Formulation of a Quantitative Method to Evaluate the Accessibility to Food Facilities Based on the Load of the Facility Utilization for Analysis of Population Distribution

Tatsuya Suzuki*, Tohru Yoshikawa2 and Ryo Sanuki3

1 JSPS Research Fellow, Architecture and Building Engineering, Tokyo Metropolitan University, Japan
2 Professor, Department of Architecture and Building Engineering, Tokyo Metropolitan University, Japan
3 Assistant Professor, Department of Architecture and Building Engineering, Tokyo Metropolitan University, Japan

Abstract
This paper aims to formulate a quantitative method of evaluating accessibility to the various food facilities, which share the same purpose as meal suppliers but different characteristics, by a common index, for analysis of population distribution. In this study, food facilities are classified into Facility Group I where food facilities cook meals and provide customers with a space to eat meals and Facility Group II where food facilities cook meals but provide no space for eating.

By comparing the transportation and initial loads, this approach models the zone where residents find that one facility is more advantageous to the others. This article also compares the loads of facilities between the case where a user makes a round trip to a facility and the case where the user stops by a facility on the way from/to his/her home. The proposed model theoretically explains the zones obtained in the preceding empirical analysis. Analysis on the locations of facilities and the population distribution around a station shows that the facilities of low initial load were located near the station to promote users to stop by, and that areas with small loads tend to have a large share of single-person households.

Keywords: meal; stopping-by; facility location; energy load; Thünen ring

1. Introduction
1.1 Background
The structure of the Japanese family has changed since the end of World War II in terms of the nuclear family, small-scale family and family diversification. The typical household form in the period of high economic growth was a husband, wife and children. However, since then the number of single-person households has been rapidly increasing. According to the Japanese national population census in 2010, the percentage of single-person households has reached 32.4%, the largest ratio among all forms of household and the Annual Health, Labour and Welfare Report 2011-2012, issued by the Ministry of Health, Labour and Welfare of Japan, expects that it will reach 37.4% by 2030. This means that, in 2010, Japan had a moderate percentage of single-person households compared with other developed regions, such as 40.4% of Germany in 2011, 34.4% of France in 2009, 32.9% of the United States, 28.9% of the United Kingdom, 28.8% of Taiwan, 27.6% of Canada and 23.9% of the Republic of Korea. This is due to an increase in the percentage of unmarried people, decrease in the total fertility rate, and aging of the population. In addition, the distribution of the single-person households is uneven. Kim et al. (2014) pointed out that in downtown Tokyo, there was a tendency for the ratio of single, middle-aged households to increase. These phenomena indicate that the family environment has been changing dramatically.

Through the change of the family environment, people's lifestyles have also changed. In particular, people used to eat their meals together as a family while the style of eating meals has diversified in recent years partly due to the development of the eating-out industry. Ham et al. (2004) indicated that single people in Korea tended to dine out more often and spend a higher amount on food-away-from-home compared to their married counterparts. Yen et al. (2013) indicated that, in single-person households of the United States, work hours played an even more important role increasing both the probability of having a meal away from home and the conditional expenditures on food-away-from-home breakfast. People now have meals outside their homes at family restaurants or fast-food restaurants, buy precooked
foods at convenience stores, or buy packed lunches or prepared foods at lunch box stores. This trend indicates that in Japan cooking and dining, which used to be done at home, is now done outside (Shigeno, R. 2004), (Tokoyama, H. 1999). In fact, the "meal from external sources" ratio defined by dividing the market size of the eating-out industry including the precooked food retailing industry by the total food and drink expenses throughout Japan has been increasing, which indicates that people have become more dependent on eating out or buying precooked foods. Most popular websites of rental apartment real-estate agencies in Japan display information on access to convenience stores and the like, which suggests that in the diversification of lifestyles people are displaying behavior outside that they used to display within their homes, and stores, restaurants and facilities are responding to this change in demand. It can therefore be assumed that the distribution of homes and that of food facilities are closely related to each other. This leads to the expectation that the accessibility to food facilities would be important in the planning of residential districts of many countries including Japan where the size of households is reducing.

