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ASSESSING THE LEVEL OF ACTIVITY OPPORTUNITIES SECURED BY RURAL PUBLIC TRANSPORT SERVICE: THE CAPABILITY APPROACH

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ABSTRACT

In an age of a shrinking, sparse and aging population in Japan, regional areas often maintain poor conditions on public transport service such as local bus service. Many residents under the poor level of public transport service can barely do daily-life activities at the adjacent downtown, such as commodity shopping, receiving regular medical care, or withdrawing deposits, etc. In considering how regional society itself should formulate a rural public transport plan to improve and support mobility and accessibility of such transport-disadvantaged people in society, this study focuses on residents' activity opportunities secured by rural public transport service.

A rural public transport plan can be understood as a description about to what extent a public transport service should secure opportunities to make all residents be capable of doing daily-life activities by using the service. Planning the level of the rural public transport service requires the aspect of well-being for assessing the level of the activity opportunities secured by the service.

This study aims at developing a methodology for this assessment, by employing Amartya Sen's capability approach, through the definitions of the activity opportunities as functionings and a set of the activity opportunities as a capability.

Securing the minimum of opportunities of wholesome and cultured activities is essentially based on securing through the mutual aid of residents themselves in regional society. Hence naturally the extent of what can be secured will be limited. Authors think that this limitation is determined by social choice for a combination of "the level of activity opportunities" secured by rural public transport service, and "the burden of costs" of the service. A collective security level of activity opportunities, which is assessed by use of the methodology proposed in this study, is expected to be useful for planning information regarding this combination.

Keywords: Rural public transport plan, Transport-disadvantaged people, Collective security level, Activity opportunities, Capability approach, Measure of accessibility satisfaction

INTRODUCTION

Japan's 3.11 earthquake resulted in reminding most Japanese of the importance of security and coexistence in all regional societies, not only in the disaster-stricken area. Regional areas in Japan are facing an age of a shrinking, sparse and aging population. In some such areas, there exist residents who can barely do daily-life activities such as commodity shopping, receiving regular medical care, or withdrawing deposits, etc. which are achieved by using public transport service such as local bus service, because of the following three reasons (Kita, 2011). The first is that, because service providers in these areas, such as shopping centres and hospitals, have taken the scrap-and-build strategy as they cannot ensure the sphere of service, the travel distance from the customers' residential areas to the location areas of adjacent service facilities has increased. The second is that, despite the presence of the transport-disadvantaged people who have no choice but to depend on public transport service such as local bus service, and also who do not own a family car or motorbike, the service levels of rural public transport, such as service frequency, number of services and time schedule, are lower than urban ones. The third is that, despite the presence of aging people with physical disabilities who are not free to go out without any support, there are no neighbouring supporters near such people. Under these circumstances, in the regional areas, when public transport service providers cannot help but pull the plug on an area due to low profitability, such areas have several "blank zones" in the sphere of public transport service. Therefore, rural public transport plans should obey new methodology which is essentially different from an urban public transport plan which does not have such blank zones.

In regional areas, one of the main purposes of local governments that maintain rural public transport service is to secure opportunities for daily-life activities which transport-disadvantaged residents cannot help but obtain by means of public transport (Kita, Tanimoto, 2009; Kita, 2012). Rural public transport plans can be understood to be a description about residents' decisions and choices among various alternatives regarding to what extent public transport service should secure opportunities to make all residents be capable of doing daily-life activities by use of the service (Kita, Tanimoto, 2009; Kita, 2012). Securing the minimum of opportunities of wholesome and cultured activities is essentially based on securing the mutual aid of residents themselves in regional society. Hence naturally the extent of what can be secured will be limited. Authors think that this limitation is determined by social choice, and is a combination of "the level of activity opportunities" secured by the rural public transport service and "the burden of costs" of the service. The methodology proposed in this paper can provide useful planning information regarding this combination in the process of assessing a collective security level of activity opportunities. In order to assess the collective security level of activity opportunities from the aspect of well-being, this study employs Amartya Sen's capability approach.

The aim of this study is to develop a methodology by which a planner for the rural public transport plan assesses the collective security level of activity opportunities. In this methodology, based on Sen's capability approach, the activity opportunities, and a set of the activity opportunities, are defined as functionings and a capability, respectively. In various variables representing the service level of public transport service, this paper focuses on time schedule. The framework of the methodology is composed of two phases. The first is the individual assessment phase. In this phase, the planner measures the functionings for each individual by use of a measure of accessibility satisfaction, and then makes each individual choose a combination of the functionings. In this regard, the accessibility-satisfaction measure, the value of which is calculated based on the time schedule, is indicative of how sufficient the accessibility is. In this study, the important thing is that not that mobility of public transport service is required for activity opportunities, but rather that accessibility to the opportunities resulting from the service is dealt with for the purpose of explicitly focusing on the activity opportunities. The second is the social assessment phase. In this phase, the planner measures the capability of each individual based on the combination of functionings that each individual has chosen, and then evaluates the collective security level of activity opportunities. This collective security level is such a level that has fallen below the capability of every resident. In the sense of focusing on a maximin rule in which the situation of the unhappiest people must be improved, the proposed methodology follows the Rawlsian principle (Rawls, 1979).

