AN EVALUATION INDEX OF BUS DIAGRAM TO EQUALIZE ACTIVITY OPPORTUNITY

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ABSTRACT

In areas where the density of transport demand is low, the local government provides public transport service, which is indispensable to the life of its residents. It is important to consider fairness when the local government does public transport planning, but the research on indices for policy assessment that can reflect fairness is very little. In this paper, we propose an index that evaluates a public transport plan from the aspect of fairness in the opportunity of activity. Then, we apply the proposed index to develop a method for finding a timetable of buses in rural areas, and demonstrate the usefulness of the method through a case study.

Keywords: Local Transport Plan, Securing Opportunity of Activity, Public Transport Service, Policy Assessment

1. INTRODUCTION

As the car ownership of the households increases, the car has come to be used for a wide variety of activities in daily life. However, because public transport is an essential means of transport in the daily life of the people who cannot use cars, many local governments supply public transport services to secure their activities.

At the same time, with the progression of an aging society, the number of elderly people who find it difficult to go out are increasing because of the decline in their physical ability. This problem has become even more serious in areas where public transport service is inconvenient. In these areas, sufficient public transport service is required of local governments.

In such situations, local governments tend to develop a public transport plan from a view point based on profitability. As a result, sufficient public transport service is not provided. For example, on routes where there are few users, only 2 or 3 buses are run per day, or the number of runs has been decreased on routes where the profit is low. The cause of such a situation may be that local governments selected a public transport plan based not on an “Index of policy assessment” but on an "Index of business evaluation".

The pattern of daily life activity of public transport users is constraint, because the route and time of public transport is generally fixed. And so, it is important to determine when users go out, and to select a route and schedule of public transport allowing them to do as many activities as possible under the restriction of the budget. For the policy assessment, it is necessary to create an index that shows how much opportunity of activity of daily life can be secured by using public transport, as Kita (2008) discussed. The index is named "a security level of the opportunity of activity". Here, we use the term "security" in the sense of "human security". The report of Commission on Human Security (2003) explains this as "Human security means creating political, social, environmental, economic, military and cultural systems that together give people the building blocks of survival, livelihood and dignity." In rural areas where residents are usually located far from hospitals or stores, public transport is not only a means of transport but also a means of life. We think it is important for our lives to be able to get to the hospital or a store, and the ability to do so be secured by using public transport. We think it is simply human security to want to secure the opportunity of activity, and we evaluate it in this study. Under such recognition, we propose an index for policy assessment based on the idea of securing a certain level of the opportunity of activity impartial for the areas where a density of public transport demand is low. In addition, the ability to apply the index to a public transport plan by using the evaluation case with a bus schedule that considers the equity of areas.

In this paper, we propose an index of the policy assessment that shows the equity of the opportunity of activity, and a method of selecting a bus schedule by using that proposed index. In addition, we will show usefulness of the index and the proposed method through a case study.

The structure of this paper is as follows. In Chapter 2, we introduce some concepts used in the proposed index with the study review, and propose an index that equalizes the security level of the opportunity of activity in Chapter 3. In Chapter 4, we show the method of setting the bus schedule by using the index. In Chapter 5, we examine the applicability of the proposed index and method. Chapter 6 is the conclusion.

2. ACCESSIBILITY INDEX

2.1 Study Review

A lot of research works on bus transport planning have been conducted. In these studies, Filippini and Prioni (2003) evaluated an appropriate corporate of bus transportation based on the operation cost. Murray and Davis (2001) discussed the fairness of the public transport service in a region based upon the use of socio-demographic and economic information. Besides these, the research on Bus Rapid Transit (e.g. Alvinsyah and Zulkati (2005), Henser and Golob (2008)) is seen as a research case of the operation planning of a bus service. However, there are few studies that research the bus service from the viewpoint of equity or security level of the opportunity of activity. Moreover, the research about the selection method of the schedule of the shuttle bus is hardly seen.

Kita (2007) shows three kinds of concepts of the equity concerning the local public transport planning. The first is the idea that equity is secured for the most part depending on the equalization of governmental investment (The amount of the investment for each area is made the same). The second is equalization in the service characteristic (equalizations of the number of bus services). The third is the idea that equalizes the opportunity of activity (the opportunities to lead life are made equal). Of these ideas, Kita describes that it is better to be based on the equalization of the opportunity of activity for public transport planning in order to secure a minimum opportunity of activity.

In the setting of a bus schedule is important to reflect the security of the opportunity of activity to the plan. Tanimoto and Miyazaki (2008) propose a technique for deciding the number of bus services according to the combination of the start time and the finish time of the activity. In addition to the idea, Kishino and Kita (2009) proposes a method of setting the bus schedule that considers the efficiency and the profit of operation (refer to 4.1).

Moreover, Tanimoto, Maki and Kita (2009) propose the accessibility index for local transport planning, which evaluates the variety of personal time distribution in a day, under restrictions between the time-spaces by using public transport. In this research, a detailed review concerning the accessibility index is done, and it is pointed out that there is a limit in the current index in using it for a public transport plan where the route and the schedule are fixed on that, and proposes a new accessibility index that can consider the restriction between the time-spaces.

