physical mobility [31]. The total number of participants in the single-person drill numbered no more than 100 people (without duplication of participants), a number that represents about 10% of the community population.



However, the effectiveness in improving self-efficacy for tsunami risk management is clear in the single-person drill. By active participation in the drill, people checked the location of evacuation routes and shelters, to which they may never have previously paid attention. Technological tools developed in the single-person drills provided individuals with one-to-one tutoring practice [22]. For example, with the production of multiscreen movies, people easily understood risk information and calculated the time they would need to evacuate. Even participants over the age of 90 were able to complete the drill and, moreover, gained 10 additional minutes to prepare to flee. Scientific demonstrations presented on the multiscreen movies arguably helped older adults to improve self-efficacy in tsunami risk management. Comments from participants were that, “I never thought I can escape from the Nankai Trough tsunami,” “I enjoyed the evacuation. I decide to visit the shelter every day from now on.” In addition, improvement of self-efficacy in tsunami drills may contribute to evacuation behavior in a real event. Hazard-related attributes, such as efficacy in protecting people and usefulness for other purposes, have been found to be significantly correlated with adoption intention and actual adjustment [16]. For example, Nakaya et al. [32] investigated people who had experienced the Tohoku Earthquake and Tsunami and found that, the rate of evacuation was significantly higher among the population who participated in evacuation drills before the event than among those who did not participate.

Therefore, for drill participants, they performed the role of initiative decision-makers other than passive followers in single-person drills. In traditional drills, the time of conducting evacuation drills, evacuation route, and destination were all decided by community leaders or government officials [6], while drill participants simply had to fulfill passive duties—to follow instructions. In a single-person drill, one has to consider the above-mentioned elements and can make decisions by him/herself. Being decision-makers in evacuation drills enabled participants to perform productive trial and error behaviors. This kind of initiative decision-making process would be important stimulation which further enhanced participants’ self-efficacy (i.e., “I decide to visit the shelter every day from now on”).

#### 4.2. *Generating Risk Communication*

Since the introduction of the single-person drill, risk information and risk communication have become key topics in tsunami risk management in Okitsu. Technological tools developed in the study provide a platform for linking and visualizing information for evacuation behavior (participants) and tsunami simulation (experts). Specifically, information obtained from participants included decisions regarding transportation means, evacuation routes and destination, and evacuation duration. All the information constitutes vital parameters in agent-based evacuation scenarios. Information obtained from experts included development of tsunami simulation models and agent-based evacuation scenarios. Demonstration of mutual information overcame drawbacks of one-way risk information transmission, and generated two-way risk communication between experts and participants [17]. The latter contributed to the development of guaranteed instruction on tsunami risk management based on both scientific and practical knowledge. For example, according to multiscreen movies, elementary school students would be caught by a tsunami on the way to Tyurei Temple if they used 10 min to prepare for evacuation. However, if they change evacuation destinations to Mukai Mt, they will have 15 min to prepare for evacuation. Though longer time preparation is not recommended, other situations including injuries while evacuating may occur among students. Thus, the primary and secondary schools in Okitsu collaborated with students’ parents to require maintenance of Mukai Mt and the road leading to it. Later, both schools chose Mukai Mt as the first destination, and Tyurei Temple as the second. This decision would be considered dangerous for tsunami evacuation without being backed up by accurate tsunami simulation calculations.

The snowball effect in drill participation as shown in Figure 4 demonstrated three important things. First, difficulties in the participant recruitment stage were largely eased with help from former evacuees. About half the participants in the single-person drill were recruited through appeals by previous evacuees. Second, during the process of communication between a former evacuee and a drill candidate, tsunami evacuation was the primary topic. The previous evacuee was also responsible for explaining what a single-person drill involved. Risk communication became a common phenomenon among community members. Finally, as discussed in many decision-making theories, information derived from social cues (i.e., observations of people evacuating) were transmitted through communication channels to those at risk [16]. For example, Kuwasawa et al. [33] found that, compared to official warnings, social cues (e.g., seeing others evacuate) were directly responsible for the decision to evacuate during the 2004 Kii Peninsula Earthquake in Japan. Similar behaviors also have been witnessed in the Tohoku Earthquake and Tsunami, in which community adults evacuated upon seeing school students running toward high ground, even before the release of evacuation recommendations [34]. Therefore, the snowball effect generated from single-person drill demonstrated the importance of risk communication through both direct information (i.e., candidate recommendation) and indirect information (i.e., seeing others do single-person drill).

