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Method of Determining Future Facility Location with Maintaining Present Accessibility

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ABSTRACT

The public services closely related to the daily lives of the Japanese people, such as firefighting, police or primary school education, are largely financed by the local governments. As the population as a whole in Japan declines, the population in local regions are forecasted to experience particularly rapid decline in the future, and it is inevitable to reduce the cost of public services provided by the local governments to keep their financial basis sustainable. In order to provide public services to the people properly and fairly, the local governments own and utilize their public facilities, such as fire stations, police stations or primary schools. On the other hand, we have to secure the accessibility, which is the condition of accessing a facility easily in a whole local city including the high population density area and low population density area. In this paper, we propose a method of determining the number of future facilities and its facility locations in which we maintain the present accessibility. In our proposed method, we determine them comparing the accessibility measurement calculated by facility location model using the present and future population. We adopted *k*-centdian model as the facility location model, which can secure the accessibility in a whole local city determining the weights of both areas. We applied our proposed method to fire station in Iwaki city, Japan. The results suggested that 7 facilities would be reduced in 2064, after 50 years from 2014. Additionally, we confirmed that the future facility location had securedaccessibility in both high and low population density area.

Keywords: Facility location, Accessibility, *k*-centdian

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1. INTRODUCTION

In our daily lives, we have been receiving many kinds of public services from the local governments, such as firefighting, police or primary school education. In Japan, these services closely related to our lives are mainly managed and provided by the local governments, while the central government has their responsibility in social welfare, defense, foreign diplomacy and so on (Ministry of Internal Affairs and Communications, 2011).

A breakdown of population changes over the past few years according to region shows, on the other hand, that it is only in certain areas (primarily in and around major urban areas) that population growth is occurring, and population decline is already considerably advanced in local areas where the public service cost per person covered by the local governments has already been increasing (Ministry of Internal Affairs and Communications, 2011).

Under such situation, the local governments have and utilize their public facilities in order to provide their variety of services to the people, and they are required to make their best efforts to reduce cost to own and run their facilities maintaining quality of public services. One of the possible ways to realize the cost cut is to shut down their public facilities and decrease the number of them as the population goes down.

On the other hand, the accessibility is regarded as an index of public service level (Talen and Anselin, 1998; Nicholls, 2001). The accessibility is the condition that a resident can be easy to access a facility. Thus we need to maintain the accessibility from a resident to facility. If we only reduce the number of facility, there is the potential that the accessibility would deteriorate depending on reduced facility location. This indicates that the future accessibility will be worse than present. To avoid such situation, we need to find not only the number of future facilities but also future facility locations in which we can maintain the present accessibility.

In order to measure the accessibility, the distance from demand point to facility is often adopted (Geurs and Wee, 2004). As one of typical measurements, there is a total weighted distance calculated by adding up from each demand point to its nearest facility (Rahman and Smith, 2000). By using this measurement, facility tends to be located in high population density area. However, if the accessibility in such area improves, the accessibility in low population density area deteriorates, because of not considering few people living in a remote area (Rahman and Smith, 2000). By contrast, there is a maximum distance that is the maximum of all distance from each demand point to its nearest facility (Calik and Tansel, 2013). This measurement can consider the distance from the farthest demand point to facility. We can take into account few people living in remote area. Since low population density area tends to locate in remote area from the facilities, the accessibility in low population density area is secured using this measurement. Although we can consider the residents living in that area, the distribution of population is not considered. Hence the accessibility in the high population density area is not secured.

In general, a local city is larger than an urban city in terms of area, and it sometimes includes both high population density area and low ones. If we only use the measurements explained above as the accessibility, we can’t secure accessibility in a whole local city. In such area, we need to secure the accessibility by taking into count the population ratio such as the high population density area and low population density area. Centdian (Ogryczak, 1997) has been presented, which is added total weighted distance to maximum distance. Additionally, an extent of considering both measurements can be controlled by the weight. Accordingly, we need to consider the future facility location using such accessibility measurement.

