

A Method to Evaluate an Urban Area by Using the Model That Calculates a Number of Facilities from an Area and a Population

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Abstract

This paper presents 1) a new mathematical model improved from a conventional model that calculates a number of facility from an area and a population in a town and, 2) by using this model, a method to evaluate the enrichment (in other words, convenience or enough) of facilities in the town where many high-rise apartments have been built (the area is hereinafter referred to as the high-rise apartment town). The conventional model uses only a nighttime population, but this paper considers a daytime population in addition to the nighttime population. Also, there has not been the method to evaluate the enrichment of facilities in a town, but we can evaluate it using this model. We apply this method to 23 special wards in Tokyo and the high-rise apartment towns, the results prove the effectiveness of the proposed method.

Keywords

Facility Density, High-Rise Apartment, Urban Studies, Urban Environments, Mathematical Model

1. Introduction

Since around year 2000, many high-rise apartments have been built in the bay area in Tokyo, Japan. This paper describes this area as the high-rise apartment town afterward. Mori (2015) finds that the town accepts many inhabitants, and Sakamoto (2016) reveals that many offices (for example, Convenience store, Dry cleaning shop, Dentist's office, Restaurant, Nursery, Kindergarten, etc.) are set up with the inhabitants moving in. Particularly, we know that the increase in family increases the nurseries, and the increase in high-rise office building increases convenience stores and dentist's offices. Figure 1 and Figure 2 show the result that Sakamoto (2016) investigated. The vertical axis of

Figure 1 shows “the number of facility every type of business/population density”, and that of Figure 2 shows “the number of facility every type of business/population”. The horizontal axis of Figure 1 and Figure 2 is the division of Koto ward, Tokyo into four groups and three towns so that the number of inhabitants in each group or town becomes nearly equal.

TOYOSU, SHINONOME and ARIAKE are the high-rise apartment towns. Figure 1 shows that there is more number of three kinds of facilities (convenience store, nursery and dentist’s office) in TOYOSU and ARIAKE than other towns, however, Figure 2 does not show this tendency. Figure 1 and Figure 2 prove the result that ARIAKE is higher in the ratio of facilities, however, it seems that TOYOSU and SHINONOME have more convenient public transportation, more shops, a larger population, etc., than ARIAKE sensuously.

This means that, in this way, we cannot evaluate the enrichment of facilities in the town, even if we look at the number of facilities by per population or a population density. If we know the standard (or suitable) number of facility, we can compare the value of a town with that of other towns and understand the characteristic of the town quantitatively. It becomes the knowledge of an urban policy or an urban study, and also helps the judgment whether a company opens a shop or an office.

We classify conventional studies in following 1) - 3).

1) About a facility location or its pattern: Balcik and Beamon (2008) consider facility location decisions for a humanitarian relief chain responding to quick-onset disasters.

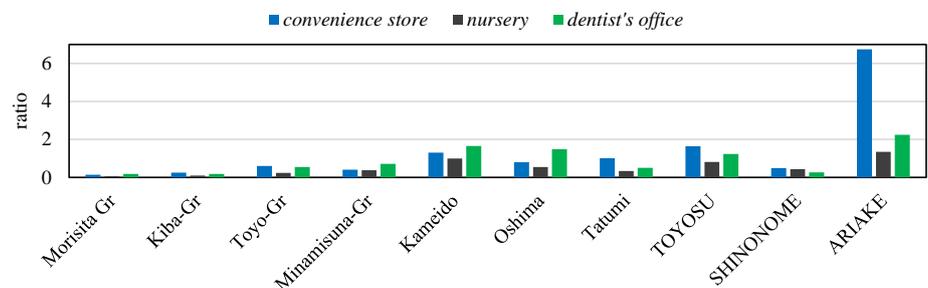


Figure 1. The number of each facility (convenience store, nursery, dentist’s office) per population density.

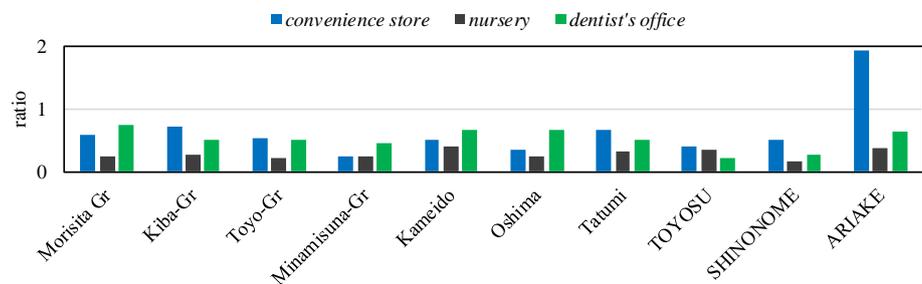


Figure 2. The number of each facility (convenience store, nursery, dentist’s office) per population.