2.2 Accessibility Index of Individual Basis

Now, it is assumed that the opportunity of activity is not secured when the bus is not run at the same time as a person's schedule of leaving home and coming back in the methods of either Tanimoto and Miyazaki (2008) or Kishino and Kita (2009). For instance, an activity which requires leaving home between 10:00 and 11:00 can use a bus which leaves between 10:00 and 11:00. However, when there is only a bus at 9:00, the departure time is not brought forward one hour and the bus is not used. It is based on the idea of maximizing the number of people whose activities are secured by the operation of the bus at times when there are many users. However, in this method, securing the opportunity of activity by adjusting the time of leaving home to the departure time of the bus is not considered. Therefore, this method does not maximize the security level of the opportunity of activity.

Next, we exploit the accessibility index that Tanimoto, Maki and Kita (2009) proposed as one of the indices that measures the security level of the opportunity of activity in this study. In the research, the accessibility index is shown by the diversity of the personal time distribution by replacing the arbitrary space-time pass in the space-time prism with time distribution. In other words, they assume that the time of a day is composed of travel time, waiting time, activity time and home time for the person who goes out using public transport, and define the index that shows the diversity of the executable time distribution as the accessibility index.

When the schedule of public transport is decided, the time to leave home and the time to come back are decided, and along with them, home time is fixed. Therefore, the accessibility index is defined as the diversity of the time distribution of the activity time, travel time, and waiting time. In that case, some executable activity patterns are set by combining the departure time and arrival time of the public transport. For instance, the activity patterns are of four types if there are two buses available for the way to and from respectively. Based on these, when the individual activity pattern that can be executed by using public transport is a, the free time that can be devoted to the activity and the travel is T_a, and the travel time of the round trip to the place of activity is M, the accessibility index A_1 is shown as eq. (1).

$$A_1 = \sum_a \frac{e^{-\beta T_a}}{\gamma}\left(1 - e^{-\gamma(T_a - M)}\right) \qquad (1)$$

Where, β and γ are parameters.

2.3 Accessibility Index of Area Basis

The accessibility index shown by eq. (1) is an individual-based index, and it is based on the idea that accessibility shows the diversity of the opportunity of activity. The authors set an index that showed the security level of the opportunity of activity of the area (Kishino, Kita and Terazumi 2009). In the research, the distribution table of the activity time, which shows the combination of the time to leave home and to come back, is described as Table 1. Departure time from home t_i and arrival time t_j are dealt with discretely for simplicity. This table shows the time distribution of the necessary activity for daily life in the area, and it is shown that the ratio of the people who leave home at time t_i and come back at time t_j is P_{ij}, where $\sum_i \sum_j P_{ij} = 1$.

Table I – Distribution Table of the Activity Time

		Time zone to come back							Total
		t_1	t_2	⋯	⋯	t_j	⋯	t_n	
Time zone to leave home	t_1	p_{11}	p_{12}	⋯	⋯	⋯	⋯	⋯	p_{1*}
	t_2		p_{22}	⋯	⋯	⋯	⋯	⋯	p_{2*}
	⋮			⋯	⋯	⋯	⋯	⋯	⋯
	t_i				⋯	p_{ij}	⋯	⋯	p_{i*}
	⋮					⋯	⋯	⋯	⋯
	t_n						⋯	p_{nn}	p_{n*}
Total		p_{*1}	p_{*2}	⋯	⋯	p_{*j}	⋯	p_{*n}	1.00

We should pay attention when making the distribution table of the activity time. If the service level of public transport, like the schedule of the bus is affected, the original time distribution of the activities will not be correctly shown in the distribution table. Therefore, one method is to use the time distribution of the activities by private cars where restriction of time or the operation schedule are free. Moreover, according to the research of Tanimoto and Kita (2005), it is shown that a person in a region where the public transport service level is low has been deciding the activity time in consideration of the schedule of public transport. Therefore, it is an appropriate method to prepare the distribution table of the activity time for all transportation.

In Table 1, the time to leave home t_i and the time to come back t_j have the width set at a fixed time. The setting of the unit is arbitrary, but it is appropriate to set 1 hour or 30 minutes to be the unit when the distribution table of the activity time is made based on an investigation of actual conditions.

We calculate the value of the accessibility index by adding the following elements to the accessibility index shown in eq. (1), based on the distribution table of the activity time shown in Table 1. This value of the accessibility index means the security level of the opportunity of activity of area-based, but not individual-based situations.

1) Limitation of activity pattern

Eq. (1) is a calculating formula of summing up individual accessibility for all the activity patterns a. To this, for sake of ease, we assume that there is one kind of individual activity pattern, and the activity pattern is assumed to be limited to one kind shown in Table 1.