Our research aims to determine the number of future facilities and its locations. As the similar research, there is the facility location planning, which has many approaches in a field of operational research. As the conventional research, the dynamic facility location model was developed, which determined facility location and relocation during the multiple time period sunder the future uncertainty condition such as variation of population.

Drezner (1995) developed the progressive *k*-median model. In this model, the single facility location was found by considering the minimization of total demand weighted distance over the multiple periods. This model was verified by finding 2 facilities locations in 4 demand points during 2 periods. Additionally, Drezner found 5 facilities locations in 100 demands point during 5 time periods as the general problem. Wey (2003) applied the progressive *k*-median model to the parking facility location. Way predicted the different parking demands (e.g. residential, commercial) by using regression model. Using them as the weight in the model, he found 2 parking locations during 2 periods (i.e. 2000, 2006).

Sweeny and Tatham (1976) developed the dynamic warehouse location model for the long planning period. In their model, the facility location minimizing total cost was determined, which added up the shipping cost from factory to warehouse and warehouse to customer, storing cost and operating cost over the time period. They demonstrated the application of 2 facilities, 5 warehouses, 15 customers in 5 year planning horizon (5 time periods).

Farahani *et al.* (2009) presented the model for determining single facility location and relocation over a time horizon. Farahani *et al.* gave the weight on demand point as a function of time. At first, in their model, where to locate facility were determined, and next when to relocate during each time period by considering the minimization of total demand weighted distance. They applied their model to the high way police station.

Ghaderi and Jabalameli (2013) presented the dynamic facility location model in which the location minimizing total costs (i.e. travel cost, operating cost) over the time period were determined. Additionally, as the constraints, they added the budget for facility at each period. They considered the health care facility location in Iraq over 5 periods by using their model.

Shilling (1980) improved the MCLP (Maximal Covering Location Problem) and developed MODL (Multi objective Dynamic Location) model, which maximized covering demand at multiple time periods under a limited number of facilities. Shilling found the optimal ambulance station locations at 2 time periods, and the relation between location and covering rate were discussed.

By constructing the dynamic facility location models that determine the facility location during the multiple periods, the number of future facility and its location were found. In the constructed models, the evaluation measurement into which forecasted demand/population from the present to the future has been integrated, and the facility location is determined by summing of the measurements value becomes the minimum or maximum over the multiple periods. However the measurements value were variable over the observation period. In this paper, we propose a method of the minimum number of future facilities and its locations while maintaining the present accessibility in the future.

This paper is organized as follows. In section 2, we describe overall flow of our method and each concept. In section 3, we apply our proposed method to Iwaki City, Fukushima in Japan and show the results. In section 4, we discuss the implication of the number of the future facilities and the accessibility of the future facility location. Finally we conclude this paper in section 5.

2. PROPOSED METHOD

In this section, we explain our method for determining the number of future facility and its location, which can maintain the present accessibility in the future. Our method is composed of the following 5 steps:

Step 1. Selecting area and target facility,
Step 2. Predicting the future population,
Step 3. Selecting of the measurement and model,
Step 4. Determining the number of future facilities,
Step 5. Determining the facility locations.

We explain the details of above steps.

Step 1. Selecting area and target facility

We select the area and the facility where we want to consider the number of future facilities and its location.

Step 2. Predicting the future population

We predict the future population in the area. We assume that the population will slowly decrease depending on ime *t*. In this paper, we employ the double logarithmic regression model to estimate future population :

$$\ln p = b + a \ln t \tag{1}$$

where *p* is the population, *b* is intercept, *a* is regression coefficient. The parameter *a* and *b* in Eq. (1) are estimated by using the aging population data in the targeted area.

Step 3. Selecting of the measurement and model

We use the Centdian and *k*-centdian model (Ogryczak, 1997) as the measurement and facility location model. This model is formulated as Mixed Integer Programming under the parameters and decision variables in Table 1.

Table 1. Summary of notations.