1.2 Related Studies and the Aim of this Study

The following shows an overview of the preceding studies of this article mainly in the research context of Japanese society. One related study investigated home meal replacement in association with the social background and another study analyzed, from the life convenience viewpoint, the relation between the accessibility to food facilities and the population distribution.

The subject of home meal replacements, on which the present study focuses, has been widely examined in fields such as economics, sociology, and home economics. For example, Tokoyama (1999) studied changes in family styles and home meal replacements and in particular focused on the possibility that the consumption of cooked foods outside the home was induced by the reduction in the household population and the aging of household members. Kajiwara (2006) analyzed from questionnaire surveys various patterns of home meal replacements from the perspective of the lifestyles and dietary awareness of young people.

In the fields of geography and city planning, there are many studies on the relation between the accessibility of food facilities and population distribution with a focus on life convenience (Arakawa et al. 1996). The studies note that people tended to choose a place to live, which is an influential factor in the population distribution, based on convenience for commuting to work. In addition, the studies assume that places where people could live a convenient and comfortable life, i.e. places with high life convenience tend to be chosen. There are many studies on the relation between life convenience and population distribution from this perspective. For example, Sadahiro (1992) analyzed the relation between the locations of various facilities such as convenience stores, supermarkets and department stores and the population density distribution from the viewpoint of accessibility. Uchihara and Yoshikawa (2009) focused on the population increase/decrease and life convenience in Hamamatsu City and Kanazawa City. Their analysis was based on the study on the distribution of local facilities including stores. Hong et al. (2012) included commercial facilities in the valuables of analysis for perceived quality of life in new towns in Korea.

There are also studies on facility locations with a focus on the accessibility, based on temporal and spatial analysis of the behaviors of the facility users. For example, based on time geography proposed by Hägerstrand (1970), Tahara and Osaragi (2008) carried out a survey in the Tokyo area with a focus on the spatial location relationship among homes, preschools, and work sites. Tanaka (2011) proposed a facility location model maximizing the numbers of commuters who can enjoy the service from start to end at the facility on their way home.

As shown above, there are many studies on home meal replacements and analyses on the city population distribution and facility locations from the viewpoint of the accessibility of the facilities. However, there are few studies on the combination of these two approaches, namely on home function replacements (Azuma, 1998) from the accessibility viewpoint. Among the few studies, Suzuki et al. (2011a, 2011b, 2012, 2013a) analyzed the distribution of home meal replacement facilities and home distribution from the accessibility viewpoint. Although they conducted empirical studies, they did not develop a theoretical model and hence did not generalize the observed phenomena. Furthermore, there remains the problem of analyzing the accessibility to various facilities.

To fill this research gap, the present study aims to formulate a quantitative method to evaluate the accessibility to the various food facilities, which share the same purpose as meal suppliers but different characteristics, by a common index, based on the pilot study by Suzuki et al. (2013b).

2. Research Method

In the present study, the food facilities mentioned in Chapter 1 are classified by their utilization form into Facility Group I where food facilities such as family restaurants cook meals and provide customers with a space to eat meals and Facility Group II where food facilities such as packed lunch stores cook meals but provide no space for eating. In this study, the effort and cost required for cooking and providing a dining space is called the load. According to Suzuki et al. (2011a, 2011b, 2012, 2013a), there are two methods of evaluating the load. One is to present the load in terms of cost. For example, the price of a take-out meal or charge for dining at a family restaurant is the
First, people's selection of facilities is modeled based on a load minimization principle. When a group of facilities is located at the origin, people living outside the origin necessarily have a load to walk to the origin to receive services. The load is proportional to the distance to the facilities and hence can be calculated by multiplying the load per unit distance by the distance. Facility Group I where users receive services in the facilities and Facility Group II where users take out the provided services have different loads since the former requires the users to simply visit the facilities but the latter requires them to not only visit the facilities but also take out what they receive from the facilities. Let \( s \) be the distance between a home and the origin where the facilities are located, \( t_i \) be the load per distance to use Facility Group I where the users do not have to bring back the service, \( t_i \) be the load per distance to use Facility Group II where the users bring back the service, and \( T_i \) and \( T_2 \) be the load of Facility Groups I and II, respectively. Using these symbols a transportation load curve can be drawn with two different slopes as shown in Fig.1.