2) Setting of margin time allotted to trip and activity

T_a in eq. (1) is defined as the time that can be allotted to the trip and the activity for individual activity pattern a. When the activity is assumed to be of one pattern shown in Table 1, T_a becomes equal to the time from departing the home t_i and the time to coming back home time t_j. Then, T_a in member 2 of eq. (1) that shows an accessibility increase by the achievement of the opportunity of activity is replaced with T_{ij} shown by eq. (2).

$$T_{ij} = t_j - t_i \tag{2}$$

3) Influence of operation schedule of bus

We assume a bus service that connects a village in a fringe area with the city center, and the residents living there can obtain the activity necessary for daily life in the city center. In addition to this assumption, it is assumed that K buses a day are operating from the village to the city center, and L buses a day are operating in the opposite direction. At that time, the departure time of the bus that goes from the village to the center is d_k, (k=1,･･･,K), the arrival time of the bus in the opposite direction is a_l, (l=1,･･･, L). The activity that leaves home at time t_i and comes home at time t_j can be executed if there is a bus that fills $t_i \geq d_k$ and $t_j \leq a_l$ at the same time, and when it doesn't meet either requirement, it is not possible to achieve the activity.

4) Adjustment of activity time matching to the schedule of the bus

When there is no bus at the desired departure time, we assume that the departure time is adjusted to use a bus running earlier than the desired time. It is also assumed that the arrival time is adjusted to use the later bus, when there is no bus at the desired coming home time. As a result of such an adjustment, the going out time becomes longer. To reflect this in accessibility, T_a (that shows tiredness according to the going out time) is replaced with $a_l - d_k$ in member 1 of eq. (1).

5) Formulation of accessibility index of area-based

By reflecting the above 1) to 4), we show the accessibility value of the area as eq. (3).

$$A = \sum_i \sum_j \frac{e^{-\beta(a_l - d_k)}}{\gamma} \left(1 - e^{-\gamma(t_j - t_i - M)}\right) P_{ij} \tag{3}$$

When there are neither d_k nor a_l that fills $t_i \geq d_k$ and $t_j \leq a_l$,

$$A_{ij} = \frac{e^{-\beta(a_l - d_k)}}{\gamma} \left(1 - e^{-\gamma(t_j - t_i - M)}\right) P_{ij} = 0 \tag{4}$$

In the paper, the value A in eq. (3) is called "Accessibility value of the area". Or it is simply called "Accessibility value".

Please note, the accessibility index shown by eq. (1) is an index that shows the diversity of the opportunity of activity for the individual. On the other hand, the accessibility value of the area shown by eq. (3) has limited the opportunity of activity, in addition to targeting the area. Therefore, it is added that eq. (1) and eq. (3) are indices with different characteristics.

3. PROPOSED INDEX TO SHOW FAIRNESS IN THE OPPORTUNITY OF ACTIVITY

3.1 Fairness in the Level of Opportunity of Activity

The accessibility value of the area was defined by the above study. The security level of the opportunity of activity can be shown by using this index. In addition, when the distribution table of the activity time and alternative bus route and/or schedule are given, the bus route and/or schedule of the maximum security level of the opportunity of activity in the area can be chosen by comparing the accessibility values. It is also possible to set the bus schedule where the accessibility value is the largest.

Next, we think about the fairness in the opportunity of activity concerning different areas by using the accessibility value. Suppose two different areas, where the distance and travel time to the city center are different although the distribution of the activity time and the bus schedule are same. Because the bus can be used at the same time, as the distribution of the activity time is same in these areas, it is thought that the security level of the opportunity of activity is the same. However, the accessibility value of the area far from the city center is smaller than the other area. This is because as travel time becomes longer, the accessibility value of the area becomes smaller, though this is natural.

There are many ideas to consider when thinking about the fairness between areas. To examine the bus service level of the rural area, Tanimoto and Kita (2005) built a model which showed the richness of the opportunity of activity. They proposed to decide the operation number of buses to equalize the difference between the richness of the opportunity of activity of private car users, who can freely decide their going out time, and the richness of the opportunity of activity secured by bus service in terms of the area.

Referring to this idea, in this study, we think the accessibility is at a maximum when one can decide his/her going out time freely, that is to say, when one conducts the activity by using a private car. And, we think that the accomplishment rate of it shows the fairness of the security level of the opportunity of activity.

It is thought that there are three methods to improve the security level of the opportunity of activity. The first one is to improve the public transport service to the places where the activity can be provided. The second is that service that supplies the opportunity of activity profits the user like home selling. The third is to change the land use to reside near the place where the activity is provided. This study examines from the view point of the first one.

3.2 Accessibility Accomplishment Level

(1) Concept of Accessibility Accomplishment Level

Based on the above recognition, we set an index of ratio of the accessibility value A when the number of bus services was given to the maximum accessibility value of the area. In this study, this index will be called "Accessibility accomplishment level".