[Gastner \(2011\)](#) studies about service establishments (e.g., post offices or gas stations) in the special cases where the population lives along a line (e.g., a road or a river). [Andres \(2014\)](#) analyzes location patterns of retail and food establishments.

2) About the stations for Electric Vehicle or Fuel Cell Vehicle: [Honma and Kurita \(2008\)](#) calculate the optimal number of hydrogen stations to the fuel cell vehicles. [Honma and Toriumi \(2014\)](#), [Wen, Laporte, Madsen, Norrelund, & Olsen \(2014\)](#) consider the problem of locating electronic replenishment stations for EVs (Electric Vehicles).

3) About a mechanical model which calculates a facility density from a population and an area: [Stephan and Dorman \(1985\)](#), [Stephan \(1998\)](#) present the mathematical model which calculates the total expenditure of facility (or office, shop, etc.) from the population of a data collection unit (e.g., a state) and its area. By minimizing this expenditure, the facility density (the number of facilities) providing a particular service to the population is obtained. [Qian, Yang, Han and Ma \(2012\)](#) calculate a facility density of post office, hospital, school and theatre using not the area data but only the population data. A characteristic of this study is to consider an index coefficient of the population of the model according to the generation and to consider GDP (Gross Domestic Product).

The studies 1) and 2) are different from our purpose. The study by [Qian, Yang, Han and Ma \(2012\)](#) does not use an area, but we have already confirmed that there is a type of business that cannot ignore an area. Therefore, this paper calculates the difference (Equation (1)) in every type of business by using a model of [Stephan \(1998\)](#) as a tool.

$$\begin{aligned} & \textit{Difference} = \textit{The number of the real facility} \\ & - \textit{The number of the facility which the mathematical model calculates} \quad (1) \end{aligned}$$

When the value of this difference is plus and big, there is more number of facilities than other towns. The negative value means (or indicates) less number of the facilities of the type of business in the town than other towns.

Here, when we use this model, it has the next problem. The population is greatly different from nighttime to daytime. In other words, the nighttime population is the number of inhabitants, but the daytime population is the number of people who comes to work or study in the town. A customer varies according to a type of business. For example, if the type of business is B to B (business-to-business, between businesses, as opposed to between a consumer and a business), it applies to daytime population. If the type of business is B to C (business-to-consumer, the sale of goods or services directly to customers), it applies to nighttime population. There is also a business of both which is B to (B + C). As an example, a target of convenience stores (open 24 hours) is both the office worker and/or the student (daytime population) and the inhabitants (night-time population).

In this way, it is necessary for us to check the target population (nighttime? daytime? or both?) by a type of business before we use this model, but the previous studies don't consider this point.

Summarizing the above, we consider the nighttime and/or daytime population in the model of Stephan (1998), and propose the method to evaluate a town by Equation (2). As an application example, we decide the parameter of the model in 22 special wards in Tokyo except Koto ward with the three high-rise apartment towns (TOYOSU, SHINONOME and ARIAKE). Tokyo has 23 special wards including Koto ward. Using the result, we prove the characteristic of the high-rise apartment towns in Koto ward.

$$T = hn + \frac{2s^\beta}{v} P^\alpha \tag{2}$$

2. The Mathematical Model Calculates the Number of Facilities from the Area and Population

2.1. G. Edward Stephan (1998)'s Model

T is the total expenditure of facility. The first term on the right side is the maintenance time (or equal to the cost), with h as the number of person-hours required per establishment and N as the number of facilities. The second term is the interaction time, with S as the average distance separating the population P from service establishments and v as the average velocity with which this distance is traversed (the distance has been doubled to represent roundtrips). α and β are investigated parameters, and Stephan (1998) shows that the value differs according to the facilities.

