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Potential of a Shopping Street to Serve as a Food Distribution Center and an Evacuation Shelter during Disasters: Case Study of Kobe, Japan

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Abstract

This study demonstrates the potential use of a shopping street with disaster-proof buildings as a temporary evacuation shelter for local residents at the time of a disaster. We propose a simple estimation method to calculate the number of people for which the retail shops and restaurants in the shopping street can potentially provide food and drink using their inventory. We also estimate the number of evacuees that can be accommodated in the vacant spaces of the buildings. Our proposed method is applied to a shopping street in Kobe, Japan. While 5,200 people in the local community are expected to evacuate at the time of an earthquake, our survey shows that, in the case of power, gas, and water outages, the total amount of available food and drink supplied by the local shops and restaurants would be approximately 1,200 and 1,700 person-days, respectively. In another case, in which alternative facilities provide electricity, gas, and water, the amount of available food increases to about 2,800 person-days. Moreover, the building can provide space for overnight stay for approximately 2,300 people. The results also suggest that, by building stockpiles of food and drink in the unoccupied

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spaces of the building, the capacity of accommodating the local evacuees will be further enhanced. Future directions for more accurate and widely applicable estimation methods are also discussed.

Keywords: retail-store inventory, evacuation shelters, shopping streets, disaster relief goods, survey analysis, Kobe, Japan

1. Introduction

The survival of affected people after disasters—one of the key discussion topics in disaster research—heavily depends on the availability of evacuation shelters and food. In Japan, while the emergency stockpile has been expanded recently, the shortage of evacuation shelters has gained significant attention. To ensure the availability of places for a short stay of evacuees, local governments generally designate community centers and school gyms as shelters. This is the same in many other countries, i.e., places that meet certain requirements are designated as shelters, and evacuation planning is implemented based on the availability of such shelters [1, 2, 3]. However, some of the designated shelters have insufficient capacity to accommodate evacuees [4] and poor accessibility [5]; thus, people often evacuate to undesignated parks and parking lots of the commercial facilities [5, 6, 7, 8]. Hence, these parks and parking lots—often referred to as "undesignated shelters"—complement the designated shelters. Undesignated shelters, however, often do not receive a sufficient amount of relief goods [9, 10] compared to the designated shelters. In undesignated shelters, people are expected to provide the relief goods essential for survival (e.g., food, water, and blankets) by themselves.

In this study, we show that local shopping streets with disaster-proof buildings have the potential to serve as both food distribution places and evacuation shelters in the aftermath of disasters. Retail shops and restaurants in shopping streets can provide affected people with food and drink using their inventory and accommodate them. We quantitatively analyzed the feasibility of our proposal in terms of supply and accommodation capacity in the aftermath of an earthquake, targeting a shopping street in Kobe, Japan. Specific goals of this study include the following: (1) To investigate the number of person-days for which the shopping street can offer its inventory. (2) To examine the number of evacuees to be accommodated by the vacant and shared spaces in the shopping street. (3) To elucidate the effectiveness of complementary measures—stockpiling relief goods in vacant spaces—if the food and drink supplied from the shopping street are insufficient for the required number of expected evacuees. (4) To demonstrate the shopkeepers' opinions—whether they can accept the provision of the inventory to investigate the feasibility of future implementation.

(5) To discuss the data and extensions required to apply our estimation method to other regions and countries. It is impossible to understand the exact number of person-days to which food and drink in the inventory are equivalent only using the available data. To extrapolate unknown values, our method relies on several assumptions. Although it is an easily applicable method in practice, some assumptions may be improved or additional data may be required according to the context. Section 7 discusses the required data and the possible extensions of the method for a more accurate estimation.

This study targets the Taisho-Suji Shopping Street in Nagata Ward, Kobe, Japan, which greatly suffered from a large fire caused by the Great Hanshin-Awaji in 1995 (1995 Kobe Earthquake). Through the recovery project, the shopping street became a fire- and earthquake-proof modern arcade street with skyscrapers and wide streets. Nevertheless, after the transformation, the number of customers decreased and that of vacant shops increased [11], the details of which are explained in Section 2. We have previously studied several aspects of such a unique context of the street [11, 12, 13, 14]. In this study, we partly intend to revitalize this shopping street from the viewpoint of disaster prevention. Through this case study, we aim to resolve the problems regarding the evacuation shelters and the stockpile of disaster relief goods as well as to develop widely applicable methods for estimating available food and drink supply from shopping streets.

The availability of facilities and buildings with large spaces as temporary evacuation shelters has been considered by previous studies—universities [15], libraries [16], roadside stations [17, 18], and religious buildings [19, 20, 21, 22]. Only a few studies have investigated commercial facilities, but they limited their focus to the capacity to accommodate evacuees [23] and accessibility to the facilities [24]. No studies have considered the potential of the buildings to serve as not only evacuation shelters but also food distribution centers. The provision of the store inventory was considered by Murao and Iwamoto [25]. Since convenience stores supplied their inventory for the customers and the local government for free after the Great Hanshin-Awaji Earthquake, the authors investigated the amount of available drinks stocked only by the convenience stores. The availability of food and drink supplied by supermarkets or restaurants was not considered. This study investigates the role of the shopping streets in supplying food and drinks. We propose a simple estimation method to identify the number of person-days served by the inventory. We suggest that shopping streets can work as evacuation shelters with stockpile warehouses where evacuees can receive food and drink on site. While this case study focuses on evacuation after an earthquake, our framework can be applied to other types of disasters that do not damage store inventory.

The remainder of this paper is organized as follows: To help contextualize this study, Section 2 explains the issues of disaster relief goods and evacuation shelters in Japan, the outline of the Japanese shopping streets, and a brief history of the targeted shopping street; Section 3 describes the framework of our strategy to use a shopping street as an evacuation shelter and a food distribution center. The outline of how to calculate the available amount of store inventory and the capacity to accommodate evacuees is also presented; Section 4 describes the study area and the survey methods; Section 5 reports the estimation results; Section 6 considers the complementary measures and shopkeepers' acceptability of the provision of inventory; Section 7 discusses the relationship of our framework with existing shelter planning efforts, the universality of the framework, and the directions to improve the estimation method; Section 8 concludes the study and describes future work.

2. Issues of evacuation shelters, disaster relief goods, and shopping streets in Japan

2.1. Evacuation shelters in Japan

In the aftermath of a disaster, people often stay in a local large space temporarily. The Japanese law—Disaster Countermeasures Basic Act [26]— distinguishes "emergency evacuation sites" to ensure smooth and speedy evacuation and "shelters" to stay temporarily. The law also requires the mayors of municipalities to designate public (elementary schools, junior high schools, and community centers) or private facilities as "designated shelters."

However, some designated shelters have insufficient capacity to accommodate evacuees [4, 27] and poor accessibility [5], while others are not well-known [5]. Thus, people often evacuate to undesignated shelters. For example, after the main shock of the 2016 Kumamoto Earthquake in Japan, at least 185 undesignated shelters existed in Kumamoto Prefecture and 36,000 people evacuated there [6]. Many evacuees spent the night in cars that parked in parks and parking lots of commercial facilities [5, 6, 7, 8]. Disaster-proof and easy-to-access large spaces are required to complement these designated shelters.

In the past disasters, undesignated shelters were managed by evacuees, local people, and facility managers [28], whereas the designated shelters were commonly managed by local officials. In undesignated shelters, evacuees are expected to be self-sufficient and meet their own needs.

2.2. Stockpile of disaster relief goods in Japan

The rapid delivery of the relief goods is essential for the survival of the evacuees. A large amount of relief goods is sent to the affected people, but it rarely reaches them successfully due to the severe damage to the transportation infrastructure [29], the shortage of fuel [30], and poor relief goods management [31]. Undesignated shelters have more difficulty in receiving the delivered relief goods and thus the inequality between designated and undesignated shelters grows [9, 28] because government and associated organizations that manage the relief goods pay less attention to the undesignated shelters or face difficulty in identifying their location [7, 10].

The Cabinet Office of Japan emphasizes the importance of stockpiling at least three days' worth of food and drink supplies [32]. Accordingly, many local municipalities store supplies to ensure the survival of the expected evacuees for three days. Nagoya City in Japan, for example, considers whether to store ten meals for 400,000 expected evacuees [33, 34]. However, such a large amount of food may become expired before being consumed; thus, it may be costlier than expected to maintain these supplies. For example, approximately 30% of 62 local governments in Japan surveyed by Mainichi Newspaper disposed of the stockpiled food due to expiration [35]. The amount of food disposed of in the past five years was reported to be approximately 1.76 million meals and the purchase and disposal cost was equivalent to at least 300 million yen (i.e., USD 2.6 million).

To resolve these problems, the rolling stock method for households has gained the attention of the public recently [36, 37, 38]. Rolling stock is the cycle of storing a certain amount of food at all times. This means regularly eating items from the stockpile and then replacing them with new items to maintain the stock even in an emergency. Our framework is structured such that the local community implements the rolling stock method. The framework would not only reduce the amount of food disposal but also lead to the provision of food on-site in the aftermath of a disaster.

2.3. Overview of Japanese shopping streets

In general, many shops such as groceries, cafes, restaurants, clothing stores, bookstores, and barber shops are concentrated along the main street or in a certain area of most towns and cities, referred to as a "shopping street" ("shotengai" in Japanese) [39, 40] . In almost all cases, these individual shops are owned and managed by different individuals, unlike shopping centers. Shop owners usually agree to build a roof over the street (or a similar feature, e.g., unified lighting, paving, sidewalk) to define the area as a single entity. Shopping streets located in the center of the cities or near residential areas provide not only merchandise and services but also opportunities to strengthen social bonds for local people; people enjoy daily conversation and special events such as traditional festivals in those areas [12].