(2) Maximum Value of Accessibility in the Ideal Situations

As we said in the previous section, the maximum value of accessibility is an accessibility value in the state where one can freely conduct activities at a time when he/she hopes. Here, we think about the maximum value of accessibility by using buses when Table 1 is given. Based on the above idea, the maximum value of accessibility by using buses is an accessibility value in the state that one can use the bus whenever he/she goes out and comes home. That is, a bus that starts at time t_i is operated for the activity that leaves home at time t_i, and a bus that arrives at time t_j is operated for the activity that comes home at time t_j without fail. Waiting time is not generated. As a result, the value of accessibility by using buses is maximized in this situation. This means the leaving home times t_1, t_2... t_I in eq. (3) are corresponding to the departure times of outward bound buses d_1, d_2... d_I, and the coming home times t_1, t_2... t_I are corresponding to the arrival times of homeward bound buses a_1, a_2... a_J, when the time of leaving home/coming home of Table 1 is divided into I/J pieces. When these are applied to eq. (3), the maximum value of accessibility, which is the value of accessibility under the infinite number of bus service, denoted as $A_{\max}$ is shown in eq. (5).

$$A_{\max} = \sum_i \sum_j \frac{e^{-\beta(t_j - t_i)}}{\gamma} \left(1 - e^{-\gamma(t_j - t_i - M)}\right) P_{ij} \tag{5}$$

(3) Accessibility Accomplishment Level

The accessibility accomplishment level A_s is defined as the ratio of accessibility values A shown by eq. (3) to maximum value of the accessibility $A_{\max}$ shown in eq. (5). That is, A_s is shown as follows.

$$A_s = \frac{A}{A_{\max}} \tag{6}$$

The accessibility accomplishment level shows the ratio of the security level of the opportunity of activity obtained under a certain bus schedule to the highest security level of it for a given area. This is an index that shows the security level of the opportunity of activity of the area by the same standard. And so, it is thought that the accessibility accomplishment level is an index that is appreciable of the fairness of the security level of the opportunity of activity.

4. A METHOD TO SELECT BUS SCHEDULE FOR MAXIMIZING THE ACCESSIBILITY

4.1 Previously Proposed Method

We proposed a method of setting the bus schedule and the number of services based on the distribution table of the activity time shown in Table 1 (Kishino and Kita, (2009)). The outline of the method is as follows.

The activity that needs to leave home at time t_i and comes back home at t_j is secured if there exist both buses that depart the residential area at t_i (or before) and arrive at the residential area at t_j (or after). The basic idea of this method is to set the departure time of the outward bus and arrival time of the incoming bus one by one to secure as much opportunity of activity as possible.

The k-th combination of the departure time and arrival time of the area of the buses is denoted as (t_i^k, t_j^k), and called the k-th service. The first step is to set the time combination of the first service (t_i^1, t_j^1). The first service is set to fit the time pair (t_i, t_j) with the maximum P_{ij}, as shown in eq. (7) where P_{ij} is the ratio of the number of people who leave home at time t_i and come back home at time t_j to the total number of people in Table 1.

$$(t_i^1, t_j^1) = \arg\max_{(t_i, t_j)} P_{ij} \tag{7}$$

The second and the following services are set in the same manner to secure as much of the opportunity of activity as possible by adding bus services one by one. The activity that needs to leave home at either time t_i^1, t_i^2... t_i^k and comes back home at either time t_j^1, t_j^2... t_j^k has been secured by combining two of those k bus services. The increment of the opportunity of activity ΔP^{k+1} secured by adding the $(k+1)$th service is given by eq. (8).

$$\Delta P^{k+1} = \sum_{i=1}^{k+1}\sum_{j=1}^{k+1} P^{ij} - \sum_{i=1}^{k}\sum_{j=1}^{k} P^{ij} \tag{8}$$

Where, P^{ij} is a ratio of the numbers of people from which the opportunity of activities are secured by the bus that leaves the area for t_i^i and the bus that arrives at t_j^j in the area.

$(k+1)$th bus service (t_i^{k+1}, t_j^{k+1}) can be obtained by searching t_i and t_j that maximize the increment of the opportunity of activity ΔP^{k+1}. It is written like eq. (9).

$$(t_i^{k+1}, t_j^{k+1}) = \arg\max_{(t_i, t_j)} \Delta P^{k+1} = \arg\max_{(t_i, t_j)} \left(\sum_{i=1}^{k+1} \sum_{j=1}^{k+1} P^{ij} - \sum_{i=1}^{k} \sum_{j=1}^{k} P^{ij} \right)$$
$$= \arg\max_{(t_i, t_j)} \left(\sum_{i=1}^{k} P^{i(k+1)} + \sum_{j=1}^{k+1} P^{(k+1)j} \right) \quad (9)$$

This process is repeated until the value of ΔP^{k+1} falls below the lower bound value beforehand. The method for deciding the lower bound value of ΔP^{k+1} is explained Kishino and Kita (2009).

