Accessibility and Availability Analysis of Temporary Fueling Sites in Rikuzentakata-City

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Abstract

Gas Stations are essential facilities in emergency situations for residents and rescuers. They were damaged in Tohoku region by the Great East Japan Earthquake in March 11th, 2011, and stopped gasoline supply. In Rikuzentakata-city, Iwate prefecture, all of its gas stations suspended sales, and the availability of gasoline by its residents significantly decreased. In response to the critical situation, the Ministry of Economy, Trade and Industry approved establishment of temporary fueling sites by using drums at shelters such as schools in affected areas where gas stations did not function sufficiently and gasoline supply was especially difficult. In the areas, rules were also established, for example, limit on the amount of refueling, distribution of numbered tickets, and giving priority to emergency vehicle refueling, due to insufficient supply of gasoline.

The temporary fueling sites started gasoline supply at five shelters in Rikuzentakata-city on March 27th. It is pointed out that this establishment recovered the availability of gas stations. However, no quantitative analysis has been conducted in terms of the effect of the establishment, though such analysis would give useful information for relief and reconstruction from future earthquakes. In order to fill this research gap, this study analyzed the effect of the establishment of temporary fueling sites in terms of the accessibility and availability by the following steps:

1) to obtain the locations of the residents in evacuated situation as well as the locations of temporary fueling sites and their performance of gasoline supply;
2) to measure the road distance between the residents and the temporary fueling sites by Network Analysis on GIS;
3) to quantify the accessibility and availability of the temporary fueling sites by considering the distance and the performance.

Keywords: gas station; GIS; network analysis; Sanriku coast; Great East Japan Earthquake

1. Introduction

The purpose of this study is to evaluate the effect of establishment of temporary fueling sites on Rikuzentakata-city in Iwate prefecture damaged by the Great East Japan Earthquake in March 11th, 2011.

1.1. Background

The Great East Japan Earthquake in March 11th, 2011 caused great tsunami disaster widely in coastal areas from Tohoku region to Kanto region. The power of the tsunami was terrible, and the tsunami swallowed every building including houses. The tsunami also damaged gas stations, which are indispensable fueling bases for vehicles. Therefore, the suffering of the gas station became a rigid limitation of every traffic action including transportation of relief supplies and staff, and the life action of local inhabitants in the turbulent period after the earthquake. The gas stations were among the facilities of which the earliest restoration was demanded.

In Rikuzentakata-city, which is the subject area of this study, all gas stations were swallowed by the tsunami and stopped gasoline supply, because all of them were in the main area of the city, which was severely damaged by the tsunami. The Agency for Natural Resource and Energy, abbreviated as ANRE, of the Ministry of Economy, Trade and Industry, abbreviated as METI, took this situation severely and installed temporary fueling sites in five places of the city.

The temporary fueling sites are equipped with temporary simple lubrication system to supply gasoline in an area where gasoline supply becomes

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short by the disappearance of the gas stations. In the city, they were placed close to the shelter sites for disaster victims. The temporary fueling sites operated until the end of May 2011 and substituted local gas stations until their restoration.

1.2. Purpose

Temporary fueling sites were first established in Rikuzentakata-city, and installed in other coastal area one after another. The sites were located in the place of emergency shelters such as school grounds. However, because it was an emergency, their locations were not necessarily determined quantitatively from the viewpoint of optimizing the accessibility of local inhabitants. Rather the priority of the optimum location is low because the demand for early restoration is stronger in such a turbulent period. Therefore, based on a given location, it becomes important how we control supply and demand to improve accessibility and availability.

The purpose of the recent study by the authors is to develop methods to improve accessibility and availability of facilities by the control of supply and demand. This article pays attention to how accessibility and availability are improved by the control of the supply. Particularly, this article intends to examine difference between the accessibility in the cases that gasoline is distributed equally five facilities and that in the case that supply of the gasoline doubles in one site and becomes three-fourth in the remaining four sites.