Sets	
I	set of demand points indexed by i
J	set of demand points indexed by j
Parameter	
p_i	standardized population on demand point i
c_{ij}	distance from demand point i to candidate point j
k	the number of facilities
w	weight in the high population density area
1-w	weight in the low population density area
Decision Variables	
x_{ij}	if demand point i is served by facility j: 1 otherwise: 0
y_j	if facility j is located: 1 otherwise: 0
z	the maximum distance

***k*-centdian model:**

$$\textit{minimize} \quad w\sum_{i\in I}\sum_{j\in J} p_i c_{ij} x_{ij} + (1-w)z \tag{2}$$

$$\textit{subject to} \quad \sum_{i\in I} x_{ij} = 1, \quad \forall i \in I, \tag{3}$$

$$\sum_{j\in J} y_j = k, \tag{4}$$

$$x_{ij} \le y_i, \qquad \forall i \in I,\ \forall j \in J, \tag{5}$$

$$c_{ij}x_{ij} \le z, \qquad \forall i \in I,\ \forall j \in J, \tag{6}$$

$$x_{ij} \in \{0, 1\}, \quad \forall i \in I,\ \forall j \in J, \tag{7}$$

$$y_i \in \{0, 1\}, \quad \forall i \in I,\ \forall j \in J, \tag{8}$$

Basically, this model is combination of *k*-median model (Rahman and Smith, 2000) and *k*-center model (Calik and Tansel, 2013).The objective function in Eq. (2) represents minimization of Centdian. The constraint in Eq. (3) ensures that all demand points are assigned to some facilities. The constraint in Eq. (4) requires that *k* facilities are located altogether. The constraint in Eq. (5) allows the assignment only candidate points which facility has been located. The constraint in Eq. (6) defines the maximum distance between demand point *i* and the nearest facility *j*. The constraints in Eq. (7) and Eq. (8) require the binary for the decision variables.

Centdian in Eq. (2) is composed of two terms. The first term is a total weighted distance defined as $\sum_{i\in I}\sum_{j\in J} p_i c_{ij} x_{ij}$, where x_{ij} is a decision variable. If a demand point *i* is served by a facility *j*, it takes 1,otherwise 0. p_i is the standardized population in demand point *i*. The standardize means the operation of dividing a population in demand point *i* by total population in the targeted area, therefore $\sum_{i\in I} p_i$ is 1. c_{ij} is a distance from demand point *i* to candidate point *j*. Since the first term is the summation of multiplication of them, it corresponds to summation of distance weighted by standardized population. Thus, if we only consider the minimization of the first term, the accessibility in high population density area is secured (*k*-median model). The second term is the maximum distance defined by *z*, which is a continuous decision variable. Thus if we only consider the minimization of the second term, the farthest demand point from the facility is treated as the priority (*k*-center model). Since low population density area tends to locate in remote area from the facilities, the accessibility in low population density area is secured.

We can control an extent of considering both terms by using the weight w and 1-w. The weight in the high population density area w is determined by using the extent of considering this area ($0 \le w \le 1$). Similarly, 1-w shows the weight in low population density area. If the weight is w = 1, the high population density area is considered by the *k*-median model. On the other hand, if the weight is w = 0, the low population density area is considered by the *k*-center model. By determining each weight as the population ratio of high population density area to low population density area, it is possible that the accessibility in a whole local area is secured. Therefore, in this paper, we define the minimized Centdian shown in Eq. (2) as the optimal accessibility.

Step 4. Determining the number of future facilities

In this step, we calculate the present and future optimal accessibility using present and future population predicted in Step 2 and *k*-centdian model. Therefore, we need to set the weight in the high population density area w and the low population density area 1-w at each period. We separate the targeting area into them depending on present and future population, and then we determine the present and future weights as the population ratio of high population density area to low population density area at each period.

