Optimal Location of Health Welfare Service Facilities for Senior Citizens

— Day-Service Facilities as an Example —

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1 Introduction

Location of facilities is considered as essential elements in various kinds of social services such as schools, hospitals and transportation stations. That also applies to health welfare service facilities for senior citizens. For instance, shortage of facilities will result in insufficient service. On the other hand, if redundant facilities are arranged, investment costs and also operating expenses will probably exceed the permissible limit. Even if the appropriate number of facilities are built and used, poorly sited facilities will result in inconvenient and unnecessary service for users. Thus, facility location modeling takes on greater importance in efficient welfare system. This paper is concerned with optimal locations of health welfare service facilities on the Nursing Insurance System, in Nagoya city.

1.1 Background

In recent years, the aging society is rapidly developing in our country. It is predicted that $\frac{1}{4}$ Japanese people will be more than 65 years old by 2015. In this super aging society, we are facing about some issues about nursing elderly as below.

- Rapid increase of people who need nursing
- Require longer-term nursing period
- Aging of nursing population
- Difficulties of family nursing

In order to solve these problems above, Nursing Insurance System was founded in 2000. After 6 years, the system was partly revised according to the change of government policy to adapt to this increasingly aging situation. I review the 2 keypoints of the New Nursing Insurance System below.

1. Preventive Nursing
2. Community-Base Nursing Service

1.2 Motive of This Research

According to the 2 points above, I consider that New Nursing System was shifted to the services used more frequently by wide range of people who need care. That simultaneously means facilities should be located where users can easily commute and receive nursing service efficiently. Therefore, I believe that this problem is appropriate for Operations Research.
I studied the same topic in my graduation thesis, and found out 2 main problems to resolve.

1. Finer division of study area
   Unit of wards district $\Longrightarrow$ Unit of town
2. Expansion of study area
   Minami,Midori,Tenpaku(3 adjacent wards in the southern part of Nagoya city) $\Longrightarrow$ the entire Nagoya city

2 Explanation of the Problem

2.1 Service Facility

Among several types of services, I especially focus on Day-Service which is one of the main nursing services and holding the biggest population of the whole nursing users. The Day-service facilities provide the bathing and meal service or other daily needed care. As for Preventive Nursing, it gives physical exercises to improve life function and the advice on the improvement in one's nutrition.

2.2 Study Area

2.2.1 Range of Area

Although the final goal is the entire Nagoya city, I begin the research by restricting to the 3 adjacent districts, i.e. Minami, Midori and Tenpaku.

2.2.2 Division of Districts

Table1 shows the number of divisions when Nagoya city is divided by such units as primary-, junior-high school districts and town. The unit of town in this study refers to *azakuiki* in Digital map 2005. I also aims to see how the accuracy of

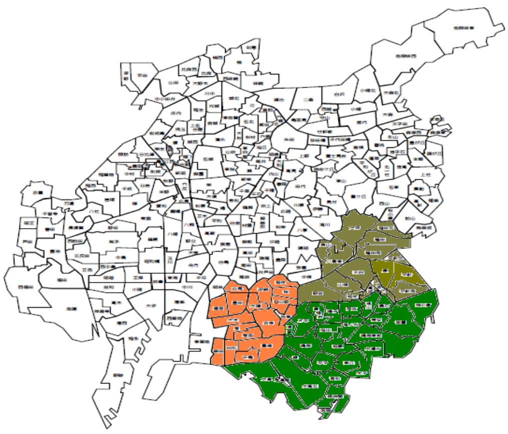

Figure 1: Study area

the solution of optimal location changes according to the fineness of divisions.

Table 1: The Number of Divisions of Area

Wards/Unit	Town	Primary	Junior-High
Minami	150	18	7
Midori	155	27	12
Tenpaku	137	16	7
3 wards	442	61	26
Nagoya	2277	260	109

Primary:primary school, Junior-High:junior-high school

2.3 Modeling

I suppose the year of 2005 as the base year and 2015 as the objective year. The object is to minimize the total traveling distance of all facilities users.The procedure is as follows.

1. Estimate the number of the facilities user over the whole study area in 2015.
2. Calculate the number of facilities which would be built newly by 2015.
3. Find the optimal number and location of new facilities to be located in each district by mathematical programming method.

3 Optimal Locations of Day-Service Facilities

3.1 Formulation

I adopt the continuous location model since the facility location can be anywhere in each division area. Also, more than 2 new facilities might be sited in 1 district. Besides, demands are not uniformly distributed for each division area.

To formulate this problem, I define indicator variables as follow.