1.3. Significance

There are some research on gas station in an emergency including Oil Information Center[1], Horikawa[2] and Ueda[3]. In contrast, there are only a few papers that have analyzed the accessibility of residents to the gas stations except for Sadahiro[4], ANRE[5] and Sanuki[6]. Particularly, no quantitative analysis has been conducted in terms of the accessibility and availability of residents to the gas stations assuming that gas stations have the limit of gasoline supply, though such analysis would be a practical study for the emergency when outbreak of huge demand is expected, and also would give useful piece of information for relief and reconstruction from future earthquakes.

The previous study by the authors to analyze accessibility to gas stations has the following two remaining problems:

1) to incorporate the capacity of facilities in the model;
2) to control supply for the facilities of which the location are fixed for the purpose of efficiency of access and of facility use.

It is the significance and the original approach of the current study to work on those problems. This study forms the first steps of the study to lead to the most suitable distribution when we can control the distribution given the total supply in all facilities.

2. Methods

2.1. Study area, cars, facilities and road network

The study area is whole Rikuzentakata-city shown in Figure 1. The city is located in the rias coast area of Sanriku District, and its population is a little less than 20,000. The target facilities are temporary fueling sites installed in five places of the city. We acquired the location and quantity of refueling results of temporary fueling sites in the city from an announcement document of ANRE[7].

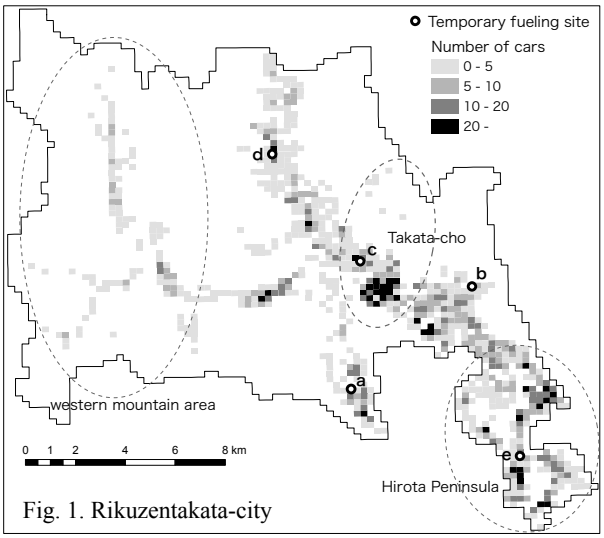

Fig. 1. Rikuzentakata-city

Part of gas stations in Ofunato-city, Iwate prefecture and Kesennuma-city, Miyagi prefecture which are adjacent to Rikuzentakata-city avoided suffering, and were able to open. However, it was difficult for the inhabitants of Rikuzentakata-city to access those facilities. Thus this study assumed that the inhabitants of Rikuzentakata-city used only the temporary fueling sites in the city for simpleness and easiness of the simulation. It also assumed that the inhabitants out of Rikuzentakata-city did not use the sites within the city for the same reason.

The locations and the number of the cars as the demand side were determined based on the distribution of buildings. The detailed process is as follows:

1) the numbers of the households in subregions were obtained from the national census in 2010;
2) the households were allocated to each building in proportion to the projection area of the building obtained from the building data in the fundamental geospatial data published by Geospatial Information Authority of Japan, abbreviated as GSI;
3) the average number of the privately-owned cars per household in Rikuzentakata-city is given by dividing the number of car in March, 2011 published by Tohoku Department of

Transportation of the Ministry of Land, Infrastructure and Transport by the total number of households;
4) the car number of each building is given by multiplying the average number of the privately-owned cars per household and the number of households in the building together;
5) the cars which overlapped with the tsunami inundation area given by Tani[8] were removed.

From the above-mentioned process the car location spots outside the tsunami inundation area were obtained, which give the demand points for this analysis. The residual oil rate of the tank of each car is assumed to be uniformly distributed between 0% and 100%, and half of the cars, which have residual oil rates less than 50%, are assumed to go to the temporary fueling sites.

We built road network data more than 3 meters of width by revising the road centerline data of the digital map 25,000 in 2002 published by GSI using road information on January, 2011. Collapse of two bridges, Kesen-Ohashi and Aneha-Ohashi, by the tsunami was reflected in the network.