After that, we calculate the present optimal accessibility at the number of the present facilities by using the present population and present weights. We regard the present optimal accessibility as the accessibility that should be maintained in the future. Next, we calculate the future optimal accessibility as the function of the number of facilities using the future population and the future weights. Finally, we compare the present and future optimal accessibility. Then we determine the number of future facilities, which the future optimal accessibility equals to the present optimal accessibility.

Step 5. Determining the facility locations

We determine the future facility location at the number of future facilities determined in Step 4. Thus, the future facility location maintained the present accessibility can be obtained.

3. RESULTS OF THE APPLICATION

In this section, we apply our proposed method to the case of the fire station in Iwaki City, Fukushima in Japan and show its results. We solved the facility location model by using the Xpress-Optimizer 26.01.04and NEOS server (Dolan*et al*., 2001).

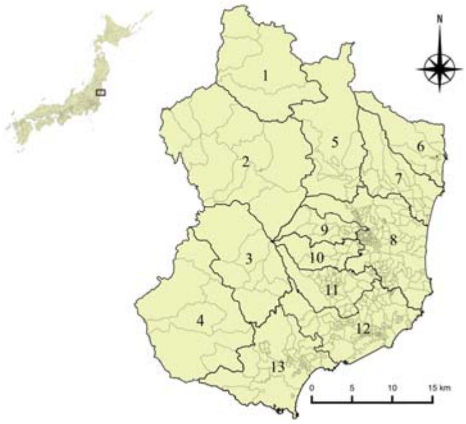

Figure 1. Map of the study and governmental areas.

3.1 Step 1. Selecting Area and Target Facility

In this paper, we chose Iwaki City in Fukushima that locates in east of Japan as a study area. And, we selected a fire station in study area to consider the number of future facilities and its facility location. Figure 1 shows the area map of Iwaki City. This area is separated into 13 governmental areas: 1. Kawamae, 2. Miwa, 3. Tono, 4. Tabito, 5. Ogawa, 6. Hisanohama-ohisa, 7. Yotsukura, 8. Taira, 9. Yoshima, 10. Uchigo, 11. Joban, 12. Onahama and 13. Nakoso. We selected 231 demand and candidate points in this area. In addition, the Euclidian distance between each point is regarded as the distance from the demand point to the facility.

3.2 Step 2. Predicting the Future Population

Based on the discussion of step 2 in section 2, we constructed the future population model in the each governmental area. In order to estimate parameter a and b in Eq. (1), we used the aging population data between 2005 and 2014 in each area. Table 2 shows the estimated results. From the p-value, the estimated results of the coefficient regression a and intercept b in all area are significant. It suggests that the population varies depending on the time in each area.

The values of the coefficient of determination R^2 are higher than 0.9 except for area 12: Because area 12 has the characteristic an inflow of the population occurs, the value of R^2 is low. Therefore using these results, we predicted the population in each area in 2064, after 50 years from 2014. Table 3 shows the predicted results. The value of the second column shows the present number of population (p_p) from the data and the fourth column shows the number of predicted population in the future (2064) (p_f). In the third and fifth column, we show the population density rates in each area at the present (p_p) and future (p_f). This value indicates to what extent population density in a whole study area is accounted by the population density in each area. We calculate the population density in each area dividing the population by the physical area size. As the summation

Table 2. Result of estimating parameter

area	Coefficient a	Intercept b	R^2
1	-62.95***	485.98***	0.98
2	-47.93***	372.68***	0.99
3	-34.60***	271.79***	0.99
4	-53.94***	417.83***	0.98
5	-33.97***	267.22***	0.97
6	-60.44***	468.31***	0.92
7	-39.31***	308.62***	0.97
8	-19.46***	159.45***	0.90
9	-18.40***	149.42***	0.92
10	-30.99***	245.96***	0.99
11	-21.61***	174.83***	0.99
12	-5.82**	55.53***	0.68
13	-20.57***	167.24***	0.98