I: the set of the districts in the study area

D_{ik} = the average traveling distance between districts i and k [m]

A = an upper bound of the total number of newly built facilities in whole study area

P_k = the total number of users who live in district k

c = the capacity of newly built Day-service facilities

c_i^0 = the total capacity of Day-service facilities in the district i in the base year

In addition, I use the following decision variables.

x_i = the number of newly built Day-service facilities located in district i

u_{ik} = the number of users who live in district i, going to the facilities in district i

With these notations, I formulate the problem which minimizes the total traveling distance of all facilities users as follow.

$$\text{Minimize} \quad \sum_{i \in I} \sum_{k \in I} D_{ik} u_{ik} \tag{1}$$

$$\text{Subject to} \quad \sum_{i \in I} x_i \leq A \tag{2}$$

$$\sum_{i \in I} u_{ik} = P_k \qquad k \in I \tag{3}$$

$$\sum_{k \in I} u_{ik} \leq c x_i + c_i^0 \qquad i \in I \tag{4}$$

$$x_i, u_{ik} \geq 0 \qquad i, k \in I \tag{5}$$

Constraint(2) states that the total number of newly built facilities from the base year(2005) through the final year(2015) should not exceed A. Constraint (3) stipulates that each of entitled users can use some facility in the study area. Constraint (4) is the total demand for all the facilities in each district must be less capacity of facilities. Constraint (5) is a standard non-negativity condition. The structure of this main problem is similar to a transportation problem, except that the value of the right hand of constraints equation(4) is changeable rather than fixed. [1][2][3]

3.2 The Used Data

3.2.1 Traveling Distance

- Between Different Districts ($i \neq k$)
  I assume D_{ik} is equal to the Euclidean distance between the barycentic coordinates of district i and k .

- Within the Same District ($i = k$)
  I calculate it by using Crofton's method, assuming the district is a circle with radius r, which is equal to $\frac{128r}{45\pi}$.

I could not get data on the barycentric coordinates and areas of subdivided districts, so, I calculated them using a function of ArcGIS software.

3.2.2 The Number of Day-Service Users in 2015 P_k

By using the past data, I performed a regression analysis using Excel, and obtained the linear regression expressions with a satisfiable value of R^2. Since I could not get the data in the unit of wards before 2002, I estimated it by proportional calculation based on the normal population data. Also for the data of number of users in the unit of town and others, I adopted the same method as above.

3.2.3 Capacity of a Newly Built Facility c

It is significant to decide the appropriate capacity of a facility with respect to both building facilities and supplying the service. In this study, I investigated the number of capacities of existing Day-Service facilities in Nagoya city. Then, I calculate the average and the mode per a facility from those, and use them as a reference to set the capacity.

Table 2: Capacity of Existing Day-Service Facilities

	Average	Mode
Capacity/ 1 facility	23.9	10

3.2.4 The Number of Newly Built Facility A

I am also interested in minimizing the total number of new facilities A, which will be built by the objective year. Since it is important that demand and supply are well-balanced, this problem attempts to determine the appropriate number of facilities as well as their locations and the allocation of demands to those facilities.

$$\text{Minimize} \quad A \tag{6}$$

I calculate the several sets of number of A and the size of c and show each of these as Scenario 1,2 which is shown in **Table3**. To obtain A, I calculate the demand which should be covered by 2015 in **Table4**, by comparing the total capacity in 2005 to the prediction number of users in 2015. And I gain the minimum number of A by dividing by the average and mode of the capacity of existing facilities shown in 3.2.3.

Table 3: Estimation of A

Scenario #	c	3 Adjacent Wards	Nagoya
Scenario 1	20	160	985
Scenario 2	50	70	395

Table 4: Increase number of Day-Service users

	x_i^0 *1	c^0*2	P_k^0*3	P_k*4	*5
Chikusa	23	494	920	1865	1371
Higashi	7	163	461	941	778
Kita	33	755	1317	2810	2055
Nishi	25	464	933	1909	1445
Nakamura	18	541	1070	2246	1705
Naka	11	281	425	921	640
Showa	16	351	773	1597	1246
Mizuho	16	380	845	1625	1245
Atsuta	12	340	464	896	556
Nakagawa	29	819	1323	2689	1870
Minato	19	555	923	1866	1311
Moriyama	18	395	702	1398	1003
Meito	18	384	780	1663	1279
Minami	17	435	1015	1881	1446
Midori	25	543	855	1565	1022
Tenpaku	21	456	623	1164	708
3 wards	63	1434	2493	4610	3176
Nagoya	308	7356	13429	27036	19330

Notations:
*1:Number of Day-Service facilities in 2005
*2:Capacity of the facilities in 2005
*3:Day-Service users in 2005
*4:Prediction number of Day-Service users in 2015
*5:Demand should be satisfied from 2005 to 2015

3.3 Procedure of Numerical Experiment

I review the procedure of numerical experiment below.
1. Nagoya city (# of divisions, $N = 16$)
2. Minami ward ($N = 150$)
3. Minami, Midori, Tenpaku ($N = 442$)
4. Nagoya city ($N = 2290$)

4 Result of Experiment

4.1 Solution

I solve the problem formulated in Section 3.1, by using XPRESS MP solver.