4.2 Newly Proposed Method in the Study

Besides the previous method, this study developed a new method for bus scheduling that maximizes the value of accessibility when the matrix of the activity time is given. When the distribution of the activity time P_{ij} is already-known, and the number of outward/incoming bus services K/L is given, eq. (3) becomes the function of the departure time and the arrival time of the bus d_k (k=1,2,･･･,K) and a_l (l=1,2,･･･,L). At that time, the bus schedule that maximizes the accessibility value is given as eq. (10).

$$\left(d_1^* \cdots d_K^*, a_1^* \cdots a_L^*\right) = \arg \max_{(d_1 \cdots d_K, a_1 \cdots a_L)} \sum_i \sum_j \frac{e^{-\beta(a_l - d_k)}}{\gamma} \left(1 - e^{-\gamma(t_j - t_i - M)}\right) P_{ij} \quad (10)$$

Where, $\left(d_1^* \cdots d_K^*, a_1^* \cdots a_L^*\right)$ is the combination of the departure and arrival time of buses that maximize the accessibility value.

Moreover, the accessibility value of the area A_r under the bus schedule obtained by eq. (10), i.e. the maximum accessibility value under the given number of bus services, can be written as eq. (11).

$$A_r = \sum_i \sum_j \frac{e^{-\beta\left(a_l^* - d_k^*\right)}}{\gamma} \left(1 - e^{-\gamma(t_j - t_i - M)}\right) P_{ij} \quad (11)$$

4.3 A Method for Selecting Bus Schedule to Equalize the Opportunity of Activity

Eq. (10) shows the setting method of the bus schedule that maximizes the accessibility for one route and one area. In addition to this, the setting of the bus schedule of two or more areas to consider the fairness in the opportunity of activity becomes possible by using the accessibility accomplishment level read in 3.2.

Suppose there are N areas. Denote the maximum value of accessibility of area n (n=1, 2... N) as A_{max}^n. The maximum value of accessibility under the given number of bus services is denoted as A_r^n by an elaborated bus schedule. In this case, accessibility accomplishment level A_s^n of area n is shown in eq. (12).

$$A_s^n = \frac{A_r^n}{A_{max}^n} \quad (12)$$

Some of the methods of adjusting the number of bus services and the bus schedule of two or more areas by using the accessibility accomplishment level are devised. It only has to be examined properly according to the purpose of the plan or the content of problems.

For instance, it is assumed that there are two areas (area 1 and area 2) where the activity pattern is different along one bus route. Now, we think about the setting of the bus schedule by which the security level of two areas of the opportunity of activity is fair. The number of outward/homeward bound bus services K/L is given based on the relation etc. between the operation cost and the passage revenue. The Accessibility accomplishment level A_s^1 and A_s^2 of area 1 and area 2 are obtained by setting the bus schedule based on eq. (10), and calculating according to eq.(5), eq.(11) and eq. (12) as follows.

$$A_s^1 = \frac{A_r^1}{A_{\max}^1}, A_s^2 = \frac{A_r^2}{A_{\max}^2} \tag{13}$$

The bus schedule that considers the fairness in the opportunity of activity is set by adjusting departure time d_k and arrival time a_l of the bus to minimize the difference between A_s^1 and A_s^2, under the condition that the number of bus services K and L do not change. It is shown as eq. (14).

$$\left(d_1' \cdots d_K', a_1' \cdots a_L'\right) = \arg \min_{\left(d_1 \cdots d_K, a_1 \cdots a_L\right)} \left|A_s^1 - A_s^2\right| \tag{14}$$

Where, $\left(d_1' \cdots d_K', a_1' \cdots a_L'\right)$ is the bus schedule after adjusting, and it is same in area 1 and 2.

Besides this, such a method is devised. The lowest standard of the accessibility accomplishment level is set beforehand. If there is an area that falls below the lowest standard, the number of bus services and/or the bus schedule of the area are adjusted. As a result, a minimum opportunity of activity is secured in any area.

5. CASE STUDY

5.1 Conditions

(1) The subject area

Here, we try to set the bus schedule to maximize the opportunity of activity based on the proposed method for two areas along a different bus route as a case study. We compare the accessibility accomplishment levels between areas, and evaluate the fairness of the bus schedule based on the result. Moreover, we compare a setting of the schedule based on the current method and an actual schedule, and consider the usefulness of the proposed method.

The subject of the case study is two bus routes in a city of 90,000 people and two areas along those bus routes. Either bus route connects the suburbs with the city center. The length of route 1 that passes area 1 is about 6km, route 2 passing area 2 is about 10km. Now, 4 buses are operated in route 1, and 7 buses in route 2.

(2) Distribution of Activity Time

First of all, we make the distribution table of the activity time of area 1 and 2 based on the result of the questionnaire concerning the daily activity that had been executed in the city in 2007. In the questionnaire, purpose, transportation used, frequency, destination, and so on of a daily trip were examined. The subjects of the questionnaire were about 10% of the citizens, and the recovery percentage was about 35%.