Table 3. Result of predicting population

area	P_p	R_p	P_f	R_f	R_{dec}
1	1,157	0.22	253	0.08	0.78
2	3,117	0.31	964	0.16	0.69
3	5,678	1.18	2,430	0.83	0.57
4	1,737	0.24	468	0.11	0.73
5	6,721	1.30	2,916	0.93	0.57
6	4,731	1.96	1,091	0.74	0.77
7	13,693	4.66	5,238	2.94	0.62
8	93,071	18.40	57,794	18.81	0.38
9	12,779	10.39	7,973	10.67	0.38
10	25,306	17.37	11,795	13.33	0.53
11	33,427	15.04	19,611	14.53	0.41
12	76,428	18.93	66,091	26.95	0.14
13	48,248	10.00	29,115	9.93	0.40

of them is the population density in a whole study area, we obtain the population density rate $R_{\text{p or f}}$ dividing a population density in each area by it. In the sixth column of Table 3, we show the decreasing rate (R_{dec}) calculated by dividing the number of decreasing from 2014 to 2064 by the number of the present population.

From the results, we found that the population in area 1, 2, 4 and 6 decreases 70-80 percent from 2014. These areas are located in the west and northwest in the study area. On the other hand, the population in area where locates in the southeast decreases 15-40 percent. We can see that the gap of the population among these areas increases during 50 years.

In this paper, we assume that the future population on the demand points in the area can be calculated by :

$$P'_{\text{p}} - (P'_{\text{p}} \times R_{\text{dec}}). \tag{9}$$

where P'_{p} is the number of population in demand point at the present. For example, in the demand points located in area 1, we use the decreasing rate $R_{\text{dec}} = 0.78$.

3.3 Step 3. Selecting of the Measurement and Model

We adopted the Centdian and k-centdian model, presented in section 2, as the accessibility measurement and facility location model.

3.4 Step 4. Determining the Number of Future Facilities

In order to determine the weights, we separate the study area into the high and low population density areas. In this time, we use the population density rate R_{p} and R_{f}, and compare them with the average value of them (7.69 percent). If the population density is higher than the average value, we regard its area as the high population density area, otherwise the low population density area. Figure 2 shows the results of separating area. We obtained the same results at both the present and future. We calculate the weights as the total population density rate in each area at each time period. Table 4 shows its result. w_{p} and 1-w_{p} indicate the present weight in the high and low population density areas, respectively. Similarly, w_{f} and 1-w_{f} indicate the future weight in each area.

At the present, there are 13 fire stations in study area. Therefore, using the population on the demand points, we calculate the present optimal accessibility at 13 facilities. We find that the value of the present optimal is 2,665. Moreover, we also calculate the future optimal accessibility as the function of the number of facilities (from 1 to 13 facilities). The optimal accessibility at the future (at 2064)is plotted in Figure 3 (red curve). Moreover, we plot the value of the present optimal accessibility in Figure 3 (blue point). From Figure 3, we find that if we maintain the present optimal accessibility (2,665)

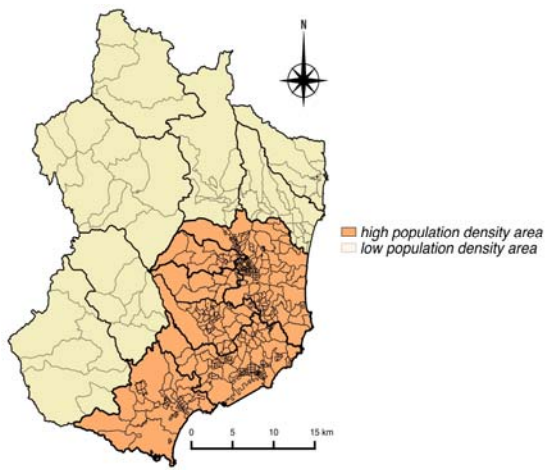

Figure 2. The definition of the high and low population density areas.