4.2 Result

I show partly the results from Experiment. **Table5** and **Table7** show the optimal allocation number of newly built facilities for each cases. I calculate the number of facilities allocated for 1000 user's as the User's Satisfaction, in both 2005(S_i^0) and 2015(S_i), shown in **Table6** and **Table7**. X_i is the total # of facilities($x_i^0 + x_i$) in 2015.

4.2.1 Nagoya city/Ward Division

The optimal solution where $N = 16, c = 50, A = 400$ is as follows. Objective Value turned out to be 60014500[m]. And by dividing it by the total number of users, I gained the average traveling distance of users as 2219.2249[m]. As shown in **Table6**, the user's satisfaction rate raised up in almost all districts in the objective year.

Table 5: Optimal Solution, x_i

Chikusa 28	Higashi 16	Kita 41	Nishi 29
Nakamura 34	Naka 13	Showa 25	Mizuho 32
Atsuta 0	Nakagawa 43	Minato 29	Minami 21
Moriyama 24	Midori 25	Meito 25	Tenpaku 15

Table 6: User's satisfaction S_i

Ward	x_i^0	X_i	P_k^0	P_k	S_i^0	S_i
Chikusa	23	51	920	1865	25	27
Higashi	7	23	461	941	15	24
Kita	33	74	1317	2810	25	26
Nishi	25	54	933	1909	26	28
Nakamura	18	52	1070	2246	16	23
Naka	11	24	425	921	25	26
Showa	16	41	773	1597	20	25
Mizuho	16	41	845	1625	18	25
Atsuta	12	44	464	896	25	49
Nakagawa	29	29	1323	2689	21	10
Minato	19	62	923	1866	20	33
Moriyama	18	39	702	1398	25	27
Meito	18	43	780	1663	23	25
Minami	17	47	1015	1881	16	24
Midori	25	49	855	1565	29	31
Tenpaku	21	36	623	1164	33	30
3 wards	63	132	2493	4610	25	28
Nagoya	308	708	13429	27036	22	26

4.2.2 3 Wards/Town Division

The result where $N = 442, c = 50, A = 400$ are shown in **Table7** and **Table8**.

Table 7: Optimal Solution,User's Satisfaction

Ward	x_i^0	X_i	P_k^0	P_k	S_i^0	S_i
Minami	17	62	1015	1881	16	32
Midori	25	63	855	1565	15	40
Tenpaku	21	54	623	1164	18	46
3 wards	63	179	2493	4610	25	38

Notations in **Table8** *1:Objective Value[m]*2:Average Traveling Distance[m]*3:Computational Time[s]

Table 8: Result

C	20		50	
A	247	248	115	116
Obj.V *1	N/A	1034880	N/A	1173700
Ave.Dist.*2	N/A	224	N/A	254
GAP	0.0621	0.0099	0.0639	0.0099
Time *3	N/A	1754.2	N/A	2368.0

5 Conclusion and Future Study

The main progress of this study compared with previous study [2] was the values of the traveling distance D_{ik}. That is, it is necessary to estimate the coefficients precisely to obtain near-optimal results. Several useful extensions to health welfare service facilities could be explored as future studies.

- Consideration of Various Types of Services
  For the different types of nursing facilities, I may need to consider that users emphasize waiting times of several facilities when they decide which facilities to use. It is important to be given expected waiting times to receive service. Deciding capacity of a facility may be related to a queuing system.

- User's Traveling Model
  There could be many ways for users to commute to facilities. My research assumed that users prefer to receiving service at the closest facility. However, sometimes users may care about convenient transportation or travel cost, and may choose service at a far-off facility. In this respect, the model of this study is not sufficient. So, it should be appropriate to generalize the cost or time-taking structure and transport network to commute each facilities. These may provide a better approximation to user behavior than a closest-facility constraint.

References

[1] Shigeru Nagano and Tatsuo Oyama: Mathematical programming analysis the reduction of the difference of districts of health welfare service facilities and their optimal locations, Communications of the Operations Research Society of Japan.

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[3] Atsuyuki Okabe,Atsuo Suzuki: Mathematics of Optimal Location, Asakura,1992.