Risk communication between evacuees and their supporters (i.e., previous evacuees, students, and experts) was seen at the implementation and recording stage. They talked about past disaster experience, evacuation preparedness, and tsunami risk management countermeasures. For example, when recording a drill, supporters asked: “we are walking on a road specifically paved for evacuation. But what should we do if this road collapses after an earthquake?” Some evacuees not only answered supporters’ questions, but also presented their opinions on the best means of conducting tsunami risk management in Okitsu. For example, an elderly person said: “the community has stockpiled emergency food. But from past experience, I think individuals should stock at least three days of water by themselves,” “disasters can happen at any time. Now I’m doing daytime evacuation drills, but I don’t know what will happen at night time. I hope the Jishubo (Jishu-bosai-soshiki) will organize a night time evacuation drill.” Communication in focus group sessions and community workshops has been useful for improving the relationships between science information users and producers in the context of risk management [35]. The activity of the single-person drill, associated technological developments, and community workshops all generated useful risk communication. The single-person drill could thus be seen as a critical way of integrating risk management and technology in the context of evacuation.

## 5. Conclusions

This study has focused on the production of technological tools to stimulate the increased tsunami risk management in a remote community, characterized by an aging population and very significant vulnerability. In collaboration with residents, the single-person drill method was implemented, focusing on individual behaviors. The production of multiscreen movies based on the drill results and scientific tsunami simulation were also developed. Over a two-and-a-half-year period, the single-person drill has been conducted 58 times. Fifty-five Version 1.0 movies of adult drills, three Version 2.0 movies of student drills, and one integrated Version 2.0 movie based on evacuation data of both adult and student drills were produced. The total participants reached 184 person-times.

This paper contributes to the current understanding of risk management in three important ways. First, for drill participants, our study shows that participants have changed their roles of passive followers to initiative decision-makers in the decision-making process of tsunami risk management. Instead of fulfilling passive duties instructed by disaster experts/officials, participants of single-person drills decided important factors of tsunami evacuation (i.e., operation time, evacuation route and destination). Our study shows that the self-efficacy of drill participants was greatly improved, and drill participants became more interested in tsunami risk management (i.e., recommending drill candidates and conducting surveys). As initiative of community members is an utmost important topic in

decision-making studies [6], our study provided empirical evidence and demonstrated the salience of the literature.

Second, for disaster experts, our study demonstrates the strength and effectiveness of interdisciplinary research on tsunami evacuation. We designed the method of single-person drill based on social science knowledge, and developed multiscreen movies by using engineering skills. Disaster experts had a chance to overcome limitations of using average statistics of disaster agents (i.e., age, moving speed), and illustrated detailed results of tsunami evacuation (i.e., even participants over the age of 90 were able to complete the drill and gained 10 additional minutes to prepare to flee). Though many studies have applied similar technologies in laboratory experiments, to date, only a few have collected evacuation drill data from community events [36]. Our study shows that the interdisciplinary research between human behavior science and engineering in the context of evacuation is effective and should be further explored in the future.

Third, for both drill participants and disaster experts, our study demonstrates the significance of performing action research to improve tsunami risk management countermeasures other than merely conducting status quo analysis. The single-person drill method not only applied knowledge from both social science and engineering, but also utilized its achievements to enhance evacuation facilities. One such example is the findings of students who can have longer evacuation preparation time to Mukai Mt than Tyurei Temple, and subsequent maintenance of Mukai Mt. Also, handrails have been installed along evacuation routes leading to high ground in responding to older people's requirement. The single-person drill method could be applied to tsunami evacuations in other areas of similar risk. We hope that our findings can help residents, researchers, and policy-makers shed additional light on tsunami risk management and the innovative potential of information technology in this context.