The period until the 1970s after World War II is considered the golden age of Japanese shopping streets [40, 41]. After this period, however, they have experienced a decline due to motorization, aging of shop owners, and growth of retail shops in the suburbs. According to the 2015 report written by the Japanese Ministry of Economy, Trade and Industry [42], nearly 70% of the shopping streets identified their condition as weakening or stagnated. The shopping streets with vacant shops are usually referred to as "shuttered streets" ("shatta-gai" in Japanese) [39, 40, 41, 43]. The revitalization of such shopping streets or the effective use of their vacant spaces is urgently needed.

2.4. History of the shopping street in Nagata Ward, Kobe

The targeted shopping street in Nagata Ward, Kobe, Japan—Taisho-Suji Shopping Street—also has many vacant shops. This shopping street suffered from great damage caused by the Great Hanshin-Awaji Earthquake in 1995. Before the earthquake, this street had the typical features of downtown areas (Figure 1). The Taisho-Suji Shopping Street suffered from catastrophic damage in the earthquake; a large fire that occurred immediately after the quake caused extensive damage because the street was densely packed with wooden houses and the narrow streets prevented fire engines from entering the area. After the disaster (about two months later), to construct fire- and earthquake-proof buildings, Kobe City proposed a recovery plan for the redevelopment of an area south of Japan Railway Shin-Nagata Station [44]. This recovery project costs approximately 270 billion yen (i.e., USD 250 million) in total and it still continues [45]. In the project, the street was transfigured into a modern shopping arcade with skyscrapers, high ceilings, and wide

Figure 1: Taisho-Suji Shopping Street before the Great Hanshin-Awaji Earthquake (in 1992) (photo by Kobe City [48])

streets (Figure 2). The buildings also have a basement floor (Figure 3) and several floors above ground.

After the transfiguration, however, there were several vacant shops especially in the basement and the second floor (Figure 4). The number of people visiting this street decreased and the street became less lively than before. The number of pedestrians and bicycles after the earthquake (in 2006) using the street decreased by approximately 30–50% compared to that before the disaster (in 1992) [46] Some vacant shops remain unrented and other space, which is for sale, remained unsold due to decreasing property values. The costly recovery project and the associated arcade street invited criticism and issues induced by the project were sometimes referred to as "reconstruction disaster" ("fukko-saigai" in Japanese) [47]. Currently, the association of the shopping street and other stakeholders work hard to revitalize the street, holding special events and other activities frequently [12, 13, 14]. Meanwhile, the arcade street constructed with a focus on resiliency against the next disaster is not used effectively to achieve the original goal. Our ideas to use disaster-proof buildings as evacuation shelters are expected to contribute to increasing the value of the street.

Figure 2: Current Taisho-Suji Shopping Street (photo by Kobe City [48])

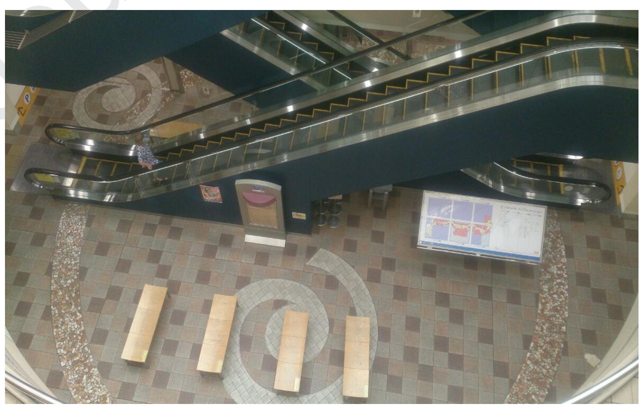

Figure 3: Shared space on the basement in Taisho-Suji Shopping Street (photo by authors)

Figure 4: Vacant shops on the second floor in Taisho-Suji Shopping Street (photo by authors)

3. Provision of inventory and use of vacant space as shelters

3.1. Outline of research framework

This subsection presents the framework to consider (1) the provision of the inventory in the shopping street and (2) the use of its vacant space as temporary evacuation shelters. Table 1 [34] shows that the needs of affected people for relief goods change over time. We focus on relief goods to ensure the survival of affected people in the aftermath of a disaster—referred to as "basic relief goods" hereafter (the shaded row in Table 1). Basic relief goods and their recipients are shown in Table 2 [49]. We assume that the "food (cookies)" and "water" in the list can be replaced with food and drink stocked as the inventory in shopping streets[1]. We also assume that vacant shops and shared space inside the buildings of the shopping street can be used for temporary evacuation. The Cabinet Office of Japan recommends stockpiling at least three days' worth of food and drink supplies to ensure the survival of affected people [32]. Therefore, in this study, we refer to the places where the affected people can stay safely for at most three days as "(temporary evacuation) shelters" and consider the role of shopping streets as shelters.

Based on these assumptions, we investigated the ability of the shopping street to provide the inventory and accommodate evacuees in the aftermath

[1]The items replaced by the inventory can be different for the targeted shopping streets.

Table 1: Change of the evacuees' needs over time (Kajihara et al. [34], edited by authors)

Stages after a disaster	Contents
1st stage	**Basic relief goods:** **food, water, blankets, milk, sanitary goods, etc.** - Emergency level is high and the quantity of each item is large. - Needs are easy to understand and similar worldwide. - Suppliers should be private companies or the government.
2nd stage	**Dishes, writing materials, etc.** - Less urgent than those required in the first stage. - Needs are easy to understand and similar worldwide. - Suppliers should be private companies or the government.
3rd stage	**Picture books, good luck flags, toys, manicure, etc.** - Emergency level is low, the diversity is high, and the quantity of each item is large - Difficult to comprehend the need of victims. - Suppliers should be individuals, especially volunteers.

Table 2: List of basic relief goods and recipients; ∗ indicates the required amount that varies with sex

Items	Recipients
Blankets	Everyone
Water	Everyone
Food (cookies)	Everyone
Powdered milk	Infants
Nursing bottles	Infants
Heat pads	Infants
Sanitary goods	Females
Diapers	Infants and people in need of nursing care
Toilet papers	Everyone*
Toilet bags	Everyone*
Bags for toilet bags	Everyone*
Portable toilets	Everyone
Partition walls	Infants and people in need of nursing care

of disasters. More specifically, the following two topics were examined:

(1) The amount of available food and drink provided by the shopping street was estimated; the number of person-days and the percentage of expected evacuees served by the inventory were calculated.

(2) The floor space available for temporary evacuation in the shopping street was investigated; the number of evacuees to be accommodated and provided with food and drink was calculated.

At the end of the case study, we demonstrated the effectiveness of storing the basic relief goods to complement the shortages in the inventory and the shops' acceptability of the provision of the inventory. Using the analysis results, we explored the future directions and the extension of our framework.

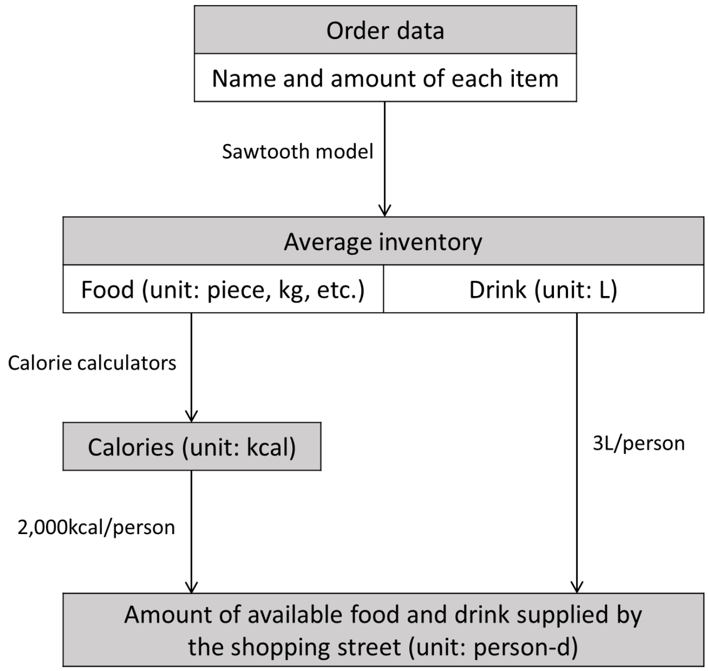

Figure 5: Procedure of calculating the amount of available food and drink supplied by the shopping street

3.2. Outline of calculation methods

This subsection introduces the methods to calculate the capacity of the shopping street (1) to supply food and drink from the inventory and (2) to accommodate evacuees.