The average service area per establishment will be the total area A , divided N by. By dimensional analysis, the distance S must be proportional to the square root of the average area. With ω as the constant of proportionality in Equation (3), leads to Equation (4)

$$S^\beta = \omega^\beta \left(\frac{A}{N}\right)^{\frac{\beta}{2}} \tag{3}$$

$$T = hn + \left(\frac{2\omega^\beta}{v}\right) A^{\frac{\beta}{2}} P^\alpha N^{-\frac{\beta}{2}} \tag{4}$$

Equation (4) permits us to minimize T with respect to N . Differentiating Equation (4), we obtain Equation (5)

$$\frac{dt}{dN} = h - \left(\frac{\beta\omega^\beta}{v}\right) A^{\frac{\beta}{2}} P^\alpha N^{-\frac{\beta+2}{2}} \tag{5}$$

Equation (5), set equal to zero and solved for N , leads to

$$N = \left(\frac{\beta\omega^\beta}{vh}\right)^{\frac{2}{\beta+2}} A^{\frac{\beta}{\beta+2}} P^{\frac{2\alpha}{\beta+2}} = kA^g P^\delta \tag{6}$$

where,

$$k \equiv \left(\frac{\beta\omega^\beta}{vh}\right)^g, \quad g \equiv \frac{2}{\beta+2}, \quad \delta \equiv \alpha(1-g)$$

2.2. The Model That We Propose

The population of Equation (6) is a town's resident population, however, the set of population data of statistics is two types of data which is nighttime population and daytime population. There are some wards which have a big difference between a nighttime population and a daytime population. For example, in Chiyoda ward in Tokyo, the daytime population is about 17 times larger than the nighttime population. Therefore, it is necessary to think about which population (either nighttime population or daytime population, or both) we should use for the model, because a target customer by a type of business is different. The target of B to B is a daytime population, B to C is a nighttime population, and B to (B + C) is both. Thus, we introduce a weighting coefficient γ in the population P of Equation (6) to distinguish between a nighttime population P_n and a daytime population P_d ,

$$p \rightarrow \{\gamma P_n + (1 - \gamma) P_d\} \quad (7)$$

Replacing Equation (6) by Equation (7) gives

$$N = kA^g \{\gamma P_n + (1 - \gamma) P_d\}^\delta \quad (8)$$

3. Measurement of the Parameters of Our Model

In this chapter, we decide the parameters (k , g , δ , γ) of Equation (8) in every type of business by using real data. As an example, we explain a method to decide these parameters by use of **Figure 3**. The vertical axis expresses the number of facility N searched in a classified telephone directory (NTT Town-Page Corporation, Web telephone directory service, www.ntt-tp.co.jp/english/). The horizontal axis expresses the value of

$A^g \{\gamma P_n + (1 - \gamma) P_d\}^\delta$ (without k) in Equation (8). By use of a simulation programming we calculate the parameters by all combinations which has the following next conditions,

- $0 \leq \alpha \leq 1, 0 \leq \beta \leq 1, 0 \leq \gamma \leq 1$
- Each step size of three values (g, δ, γ) is 0.01 in the calculation program
- Program loops are nested to three levels for all combinations (g, δ, γ)

The red straight line drawn in **Figure 3** is the linear regression with no intercept calculated by the method of least squares. The values when the correlation coefficient is becomes maximum are the parameters (g, δ, γ), and the slope of the regression line becomes k of Equation (8).

In the 23 special wards in Tokyo, we use the statistics data of 22 wards except Koto ward with the three high-rise apartment towns to examine in the following chapter. The data are based on Basic Resident Register as of January 1, 2016.

Table 1 shows the number (No.) used for Tables or Figures, about the 22 special wards in Tokyo (No. 1 - No. 22) and the high-rise apartment towns (No. 24) in Koto ward (No. 23). **Table 2** shows the list of type of business to investigate and the number (No.) used for Tables or Figures. The third row of **Table 2** is an assumption of the target customers by a type of business.

At first, **Figure 4** shows the correlation coefficient by the conventional model Equation (9).

$$N = kA^{1/3}P^{2/3} \tag{9}$$

The parameters of Equation (9) are fixed values $g = 1/3$, $\delta = 2/3$ (Stephan & Dorman, 1985, Qian, Yang, Han, & Ma, 2012) and the population P is a nighttime population. We make a calculation in each case where the population P is a daytime or nighttime population. This result (see **Figure 4**) shows that the most suitable population varies according to a type of business.