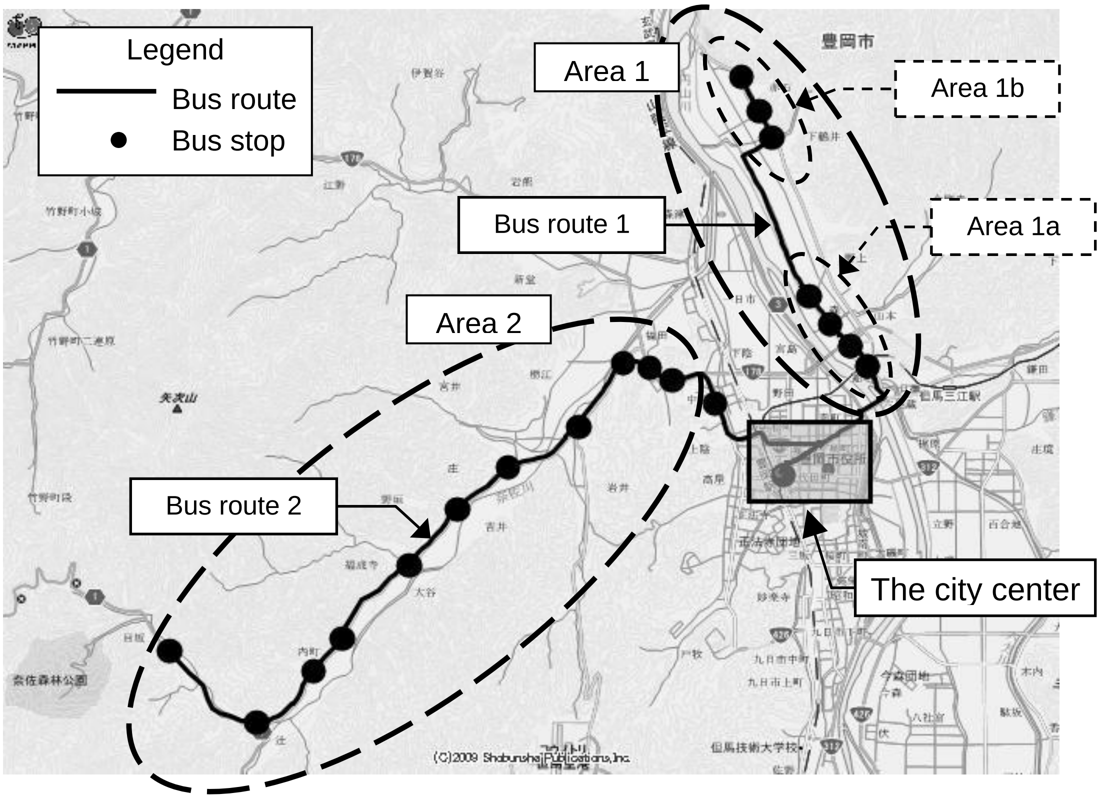

Figure 1 – Outline of Subject Bus Route and Area

The distribution table of the activity time is made for all transportation based on the idea shown in 2.3. Moreover, because public transport use is almost exclusively limited to shopping and going to hospitals regularly in these areas, the distribution table of the activity time targets only those two purposes. The result is shown in Table 2.

Table 2– Distribution Table of the Activity Time of the Subject Area

Area 1 (unit: permil)

		Arrival time										
		8	9	10	11	12	13	14	15	16	17	total
Departure time	7	0	0	1	2	3	0	1	0	0	0	7
	8	0	0	10	31	28	1	3	1	1	0	76
	9		0	17	59	24	6	3	1	1	0	110
	10			0	140	94	9	3	2	3	0	250
	11				0	192	1	6	0	2	0	201
	12					0	2	2	6	6	2	18
	13						0	70	43	6	5	124
	14							0	55	23	25	103
	15								0	81	0	81
	16									0	31	31
	17										0	0
total		0	0	29	231	341	19	87	108	123	62	1,000

Area 2 (unit: permil)

		Arrival time										
		8	9	10	11	12	13	14	15	16	17	total
Departure time	7	0	0	1	0	16	0	0	0	0	2	19
	8	0	0	13	11	19	0	2	0	0	0	45
	9		0	5	75	5	4	0	4	4	0	97
	10			0	94	80	44	19	7	2	0	246
	11				0	3	16	12	0	0	0	31
	12					0	31	15	1	0	0	46
	13						0	0	44	2	0	46
	14							0	51	49	9	109
	15								0	202	29	231
	16									0	130	130
	17										0	0
total		0	0	19	180	123	94	48	107	259	170	1,000

5.2 Results

(1) Setting the bus Schedule for Maximizing the Accessibility Value

Next, we set the bus schedule to maximize the opportunity of activity. To set the bus schedule, the following conditions are required. It is assumed that for a round trip bus operation the buses leave the city center, turn in area 1 or 2, and return to the city center, because the office and garage of the bus company is in the city center. Moreover, because the distribution table of the activity time is set in one hour intervals, the minimum operation interval of the bus is assumed to be one hour. The number of bus services is matched to an actual operation number of the subject route, and so it is assumed 4 times a day for route 1 and 7 times for route 2. The value of the parameter used to calculate the accessibility is assumed to be β=0.188 and γ=1.814 as quoted from the research of Tanimoto, Maki and Kita (2009). The time between areas 1 and 2 and the city center is 15 and 30 minutes respectively, according to actual operation times.