3.2.1. Capacity to supply inventory

The steps to calculate the amount of available food and drink supplied by the shopping street and the number of evacuees served by the inventory are outlined in Figure 5. First, we conducted a survey targeting all retail shops and restaurants and collected the order data. We then estimated the available food and drink supply that exists as the inventory. We assume that the average inventory can be supplied by each shop and restaurant. The average amount was estimated using a sawtooth model (Figure 6), widely used in the logistic research [50, 51]. In the model, the inventory is consumed constantly and when consumed completely, a certain amount Q is delivered. No safety stock is assumed and thus the average inventory is $Q/2$. We estimated the

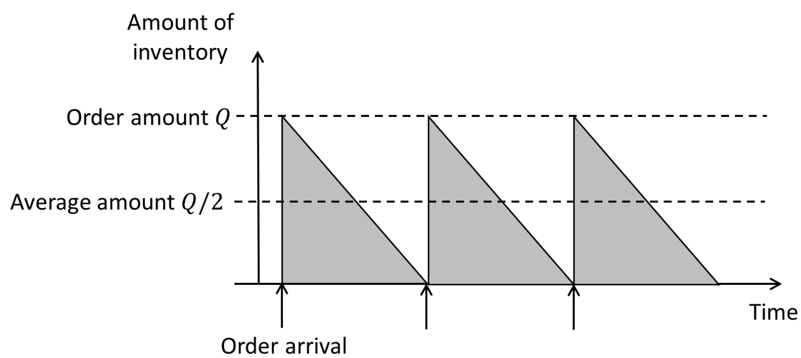

Figure 6: A sawtooth model of arrival and reduction of inventory

average inventory for each item by collecting information on the names of delivered items and their amount (unit: piece, kg L, etc.). If we could not collect data from some of the shops, then we used the databases published by the related associations and the government. We used the number of calories (unit: kcal) to estimate the amount of available food and employed calorie calculators provided by the government and private companies [52, 53, 54, 55].

We assume that one person needs 2,000 kcal [56] and 3 L of water [49] per day immediately after the disaster and investigated the number of person-days provided with available food and drink in the shopping street. The percentage of the expected evacuees to receive items from the inventory in the total number of evacuees was also calculated.

3.2.2. Capacity to accommodate evacuees

We calculated the area of vacant space (e.g., empty lots and shared space) for temporary evacuation using the floor plans of the buildings. We assume that one person needs 2–3 m^2 of floor space in temporary shelters [57, 58] and that 3 m^2 is required for one person. We calculated the number of evacuees who receive food and drink in the shopping street and can be accommodated in the buildings.

4. Outline of survey

4.1. Study area

The Taisho-Suji Shopping Street introduced in Subsection 2.4 is located in the shaded area in Figure 7. We studied the shops and restaurants in

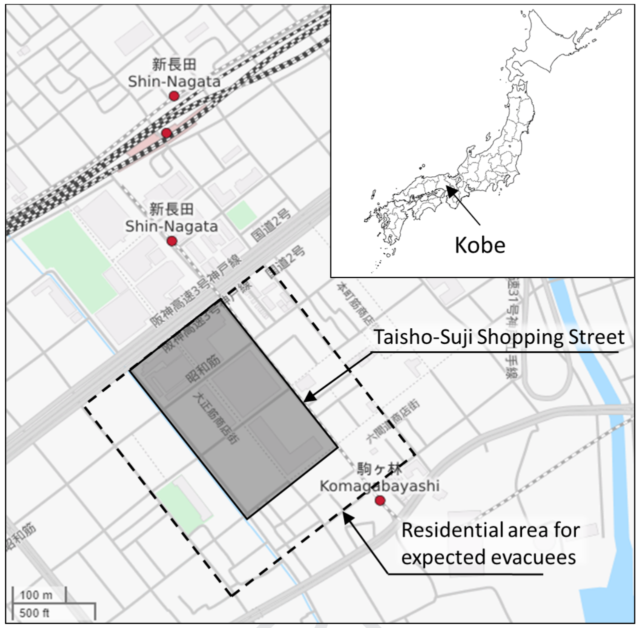

Figure 7: Target area and shopping street in Nagata Ward, Kobe, Japan; the shaded area represents the Taisho-Suji Shopping Street; expected evacuees live in the area marked by the dashed line ©OpenStreetMap contributors

six buildings constructed as part of the recovery project after the Great Hanshin-Awaji Earthquake[2]. As described in Subsection 2.4, the buildings are earthquake- and fire-proof and have much vacant space such as shared space (Figure 3) and vacant shops (Figure 4). Such space is expected to work effectively as temporary shelters during disasters.

We expect that, as a benchmark, people living in the area marked by the dashed line in Figure 7 evacuate to the shopping street[3]. According to the 2015 census [59], the number of residents or the expected evacuees in the area is $N = 5{,}219$. We assume that the residents evacuate after earthquakes[4].

[2] The Taisho-Suji Shopping Street does not include all the shops and restaurants in the buildings, only those that belong to the shopping street association. For simplicity, however, this study refers to all shops and restaurants in the buildings as the "Taisho-Suji Shopping Street."

[3] This area corresponds to 4–7 Udeduka-Cho; 4–7 Kubo-Cho; 4–7 Futaba-Cho; 1–3 Komagabayashi-Cho; and 4 Shoda-Cho in Nagata Ward, Kobe.

[4] Hazard maps in Kobe [60] indicate that the target area is not included in areas vul-

Table 3: Variety and the number of shops and restaurants and the number of valid responses of the survey

Type of business	Number of shops	Number of valid responses	How to deal with
Meat shops	3	2	The amount of inventory of responding shops was estimated based on answers from responding shops; that of non-responding shops was estimated based on answers from responding shops as the alternative.
Fish shops	7	1	
Bakeries	1	1	
Restaurants	46	5	
Convenience stores	1	0	The amount of inventory was estimated based on various public databases.
Supermarkets	2	0	
Vegetable stores	2	0	The shops were excluded from the analysis.
Else	6	0	
Total	68	9 (Response rate: 13%)	

4.2. Survey method

The first column in Table 3 presents the type of businesses expected to supply food and drinks from the inventory. The second column presents the number of shops that belong to each type. We requested the stores to respond with the types of food and drinks in their inventory and their amount per order. We visited the shops and handed the questionnaire sheets out on September 28, 2017 and collected the sheets back on October 16, 2017. The third column in the table illustrates the number of samples that responded to the questions. The floor plans for the buildings, which were needed to calculate the area of empty space as described in Sub-subsection 3.2.2, were provided by the management company.

nerable to flooding, tsunami, and high tides. Landslide is also expected to rarely occur.

4.3. Detailed estimation methods

4.3.1. Type of business targeted for the estimation

How to deal with each type of business for the estimation is shown in the fourth column in Table 3.

Meat shops, fish shops, bakeries, and restaurants

We acquired answers from some shops that belong to these types of businesses. The amount of available food and drink supplied by the responding shops was calculated based on their answers; the amount supplied by non-responding shops was extrapolated from the answers of the responding shops.

Convenience stores and supermarkets

In Japan, the convenience stores are small retail stores that sell daily necessities as well as bread, box lunches, rice balls, cake, chocolates, and candy [61, 62], but they rarely sell fresh fruits and vegetables, meat, or fish. They are usually open for 24 h a day all year[5]. In contrast, supermarkets have larger floor space, operate during the day, and the range of merchandise includes fresh food.

Although we obtained no responses from the convenience stores or supermarkets, these shops were considered important to serve as food providers because they are expected to have a wide variety of food and drink. Therefore, the amount of available food and drink supplied by these types of business was estimated using the public databases [63, 64, 65, 66], provided by private associations and the government, and from the results of the previous studies [67, 68, 69].

Vegetable stores and else

We received no answers from vegetable stores or other types of stores (e.g., tea shops and condiment shops). We also found no rich databases associated with them. Therefore, it was difficult to estimate the amount of inventory for these types of businesses and thus we excluded them from the analysis. These difficulties should be addressed in future work.

Overall, this study considers the supply from 60 shops and restaurants, excluding the shops belonging to "vegetable stores" and "else" categories.

[5]In some countries, similar services are provided by "corner shops," "general stores," or "drug stores."

Table 4: Available food according to the category of business ("-" means no food supply.)

Type of business	Case without utilities	Case with substitute utilities
Meat shops	Processed foods	Raw meat
Fish shops	Processed foods	Raw fish
Bakeries	Displayed products	Products made from ingredients in the inventory
Restaurants	-	Dishes made from ingredients in the inventory
Convenience stores	Staple food; discretionary food	-
Supermarkets	Staple food; discretionary food	Vegetable and fruit; meat; fish

4.3.2. Calculation process by type of business

Available food depends on the situation after the disaster; thus, the following two cases are considered: (1) the case of power and water outage (referred to as "the case without utilities" hereafter) and (2) the case of substitute power and water supply ("the case with substitute utilities").

In the first case, there is no supply of electricity, gas, and water; in the second case, power generators, gas cylinders, and well water are available as substitute power and water supplies. That is, in the first case, only food that generally does not have to be heated can be supplied (i.e., fresh food such as vegetables and raw fish and meat is not provided). However, in the second case, food that requires heat can be supplied additionally. In the study area, there exist wells near the street, and power generators and gas cylinders can be stored in the vacant space of the street. By examining how much the supply from the shopping street increases in the second case, we highlight the importance of using wells and storing power generators and gas cylinders.

In the following, we explain available food resources in each case, also summarized in Table 4, and describe the methods to calculate the average amount of food and its equivalent calories by the type of business.

Meat shops and fish shops

We assume that even in the case without utilities, processed foods (e.g., roast pork and ham) can be supplied; in the case with substitute utilities, fresh meat and fish can be cooked and supplied.