The users also need to pay for the received services and the price varies depending on the facilities and the services. Unlike the load for the transportation, this load, called the initial load, is for the users' use of the facilities and is the same for every user. Let \( c_1 \) and \( c_2 \) be the initial loads for Facility Groups I and II, respectively. The load curve, including the initial load, is given in Fig.2, where the difference between the transportation cost and the service price is taken into consideration. The position of the crossing point \( s^* \) is determined by the service price, i.e. the initial load. If it is assumed that a person living at distance \( s \) from the origin chooses to take action to minimize each load, the type of facilities that he/she uses changes depending on whether the load is the lower or upper side of boundary point \( s^* \) shown in Fig.3, where \( s^{**} \) shows the maximum walkable distance.

This result indicates that a doughnut-shaped zone, where users find one facility more advantageous compared to the others, can be defined on a two-dimensional map. Let us call the zone a facility utilization zone. Even though the function of the facility is different, the formulation of the facility utilization zone is similar to the city land use model by Alonzo (1964) and to the Thünen ring forming process in Thünen's agricultural site location theory of an isolated country (von Thünen 1826). The difference between the developed model and the Thünen-Alonzo model is that in the former the loads per distance of going and returning may change and the initial loads exist, though the shapes of the facility utilization zone do not change. Therefore, the concentric circle zone mentioned in the paper of Suzuki et al. (2011a, 2011b, 2012, 2013a) can be explained with the proposed model (Fig.4).

When multiple facilities are located in different places, Voronoi diagrams are frequently used to describe the business areas of the facilities (Okabe et al. 2000). In simple Voronoi diagrams, the facilities are treated equivalently and the facility utilization zone to which each map point belongs is determined only by the distance to the facility. Therefore, the boundary of the facility utilization zone is a perpendicular bisector of the line connecting two facilities. This defines the nearest neighbor facility utilization zones (Fig.5).

On the other hand, the transportation load curve has two slopes, which correspond to the migration to
facilities and the conveyance of the received services, respectively. In addition, each facility has its own initial load. The load distribution therefore takes the form shown in Fig.6. The boundary between two facilities is defined by the area connecting the crossing points of the equi-load lines of the facilities.

Let us formulate this area by using a plane. Let \((a_1, b_1)\) and \((a_2, b_2)\) be the position of Facility Groups I and II respectively on a plane. We consider a three-dimensional space with the plane and a height axis. A straight line extending from an apex \((a_1, b_1, c_1)\) in the direction to \((1, 0, t_1)\) is rotated around the vertical axis crossing the apex. This forms a circular cone, which represents the load of Facility Group I. A circular load representing the load of Facility Group II can also be drawn in the same way. The crossing line of these two downward circular cones is projected onto the horizontal plane, which represents the boundary of the facility utilization zones (Fig.6.). The boundary can be expressed by the following formula:

\[
t_1V[(x-a_1)^2 + (y-b_1)^2 + c_1] = t_1V[(x-a_2)^2 + (y-b_2)^2 + c_2].
\]

2.1.2 Model with Form of Behavior Taken into Consideration

The above-mentioned basic model is now extended to take account of behavioral forms of utilizing facilities. In general, there are two behaviors of using the facilities: Making a round trip to a facility and stopping by a facility. The former behavior to utilize a facility can be described with the basic model introduced in 2.1.1. The latter behavior was modeled by Suzuki (2002), Kurita et al. (2008) and Miyagawa (2010), and Isono et al. (2011) studied an oval zone that represents the load of Facility Group I. A circular load representing the load of Facility Group II can also be drawn in the same way. The crossing line of these two downward circular cones is projected onto the horizontal plane, which represents the boundary of the facility utilization zones (Fig.6.). The boundary can be expressed by the following formula:

\[
t_1V[(x-a_1)^2 + (y-b_1)^2 + c_1] = t_1V[(x-a_2)^2 + (y-b_2)^2 + c_2].
\]