Table 3 is the calculation results of the method that we propose (Equation (8)). As the minimum of the coefficient of correlation is 0.86, our model has an extremely high correlation about all types of business compared with **Figure 4**. **Figure 5** shows the second

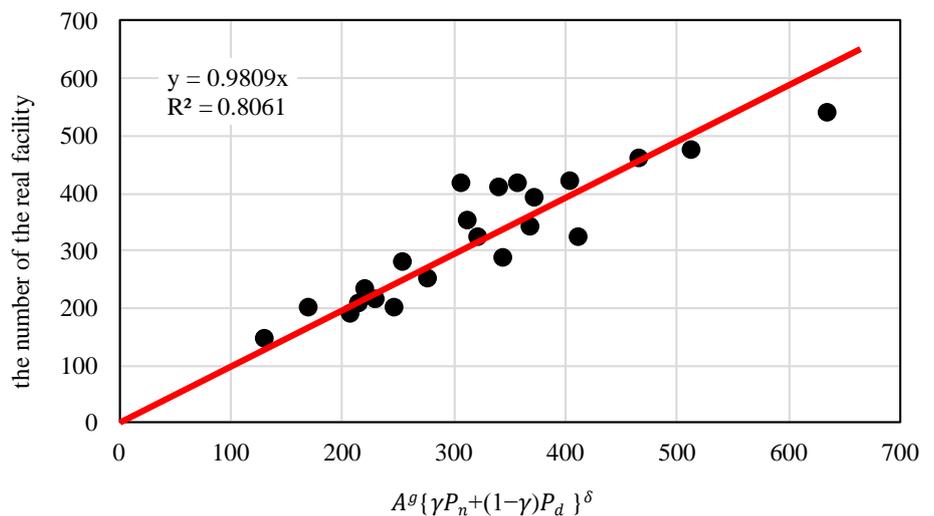


Figure 3. The real number of one facility vs. the term on the right side of Equation (8).

Table 1. No. used for tables or figures, about the 23 special wards in Tokyo and the high-rise apartment towns.

Number (No.) used for Figures or Tables	1	2	3	4	5	6	7	8
Ward	Chiyoda	Chuo	Minato	Shinjuku	Bunkyo	Taito	Sumida	Shinagawa
Number (No.) used for Figures or Tables	9	10	11	12	13	14	15	16
Ward	Meguro	Ota	Setagaya	Shibuya	Nakano	Suginami	Toshima	Kita
Number (No.) used for Figures or Tables	17	18	19	20	21	22	23	24
Ward	Arakawa	Itabashi	Nerima	Adachi	Katsushika	Edogawa	Koto*	TOYOSU, SHINONOME, ARIAKE

Koto* Koto ward except No. 24 (TOYOSU, SHINONOME and ARIAKE).

Table 2. No. used for Tables or Figures, about the list of type of business and an assumption of target customers.

Number (No.) used for Figures or Tables	1	2	3	4	5	6
Type of business	CVS	laundry shop	nursery	dentist	pharmacies or drugstores	leasing company
Supposition Target	B to B + C	B to C	B to C	B to B + C	B to C	B to B
Number (No.) used for Figures or Tables	7	8	9	10	11	
Type of business	caterers	takeout food store	delivery to home restaurant	sports club	gas station	
Supposition Target	B to B	B to B + C	B to C	B to B + C	B to B + C	

CVS: Convenience Store nursery: We use a capacity of the nursery school not a number of facilities, because an acceptable capacity is greatly different by a scale of facility [× 1000].

Table 3. The calculation results of the method that we propose.

No.	1	2	3	4	5	6	7	8	9	10	11
g	0.16	0.00	0.17	0.00	0.05	0.00	0.03	0.03	0.00	0.13	0.64
δ	0.72	0.93	0.70	0.91	0.77	0.99	0.48	0.65	0.99	0.86	0.36
γ	0.00	0.88	0.99	0.40	0.71	0.00	0.00	0.00	0.38	0.00	0.00
$1 - \gamma$	1.00	0.12	0.01	0.60	0.29	1.00	1.00	1.00	0.62	1.00	1.00
correlation coefficient	0.99	0.97	0.99	0.98	0.99	0.86	0.93	0.99	0.94	0.88	0.94
k	1.34	0.51	0.68	1.18	1.94	0.05	1.00	0.77	0.065	0.074	0.43