Table 4. Present and future weights

Time period	area	
	high population	low population
Present	0.901(w_{p})	0.099(1-w_{p})
Future	0.942(w_{f})	0.058(1- w_{f})

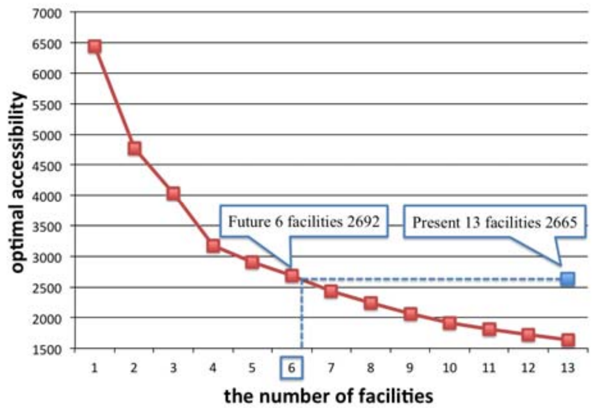

Figure 3. The accessibility as the function of the number of facilities.

in the future, we need to 6 facilities at the future. The value of the corresponding accessibility is 2,692. Therefore, we conclude that 6 facilities are sufficient in study area at the future (at 2064).

3.5 Step 5. Determining the Facility Locations

In step 4, we conclude that, 50 years later, 6 facilities will be enough to maintain the present accessibility. Thus, we need to find the location of its 6 facilities.

Figure 4 shows the results of the facility location. The blue marks show the facility location. The black points are the demand points, and the black lines link the demand point and facility location. We can see that in high population density area, there are 4 facilities. On the other hand, there are 2 facilities in low population density area. The facility B, C, D copes with most of the demand points where locate in the high population density area. The facility E copes with the demand points in the low population density area. However, we can find that the facility A and F relatively homogeneously copes with the demand points in both areas.

4. DISCUSSION

In the section 3, it is cleared that 6 facilities are sufficient to maintain the present accessibility at the future (2064). Namely, this result indicates that 7 facilities would ideally be reduced during 50 years. Thus, it is expected that the cost can be reduced significantly.

We want to confirm whether we can consider two measurements (total weighted distance and maximum distance) and secure the accessibility in both the high and low population density areas in the *k*-centdian model. For this purpose, we compare the measurements found by *k*-centdian model with them found by *k*-median model and *k*-center model. In the Table 5, we show the number of demand points, the weighted total distance and the maximum distance of each facility in three models, and these average, maximum and minimum values, respectively. Figure 5 and 6 show the result of 6 facilities location determined by the *k*-median model and the *k*-center model, respectively. The marks in these figures are similar to Figure 4.

In the *k*-median model, all 6 facilities are located in the high population density area. Since the *k*-median model is the condition of considering the high population density areas, all facilities are assembled in this area. The average weighted distance (93,933) is the smallest in three models. The average maximum distance (13.578) is the biggest in three models. The maximum distance (30.680) appears in low population density area in the allocation of facility A.

In the *k*-center model, there are 2 facilities in the high population density area. On the other hand, there are 4 facilities in low population density area. Since the *k*-center model is the condition of considering low population density area, the facilities can be located in this area comparing the other model. The average maximum distance (9.257) is the smallest in three models. The average total weighted distance (174,428) is the biggest in three models. The maximum weighted total distance (641,785) appears in the high population density area in the allocation of facility A.

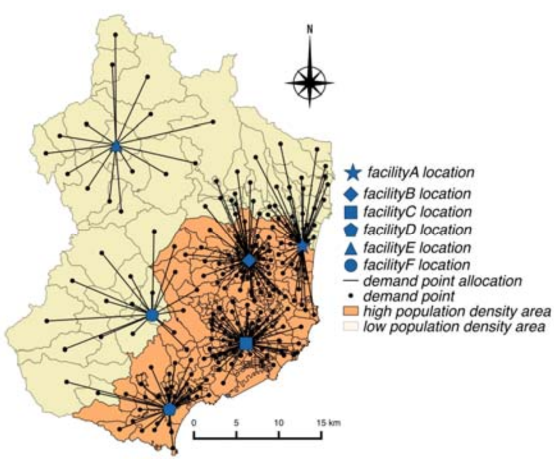

Figure 4. 6 facilities location at the future (2064).