The structure of this paper is as follows: the framework of the methodology in chapter 2, the mathematical models in chapter 3 and a numerical example in chapter 4.

FRAMEWORK

A basic concept of drawing up a rural public transport plan, as illustrated in Figure 1, is that it is thought that residents themselves choose a combination of the level of activity opportunities secured by public transport service and the burden of costs of the service (Kita, Tanimoto, 2009; Kita, 2012). In order for the residents to choose any combination, a planner for the rural public transport plan is required to provide a list of the combinations for them in the easiest manner possible. In particular, the object of this study is an assessment methodology regarding the security level of activity opportunities.

The proposed methodology is premised on the following assumptions. The first is that the types of daily-life activities necessary for the residents can be specified by themselves is common knowledge. In this regard, however, it does not matter if the preference ordering of the activities is different from person to person. The second is that all residents are aware of the presence of other residents who are not free to carry out daily-life activities that are living in the same area. The third is that all residents can understand the accessibility-satisfaction

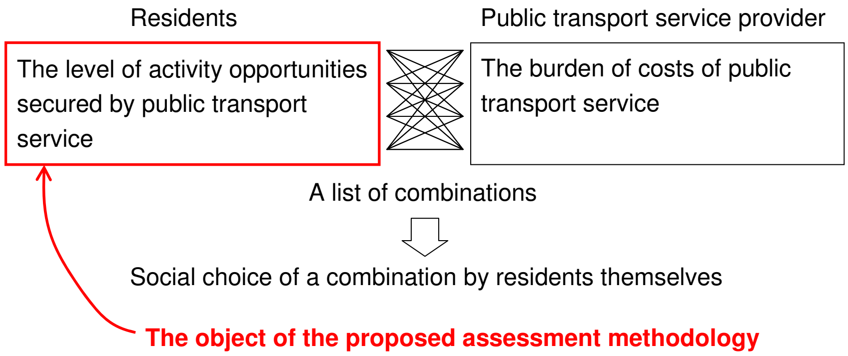

Figure 1: A basic concept of rural public transport plan and the object of the proposed methodology.

measure, which is indicative of how sufficient accessibility is, as a substituting measure for the security level of activity opportunities. The fourth is that all residents have a preference ordering for a list of combinations of the functionings.

In the proposed methodology, the planner follows the path of the process flowchart as illustrated in Figure 2.

The first phase is individual assessment. Firstly, with respect to the types of public transport services, the types of daily necessary activities, the slots of time in which the activities can be secured, etc., the planner sets several conditions which should be covered in the rural public transport plan. Secondly, focusing on time schedule in various variables representing the level of service of the public transport, and defining a functioning of the resident as an opportunity that makes him/her be capable of doing various activities under a given time schedule, the planner measures the value of the functioning by use of the accessibility-satisfaction measure. Thirdly, defining a set of opportunities that make the resident be capable of doing various activities under various time schedules as a capability of the resident, and focusing on a frontier of the capabilities emerging on the space where the axis of coordinate represents the functioning, the planner makes each resident choose a combination of the functionings on the frontier.

The second phase is social assessment. Firstly, employing an expected accessibility-satisfaction measure, the value of which is calculated based on the combination of the functionings chosen by each individual, the planner evaluates the value of the capability of each individual. Secondly, in order to check the collective security level of activity opportunities, the planner checks whether or not there exists a resident whose capability does not exceed a given security level. If such a resident exists, then the planner revises the time schedule because the situation of the unhappiest resident must be improved. Otherwise such a security level which has fallen below the capability of every resident is considered to become the collective security level of activity opportunities as a reasonable level. In this sense, the social assessment follows a maximin rule (Rawls, 1979).