2.2. Assumption on the behavior pattern

The temporary fueling sites in Rikuzentakata-city were run by a system that the local government distributed numbered tickets which appointed the refueling day and place. The car of the person who brought the ticket was refueled. This means that the facility for each customer was determined beforehand. Because no information about how the tickets were distributed is available, this study assumed the following condition:

A) every person was permitted to refuel only once;
B) cars near to the facilities took priority for refuleing;
C) refueling of the day was finished when oil stock of each facility became zero;
D) oil stock of every facility was restored on every morning.

3. Analysis

3.1. Accessibility and availability when the numbers of refueling cars are equal

3.1.1. Assumption

This section examines the accessibility and availability of inhabitants to facilities reflecting supply of the temporary fueling sites per day.

METI announced[7] that the number of the refueling cars at the five sites was 650 per day. Using the distribution of demand given in chapters 2, this study simulated the refueling of inhabitants by assuming the following three conditions:

1) the gasoline supply assigned to the five sites were equal;
2) if the nearest facility was unavailable, the inhabitants checked whether the next nearest facility was available repeatedly;
3) the cars which were not refueled because of oil stock shortage followed the same steps on the next day.

This study calculates two indexes, site ranks and day ranks, for evaluating the accessibility and availability in addition to distances. Site ranks show the maximum number of checked sites by cars. Day ranks show the maximum days needed for refueling by cars.

3.1.2. Results

The number of the cars accessible to the sites within 1 km was 488, which was 10.5% of the whole as shown in Figure 2. The number between 1 and 2 km was 1,456, 31.2%. The cars which were forced to travel more than 10 km amounted to 597, 12.8%, which is relatively a small number but cannot be ignored.

Figure 8 illustrates the distance distribution on the city map. The color of each grid of the figure shows the maximum distance to the site from each building representing the location of the cars within the quarter square grid of the standard grid square system by Japanese Government. Naturally, the inhabitants in the central city located in the center of the map can access in a short distance because temporary fueling sites exist nearby. Long distance movements more than 10 km are necessary in the western mountain district, and the distance exceeds 20 km in the westernmost grid. Some grids have distances more than 10 km even in Takata-cho, which locates in the central city, as well as at the root or the tip of Hirota Peninsula in the east side.

The cause of the long distances differs in each district. In the former mountain district, the locations of the sites are far from the inhabitants. In the latter central and eastern area, it is characteristic that site ranks become the fourth or the fifth. In addition, day ranks are from 6 to 8 days. The reason for the low accessibility in these areas despite the existence of sites in the neighborhood is that parts of the inhabitants were forced to the use of far-off sites by competing with the others.

3.2. Effect of controlling the numbers of refueling cars

3.2.1. Assumption

In the previous section, the number of refueling cars of each site was assumed to be 130 per day. In this section, this assumption will be relaxed. Keeping the total number, 650 cars, per day, we double the number of one site, which equals 230, while reduce those of the remaining four sites to three fourth, which equal 97.5 cars. This section will evaluate the changes in accessibility and availability caused by this rearrangement. The