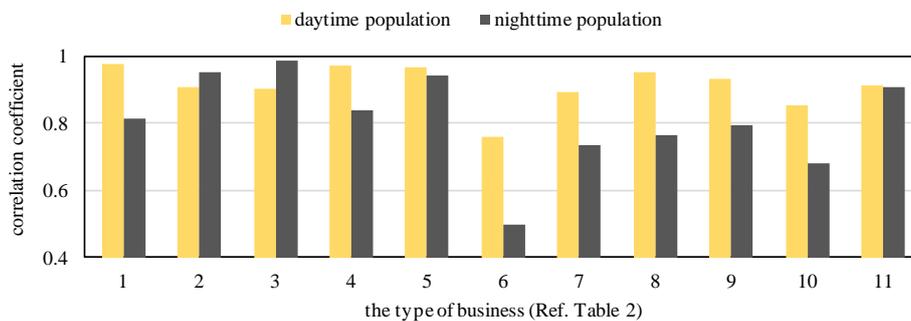


Figure 4. The correlation coefficient by the conventional model Equation (9).

row (g) and the third row (δ) of **Table 3**. As pointed out in chapter 1, depending on a type of business, the number of facilities are influenced by an area (No. 1, 3, 10 and 11). Therefore, the model cannot ignore the area. **Figure 6** shows the fourth row (γ) and the fifth row ($1 - \gamma$) of **Table 3**. We regarded No. 2, 3, 5 and 9 as a type of B to C that target the nighttime population. **Figure 6** shows that No.2, 3 and 5 are in agreement with our assumption, however, No. 9 is greatly in influenced by the daytime population. No. 6 and 7 are a type of B to B for office workers, but it is revealed that No. 1, 8 and 10 also have high correlations with the daytime population. No. 4 and 11 B to (B + C) is same as what we thought.

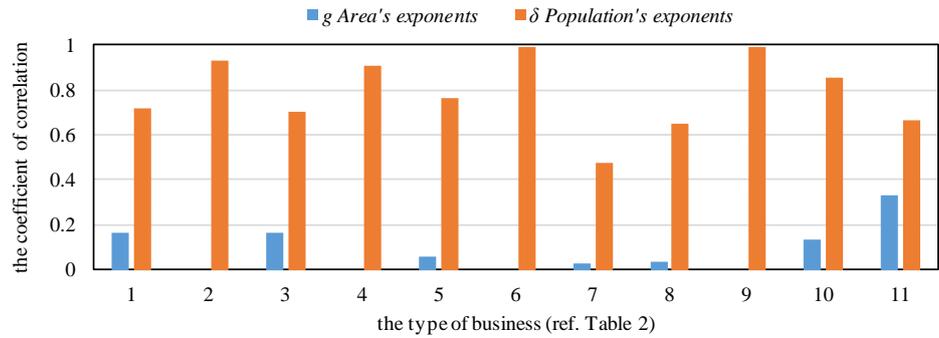


Figure 5. g and δ of Table 3, Value of the area' exponents and the population' exponents are most suitable for every type of business.

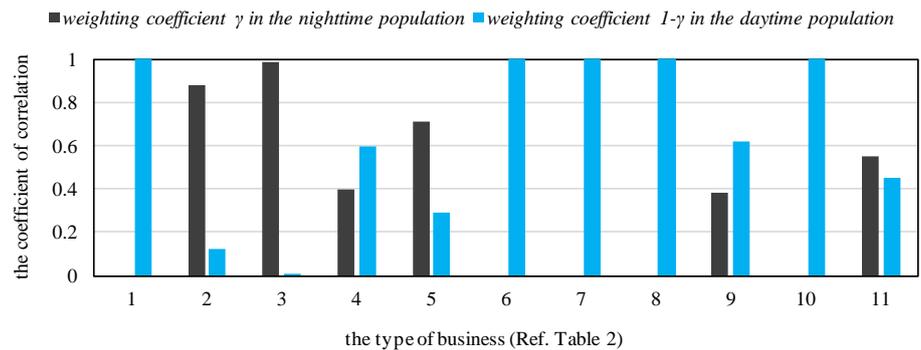


Figure 6. The weighting coefficient of the nighttime population and the daytime population when the coefficient of correlation becomes the maximum every type of business.

4. Evaluate Ability of the High-Rise Apartment Town

In this chapter, we calculate the value of the right side of Equation (8) by using the value of Table 3. By the difference between the calculated value and the real N , (Equation (1)), we evaluate the enrichment of facilities in the high-rise apartment town. Figure 7 shows the result in comparison with Figure 1 and Figure 2, indicating that the number of facilities of TOYOSU and SHINONOME are more substantial than ARIAKE. ARIAKE has many convenience stores for several reasons which are, other than being the high-rise apartment town, heavy traffic due to many larger-scale distribution companies and a number of people gathering in many event halls. Because TOYOSU has companies and inhabitants more than ARIAKE, there are many three kinds of facilities (convenience store, nursery and dentist's office). This result accords with the actual feeling.