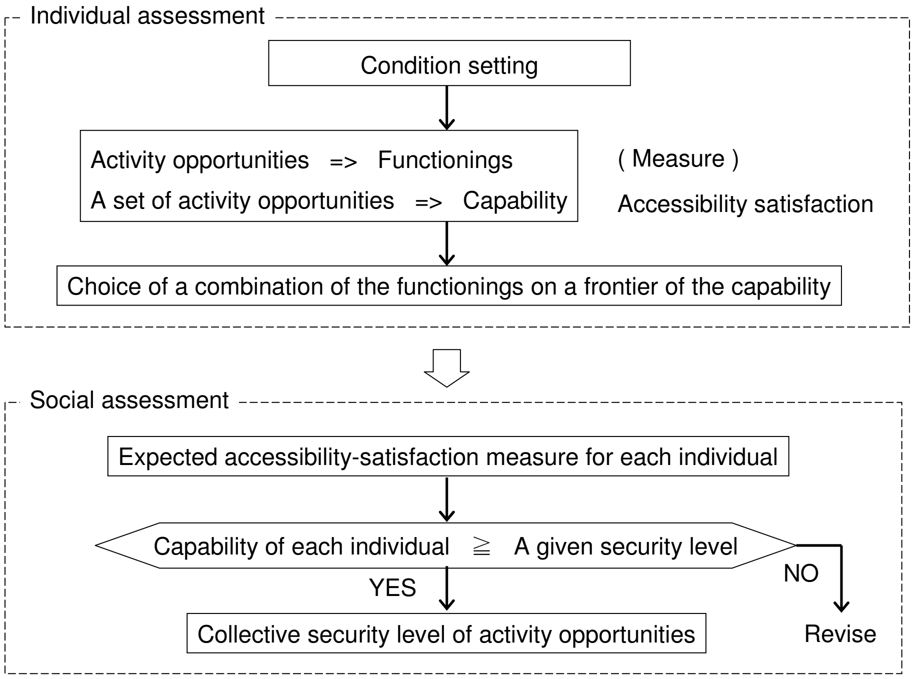

Figure 2: Process flowchart on the proposed methodology.

MODELS

Premises

In a regional area separated into two locations consisting of a central city and an aging village, the target of this study is the residents in the village. The aggregate number of the residents is set as N. The means of transport intended for the residents moving between the two locations is only a local bus service. The place of beginning and ending the bus-service operation, i.e. bus garage, is located in the city. The bus service frequency is at a very low level in the present situation. The travel time between the two locations keeps at a constant level. The residents in the village do daily necessary activities at the facilities in the city by using this bus service. A finite set of activity types is defined as $\mathbf{\Lambda}$.

Now we assume that the activity time of the residents and the time schedule of the bus can be calculated based on a common minimum unit of time feasible in a day, $\bar{\tau}$. A set of times counted per $\bar{\tau}$ in a day is defined as $\mathbf{T}$. In members of $\mathbf{T}$, a time t' behind a given time t in a clockwise fashion is described as $t < t'$, as a matter of practical convenience. Then we have $t' = t + i\bar{\tau}$ for any natural number i. Regarding opening time of a facility providing a given activity $\lambda \in \mathbf{\Lambda}$, a set of the opening times is defined as $\mathbf{T}^{\lambda}$ in the universal set $\mathbf{T}$. Any scheduled starting time and any scheduled ending time of a given activity $\lambda \in \mathbf{\Lambda}$ become members of $\mathbf{T}^{\lambda}$.

Individual assessment

Accessibility

Regarding an ordered pair $\omega = (a, d)$ consisting of an arrival time $a \in \mathbf{T}$ and a departure time $d \in \mathbf{T}$ of the bus at a facility, a set of time schedules satisfied with the condition of $a < d$ is defined as $\mathbf{D}$. The set $\mathbf{D}$ is defined as the following equation.

$$\mathbf{D} = \{\omega = (a, d) \subseteq \mathbf{T} \times \mathbf{T} \mid a < d, {}^{\forall}a\, {}^{\forall}d \in \mathbf{T}\} \tag{1}$$

Regarding a scheduled starting time $s \in \mathbf{T}^{\lambda}$ and a scheduled ending time $e \in \mathbf{T}^{\lambda}$ of a given activity λ, the schedule cost for the wait time when arriving ahead of time or departing behind schedule, and the schedule cost for the break-up when arriving behind schedule or departing ahead of time are defined as $c^{\lambda}_{\mathrm{as}}$ and $c^{\lambda}_{\mathrm{de}}$, respectively. The $c^{\lambda}_{\mathrm{as}}$ and $c^{\lambda}_{\mathrm{de}}$ are defined as the following equations (Kita, Tanimoto an d Kishino, 2011).

$$c^{\lambda}_{\mathrm{as}}(a) = \gamma^{\lambda}_{\mathrm{as}} \mathrm{E}\left[\max\{s - a, 0\}\right] + \gamma^{\lambda}_{\mathrm{sa}} \mathrm{E}\left[\max\{a - s, 0\}\right] \tag{2a}$$
$$c^{\lambda}_{\mathrm{de}}(d) = \gamma^{\lambda}_{\mathrm{de}} \mathrm{E}\left[\max\{e - d, 0\}\right] + \gamma^{\lambda}_{\mathrm{ed}} \mathrm{E}\left[\max\{d - e, 0\}\right] \tag{2b}$$