Regarding the responding shops, the following steps were executed to calculate the calories (unit: kcal) of the food items:

(1) Evaluate whether the food is suitable for eating raw.
(2) Based on the amount Q (unit: kg) of food arrived per order, calculate the average inventory $Q/2$ (unit: kg) using the sawtooth model (Figure 6).
(3) Using calorie calculators, estimate the calories (unit: kcal) of the average inventory (unit: kg)

Regarding non-responding shops, the following steps were taken to calculate the calories (unit: kcal), given that the amount of supply from a shop is proportional to the floor space:

(1) Based on the results of the responding shops, calculate the average supply per unit area (unit: kcal/m^2) according to the type of business.
(2) Multiplying its value (unit: kcal/m^2) by the floor space (unit: m^2) of a non-responding shop, estimate the calories (unit: kcal) of the amount of supply from the non-responding shop.

Further details are described in Appendix A.

Bakeries

In the case without utilities, only the displayed products are supposed to be available. A technical limitation of the survey is that it is difficult to impose on the shops the burden of listing all of their products; thus, only five best selling products were considered. In the survey, we asked each bakery the "name" of the five best-selling products and the "amount of each product per display (unit: piece)." The following are the steps to calculate the calories:

(1) Based on the amount (unit: piece) of each best-selling product displayed in the shop at a time, calculate the average amount of each product displayed (unit: piece).
(2) Using calorie calculators, estimate the calories (unit: kcal) of the average amount (unit: piece).

In the case with substitute utilities, we assume that bakeries can supply products as usual by cooking the average amount of ingredients in the inventory. In the survey, we also asked "how many days does your shop use the ingredients purchased per order?" From this order data, we estimated the calories as follows:

(1) Calculate the average amount of ingredients (unit: d).
(2) Calculate the amount of five best-selling products (unit: piece) made from the average amount of ingredients (unit: d).
(3) Estimate the calories (unit: kcal) of the five best-selling products (unit: piece).

Further details are shown in Appendix A.

Restaurants

In the case without utilities, restaurants are supposed to provide no food because they cannot cook.

In the case with substitute utilities, similar to bakeries, restaurants are supposed to provide dishes on the menu as usual, cooking the stocked ingredients. Due to the limitations of the survey, only the top five dishes in terms of the average daily sales were considered. In the survey, we asked the "name" and "average daily sales (unit: meal)" of each dish. The question "How many days does your restaurant use the ingredients purchased per order?" was also asked. The steps to estimate the calories supplied by the responding restaurants are almost the same as those taken for bakeries; the steps to estimate those supplied by the non-responding restaurants are almost the same as those taken for meat and fish shops.

Convenience stores and supermarkets

The public databases restricted us to estimate the calories of each category of food rather than the individual food. More specifically, we had to limit our focus to the following categories:

- "Staple food": cooked rice, bread, cooked noodles, and similar foods.
- "Discretionary food": cake, chocolates, candy, and similar foods.
- "Vegetable and fruit": fresh vegetables and fruits.

- "Meat": fresh meat and meat products.
- "Fish": fresh seafood and dried marine products.

In the case without utilities, both convenience stores and supermarkets are supposed to supply "staple food" and "discretionary food," which are eaten without cooking.

In the case with substitute utilities, only supermarkets are supposed to provide "vegetable and fruit," "meat," and "fish" to affected people because supermarkets generally have a larger amount of food in these categories than the convenience stores (Sub-subsection 4.3.1).

The calories of each category of food were calculated through the following steps:

(1) Derive the "price of the average inventory (unit: yen)" from the "price of the total amount of each category of food delivered per order (unit: yen)." In the sawtooth model (Figure 6), the latter value is equivalent to the "consumption between orders,' which can be estimated based on the public database.
(2) Estimate the average inventory (unit: piece), based on its price (unit: yen). For this estimation, the price of a representative item (unit: yen/piece) in each category is considered.
(3) Convert the average amount (unit: piece) into calories (unit: kcal). For this estimation, the calories of the representative item (unit: kcal/piece) in each category is used.

Additional details of the calculation are described in Appendix B.

Regarding drinks, all items (except alcohol) are supposed to be supplied from all types of businesses even in the case without utilities. The methods to estimate the amount (unit: L) of available drink are similar to those for food. In convenience stores and supermarkets, categories referred to as "refreshing drink" and "milk beverage" (i.e., milk and lactic acid beverage) are considered. The details of estimation are demonstrated in Appendix A and Appendix B.

5. Estimation Results

5.1. Capacity to supply inventory

The estimation results of the total calories (unit: kcal) of food and the total amount (unit: L) of drinks supplied from the shopping street in the

Table 5: Estimation results of total amount of food and drink supplied from the shopping street

Type of business	Food		Drink
	Case without utilities	Case with substitute utilities	
Total supply from 60 shops	2,404,820 kcal	5,547,414 kcal	4,989 L
Equivalent person-d (unit: person-d)	1,202	2,774	1,663

case without utilities and with substitute utilities are depicted in Table 5. Figure 8 represents the breakdown of the total calories of food by business type; Figure 9 represents that of the total amount of drinks. The last row of Table 5 lists the number of person-days that were served the total calories (unit: kcal) of food and the amount (unit: L) of drink. As Table 5 shows, total calories of available food become approximately 2.3 times larger in the case with substitute utilities than those in the case without utilities.

If we distribute the available food from the shopping street to each person as a one-day meal, 1,202 and 2,774 people are served in the cases without and with substitute utilities, respectively, on the first day of a disaster, as Table 5 shows. These results mean that available food in the shopping street is 23% and 53% of the total amount of food required for the expected evacuees (N = 5,219) on the first day. They also imply that the capacity to supply the inventory for evacuees nearly doubles if the food is cooked using power generators, gas cylinders, and well water.

5.2. Capacity to accommodate evacuees

The Taisho-Suji Shopping Street has vacant spaces (e.g., vacant shops and shared space) available for use as evacuation shelters. We estimated the floor space via the floor plans of the buildings. We found that approximately 6,900 m^2 is available to serve as shelters.

In the case without utilities, to accommodate 1,202 people who receive food from the shopping street, 3,606 m^2 (= 1,202 people × 3 m^2/person) of

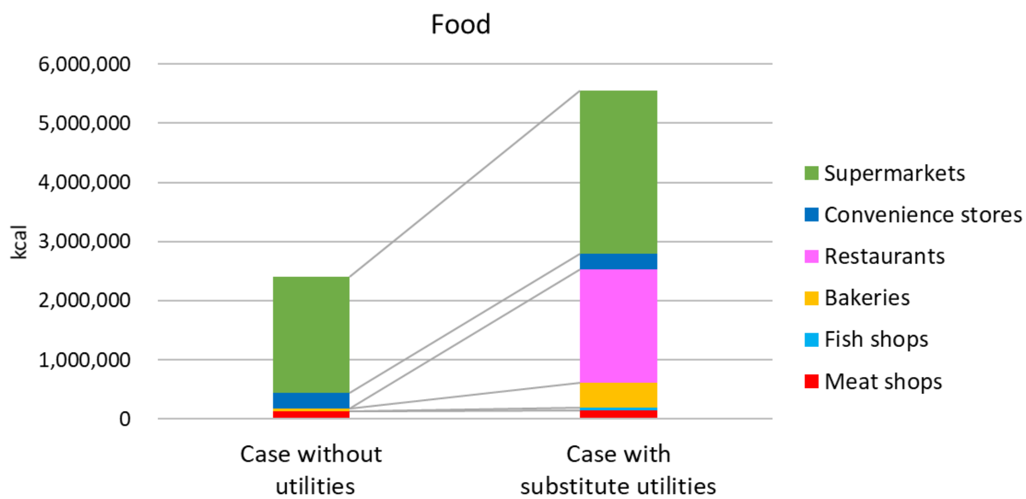

Figure 8: The breakdown of the total calories of available food (unit: kcal)

vacant space is required. This required space can be provided by the available vacant space (6,900 m^2) in the shopping street. In other words, the shopping street can accommodate everyone who receives food supplied from the shopping street.

In the case with substitute utilities, to accommodate 2,774 people who receive food from the shopping street, 8,322 m^2 (= 2,774 people × 3 m^2/person) of vacant space is required. The required space cannot be met by the available vacant space (6,900 m^2) in the shopping street. The shopping street, however, can accommodate 2,300 people (= 6,900 m^2 ÷ 3 m^2/person)—83% of people who receive food provided from the shopping street (2,300 people/2,774 people). Finally, 474 remaining people (2,774 people − 2,300 people) are assumed to stay in neighboring facilities (e.g., other designated shelters, large parking lots of parks in case of earthquakes, and the upper floors of tall public buildings in case of flood) where they can be accommodated, instead of the buildings of the shopping street.

In summary, the Taisho-Suji Shopping Street is highly likely to serve as an evacuation shelter for people who receive food supplied from the shopping street. That is, disaster-proof buildings with large vacant spaces can effectively complement the designated shelters. Our framework can contribute to using the unoccupied space efficiently and achieving one of the original purposes of constructing these buildings. The potential to serve as shelters

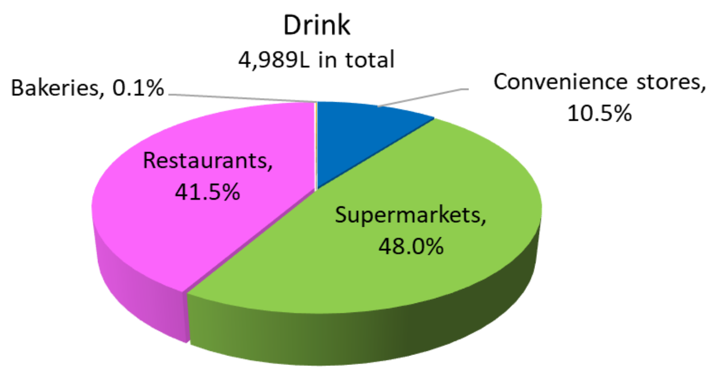

Figure 9: The breakdown of the total amount of available drink (unit: L)

would be increased if tents and thermal sheets, which enable evacuees to stay outside of the street or neighboring parks, are stockpiled in the unoccupied space of the shopping street.