However, Figure 8 shows that there are few number of the convenience store and the dentist's office because the area of the high-rise apartment town is larger than that of other wards. The town where houses crowd has more the convenience store and the dentist's office. On the other hand, in the high-rise apartment town, the nursery is increased because the number of families suddenly increased, and Figure 9 shows descending order of the capacity of nursery facilities. In the 23 wards in Tokyo, the high-rise apartment town has the largest capacity of the nursery.

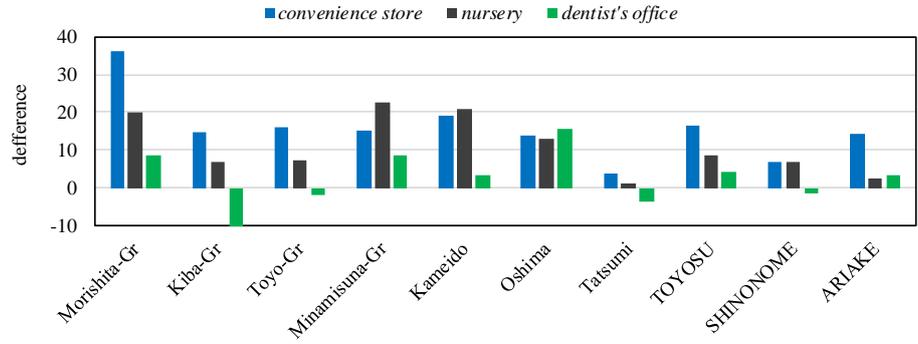


Figure 7. Differences between real N and the right side of Equation (8), Comparison in Koto ward, Characteristic of the high-rise apartment town.

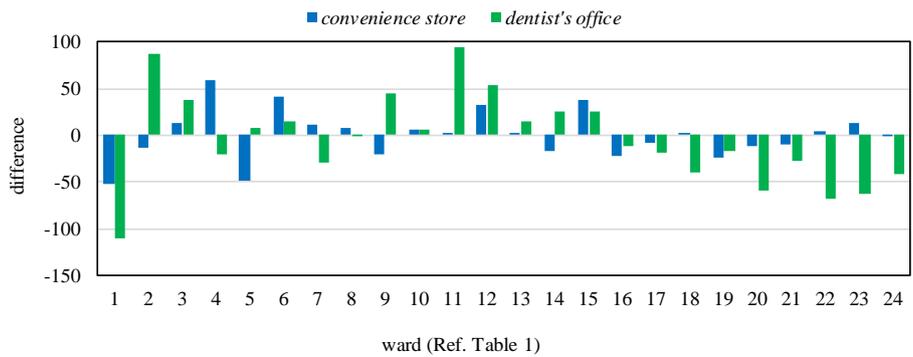


Figure 8. Differences between real N and the right side of Equation (8), CVS and the dentist's office.

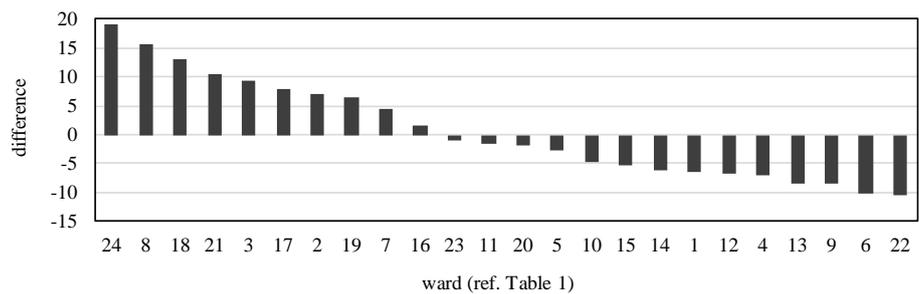


Figure 9. Differences (Equation (1)) between real N and the right side of Equation (8), the capacity of the nursery facilities.

5. Conclusion

This paper improved a conventional model, and clarified that the correlation of number of the facility and either a nighttime population or a daytime population is high according to a type of business. Using our model, we proposed the method to evaluate the enrichment of facilities in a town, and developed the method to indicate the characteristic of the high-rise apartment town, which we were not able to clarify in our previous study.

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