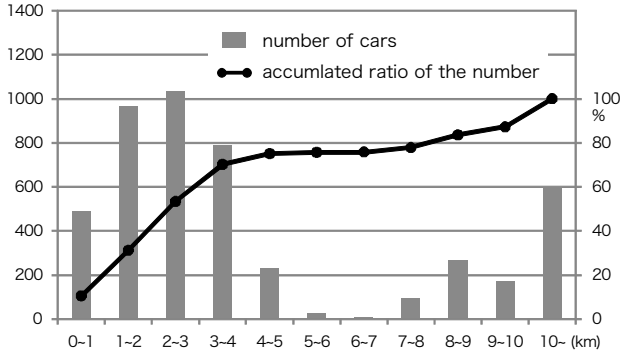

Fig. 2. Number and accumulated ratio of original case

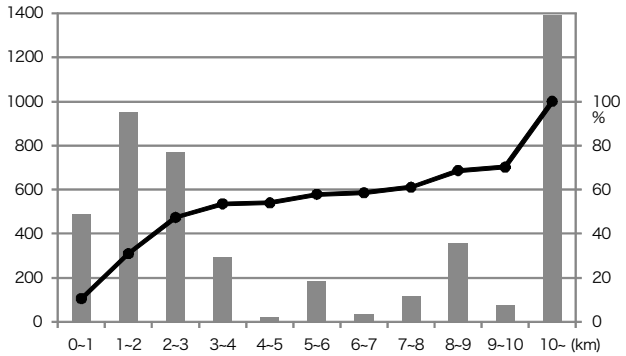

Fig. 3. Number and accumulated ratio of case A

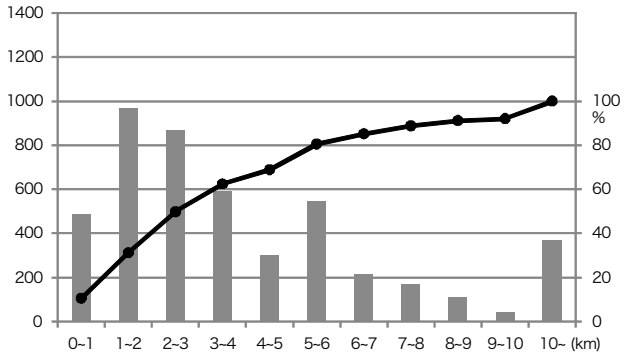

Fig. 4. Number and accumulated ratio of case B

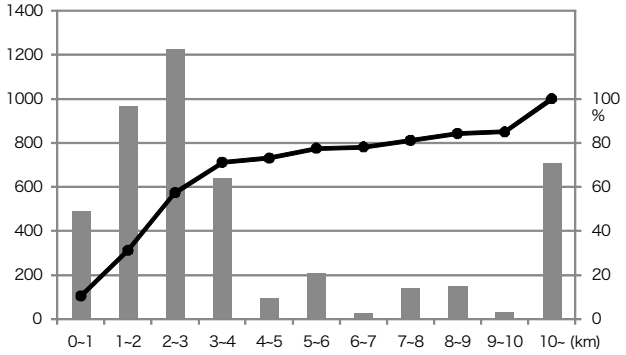

Fig. 5. Number and accumulated ratio of case C

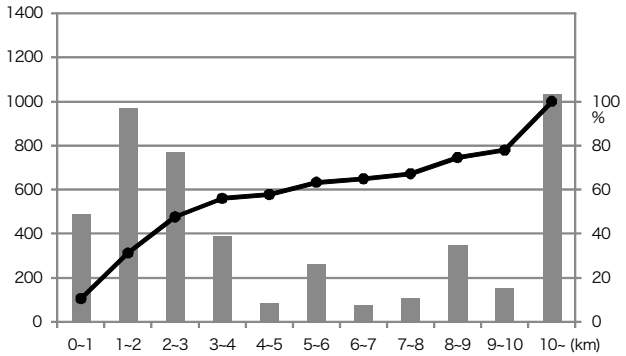

Fig. 6. Number and accumulated ratio of case D

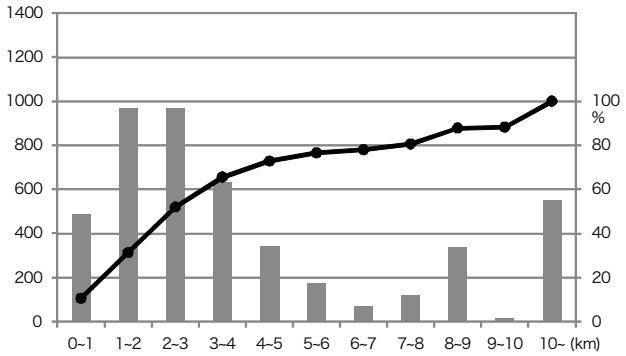

Fig. 7. Number and accumulated ratio of case E

optimum selection of temporary fueling site with double number of refueling cars will be also determined.

We analyzed the following five cases:
case A to double the number of site A;
case B to double the number of site B;
case C to double the number of site C;
case D to double the number of site D;
case E to double the number of site E.