First, we consider the case in which we use \(F_2\) of Facility Group II on the way back to the home (end point). As in Fig.7., the start point (the station) and the via point (the facility) divide the area into \(A, B\) and \(C\). In the figure, \(O\) indicates the station and \(F_2\) indicates the facility. If the home is in \(A\) or \(C\), simple transportation load \(t_1\) increases to service-conveyance load \(t_2\) and the slope of \(t_2-t_1\) increases. The load is lowest equivalent to the initial load \(c_2\), in the case where the home is located in the same place as \(F_1\). When the home is in \(B\), the resident passes by his/her home to go to \(F_2\) and then returns to the home. Let the distance from \(O\) to \(F_2\) be \(d_1\) and that from \(O\) to the home be \(x\). Then the load in this case is given by \((d_2-x)(t_1+t_2)+c_2\). Therefore, the load increases as shown in Fig.7. On the other hand, for Facility Group I, there is no increase in the service-conveyance load and the transportation load is always maintained at \(t_1\). In this case, the slope can be obtained by inserting \(t_1\) to \(t_2\) and \(c_1\) to \(c_2\) in Fig.7. If we assume that Facility \(F_1\) of Facility Group I is located farther from the station than \(F_2\), the graph appears as shown in Fig.8.

If the home is taken as the start point, the slope in Area A and C is always zero. First, let us focus on Facility \(F_2\), which requires a service-conveyance load. In this case, the load \(d_1(t_2-t_1)\) is needed in addition to the initial load \(c_2\). In Area B, the load can be calculated in the same manner as that described above and given by \(d_2(t_1+t_2)-2xt_1+c_2\) (Fig.9.). In the case where the user utilizes Facility \(F_1\), the load slope and the lowest load are both different between the case where the home is taken as the start point and the case where the home is taken as the end point. In contrast, there is no change in the graphs if the user utilizes Facility \(F_1\) (Fig.10.).

3. Application of Model

In this chapter, the model described in Chapter 2 is applied to the actual facility and population distribution. First, in order to illustrate the formulated model, it is applied to the distribution of facilities around Keio-Horinouchi station in Hachioji City, a suburban municipality of Tokyo Metropolis. Second, the relationship between the facilities and the share of

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\text{Fig.7. Group II (on the way back home)}
\]

\[
\text{Fig.8. Group I and Group II (on the way back home)}
\]

\[
\text{Fig.9. Group II (the home is taken as the start point)}
\]

\[
\text{Fig.10. Group I and Group II (the home is taken as the start point)}
\]
The single person households around all the stations is analyzed in Hachioji City.

### 3.1 Facility Distribution around a Station

The study target is the facilities in a 1200-m linear distance from Keio-Horinouchi Station to take account of the maximum walkable distance of the users. The six selected facilities are listed in Table 1. with their initial and transportation loads (Suzuki et al., 2013a).

For simplicity, only the energy load is focused on and only the linear distance is considered. Homes are distributed over an area of 1200-m linear distance from the station. In the following, it is assumed that the residents living in the area utilize the facilities for which the required energy load is the smallest.

### Table 1. Initial and Transportation Energy Loads

| Facility Type              | Transportation (j/min) | Initial (j) |
|----------------------------|------------------------|-------------|
| Lunchbox stores            | 0.2009                 | 138.2286    |
| Cafes                      | 0.1884                 | 224.4743    |
| Convenience stores         | 0.2009                 | 138.2286    |
| Fast food restaurants      | 0.1884                 | 177.7836    |
| Family restaurants         | 0.1884                 | 360.5402    |
| Supermarkets               | 0.2009                 | 225.7160    |

Reference: a) Yada, Y. (2008) Path Analysis in a Supermarket and String Analysis Technique. Proceedings of the Institute of Statistical Mathematics Vol. 56, No. 2, 199–213 in Japanese. b) Ministry of Health, Labour and Welfare. Exercise and Physical Activity Guide for Health Promotion 2006. c) Statistic Bureau, Ministry of Internal Affairs and Communications. Time Use and Leisure Activities (2012) d) Statistic Bureau, Ministry of Internal Affairs and Communications. Housing and Land Survey (2008) e) The NHK Japanese Time Use Survey (2005) f) http://trendy.nikkeibp.co.jp/ g) http://www.nikkeibp.co.jp/associe/
Fig.11. shows the distribution of the station and facilities. The facilities are distributed in the northwest direction from the station because a large residential development area and a golf course are located on the southeast side of the station.