On the basis of the schedule costs defined above, a measure of accessibility for an individual $n \in N$ is defined as the following equation, where the parameter β_n represents the friction of decay depending on utilizing ability of the individual n, and the parameter c represents the friction of transport.

$$f^{\lambda}_{n}(\omega) = (1 - c)\exp[-\beta_n\{c^{\lambda}_{\mathrm{as}}(a) + c^{\lambda}_{\mathrm{de}}(d)\}] \tag{3}$$

Now a measure of the accessibility with which any resident who can only use the bus service may be provided with on-time travel by use of a family car is defined as $A_{\mathrm{car}} = 1 - c_{\mathrm{car}}$. In order to express how the value of the accessibility of the bus, $f^{\lambda}_{n}(\omega)$, is sufficient for the value of the on-time accessibility, A_{car}, we introduce the following measure, where $0 < \tilde{f}^{\lambda}_{n}(\omega) < 1$.

$$\tilde{f}^{\lambda}_{n}(\omega) = \frac{f^{\lambda}_{n}(\omega)}{A_{\mathrm{car}}} \tag{4}$$

We term Equation (4) an "accessibility-satisfaction measure", which is provided by a time schedule ω for an activity λ of an individual n.

Functioning

A set in which members of the set $\mathbf{\Lambda}$ have been arranged, in order of $\hat{1}, \hat{2}, \cdots, \hat{r}$ from the most important activity intended for an individual n, is defined as $\mathbf{\Lambda}_n$. The $\mathbf{\Lambda}_n$ is defined as the following equation.

$$\boldsymbol{\Lambda}_n = \{ \lambda_k \mid k = \hat{1}, \hat{2}, \cdots, \hat{r}-1 ; \lambda_k \succ \lambda_{k+1} \} \tag{5}$$

When a measure of the accessibility satisfaction with which a given time schedule $\omega = (a,d)$ provides the k th important activity $\lambda_k \in \boldsymbol{\Lambda}_n$ for an individual n is defined as $\tilde{f}_n^{\lambda}(\omega)$, the $\tilde{f}_n^{\lambda}(\omega)$ is considered to express the opportunities making the individual n being capable of doing any activity λ_k by use of a given time schedule $\omega = (a,d)$. For all activities of λ_k, a set of functions regarding $\tilde{f}_n^{\lambda_k}$ is defined as $\mathbf{f}_n$. In this regard, an evaluated value $A_n^{\lambda_k}$ for the opportunity of a given activity λ_k can be expressed by using the function $\tilde{f}_n^{\lambda_k} \in \mathbf{f}_n$ corresponding to the λ_k, as follows:

$$A_n^{\lambda_k} = \tilde{f}_n^{\lambda_k}(\omega) \quad {}^{\exists}\tilde{f}_n^{\lambda_k} \in \mathbf{f}_n . \tag{6}$$

Equation (6) expresses the structure of individual assessment when under a given time schedule ω an individual n assesses the opportunity of the k th important activity λ_k, whether or not to do the activity in fact. The function $\tilde{f}_n^{\lambda_k}$ of equation (6) indicates the correspondence of a given time schedule ω to a value of the accessibility-satisfaction measure, $A_n^{\lambda_k}$, provided by the ω. We term the function $\tilde{f}_n^{\lambda_k}$ a “functioning” of the individual.

In plain writing, for example, the accessibility A provided by given three time schedules $\omega_1, \omega_2, \omega_3$ is expressed as $(f^1(\omega_1), f^1(\omega_2), f^1(\omega_3)) = (A_1^1, A_2^1, A_3^1)$ with respect to the functioning f^1, or $(f^2(\omega_1), f^2(\omega_2), f^2(\omega_3)) = (A_1^2, A_2^2, A_3^2)$ with respect to the functioning f^2, and then the consequences depend on the set $\mathbf{f}$ consisting of $f^1, f^2 \in \mathbf{f}$. Such a “lattice of functionings” means the capability.

Capability

Given a set of time schedules, $\mathbf{D}$, and a set of functionings, $\mathbf{f}_n$, an opportunity set of functionings potentially achieved by an individual n is defined as the following equation.

$$Q(\mathbf{D} : \mathbf{f}_n) = \left\{ A_n^{\lambda_k} \mid {}^{\exists}\omega \in \mathbf{D},\ {}^{\exists}\tilde{f}_n^{\lambda_k} \in \mathbf{f}_n ;\ A_n^{\lambda_{k'}} = \tilde{f}_n^{\lambda_{k'}}(\omega) \right\} \tag{7}$$

We term Equation (7) a “capability” of the individual n.