3.2.2. Results

Figures 3, 4, 5, 6 and 7 show the histograms of the car numbers in each distance zone in the five cases of doubling the number of refueling cars of one facility. The accumulated ratios less than 2km are 31.2% in the original case of equal numbers, 30.9% in the case A, 31.2% in the case B, 31.2% in the case C, 31.1% in the case D and 31.2% in the case E. They are approximately equal.

The accumulated ratios less than 4km are 70.2% in the original case, 53.5% in the case A, 62.5% in the case B, 71.1% in the case C, 56.0% in the case D, 65.6% in the case E. This result suggests that the reinforcement in site C is most effective.

The ratio more than 10km is 12.8% in the original case. Compared with this percentage, the case A shows 29.8%, 17.0% higher, the case B shows 7.9%, 4.9% lower, the case C shows 15.1%, 2.3% higher, the case D shows 22.1%, 9.3% higher, and the case E shows 11.8%, 1.0% lower. This result suggests that the case B is most effective.

Figure 14 shows the average movement distance of each case. Compared with the distance in the original case, the case A shows 39.8% higher, the case B shows 7.7% lower, the case C 1.4% lower, the case D shows 28.1% higher, and the case E shows 1.1% lower. This result suggests that the case B is most effective in reducing the average distance in Rikuzentakata-city. The case C and D also reduce the average distance, but their effects are smaller