There are two main limitations of this study. The first limitation is in the research design. Initially, the single-person drill targeted older adults, and thus, the appeal of the drill to younger persons requires revision. Generally, young people are more confident in quickly running to higher places, making them less likely to take part in drills. Development of a new method of tsunami drills, or new technologies (i.e., smartphone applications) might be needed to collect data on young people's evacuation behavior. The second limitation concerns the high cost of producing multiscreen movies. Research funding was used for cleaning the drill data, transforming data on tsunami risk into tsunami animation, and editing the four-framed multiscreen movies. We continue to work on tsunami evacuation drills to overcome these two limitations.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

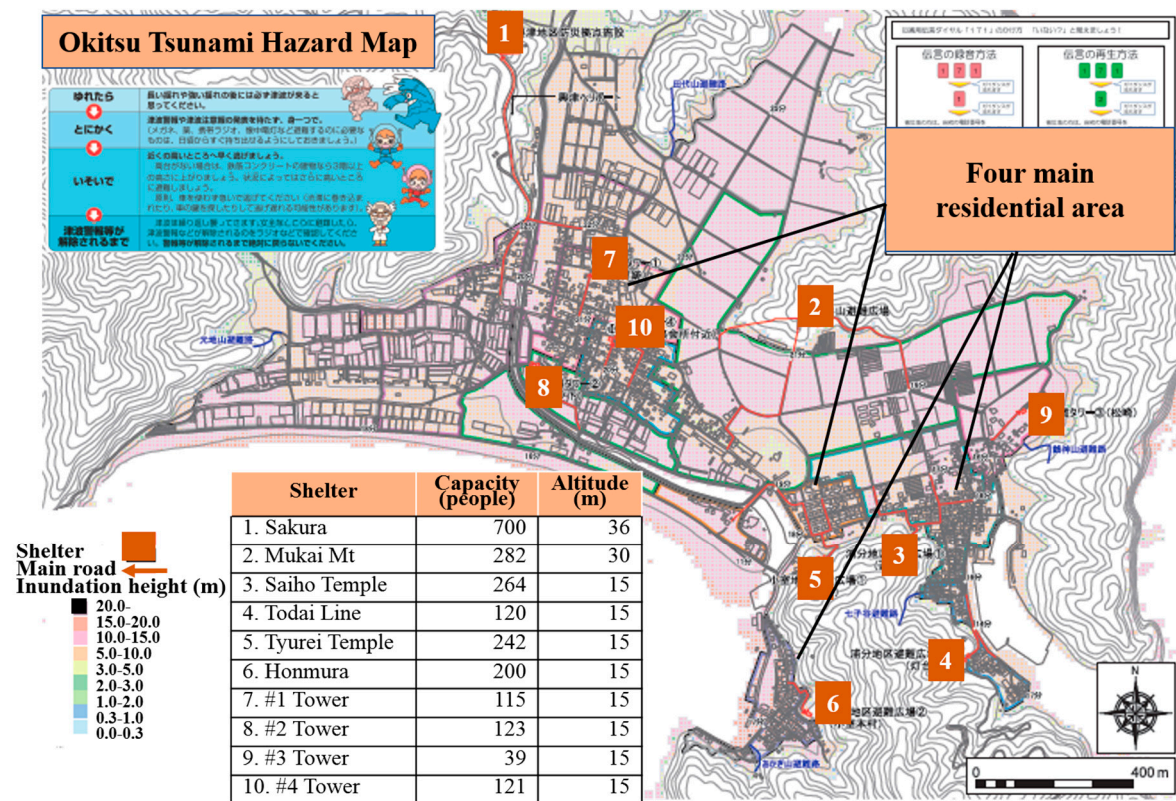


Figure A1. Okitsu Tsunami Hazard Map. Source: Shimanto Town HP [37], translation was by the first author.

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