Now in order to avoid the complicated process in which the $A_n^{\lambda_k}$ corresponding to all members of $\boldsymbol{\Lambda}_n$ is dealt with on the $\hat{r}$ dimensional space, we alternatively consider to deal with a Cartesian coordinate system of $A_n^{\lambda_k}$ and $A_n^{\lambda_{k'}}$ corresponding to the first important activity λ_k and the second important activity $\lambda_{k'}$. If under a given security level there are not any time schedules which can secure the activity opportunities regarding λ_k and $\lambda_{k'}$, we consider to deal with another Cartesian coordinate system using the third important activity $\lambda_{k''}$, or to deal with former system under the lower security level. This idea is based on a “lexicographic ordering rule”.

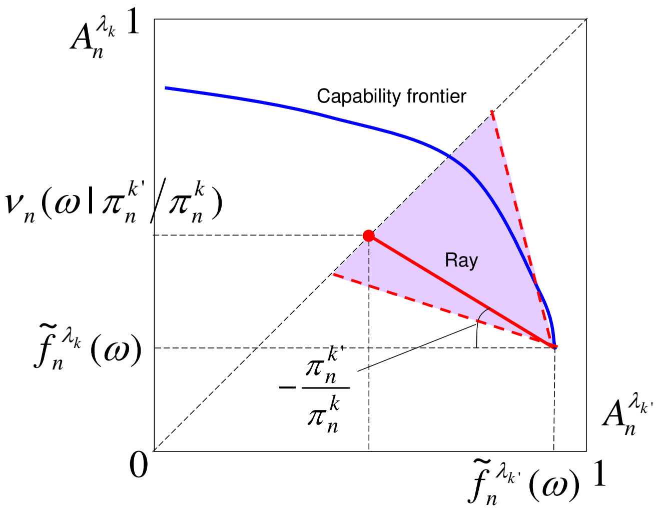

Figure 3: The value of capability

According to this lexicographic ordering rule, we consider a plane surface with two axes of coordinate, $A_n^{\lambda_k}$ and $A_n^{\lambda_{k'}}$, where $0 \le A_n^{\lambda_k}, A_n^{\lambda_{k'}} \le 1$. In this plane surface, each axis of coordinate represents the achieved level of functioning. We term this plane surface a "functioning plane".

On the functioning plane, when plotting every coordinate $\left(\tilde{f}_n^{\lambda_k}(\omega),\ \tilde{f}_n^{\lambda_{k'}}(\omega)\right)$ corresponding to all of $\omega \in \mathbf{D}$, we can draw a frontier curve as illustrated in Figure 3, because the $\mathbf{D}$ is the finite set. This frontier curve expresses a frontier regarding the capability $Q(\mathbf{D}:\mathbf{f}_n)$. We term this frontier curve a "capability frontier". Figure 3 illustrates by an example the case that the capability frontier is concave with respect to the origin, while the case of convex will occur.

The following is that the idea of this study is noted regarding individual assessment of capability.

Firstly, after drawing a 45 degree line from the origin on the functioning plane as illustrated in Figure 3, consecutively we draw a "ray" along a gradient toward this 45 degree line from a coordinate corresponding to each value of $A_n^{\lambda_k}$ and $A_n^{\lambda_{k'}}$ defined by an arbitrary time schedule $\omega \in \mathbf{D}$. In this study, we consider a vertex of this ray to the 45 degree line as the value of capability. The more the vertex corresponding to arbitrary time schedule locates on the upper right of the 45 degree line from the origin, the higher the capability is valued. When each individual chooses this ray, the value of capability can be evaluated.

Secondly, we define the following equation. Equation (8a) can be changed as $-\pi_n^{k'}/\pi_n^{k} = (\mathrm{E}[A_n^{\lambda}] - \tilde{f}_n^{\lambda_k})/(\mathrm{E}[A_n^{\lambda}] - \tilde{f}_n^{\lambda_{k'}})$, as described in Figure 3. Accordingly, the vertex of arbitrary ray to the 45 degree line represents the $\mathrm{E}[A_n^{\lambda}]$ of equation (a). We term $\pi_n^{k'}/\pi_n^{k}$ a "combination ratio of functionings" regarding λ_k and $\lambda_{k'}$.