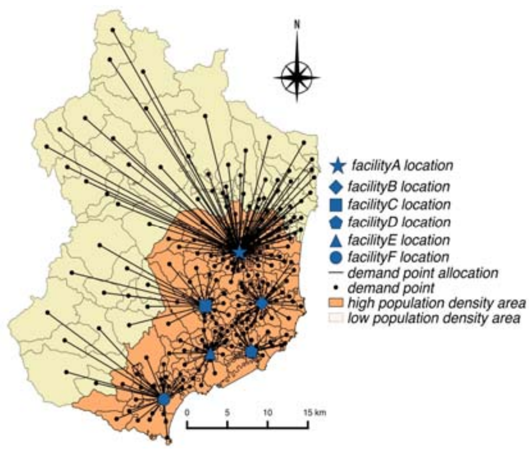

Figure 5. 6 facilities location by *k*-median model at the future (2064).

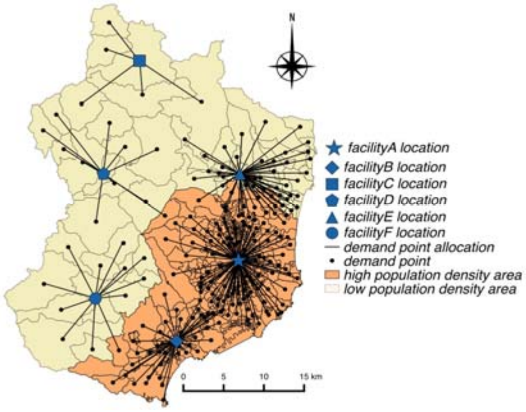

Figure 6. 6 facilities location by *k*-center model at the future (2064).

In the *k*-center model, there are 2 facilities in the high population density area. On the other hand, there are 4 facilities in low population density area. Since the *k*-center model is the condition of considering low population density area, the facilities can be located in this area comparing the other model. The average maximum distance (9.257) is the smallest in three models. The average total weighted distance (174,428) is the biggest in three models. The maximum weighted total distance (641,785) appears in the high population density area in the allocation of facility A.

In the *k*-centdian model, we make a comparison between each measurement calculated by *k*-centdian model and measurement in which each minimization model doesn't consider. Comparing with the average total weighted distance (174,428) calculated by *k*-center model, it calculated by *k*-centdian model (112,419) decreases by 35.6 percent. Similarly comparing with average maximum distance (13.578) calculated by *k*-median model, it calculated by *k*-center model (11.228) decreases by 17.3 percent. Therefore, we can confirm that each measurement can be considered in the *k*-centdian model.

We discuss whether accessibility in both areas can be secured at the *k*-centdian model. In order to do this, we create Table 6 from Table 5. Table 6 shows the demand points and the total weighted distance, which separated by high and low population density area. From Table 6, the total weighted distances of the *k*-center model in both high and low population density area is bigger than those of the *k*-centdian model. The total weighted distance of the *k*-median model in the high population density area is the smaller than that of the *k*-centdian model. By contrast, the total weighted distance of *k*-median model in the low population density area is bigger than that of the *k*-centdian model. Similarly, this implication can be seen in the average total weighted distance. In order to discuss this implication concisely, we create Table 7 from Table 6.Table 7 shows the distance per person in both areas, dividing the total weighted distance by the total future population in both areas.

From the Table 7, the distance per person of the *k*-center model in the high population density area is smaller than that in the low population density area. The accessibility in the high population density area is better. This is attributed to the location of facility A where is nearly located in big demand point. By contrast, the distance per person in both areas of the *k*-centdian model is smaller than that of the *k*-center model. Consequently, the *k*-centdian model can secure the better accessibility than the *k*-center model.