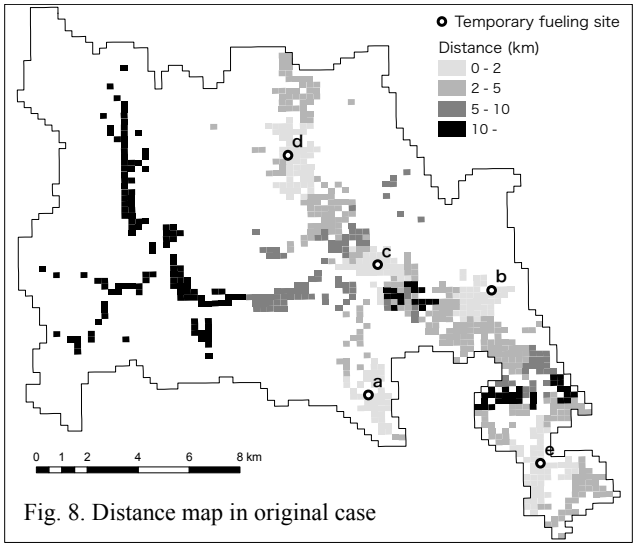

Fig. 8. Distance map in original case

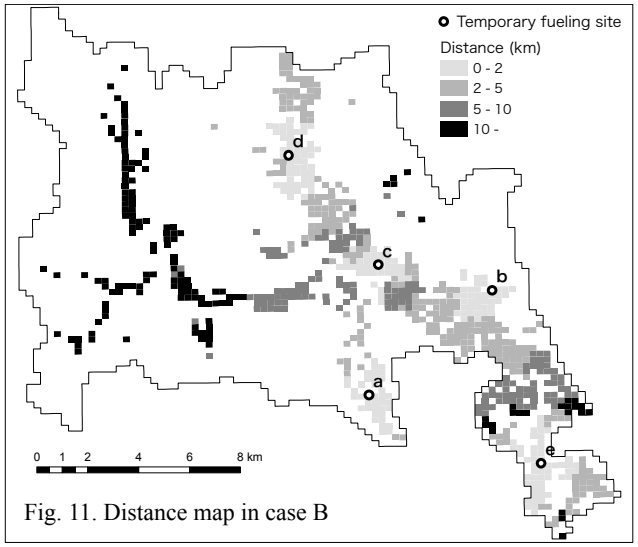

Fig. 11. Distance map in case B

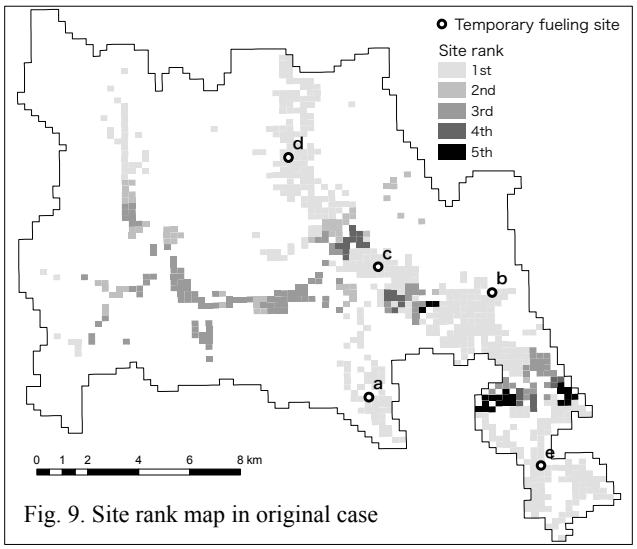

Fig. 9. Site rank map in original case

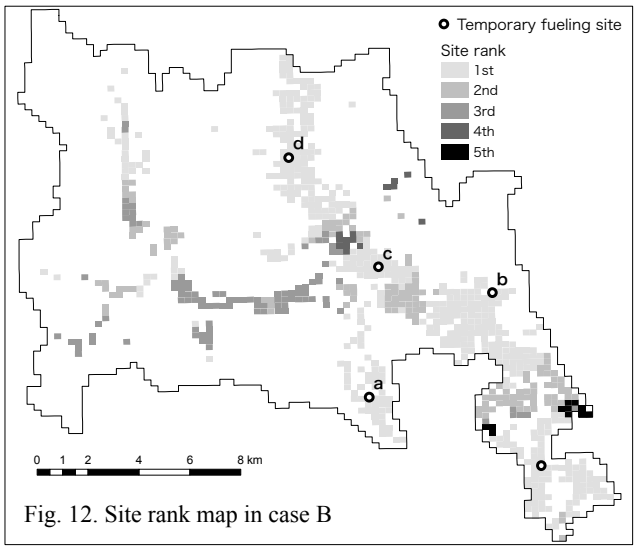

Fig. 12. Site rank map in case B

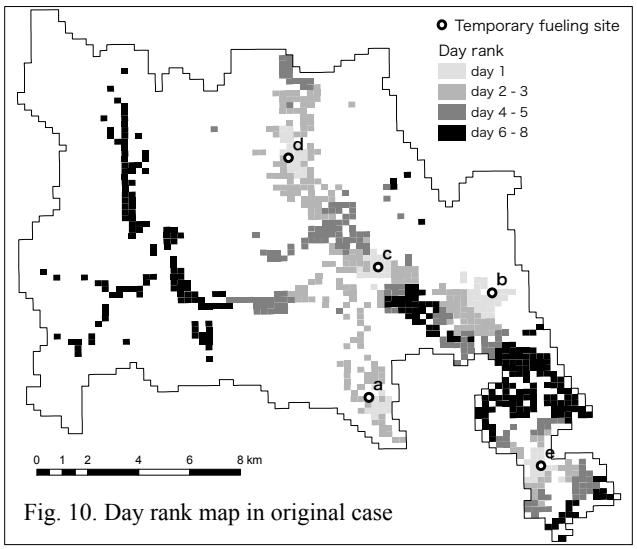

Fig. 10. Day rank map in original case

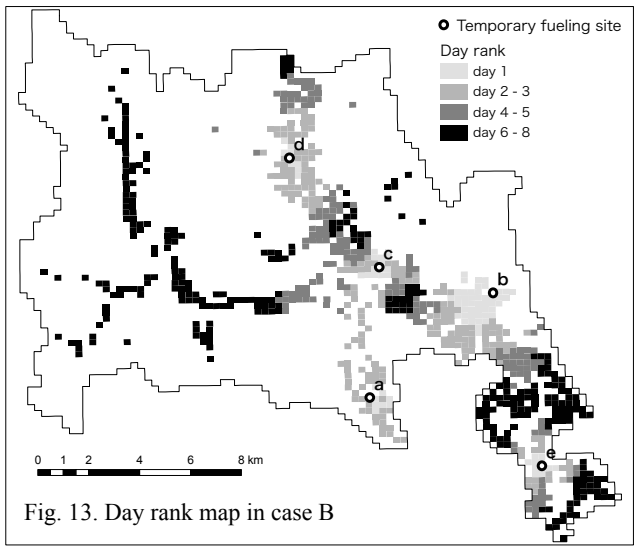

Fig. 13. Day rank map in case B

than that of the case B. In contrast, the average distance is much longer in the case A as well as D than the original case. The case A shows approximately one and half times as much a distance as the original case, because the number of cars with more than 10km increases remarkably as is seen in Figure 3.

The maximum distance shown in Figure 15 of the case E is 25.7 km, longer than that in the original case, which shows 16.7 percentage of increase. Those in the other cases are the same as that in the original case.

3.2.3 Maps of the case B

The comparison of the changes in the number of cars with distances more than 10km and of the average movement distances suggest that the case B is most effective in improvement of accessibility. Figure 11, 12 and 13 show the maps of distances to the sites, site ranks and day ranks of the case B.

Compared with the original case, the maximum distance decreases in Takata-cho. Some grids of Hirota Peninsula show accessibility improvement. In contrast, grids with long distances exist in the mountain area located in the north of Takata-cho. The western mountain area shows little change in the distance.

Figure 12 indicates that the number of the grids where the site rank equals 5, which is its maximum value, is less than that of the original case.

These results show that we can improve the accessibility of inhabitants to the temporary fueling sites by controlling gasoline supply.