Fig.12. shows the distribution of the energy load of the round trip, hereinafter abbreviated as round-load, from a home to a facility. An equi-load concentric circle is formed centering on a facility. However, for family restaurants, no such circle is formed since the utility of their neighboring facilities is higher. Users living in a particular area may find one facility more advantageous to the others. Fig.13. shows such areas, i.e. the facility utilization zones, for each facility. As mentioned above, family restaurants are close to other facilities and hence they do not usually form their own facility utilization zones. Supermarkets and fast food restaurants are often located near convenience stores or lunch box stores and hence some of them do not have their own facility utilization zones.

Fig.14. shows the load distribution of a user who stops by a facility on the way from his/her home, hereinafter abbreviated as from-home-load. As can be seen in the figure, equi-load lines are formed radially from the station, and the load is small if a facility of small initial load is located near the station. Fig.15. shows the facility utilization zone of each facility. The zones are formed only for three convenience stores and one lunch box store near the station. This result indicates that it is necessary for a facility to be located near the station in order to be utilized by users if user behaviors starting from their homes are considered.

Fig.16. shows the distribution of the load of a user who stops by a facility on the way to his/her home, hereinafter abbreviated as to-home-load. An egg-shaped equi-load line is formed on the line connecting the station and the facility. In comparison to the case where the user stops by the facility on the way from his/her home, the effect of utilizing facilities that are not located near the station is higher. Fig.17. shows the facility utilization zone of each facility, which has many zones of lunch box stores and convenience stores. In comparison to the case where the user stops by the facility on the way from his/her home, the fact that the initial load for a facility remote from the station is lower than that for a facility near the station affects the zone formation.

Fig.18. shows the lowest load distribution for three behavior patterns: One round trip behavior and two stopping-by behaviors. In the round trip to a facility, all the loads for the round trip behavior are taken into account. In contrast, if a user stops by a facility on the way somewhere, the load for the user to move from the start point to the end point directly, which is necessary even if the user does not stop by the facility, is not included. Thus, the stopping-by behaviors are advantageous. Hence, Fig.18. is similar to the combination of Figs.14. and 16., and receives little impact from Fig.12. There are few facilities located on the southeast side. Hence the southeast side has a high load distribution. Fig.19. shows the facility utilization zone for each facility. There are many facility utilization zones of the facilities near the station including convenience stores and lunch box stores of small initial load.

3.2 The Relationship between the Facilities and the Share of Single-Person Households

By applying the proposed model, we analyzed the relationship between loads of utilizing various facilities and the share of single-person households in administrative districts, called small areas in the Japanese Census, in Hachioji City.
Table 2. Regression Analysis

| Distance | Observations | $R^2$ | Adjusted $R^2$ | Standard error | F     | Probability |
|----------|--------------|-------|---------------|----------------|-------|-------------|
| 0-500m   | 9            | 0.977 | 0.969         | 0.023          | 127.613 | 0.000       |
| 500-1000 | 54           | 0.52  | 0.491         | 0.112          | 18.023  | 0.000       |
| 1000-1500| 42           | 0.519 | 0.482         | 0.128          | 13.693  | 0.000       |

Table 3. The Adopted Explanation Variables

| Distance | Model | Coefficient | Standard error | Standardized coefficient | t     | p>|t| |
|----------|-------|-------------|----------------|--------------------------|-------|---|
| 0-500m   | Constant | 35.238  | 3.009  | 11.712  | 0.000 |
|          | The round-load of the fast food restaurant (J) | -0.073 | 0.013 | -0.853 | 0.000 |
|          | The round-load of the convenience store (J) | -0.095 | 0.025 | -0.463 | 0.000 |
| 500-1000 | Constant | 14.051  | 2.287  | 4.655  | 0.000 |
|          | The round-load of the convenience store (J) | -0.107 | 0.025 | -0.557 | 0.000 |
|          | The round-load of the fast food restaurant (J) | -0.048 | 0.029 | -0.433 | 0.000 |
| 1000-1500| Constant | 33.387  | 5.953  | 5.608  | 0.000 |
|          | The round-load of the convenience store (J) | -0.029 | 0.018 | -0.463 | 0.000 |
|          | The round-load of the fast food restaurant (J) | -0.091 | 0.029 | -0.433 | 0.000 |
|          | The round-load of the family restaurant (J) | -0.038 | 0.014 | -0.853 | 0.000 |