The bus schedule of route 1 and 2 are set by using Table 2 and eq. (10) under these conditions, and accessibility value A_r^1 and A_r^2 are calculated by using eq. (11). The result is shown in Table 3.

Table 3– Result of Setting Bus Schedule to Maximize the Accessibility Value

Area 1

Number of buses	Deperture time from area 1 to the city center											A_r^1	A_s^1
2		9:00				13:00						0.112	0.402
3		9:00				13:00					18:00	0.176	0.635
4	8:00		10:00			13:00					18:00	0.206	0.744
5	8:00		10:00			13:00			16:00		18:00	0.225	0.813
6	8:00		10:00		12:00	13:00		15:00			18:00	0.238	0.860
7	8:00		10:00	11:00	12:00	13:00			16:00		18:00	0.249	0.899
											A_{max}^1	0.277	

Area 2

Number of buses	Deperture time from area 2 to the city center											A_r^2	A_s^2
2							14:00				18:00	0.081	0.326
3		9:00					14:00				18:00	0.154	0.623
4	8:00				12:00			15:00			18:00	0.177	0.717
5	8:00		10:00			13:00		15:00			18:00	0.194	0.787
6	8:00		10:00		12:00		14:00		16:00		18:00	0.209	0.848
7	8:00		10:00		12:00		14:00	15:00		17:00	18:00	0.221	0.893
											A_{max}^2	0.247	

(2) Calculation of the Accessibility Accomplishment Level

In addition, the maximum accessibility value of each area A_{max}^1 and A_{max}^2 are calculated, and the accessibility accomplishment level of each area, A_s^1 and A_s^2, are calculated by using eq. (12). The maximum value of accessibility A_{max}^1 and A_{max}^2 are assumed to be the accessibility value when the bus is operated every one hour, because the distribution table of the activity time is set at one hour intervals. The results are also shown in Table 3.

5.3 Discussion

(1) Value of Accessibility

As a result of the case study, the accessibility value of each area, $A_s^1$and A_s^2, are 0.206 and 0.221, and the accessibility accomplishment level $A_s^1$and A_s^2 are 0.744 and 0.893, respectively. Because the maximum value of accessibility of area 1 $A_{\max}^1$ is larger than that of area2 where the length of route 1 is shorter than route 2, the difference between the accessibility accomplishment level A_s^1 and A_s^2 is greater than the difference between the accessibility A_r^1 and A_r^2.

According to Table 3, many bus services are set between 8:00 and 13:00 in area 1, where many activities are seen in the morning, and many bus services are set between 14:00 and 18:00 in area 2, where many activities are seen in the evening. Thus, it can be said that the proposed method can take the distribution of timing of activity into consideration in bus scheduling.

(2) Comparison of the Result by Difference of the Method

First, in order to evaluate the proposed method, we compare the bus schedule set by the previously proposed method shown in 4.1 and the actual bus schedule based on the case study. The result is shown in Table 4.

The bus service is intensively set from about 10:00 to 17:00 when a lot of activities exist, because the bus schedule is set to maximize the number of people whose opportunity of activities are secured in the current method. Therefore, both the values of accessibility index A_r and the accessibility accomplishment level A_s become higher than those in the previously proposed method.

Secondly, we compare the obtained bus schedule with the actual one. In many cases, carriers decide the bus schedule empirically based on the data of the number of passengers. As for the actual schedule shown in Table 4, buses are operated from 7:45 to 17:00, and the value of accessibility index and the accessibility accomplishment level are higher than the previously proposed method. However, buses might not be operated in the morning with a lot of activity as shown in Table 2. For instance, there is a time that a bus is not operated for more than four hours in area 1 in the morning although there are a lot of activities for that time. Because of this, both the accessibility value and the accessibility accomplishment level are lower than the proposed method. On the other hand, when the bus is operated from 8:00 to 18:00 around the time of many activities, then the accessibility value and the accessibility accomplishment level are higher than those by the other methods.

From these, the proposed bus scheduling method can secure the higher level of the opportunity of activity than the previously proposed method and the actual schedule.

Table4– Comparison by difference of the method

Area 1

Category	Deperture time from area 1 to the city center										A_r^{1}	A_s^{1}	A_{max}^{1}
This study	8:00		10:00			13:00				18:00	0.206	0.744	0.277
Previous Method			10:00	11:00		13:00		15:00			0.140	0.504	
Actual Schedule	7:45				12:00		14:00		17:00		0.175	0.633	

Area 2

Category	Deperture time from area 2 to the city center										A_r^{2}	A_s^{2}	A_{max}^{2}
This study	8:00	10:00		12:00		14:00	15:00		17:00	18:00	0.221	0.893	0.247
Previous Method		10:00	11:00		13:00	14:00	15:00	16:00	17:00		0.161	0.651	
Actual Schedule	7:11	7:55	9:00	12:03			14:53	15:58		17:45	0.200	0.809	

(3) Coordination of Bus Schedule Considering the Equity in the Opportunity of Activity

Now, area 1 is divided into two subareas, area 1a and 1b as shown in Figure 1. Then, we tried to divide the distribution table of the activity time into those two areas as shown in Table 5, and to set the bus schedule in a similar way to that shown in 4.3. The result obtained was that the departure time of 3 of the buses are the same and one bus is different as shown in Table 6.