4. Conclusions

This study analyzed accessibility and availability of inhabitants in Rikuzentakata-city to temporary fueling sites by comparing the distances in cases with different gasoline supply. This analysis shows the following result.

Firstly under the assumption that supply of each facility is equal, approximately 10% of overall cars can access temporary fueling sites with distances less than 1km, and a little over 40% of cars can access the sites with those less than 2km. In contrast, approximately 600, 12.8% of the whole cars, were forced to travel more than 10 km, which we cannot ignore.

Secondly the case of doubling the supply of site B is effective in terms of reducing the average movement distance. In contrast, other cases of changing supply might rather bring about improper results. The case A increases the average movement distance by approximately 40%. Therefore, the study suggests that examinations are recommended to determine the supply.

Thirdly, though the case B improved the average movement distance by 7.7% compared with the original case, this improvement is small. This result implies that distributing the same amount of gasoline to all temporary fueling sites may be appropriate for avoiding confusion in the process of gasoline distribution to the sites in such an emergency. Therefore, a remaining problem of this study is to develop a simulation method that allows more flexible assumption of the quantity of distribution of gasoline.

Finally, because this study is based on given location of temporary fueling sites, development of method for derivation of the most suitable solution of location and gasoline supply simultaneously.

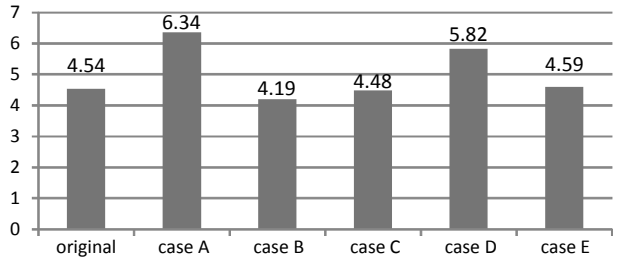

Fig. 14. Average distance in each case

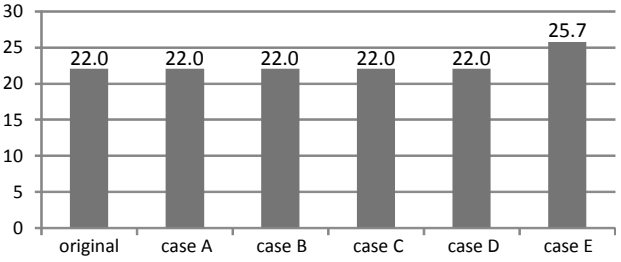

Fig. 15. Maximum distance in each case

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