6. Complementary measures and feasibility of implementation

This section explores the extensions and the development of our proposed framework. Subsection 6.1 shows the effectiveness of stockpiling the basic relief goods in unoccupied spaces of the shopping street to complement the shortage of the inventory; Subsection 6.2 illustrates the shopkeepers' acceptability of providing their inventory.

6.1. Stockpile of basic relief goods in vacant spaces of shopping street

Even if the evacuees who receive food from the shopping street stay in the vacant space of the shopping street in the case without utilities, the street still has 3,294 m^2 of the vacant space (6,900 m^2 of the total vacant space − 3,606 m^2 of the space required for the evacuees who receive food from the shopping street). We assume that this remaining space is used for stockpiling the basic relief goods—food (cookies), water, blankets, powdered milk, nursing bottles, sanitary goods, toilet papers, and others (Table 2)—to complement the store inventory (i.e., food for 1,202 people and drink for 1,663 people on the first day of disasters). This section estimates the amount of basic relief goods and the floor space needed for stockpiling. As a benchmark, we consider the stockpile of basic relief goods to ensure three days survival of all expected evacuees[6]. The second column of Table 2 shows the recipients of basic relief goods by the item. It indicates that the required amount of relief goods varies according to the number of each recipient (i.e., females, infants, and people in need of nursing care). We estimated the number of recipients among expected evacuees using the census data [59] and derived the required amount of basic relief goods. The details of the calculation are described in Appendix C.

As a result, we found that the total amount of basic relief goods required for the three-day survival of the expected evacuees is $335\,\mathrm{m}^3$ and the floor space required for the stockpile is $167\,\mathrm{m}^2$. The required area ($167\,\mathrm{m}^2$) is much smaller than the unoccupied space ($3{,}294\,\mathrm{m}^2$) in the shopping street. Thus, it is possible to store the basic relief goods in the vacant space of the shopping street for the case without utilities. Even if we stockpile the basic relief goods, $3{,}127\,\mathrm{m}^2$ ($= 3{,}294\,\mathrm{m}^2 - 167\,\mathrm{m}^2$) of vacant space is still available. Using this space, the shopping street can accommodate additional 1,042 people ($= 3{,}127\,\mathrm{m}^2 \div 3\,\mathrm{m}^2$/person). Hence, if the basic relief goods are stocked in the vacant space for the case without utilities, all expected evacuees can receive three days' worth of meals and 2,244 people ($=$ 1,202 people $+$ 1,042 people) can be accommodated there. The number of people accommodated accounts for 43% ($=$ 2,244 people $\div$ 5,219 people) of all expected evacuees. These findings imply that stockpiling the basic relief goods in shopping streets is highly effective if the utility outage is expected after a disaster.

6.2. Shopkeepers' acceptability

The amount and variety of available inventory increase as more shops cooperate in the provision. That is, the effectiveness of providing the inventory is enhanced by cooperation of each shop.

In the questionnaire survey, we asked whether each shop can accept the provision of their inventory during disasters. More specifically, we asked them "will your shop supply your inventory if efforts to provide the inventory for local evacuees are introduced in your community?" They were given the following choices: "provide the inventory for free," "provide for a fee," "conditionally provide," "not provide," "not sure," or "else." We also asked them to write any additional comments at the end of the questionnaire sheets.

[6] The number of days that should be ensured by the basic relief goods varies depending on the target area.

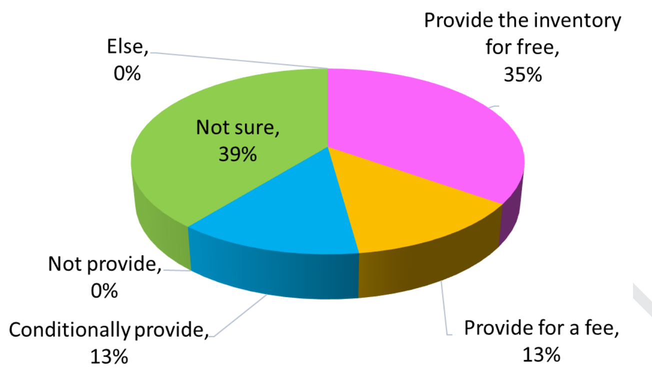

Figure 10: The breakdown of answers to the question on the possibility of supply of inventory ($n = 23$)

The results of the survey are summarized in Figure 10[7]. No shops answered "not provide" but approximately 60% of the samples selected either "provide the inventory for free," "provide for a fee," or "conditionally provides." In free-response questions, some shops expressed positive opinions; e.g., "our shop can be used as a kitchen and a shelter." Considering no disagreement with the provision of the inventory and the positive opinions, the cooperation of each shop for future implementation is highly expected. Some shops answered "conditionally provide" wrote "our shop will be able to supply under the cooperation with the local municipality," while others stated that "our shop can cooperate for a limited period after disasters." Based on such comments, the acceptability will be further enhanced if the concerns regarding the cooperation with the local municipalities and the period of supply are addressed.

[7]Some shops that did not answer the question regarding the inventory in Section 4 answered the question in this section. Including them, we received $n = 23$ responses in total.

7. Discussion

7.1. Relationship between the proposed framework and existing shelter planning efforts

The problems associated with evacuation shelters should be discussed along with those associated with the logistics of the disaster relief goods. Local governments in Japan have authorized “designated shelters” [26] that prioritize the protection of evacuees from disasters, and some of them are thus unequipped with emergency facilities such as water tanks and gas cylinders. Local governments plan the logistics of the distribution of relief goods, i.e., how to transport relief goods, which are stockpiled in warehouses, to the designated shelters. In large-scale disasters, local governments also procure relief goods from outside the locality, especially from the national government. They obtain water tanks and gas cylinders for unequipped shelters and arrange for volunteer staff in shelters, cooperating with other stakeholders such as non-governmental organizations. The government-led strategies in shelter and relief goods planning are the same as in many other countries [1, 2, 3].

However, government-led shelters are often unable to accommodate all the evacuees in large-scale disasters. As described in Section 1, some evacuees temporarily stay in the parking lots of parks—“undesignated shelters,” which also need relief goods delivery.

The framework proposed in this study complements the government-led planning efforts in societies such as Japan, in which the efforts are centered around the shelter and relief goods delivery planning. Hence, the results of this study—on the first day of a disaster, 1,202 people, i.e., approximately one-fourth of the expected evacuees, can receive food (Table 5) and stay (Subsection 5.2) in the shopping street even when there are no utilities, and the number increases when there are substitute utilities—imply that the shopping street has a sufficient complementary accommodation capacity.

In societies where the government-led policies are not dominant (i.e., local residents and communities are expected to take countermeasures autonomously), our framework plays a central role in community-based planning. In such cases, an increased supply of goods and a higher accommodation capacity are required. If Japan were such a society, our results would imply that the capacity of the studied shopping street was not large enough.

Furthermore, our concept can potentially revolutionize the conventional approach to the logistics of relief goods, which concentrates on how to transport the goods to the shelters [70, 71, 72, 73]. Our approach states that people should evacuate to local places where food exists beforehand. In our analysis, we did not consider the problem of undelivered goods caused by, for example, road closures. Moreover, if utilities are not collapsed in the disaster, we no longer have to arrange for water tanks or gas cylinders after a disaster. If we recognize the role of the shopping streets as shelters, long-term planning for disaster prevention should involve the redevelopment of existing shopping streets. In other words, long-term planning should focus on scaling up the shopping street by building disaster-proof buildings and enlarging markets driven by the larger use by the local residents in daily life. Thus, discussion on disaster logistics should shift its focus to improving the efficiency and stability of daily logistics.

7.2. Applicability of the shopping street concept to other regions and countries

As described in Subsection 2.4, our target shopping street in Nagata Ward, Kobe, Japan has a unique history—after it was severely damaged by the earthquake, it was transformed into the street with disaster-proof buildings, but it has many vacant shops. While we focus on such a unique street, our framework has a certain universality.

In recent years, not only Japan but also other countries have been experiencing a decline in traditional shopping streets [40]. Multi-functional large shopping malls are being constructed in the suburbs, which are mostly accessible by car. However, in terms of accessibility, shopping streets located in the center of towns and cities are considered more effective as evacuation shelters. As more vacant shops exist, the capacity to accommodate evacuees increases.

However, as more grocery shops and restaurants exist in shopping streets, a wider variety and larger amount of food and drink become available. Hence, shopping streets with many vacant shops have a lower capacity to serve as food distribution centers. In this sense, the capacity to accommodate evacuees and supply the inventory are negatively correlated. If shopping streets with many vacant shops are used as evacuation shelters, stockpiling the basic relief goods in vacant spaces is considered effective in the short term (Subsection 6.1). As an alternative, people should store food in their own houses and evacuate to the shelters with their goods. In the long term, if people expect the provision of the inventory from the shopping streets, they may go shopping there more regularly and the shopping street may flourish. If the consumption becomes larger, the inventory would also increase, which increases the supply of the inventory during disasters. To achieve such positive feedback, appropriate measures to prevent the free ride are required, which will be a topic of our future work.