Then, the accessibility accomplishment levels were compared when the departure time of the fourth bus service of area 1a was made 18:00 and when the fourth one of area 1b made 17:00. Case 1 in Table 7 shows the result of the former, and Case 2 shows the latter. The difference of the accessibility accomplishment level of case 1 is smaller than that of case 2 according to Table 7. Therefore, the bus schedule that considers the fairness of area 1a and 1b can be adjusted by changing the starting time of the fourth bus service of area 1a to 18:00.

Thus, the bus schedule that considers the equity of areas can be selected based on the proposed method in this study.

Table 5– Distribution Table of the Activity Time of the Area 1a and 1b

Area 1a (unit: permil)

		Arrival time										
		8	9	10	11	12	13	14	15	16	17	total
Departure time	7	0	0	1	2	0	0	1	0	0	0	5
	8	0	0	9	28	26	1	4	0	1	0	69
	9		0	14	58	23	4	4	0	1	0	102
	10			0	140	72	5	0	3	1	0	221
	11				0	227	0	3	0	3	0	233
	12					0	2	2	7	6	2	20
	13						0	74	45	8	6	133
	14							0	60	27	15	103
	15								0	85	0	85
	16									0	31	31
	17										0	0
total		0	0	24	228	348	12	88	115	130	54	1,000

Area 1b (unit: permil)

		Arrival time										
		8	9	10	11	12	13	14	15	16	17	total
Departure time	7	0	0	0	0	14	0	0	0	0	0	14
	8	0	0	18	42	36	0	1	6	1	0	104
	9		0	32	63	30	15	0	3	1	0	145
	10			0	140	188	24	13	0	12	0	377
	11				0	42	8	16	0	0	0	65
	12					0	0	0	2	7	0	9
	13						0	54	33	0	0	87
	14							0	31	5	67	104
	15								0	66	0	66
	16									0	30	30
	17										0	0
total		0	0	51	245	309	47	84	75	92	97	1,000

Table6– Schedule to maximize the opportunity of activity in area 1a and 1b

Area	Deperture time from area 1 to the city center					A_r	A_s	A_{max}
1a	8:00	10:00	13:00	17:00		0.217	0.747	0.290
1b	8:00	10:00	13:00		18:00	0.207	0.758	0.274

Table7– Adjustment of the schedule to equalize the accessibility accomplishment level

Case	Area	Deperture time from area 1 to the city center					A_r	A_s	A_{max}	$\|A_s^{1a}-A_s^{1b}\|$
Case 1	1a	8:00	10:00	13:00		**18:00**	0.215	0.739	0.290	0.018
	1b	8:00	10:00	13:00		18:00	0.207	0.758	0.274	
Case 2	1a	8:00	10:00	13:00	17:00		0.217	0.747	0.290	0.025
	1b	8:00	10:00	13:00	**17:00**		0.197	0.721	0.274	

6. CONCLUSION

In this study, we proposed a new index for policy assessment of local transport planning to consider the equity of the security level of the opportunity of activity by improving the accessibility index that Tanimoto, Maki, and Kita (2009) had developed to exploit public transport planning in rural areas. Here, security level means the level of the opportunity of activity that is carried out by local transport services from the view point of human security. We also developed a method for selecting a bus schedule by applying the proposed index. The method can give a bus schedule with a higher accessibility accomplishment level than the previously proposed method and the real bus schedule through the case study. Then, we applied the index to develop a method for the bus schedule that considered the equity of two areas which was also concretely shown in the case study. The usefulness of the proposed index and method was also demonstrated in the case study.

In this study, we thought that not the accessibility value but the accessibility accomplishment level should be an index to evaluate the equity of the security level of the opportunity of activity. This is dependent on the idea that the accessibility is maximized when one can decide his/her activity time without restriction, and that the accomplishment rate shows the equity of the security level of the opportunity of activity. This is a new proposition in this study.

The accessibility value proposed in this study targets rural areas. Therefore, fatigue due to the longer travel time and waiting time is reflected. If the access time from home to the bus stop or fatigue by age can be reflected in the accessibility, the index will be more sophisticated.

Although this paper's purpose was for the selection of a bus schedule, the method shown in this study can be applied to not only the setting of a bus schedule but also other planning issues. For instance, the proposed method can also be applied to route selection if the distribution table of the activity time and the travel time is changed, and the accessibility index is reflected by them.

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