In the *k*-median model, the distance per person in the high population density area is the smallest and the distance per person in low population density area is the biggest. Considering these results, the accessibility in the low population density area considerably deteriorates instead of securing the accessibility in the high population density area. In the *k*-centdian model, although the distance per person in the high population density area increases by near 1km/person, the distance per person in the low population density area is smallest value. Therefore, the *k*-centdian model can secure the better accessibility in low population density area than the *k*-median model.

Table 5. Comparison among three facility location models

Facility location model		Facility								
		A	B	C	D	E	F	Average	Maximum	Minimum
k-centdian	a	45	59	61	32	16	18	39	61	16
	b	64,162	177,043	306,183	81,321	17,500	28,303	112,419	306,183	17,500
	c	12.272	10.509	6.775	12.562	12.804	12.445	11.228	12.804	6.775
k-median	a	103	32	26	17	24	29	39	103	17
	b	266,612	52,303	77,136	62,218	38,345	66,984	93,933	266,612	38,345
	c	30.680	6.072	17.052	4.802	5.117	17.744	13.578	30.680	4.802
k-center	a	103	43	6	12	54	13	39	103	6
	b	641,785	213,265	8,116	10,338	155,910	17,156	174,428	641,785	8,116
	c	9.453	9.521	9.337	9.630	9.637	7.965	9.257	9.637	7.965

a: the number of demand points.
b: the total weighted distance (person×km).
c: the maximum distance (km).

Table 6. Comparison between the high population density area and low population density area

Facility location model		Facility A	B	C	D	E	F	Total	Average
k-centdian	a	20	48	61	30	0	6	165	28
	b	25	11	0	2	16	12	66	11
	c	34,327	159,426	306,183	79,302	0	15,823	595,061	99,177
	d	29,835	17,617	0	2,019	17,500	12,480	79,451	13,242
k-median	a	50	32	18	17	24	24	165	28
	b	53	0	8	0	0	5	66	11
	c	149,476	52,303	52,784	62,218	38,345	61,734	416,860	69,477
	d	117,136	0	24,352	0	0	5,250	146,738	24,456
k-center	a	103	43	0	1	17	1	165	28
	b	0	0	6	11	37	12	66	11
	c	641,785	213,265	0	2,991	87,817	3,628	949,486	158,248
	d	0	0	8,116	7,347	68,039	13,528	97,084	16,181

a: the number of the demand points in the high population density areas.
b: the number of the demand points in the low population density areas.
c: the total weighted distance in the high population density areas (person×km).
d: the total weighted distance in the low population density areas (person×km).

Table 7. Comparison of the distance per person

model	area: high population	low population
k-centdian	3.09	5.95
k-median	2.17	10.98
k-center	4.94	7.27

(km)

We confirmed that the *k*-centdian model could secure the accessibility in both areas. However, there are some issues in our proposed method. Firstly, we assume that all facilities are same scale. In *k*-centdian model, we needs to consider the facility scale to discuss the cost in detail. However, in our proposed method, we can discuss the facility scale using the total weighted distance. For example, the facility C where the total weighted distance is the biggest should be biggest scale. Second issue is a method for determining the weight. There is a potential that the accessibility would be better in other weight. Although we determined the weight as the total population density rate in both areas in this paper, we need to examine improved method.

5. CONCLUSION

We proposed a method of determining the number of facility in the future and the facility locations, which can maintain the present accessibility.

In order to confirm the effectiveness of our proposed method, we applied our proposed method to the fire station of Iwaki City, Fukushima in Japan and show the results. As the results, it was cleared that 6 facilities were sufficient after 50 years. This result suggests the sweeping reduction of the cost. Concerning about the future facility location, we also confirmed whether the *k*-centdian model considered the total weighted distance and maximum distance. Additionally, we confirmed whether the accessibilities in both high and low population density areas were secured by the *k*-centdian model.

There are some extensions for our proposed method (model). We pointed out in last paragraph in section 4. Additionally, we need to consider not only 2 times periods but also more time periods. In order to discuss the cost and the facility location in detail, we need to add these topics to the future works.

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