Large shopping malls with good accessibility also have the potential to become temporary evacuation shelters. In fact, local residents evacuated to an accessible shopping mall to protect themselves from Cyclone Yasi, which struck Australia in 2011 [74]. Since convenience stores and supermarkets stock a large amount of goods (Figures 8 and 9), large shopping malls with many shops have the potential to supply a large amount of food and drink. Although malls may have less vacant shops, they have large open spaces such as rest areas, which can be utilized during disasters. In summary, shopping malls located in the center of towns and cities or near residential areas have the potential to work as both temporary shelters and food distribution centers. Unlike shopping streets, a shopping mall is generally owned and managed by one company and thus the management of the shelter is a topic to be discussed in future work.

7.3. Required data and possible extensions for more accurate estimation

To estimate the average inventory, this study applied a method with an emphasis on simplicity. In this method, if the name of each food and drink item and their amount Q delivered per order are identified, the average inventory is estimated to be $Q/2$. The method, however, heavily depends on the sawtooth model (Figure 6) with the assumption that the inventory is consumed constantly and replenished as soon as it runs out. This assumption is valid for convenience stores. They are open 24 h a day all year and immediately after the inventory runs out, the item is expected to be delivered. Thus, estimations for the convenience stores are considered relatively accurate. However, the estimation becomes relatively inaccurate if the shops receive items at different times, if they are open during limited hours, or they have a safety stock. For example, consider the case in which a shop have a safety stock in the amount of Q_0 (Figure 11). Then, the item (Q) is delivered to the shop when it opens (9:00 a.m.) and it is completely consumed when it is closed (9:00 p.m.) on the same day. In this case, the average inventory between the orders, including the hours the shop is closed and disasters may occur, is $Q_0 + Q/4$. This is equal to the amount estimated using our estimation method (i.e., $Q/2$) if the amount of the safety stock is $Q_0 = Q/4$. Otherwise, $Q_0 + Q/4$ is unequal to $Q/2$. Another case in which the shops order the items once in several days also demonstrates the difference in the

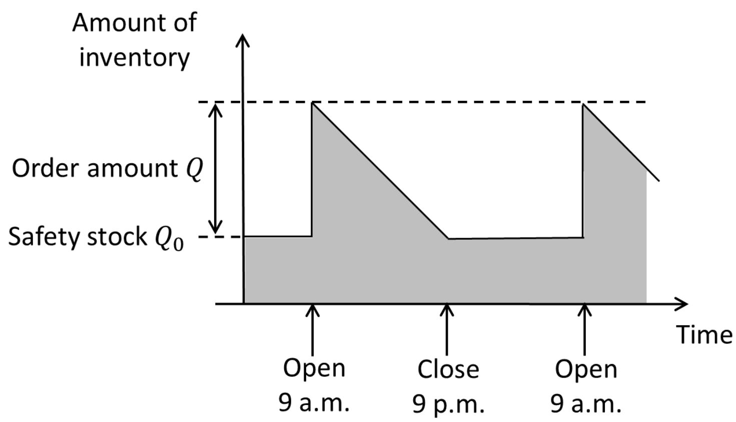

Figure 11: Different patterns of arrival and reduction of inventory from that in Figure 6

average inventory. In this case, since a large number of items are stocked for several days, the inventory becomes larger during closing hours than that of the shops that order the items once a day. The average inventory supplied by the entire shopping street can also vary if the timing of the order is different for each shop or if some shops are open 24 h a day while others are not. Overall, the average inventory depends on the timing of the order and the amount of the safety stock for each shop and calculating those values is crucial for a more accurate estimation.

Estimation for the responding shops should be further improved in the future. For example, we requested bakeries and restaurants to only list their five best selling products and menus (Sub-subsection 4.3.2) to reduce the burden of listing all of them. Although using only the top five products is sufficient for the estimation because a small number of products generally occupy a large volume of sales, considering all the products would lead to a more accurate estimation. Therefore, the collection of detailed product and menu information should be improved in the future.

Estimations for the non-responding shops should also be improved in future work. In this study, we estimated the amount of supply from non-responding meat shops, fish shops, and restaurants, using the data of the responding shops. More specifically, using the data obtained from the responding shops, we calculated the "average supply per area (unit: kcal/m^2 and L/m^2)" for each type of business. Subsequently, by multiplying it by the floor space of the non-responding shops, we estimated the supply from the non-responding shops. This calculation, however, did not consider the differences in the menus of the restaurants. The study area includes a variety of restaurants such as cafes, Chinese restaurants, and Japanese restaurants. If the menu is largely different for each restaurant, provided calories per area can significantly vary and consequently, the estimation becomes less accurate. Future work should (1) divide the restaurants into different categories (e.g., cafes, Chinese restaurants, Japanese restaurants, etc.) and estimate the supply from the non-responding restaurants by category or (2) develop an index associated with the variation in the supply from each restaurant. Although this study used a simple method because of the small sample size, future work should use more advanced statistical methods depending on the sample size. The relationship between the supply from each shop and their floor space and other shop attributes will help us identify the amount of supply from the non-responding shops more accurately.

Since we received no response from convenience stores and supermarkets on their inventory, we used public databases provided by the government and the related associations. In calculating the food calories, we used the calorie value of representative items included in each category (e.g., “staple food” and “discretionary food”), but we ignored the variation in the calories per item within each category. If the variation becomes larger, the estimation becomes inaccurate. Future work should identify the variation in the calorie value per item using the survey results and develop an index that considers that variation.

The damage to the inventory caused by disasters should also be explored in future work. Since this study targeted a shopping street with disaster-proof buildings, catastrophic damage to buildings and the inventory is less expected. However, if large earthquakes occur, some overhead merchandise may fall and be unavailable to eat. The investigation of the failure rate of the inventory against the impacts of hazards will improve the estimation as it considers the potential decrease in supply.

The diversity and special characteristics of evacuees should be considered further. To calculate the amount of inventory in units of person-days, we assumed that one person needs 2,000 kcal per day, i.e., the average required calories for people who are one-year old or older [56]. Nevertheless, the required calories vary between infants, elderly people, people in need of nursing care, and other physically handicapped people. If we consider population composition and use the required calories for each group, more accurate estimations can be obtained. In addition to the required calories, the food allergy problem should be considered [75]. Since it is difficult to collect data from all allergy sufferers in the community, the allergen information of the store inventory should be revealed to provide the allergy sufferers necessary nutrients.

Extensions according to seasons, climate, and community characteristics are also key in wide applications. In the case without utilities, we did not consider the supply of fresh food such as vegetables and raw fish and meat (Table 4) because of the hygiene concerns; however, some vegetables can be eaten raw and are in season only during a certain period of time. Therefore, the availability of such food can increase the supply at the time of disasters. In addition, in some communities, a certain number of shopkeepers and employees reside outside of the community. If, in such communities, the disaster occurs during the nighttime (i.e., the time when many shops are closed), shops whose owners and employees live in the community will play a central role in the provision of the inventory. Inventory calculations for daytime and nighttime conditions are important to proceed with our framework.

Finally, the method to calculate the capacity to accommodate the evacuees can still be improved. In this study, we assumed that all empty spaces are used exclusively for personal spaces in which evacuees can sit and lie down (Subsection 5.2) and for stockpiling of basic relief goods (Subsection 6.1) to derive the number of evacuees to be accommodated. Future work should focus on other types of space usage (e.g., walking space, space of working desks for checking the presence and health conditions of evacuees, and prayer space) for more accurate estimation. The capacity to accommodate evacuees would also be restricted by the number of toilets and bathroom sinks, and not only by the floor space. Future work should also determine the number of available permanent toilets in the targeted buildings and that of the temporary toilets available at the time of the disaster.

8. Conclusion

Thus far, the distribution of relief goods to evacuation shelters from the outside after large-scale disasters has been intensively studied. Those goods, however, often fail to reach the destinations due to problems such as the road network failure. Therefore, we proposed a framework to use local disaster-proof buildings with pre-existing food supplies as evacuation shelters. More specifically, this study focused on the potential of shopping streets to provide local people with food and drink, stocked as inventory, in the aftermath of disasters. The use of the disaster-proof buildings as temporary evacuation shelters was also considered. Our framework contributes to the understanding that local people can evacuate to the disaster-proof shelters and receive the disaster relief goods—the store inventory—on-site. To quantitatively examine the proposed framework, we developed a simple calculation method to estimate the amount of inventory and the floor space required to accommodate evacuees. Our method was applied to a shopping street in Nagata Ward, Kobe, Japan. We found that the total amount of food supplied by shops and restaurants is for 1,202 person-days in the case without electricity, gas, and water supply and 2,774 person-days in the case with substitute utilities. These results mean that the meals of 23% and 53% of expected evacuees required on the first day after the disaster can be met in the case without utilities and with substitute utilities, respectively. We also showed that almost all the evacuees who receive food supplied from the shopping street can be accommodated there. Additionally, we illustrated the effectiveness of stockpiling the basic relief goods in the case without utilities and the high shopkeepers' acceptability of provision of inventory. We discussed the applicability of our method to estimate the average inventory as well as the future directions to improve the method.