$$\nu_n(\omega \mid \pi_n^{k'}/\pi_n^{k}) = \mathrm{E}\left[A_n^{\lambda}\right] = \pi_n^{k}\tilde{f}_n^{\lambda_k}(\omega) + \pi_n^{k'}\tilde{f}_n^{\lambda_{k'}}(\omega) \quad \text{(8a)}$$

$$\pi_n^{k} + \pi_n^{k'} = 1 \quad \text{(8b)}$$

The $\mathrm{E}[A_n^{\lambda}]$ of equation (8a) represents the expected accessibility-satisfaction measure. Besides, the $v_n(\omega \mid \pi_n^{k'} / \pi_n^{k})$ of equation (8a) represents a function for individually assessing a time schedule ω, as being the level of $\mathrm{E}[A_n^{\lambda}]$ for the capability on the basis of the $\pi_n^{k'} / \pi_n^{k}$ chosen. We term the v_n an “individual assessment function”.

Thus, in individual assessment in this study, the expected value of functionings based on the combination ratio of functionings which an individual chooses is the value of capability. This is an operational meaning to the capability approach in this study.

Social assessment

In social assessment, we consider that important activity opportunities for each individual can be socially secured according to several ranks. Then, as the criteria required regarding the security level of activity opportunities, we provide an example as shown in Table 1.

When defining a set of these ranks as L and a security level according to a rank $l \in L$ as θ_l, where $0 < \theta_l < 1$, we define a set of the security levels, θ_l, as $\boldsymbol{\theta}$. We assume that the $\boldsymbol{\theta}$ depends on only the activity opportunities which should be socially secured.

In this study, the situation that an accessibility-satisfaction level, $A_n^{\lambda_k}$, exceeds a given security level, $\theta_l \in \boldsymbol{\theta}$, is expressed as “an individual n has the activity opportunities of rank l for the k th important activity, λ_k, by use of the time schedule ω satisfying $\{\omega \mid \min(\tilde{f}_n^{\lambda_k}(\omega)) \geq \theta_l\}$”. Besides, we term the time schedule ω satisfying $\{\omega \mid \min(\tilde{f}_n^{\lambda_k}(\omega)) \geq \theta_l\}$ a “time schedule securing the activity opportunities of rank l for the activity λ_k”.

NUMERICAL EXAMPLE

Setting

The public transportation service is set as only a local bus service. Two activity types are set, medical examination λ_1, and shopping λ_2, in order of importance. The minimum increment of time, $\bar{\tau}$, is set as 1 hour, and the possible operating time for bus service, T_ψ, is set as the time between 7:00 and 22:00, with bus service at 1 hour intervals.

Table 1: Criteria of the security level of activity opportunities (Example)

Rank	Criterion
1	Can do any activity without any difficulty
2	Can not very well do any activity
3	Can manage to do any activity with difficulty
4	Can not do any activity

In addition, the opening time of the hospital where medical examination λ_1 is provided is set as T^{λ_1}, and the opening time of the store where shopping λ_2 occurs is set as T^{λ_2}. Then, it is assumed that the residents' scheduled activity starting time s and scheduled activity ending time e regarding medical examination λ_1 and shopping λ_2 are each uniformly distributed over T^{λ_1}, T^{λ_2}. When the maximum and minimum values for the scheduled activity starting time are defined as $\bar{s}$, and $\underline{s}$, respectively, and the maximum and minimum values for the scheduled activity ending time are defined as $\bar{e}$, and $\underline{e}$, respectively, formula (2a)(2b) can be derived as follows (Appendix).

$$c_{\rm as}^{\lambda}(a) = \gamma_{\rm as}^{\lambda}(\bar{s} - a)/2 + \gamma_{\rm sa}^{\lambda}(a - \underline{s})/2 \tag{9a}$$

$$c_{\rm de}^{\lambda}(a) = \gamma_{\rm de}^{\lambda}(\bar{e} - d)/2 + \gamma_{\rm ed}^{\lambda}(d - \underline{e})/2 \tag{9b}$$

where the term such as $(\bar{s} - a)$ means a time interval, i.e., a period between times.

Here, the parameters for the measure of accessibility for both the medical examination and shopping are defined as c_{ψ} = 0.5, β = 1.0, $\gamma_{\rm as}^{\lambda}$ = 1.0, $\gamma_{\rm sa}^{\lambda}$ = 1.2, $\gamma_{\rm de}^{\lambda}$ = 1.2, and $\gamma_{\rm ed}^{\lambda}$ = 1.0.