As preceding studies, Suzuki et al. (2011a, 2011b, 2012, 2013a) have shown that an area with lower load or around stations tends to have a lower share of single-person households, although a statistical analysis of the relationship of the three factors has not been conducted. As the city is located in the commutable area of Tokyo, residents and facilities tend to gather around the stations, as shown in the previous section. This indicates that the relationship between the facilities and the population may differ according to the distance to the stations. Thus, the areas around the stations are divided by the road distance to the nearest station into the following three zones where the relationship is analyzed separately: the zone within 500 m, the zone between 500 m and 1000 m, and the zone between 1000 m and 1500 m.

We calculated the road distance to the nearest station from the central points of all the basic unit blocks of the census. We also obtained the three types of loads, i.e. the round-load, the from-home-load and the to-home-load, of the six selected facilities listed in Table 1., from the central points. Through weighting the distance and the loads by the population of each unit block of the census in the small areas, we obtained the weighted average distance and loads of each small area. In each of the three distance zones, stepwise forward regression analysis was applied, in which the share of the single-person households is the objective variable and the loads are the explanation variables. The Pin and Pout of the stepwise forward regression are 0.05 and 0.1, respectively.

The summary of the regression analysis is shown in Table 2. and the adopted explanation variables are shown in Table 3. In the distance zone within 500 m, the from-home-load of the fast food restaurant and the round-load of the supermarket are adopted. According to the increase in the loads, the share of single-person households decreases. The decision coefficient is high, and the F-value is highly significant. In the distance zone between 500 m and 1000 m, the round-loads of the convenience store, fast food restaurant and family restaurant are selected. Only the sign of the partial regression coefficient of the round-load of the family restaurant is opposite. The round-load of the family restaurant has a negative correlation of -0.352 to the share of the single-person households, but has a strong positive correlation, of 0.608 and of 0.751, to the round-loads of the convenience store and fast food restaurant, respectively. This implies the existence of the multicollinearity. In the distance zone between 1000 m and 1500 m, the round-load of the cafe and the to-home-load of the convenience store are adopted. The signs are negative, but the decision coefficient is moderate. In summary, even though the result might not be stable because of the multicollinearity, in the proximity of the stations, small areas with small loads tend to have a large share of the single-person households.

4. Conclusions

This article formulates a quantitative method to evaluate the accessibility to food facilities with a common index. This approach is modeled by comparing the transportation and initial loads and the zone formation of the facilities. This article also compares the loads of facilities between the case where the user makes a round trip to the facility and the case where a user stops by the facility on the way somewhere. In the latter case, the shape of the equilibrium lines differs from those reported in preceding studies. The proposed model theoretically explains the facility utilization zones obtained in the preceding analysis.

Analysis on the locations of near-station facilities around a station in Hachioji City showed that the facilities of low initial load, such as convenience stores or lunch box stores, were located near stations to promote users to stop by on their way from/to the station. In contrast, family restaurants and supermarkets were located near stations to encourage users to simply travel to and return from the facilities. These two types of facilities thus had different customer targets. The empirical study around all the stations of Hachioji City shows that areas around the stations with small loads have a strong tendency to have large shares of single-person households. These results suggest that the accessibility to food facilities would be important in the planning of residential districts of the regions where the size of households is reducing.

4.1 Remaining Problems

The following issues remain. This paper employs two types of loads for the analysis, the load of...
transportation on foot and the load of the conveyance of received services, i.e. purchased food. In actual situations, the transportation load has greater variety due to the variety of transportation means. For example, remote users may use bicycles or cars. In order to evaluate the facilities on the same basis, the transportation load needs to be modeled with various transportation means taken into account.

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