Our final goal is to implement this framework in practical applications. Our survey showed that a large proportion of shops and restaurants are willing to cooperate in the provision of their inventory. Some positive opinions are likely based on the altruism of shopkeepers. Mutual help based on altruism is widely observed regardless of the socio-cultural background [76] and thus our framework has the potential to be implemented throughout the world. Meanwhile, others may expect a long-term return from local residents. During the failure of the water supply system after the Great Hanshin-Awaji Earthquake, a market located near the targeted street had well water and supplied it to local residents. Next, some of those residents started to go shopping in the market. In other words, people who had been helped started to vitalize the market in the long run [12, 77]. This example implies the possibility of a long-term return from the local residents. The ways to collaborate for future implementation should be developed through action research, which is the topic of future work.

The shopping arcade is a commercial format, which is commonly found all around the world [40], and thus our case study is applicable to the shopping streets in other countries. In addition, using our framework, the roles of large shopping malls and supermarkets close to the residential areas can be studied. Meanwhile, many issues remain to be addressed. (1) The number of available tableware and kitchens in the restaurants and supermarkets should be investigated [75]; the stockpile of tableware as relief goods should also be considered. (2) The availability of substitute utilities should be explored; i.e., the number of available gas cylinders and well water should be determined. (3) In the implementation stage, many issues regarding multi-stakeholder coordination should be tackled. The issues would include the allotment of people between the shopping street and the original designated shelter, and the assignment of roles necessary for the shelter management. To help local people comprehend the proposed framework, the local government may need to mediate the communication.

Acknowledgement

We are deeply grateful to Shin Nagata Town Management Company Ltd. and its former president, Masayuki Shishida, for the kind support extended towards the survey. Furthermore, we express our special thanks to the shops in Nagata Ward, Kobe, Japan. This work was partly supported by JSPS KAKENHI (Grant No. 16K06537 and 18K13845).

Appendix A. Calculation methods for the amount of inventory in meat shops, fish shops, bakeries, and restaurants

Here, we present the details of the methods to estimate the available food and drink supplied from meat shops, fish shops, bakeries, and restaurants.

Appendix A.1. Responding shops

First, we focus on the shops that responded to the questions on their inventory.

Appendix A.1.1. Food

Meat shops and fish shops. The steps to estimate the calories (unit: kcal) of food supplied from meat shops and fish shops are described as follows.

(1) Evaluate whether the named food item is suitable for eating raw.
We asked each shop to give the “name” of each item they order. Through the answers, we can identify the name of each item that constitutes the inventory. If the item is suitable for raw consumption, it is

assumed to be supplied even in the case without utilities. For example, if "ham" is the ordered item, then it is assumed to be available even in the case without utilities because it can be eaten without cooking.

(2) Calculate the average inventory (unit: kg).
Regarding each item in (1), the "amount of the item arrived per order (unit: kg)" was also asked. Consequently, we can identify the amount as Q kg. In the sawtooth model (Figure 6), we derive the average inventory as $Q/2$ kg. For example, if "6 kg of ham is delivered per order" is stated, the average inventory is calculated to be 3 kg.

(3) Estimate the calories (unit: kcal) of the average inventory (unit: kg).
By using calorie calculators [52, 53, 55], the average inventory (i.e., $Q/2$ kg) is converted to calories (unit: kcal). For example, ham has 196 kcal per 100 g [52] and thus the average inventory (i.e., 3 kg) is equivalent to 5,880 kcal (= 3 kg × 196/0.1 kcal/kg).

Bakeries. The steps to calculate the calories (unit: kcal) supplied from bakeries in the case without utilities are as follows.

(1) Calculate the average amount of products displayed (unit: piece).
In the survey, we asked each bakery "how much (unit: piece) does your shop display each of your top five products at a time ?" Consequently, we can identify the amount of each product per display as Q pieces. Using the sawtooth model, we can estimate the average amount of each product displayed until it runs out as $Q/2$ pieces. For example, one of the top selling products and its amount per display are "red bean bun" and "60 pieces," respectively; thus, we can identify the average amount of product displayed until it runs out as 30 pieces. This calculation method was applied to each product identified as five best-selling products.

(2) Estimate the calories (unit: kcal) of the average amount of each product displayed (unit: piece).
Using calorie calculators [54, 55], we can convert the average amount of each product displayed until it runs out (i.e., $Q/2$ pieces) into calories (unit: kcal). For example, the calories of a "red bean bun" is 280 kcal [55] and thus the average calories of the displayed amount are estimated at 8,400 kcal (= 30 pieces × 280 kcal/piece).

The methods to estimate the calories (unit: kcal) supplied in the case with substitute utilities are shown as follows.

(1) Calculate the average amount of ingredients in the inventory (unit: d). In the survey, we asked each bakery "how many days does your shop use the ingredients purchased per order?" The answer to this question allows us to identify that the shop purchases the ingredients so that it can sell the products for Q d. In the sawtooth model, the average amount of ingredients is for sale for $Q/2$ d. In other words, we assume that the shop can sell the products for $Q/2$ d, cooking the ingredients purchased per order. For example, if a bakery purchases the ingredients for a "four-day" sale in an order, the average amount of ingredients is for a two-day sale; thus, the bakery can provide the products for two days, cooking the average amount of ingredients.

(2) Calculate the amount of products (unit: piece) made from the average amount of ingredients (unit: d).
In the survey, we asked each shop about "the average sales amount of five best-selling products (unit: piece) in a day." We identified the average amount R (unit: piece) of each best-selling product in a day. Hence, by cooking the average amount of ingredients for a $Q/2$-d sale, which was derived in (1), the shop can provide $R \cdot Q/2$ pieces of each product in the case with substitute utilities. For example, if "100 pieces" of red bean buns are sold in a day on average, by cooking the ingredients equivalent to a two-day sale, the shop can serve 200 pieces (= 100 pieces × 2-d sale) of red bean buns.

(3) Estimate the calories (unit: kcal) of the amount of each product (unit: piece) made from the average amount of ingredients.
Using calorie calculators [54, 55], we can estimate the calories (unit: kcal) of the amount $R \cdot Q/2$ (unit: piece) of each product.

Appendix A.1.2. Drink

Here, we describe the methods to estimate the average amount of available drinks (unit: L). We asked each shop to give the "name" of each drink item it orders and the "amount Q of each item delivered per order (unit: L)." Using the answers, the average amount of each stocked item is estimated at $Q/2$ L in the sawtooth model. For example, if "6 L" of "bottled water" is delivered in an order, the average inventory is derived as 3 L. The calculation for each item sold by each shop allows us to estimate the total amount (unit: L) of drinks supplied from the shopping street.

Table A.6: Average amount of available food and drink that meat shops, fish shops, and restaurants provide

Type of business	Food (unit: kcal/m^2)		Drink (unit: L/m^2)
	Case without utilities	Case without substitute utilities	
Meat shops	1,708	1,750	0
Fish shops	0	147	0
Restaurants	-	457	0.52

Appendix A.2. Non-responding shops

Next, we focus on the non-responding shops.

(1) Using the data from the responding shops, calculate the average amount of food and drink supply per unit area (unit: kcal/m^2 and L/m^2, respectively) by the type of business.
As we conducted the door-to-door survey, we were able to identify the shops that responded to the questionnaire. In addition, we determined the floor space of each shop via the floor plan of buildings. Therefore, we could identify the floor space (unit: m^2) of each responding shop. Using the floor space of each responding shop as well as the results of total calories of food (unit: kcal) and the total amount of drinks (unit: L) supplied from each responding shop as derived in Appendix A.1, we can derive the "calories of food and the amount of drink per unit area (unit: kcal/m^2 and L/m^2, respectively)" supplied from each responding shop in the case without utilities and that with substitute utilities, respectively. The average by business type is taken and the results are listed in Table A.6.

(2) Estimate the calories (unit: kcal) of food and the amount (unit: L) of drinks supplied by the non-responding shops by floor space.
Using the floor plan, we can identify the floor space (unit: m^2) of each non-responding shop. Thus, by multiplying it by the average calories of food and the average amount of drinks per unit area (unit: kcal/m^2 and L/m^2, respectively) of the type of business that the non-responding

shop belongs to, we can obtain the amount of food and drink supplied by each non-responding shop (unit: kcal and L, respectively). For example, given that the floor space of non-responding restaurant A is $100\,\mathrm{m}^2$, as Table A.6 shows, the average supply of food and drink per unit area for a restaurant is $457\,\mathrm{kcal/m}^2$ (in the case with substitute utilities) and $0.52\ \mathrm{L/m}^2$, respectively. Therefore, restaurant A is estimated to serve 45,700 kcal ($= 457\ \mathrm{kcal/m}^2 \times\ 100\,\mathrm{m}^2$) of food and 52 L ($= 0.52\,\mathrm{L/m}^2 \times\ 100\,\mathrm{m}^2$) of drink.

Appendix B. Calculation methods for the amount of inventory in convenience stores and supermarkets

We describe the details of the estimation of the amount of each category of items (unit: kcal and L) supplied from convenience stores and supermarkets.

Appendix B.1. Convenience stores

The following steps present the method to estimate the calories (unit: kcal) of each "staple food" and "discretionary food" and the amount (unit: L) of each "refreshing drink" and "milk beverage" supplied from a convenience store.