As numerical examples, the following two cases will be considered. In Case 1, medical examination λ_1 has $\bar{s}$ = 9:00, $\underline{s}$ = 11:00, $\bar{e}$ = 15:00, $\underline{e}$ = 17:00, and shopping λ_2 has $\bar{s}$ = 9:00, $\underline{s}$ = 11:00, $\bar{e}$ = 13:00, $\underline{e}$ = 15:00. In Case 2, medical examination λ_1 has $\bar{s}$ = 9:00, $\underline{s}$ = 11:00, $\bar{e}$ = 13:00, $\underline{e}$ = 15:00, and shopping λ_2 has $\bar{s}$ = 14:00, $\underline{s}$ = 15:00, $\bar{e}$ = 15:00, $\underline{e}$ = 17:00.

Results and discussion

The results of Case 1 and Case 2 are shown in Figure 4 and Figure 5. However, $\pi_1 : \pi_2$ is set as 1:1. In addition, the security level of activity opportunity for rank 1 and rank 2 was set at 0.6 and 0.4, respectively.

In Case 1 of Figure 4, the time schedule to secure activity opportunity at rank 1 is represented by a set of blue points enclosed by a red circle in Figure 3. The time schedule where the expected accessibility-satisfaction measure was highest is (10:00, 15:00). In addition, when the time schedule is (10:00, 14:00), this time schedule is one that the value of the expected accessibility-satisfaction measure is lowest in the set of schedules where the value of the expected accessibility-satisfaction measure is higher than the security level for rank 1. However, when looking at individual activities, this time schedule does not satisfy the rank 1 security level regarding medical examination, and instead satisfies the security level of rank 2.

In Case 2 of Figure 5, a time schedule where the expected accessibility-satisfaction measure satisfies a rank 1 security level for activity opportunity no longer exists. Therefore, a rank 2 security level will be focused on. As in Figure 4, time schedules to secure activity opportunity at rank 2 are shown in Figure 5, represented by a collection of blue points enclosed within a red circle. Of these time schedules, (12:00, 15:00) is the only time schedule where the

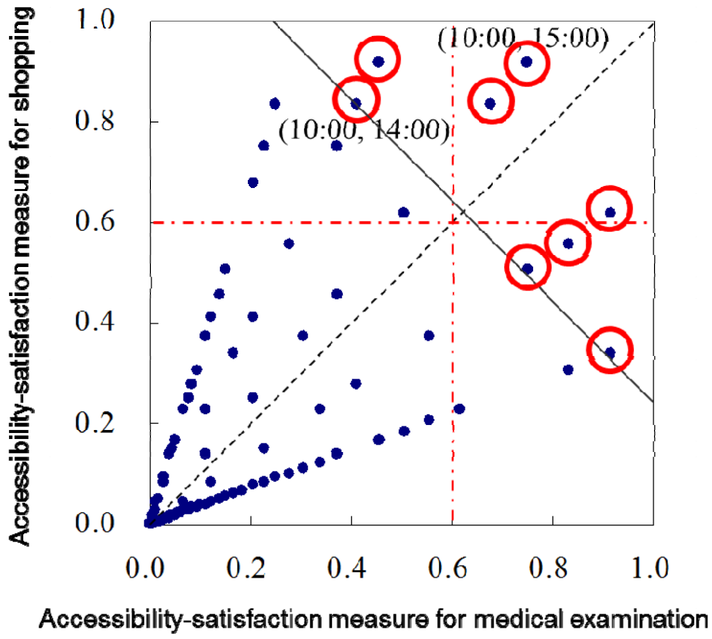

Figure 5: Capability of public transport service in Case 1

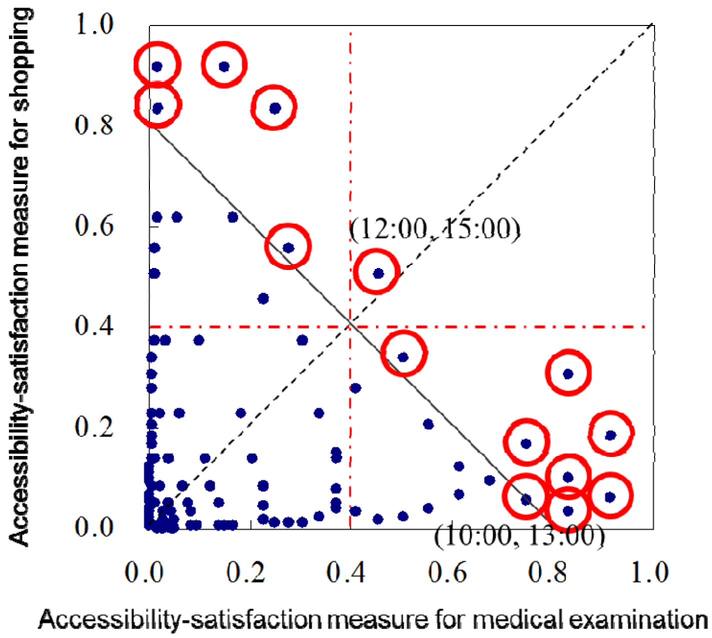

Figure 4: Capability of public transport service in Case 2

expected accessibility-satisfaction measure satisfies a rank 2 security level as well as the security level for individual activities.

Regarding medical examinations and shopping, looking at the scheduled activity time starting at the scheduled activity starting time to scheduled activity ending time, Case 1 is set in such a way that the scheduled activity time for shopping is included in the scheduled activity time for medical examination. In this case, there is a high possibility that residents will conduct both shopping and medical examination in the urban area in accordance with a single time schedule. Thus, if the activity is complementary, the capability frontier becomes concave with respect to the origin, as shown in Figure 4. Therefore, in this case, it becomes easy to create a time schedule where the expected accessibility-satisfaction measure satisfies the security level of both activities.

Case 2, on the other hand, is set in such a way that the scheduled activity time for shopping comes after the scheduled activity time for medical examination. Hence, if the activity is substitute, the capability frontier becomes convex with respect to the origin, as shown in Figure 5. Consequently, it becomes difficult to create a time schedule where the expected accessibility-satisfaction measure satisfies the security level of both activities without reducing the security level any further. In this case, rather than insisting on securing activity opportunities with a single time schedule, there is a need to consider increasing the number of services.

CONCLUSION

In this paper, in order to evaluate activity opportunities provided by rural public transport service, first, we quantified accessibility satisfaction of activity opportunities, employing a measure which has time schedule of the public transport service as a variable. Then, we defined the expected accessibility-satisfaction measure by using a comparison ratio of functionings that are desirable from a normative perspective between different activities. Next, we provided an activity opportunity security level relating to the rank of importance of the activity. In addition, we defined a time schedule that provides an expected accessibility-satisfaction measure that is higher than this security level, as capability of public transport service to secure activity opportunities. Lastly, we proposed a graphical solution to the evaluation of time schedule to secure activity opportunity, and considered the relationship between the capability of public transport service and the substitutability and complementarity of activity opportunities, using a numerical example.

If the activity opportunity is complementary, eventually there is a need to make a choice among time schedules when there was more than one time schedule that secured the activity opportunity. Furthermore, if the activity opportunity is substitute, there is a need to think about increasing the number of public transport services when the activity opportunity has a high security level. Regarding this “method of decision-making”, it is advisable that each regional area choose from a combination of “level of service” and “burden of cost”. At that time, it is necessary to evaluate an appropriate service level that is comparable to the burden of cost. The evaluation method proposed in this paper should be employed in situations where such evaluation occurs.

APPENDIX

Derivation of formula (9a) (9b) is shown below. The elicitation process of both formulae is the same, so only formula (9a) is derived.

$$\mathrm{E}\left[\max\{s-a,0\}\right]=\int_{\underline{s}}^{a}0\cdot\bar{f}(s)ds+\int_{a}^{\bar{s}}(s-a)\bar{f}(s)ds=\int_{a}^{\bar{s}}s\cdot\bar{f}(s)ds-a\cdot\overline{F}(\bar{s})+a\cdot\overline{F}(a)$$

$$\mathrm{E}\left[\max\{a-s,0\}\right]=\int_{\underline{s}}^{a}(a-s)\cdot f(s)ds+\int_{a}^{\bar{s}}0\cdot f(s)ds=a\cdot F(a)-a\cdot F(\underline{s})-\int_{\underline{s}}^{a}s\cdot f(s)ds$$

When distributed uniformly, $\overline{F}(s)$ and $F(s)$ are defined as $\overline{F}(s)=\frac{s-a}{\bar{s}-a}$ and $F(s)=\frac{s-\underline{s}}{a-\underline{s}}$, respectively. Accordingly, $\overline{F}(\bar{s})=1$, $\overline{F}(a)=0$, $F(\underline{s})=0$ and $F(a)=1$. Therefore,

$$c_{\mathrm{as}}^{\lambda}(a)=\gamma_{\mathrm{as}}^{\lambda}\mathrm{E}\left[\max\{s-a,0\}\right]+\gamma_{\mathrm{sa}}^{\lambda}\mathrm{E}\left[\max\{a-s,0\}\right]=\gamma_{\mathrm{as}}^{\lambda}\left(\frac{\bar{s}+a}{2}-a\right)+\gamma_{\mathrm{sa}}^{\lambda}\left(a-\frac{a+\underline{s}}{2}\right)$$
$$=\gamma_{\mathrm{as}}^{\lambda}\left(\frac{\bar{s}-a}{2}\right)+\gamma_{\mathrm{sa}}^{\lambda}\left(\frac{a-\underline{s}}{2}\right)$$

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