(1) Derive the price of the average inventory (unit: yen) from the price of the total amount of each category delivered per order (unit: yen).
In the sawtooth model (Figure 6), the price of the total amount of each category of items per order, denoted by R yen, is equivalent to the "consumption between orders (unit: yen)" of each category. It is approximated by multiplying three factors together: (I) "the period between orders (unit: h)," (II) "the average number of customers during the period between orders (unit: people/h required between orders)," and (III) "the average purchase value of each category of items per customer (unit: yen/person)." These three values are identified as follows:

(I) The period between orders
This value is identified if the frequency of the order of each category of items is identified. Based on the previous studies [67, 68], the frequency is determined as listed in the second row of Table B.7. For example, as the frequency of the order of "staple food" is "three times per day," the period between orders is determined as "8 h" ($= 24\,\mathrm{h} \div 3\,\mathrm{times/d}$).

(II) The average number of customers during the period between orders
This index is estimated via the "national average number of customers in a day per store," which is derived as "the total number of customers in a year for all stores in Japan" [63] ÷ "the number of all stores in the country" [63] ÷ "365 d."

(III) The average purchase value of each category of items per customer
This index is approximated by multiplying three factors together: (i) "the average sales amount per customer," (ii) "the proportion of the purchase value of food and drinks to the total purchase value," and (iii) "the proportion of the purchase value of each category to the purchase value of food and drink." These three indices are identified as follows:

(i) The average sales amount per customer
This value is derived from public databases ("the national average sales amount per customer" [63]) .

(ii) The proportion of the purchase value of food and drink to the total purchase value
This index is equivalent to the proportion of "the total sales of food and drink" [64] to "the total sales of merchandise and service" [64] for all convenience stores.

(iii) The proportion of the purchase value of each category to the purchase value of food and drink
This index is estimated from the data on the purchase value of each category of food and drink for a customer in a year [65].

Based on these data and methods, the price of the total amount of each category of items delivered per order, R yen, is derived. Accordingly, the price of the average inventory is estimated to be $R/2$ yen using the sawtooth model.

(2) Estimate the average inventory (unit: piece, bottle) from its price (unit: yen).
One representative item is picked from each category. Given the small variation in the prices of the items in each category, we estimate the average inventory of each category (unit: piece or bottle) from its price ($R/2$ yen) using the unit price p (unit: yen/piece or yen/bottle) of the representative item. In other words, the average inventory of each category is derived as $(R/2)/p$ (unit: piece or bottle). In this study, representative items and unit prices p are specified as shown in the third and fourth rows of Table B.7, respectively.

(3) Convert the average inventory (unit: piece, bottle) into calories (unit: kcal) and liters (unit: L).
Regarding food, given the small variation in the calories of items in each category, we estimate the calories (unit: kcal) of the average inventory (i.e., $(R/2)/p$ pieces) of each category using the calories per representative item (i.e., k kcal/piece). In other words, the calories of the average inventory of each category are estimated at $((R/2)/p) \cdot k\,\mathrm{kcal}$. Similarly, regarding drinks, we convert the average inventory (i.e., $(R/2)/p$ bottles) of each category into liters (unit: L) using the volume of a bottle of the representative item (i.e., l L/bottle). That is, the amount of the average inventory becomes $((R/2)/p) \cdot l\,\mathrm{L}$. In this study, we specified the values of k kcal/piece [55] and l L/bottle as listed in the fifth row of Table B.7.

Using this procedure, we identified the calories (unit: kcal) of each "staple food" and "discretionary food" and the amount (unit: L) of each "refreshing drink" and "milk beverage" supplied from a convenience store as listed in the last row of Table B.7.

Table B.7: Data used for estimating the amount of available food and drink stocked in a convenience store

	Staple food	Discretionary food	Refreshing drink	Milk beverage
Frequency of order	3 times/d	3 times/wk	3 times/wk	3 times/d
Representative item in each category	Rice ball	Chocolate	500 ml of bottled water	200 ml of milk
Unit price of the representative item (p yen)	150	120	130	120
Calories or liters of the representative item (k kcal/piece or l L/bottle)	173 kcal/piece	279 kcal/piece	0.5 L/bottle	0.2 L/bottle
Calories or amount of total supply	21,455 kcal	212,510 kcal	270,017 L	4,190 L

Appendix B.2. Supermarkets

We describe the methods to estimate the calories (unit: kcal) of each category of food—"staple food," "discretionary food," "vegetable and fruit," "meat," and "fish"—and the amount (unit: L) of each category of drink—"refreshing drink" and "milk beverage"—available from a supermarket. The steps of estimation are almost the same as those described for convenience stores. Differences include the following: (A) different databases are used. (B) "Vegetable and fruit," "meat," and "fish" can be additionally supplied even in the case without utilities. In the following, we only present the steps that are different from those for convenience stores.

(1) Derive the price of average inventory (unit: yen) from the price of total amount of each category delivered per order (unit: yen).
   (I) The period between orders
   Based on a previous study [69] and the results of our survey with meat and fish shops, the period between the orders for each category is specified as the second row of Table B.8. The period for "staple food" is specified as "once per day"; the periods for "discretionary food," "refreshing drink," and "milk beverage" are specified as the same values as listed in the second row of Table B.7.
   (II) The average number of customers during the period between orders
   This value is estimated from the average number of customers per day for each supermarket according to its floor space [66]. Therefore, we can identify the average number of customers per day for each supermarket in the shopping street. Consequently, we can estimate the average number of customers during the period between orders.
   (III) The average purchase value of each category per customer
      (i) The average sales amount per customer
      This value by the floor space of supermarkets is obtained from the public database [66].
      (ii) The proportion of the purchase value of food and drink to the total purchase value
      This value by the floor space is available from the public database [66].

(iii) The proportion of the purchase value of each category to the purchase value of food and drink
This value per customer is acquired from public databases [65, 66].

(2) Estimate the average inventory (unit: pack, piece, bottle) using its price (unit: yen).
The name and price of each representative item of "vegetable and fruit," "meat," and "fish" are demonstrated in the third and fourth rows of Table B.8, respectively. The name and price of a representative item of "staple food," "discretionary food," "refreshing drink," and "milk beverage" are shown in the third and fourth rows of Table B.7, respectively.

(3) Convert the average inventory (unit: pack, piece, bottle) into calories (unit: kcal) and liters (unit: L).
Regarding "vegetable and fruit," "meat," and "fish," the calories per representative item (i.e., k kcal/pack or kcal/piece) are listed in the fifth row of Table B.8. Regarding other categories—"staple food," "discretionary food," "refreshing drink," and "milk beverage"—the same k kcal/piece and l L/bottle are used as described in the fifth row of Table B.7.

Table B.8: Data used for estimating the amount of available food and drink stocked in a supermarket

	Vegetable and fruit	Meat	Fish
Frequency of order	once/d	once/d	once/d
Representative items	A cabbage	A pack of beef shoulder chops (100 g)	A horse mackerel
Unit price of the representative item (p yen)	250	400	279
Calories of the representative item (k kcal/piece or kcal/pack)	230	201	54

Appendix C. Calculation methods for the required amount of basic relief goods and the floor space for stockpiling

Here, we describe the methods to estimate the required amount of basic relief goods and the floor space to stockpile them.

Appendix C.1. Number of recipients of each item in basic relief goods

To estimate the required amount of basic relief goods, the number of recipients of each item that constitutes the goods should be identified. Based on our previous study [49], we assume the recipients of each item as listed in the second column of Table 2. As the table shows, the sanitary goods are provided for females; powdered milk, nursing bottles, heat pads, diapers, and partition walls are for infants; diapers and partition walls are for people in need of nursing care; the rest of the items are for everyone. As the bathroom habits are different for females and males, the required number of bathroom supplies (i.e., toilet papers, toilet bags, and bags for toilet bags) are also different. Thus, we also need to determine the number of males. The method to identify the number of recipients of each item (i.e., males, females, infants, and people in need of nursing care) is shown below.

We denote the number of expected evacuees in the study area as N. We also denote the number of males and females as N_m and N_f, respectively—$N = N_m + N_f$. N, N_m, and N_f are determined as the number of residents, males, and females who live in the target area, respectively, using the census data [59].

The number of infants and people in need of nursing care are denoted by N_b and N_c, respectively. The number of infants, N_b, is approximately determined by the "number of 0- to -4-year-old children" in the census data. According to Ito et al. [49], the number of people in need of nursing care occupies 0.5% of the entire population on the national average. Thus, the number of people in need of nursing care, N_c, is estimated as $N_c = N \cdot (0.5/100)$.

This procedure was applied to our case study area. As a result, the total number of expected evacuees was $N = 5{,}219$; the number of males and females among them was $N_m = 2{,}388$ and $N_f = 2{,}831$, respectively; that of infants and people in need of nursing care was $N_b = 184$ and $N_c = 26$, respectively.

Appendix C.2. Required floor space to stockpile basic relief goods

After calculating the number of recipients of each item, we can estimate the amount of basic relief goods to ensure their survival for a certain period, denoted by $V\,\mathrm{m}^3$, following Ito et al. [49]. To estimate the number of portable toilets, we need to determine the number of Japanese style toilets that are available even in the aftermath of disasters. (In our case study, 20 Japanese style toilets were assumed to be available in the shopping street.)

The required floor space for basic relief goods, denoted by $A\,\mathrm{m}^2$, is calculated as $A = V/2$, given that the height of the stockpile is $2\,\mathrm{m}$ [49]. (The height of stockpile varies for each shopping street; e.g., it depends on the height of the vacant space and the height of people who manage the shelter.)

Applying these methods to our case study, we obtained $V = 335\,\mathrm{m}^3$ and $A = 167\,\mathrm{m}^2$ as the required amount of basic relief goods and the floor space for stockpiling, respectively.

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