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Kita, Hideyuki
Komoda, Satoshi
Ozaki, Rizumu

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A quantified planning method of local public transport services for expanding residents' activity opportunities

Hideyuki Kita [a,*], Satoshi Komoda [b], Rizumu Ozaki [c]

[a] Professor Emeritus, Kobe University, Kobe, 657-8501, Japan, and Chodai Co. Ltd., Osaka, 550-0013, Japan
[b] Hanshin Electric Railway Co. Ltd., 1-1-24 Ebie, Fukushima, Osaka, 553-8553, Japan
[c] ATEC Co. Ltd., Honmachi, Shibuya, Tokyo, 151-0071, Japan

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ABSTRACT

The purpose of public transport is to expand activity opportunities of residents. Many public transport planning methods focus on the needs of residents. However, residents can adapt to the environment and form limited needs in areas with low public transport service levels, such as rural areas. Therefore, it is important to focus on activity opportunities (various states of people (being) and actions (being able)) rather than needs. The authors constructed a method for local public transport planning that focuses on activity opportunities; however, the variables and solutions of the model were abstract and thus did not reach the stage of practical application. Therefore, this study aimed to put into practical use a supporting method for local public transport planning. This method consists of a "measurement model for activity opportunity," in which a given bus service and the ability to use it are variables, and an "evaluation model for planning alternatives" that incorporates a social relationship function and disparity principle. Through a case analysis in a rural area to which this method was applied, its usefulness was verified, and it was confirmed that it can contribute to public transport planning to increase activity opportunities.

1. Introduction

Public transport services have basically been provided by private companies, in Japan. However, with the progress of motorization, it has become difficult to provide sustainable services, particularly in rural areas. The decline in public transport services has restricted the activities of residents who cannot use cars, such as the elderly (Ministry of Economy and Trade and Industry, 2015). Thus, local governments have been forced to take support measures, such as operating community buses (Ministry of Agriculture and Forestry and Fisheries, 2017). Since the deregulation of the bus market in 2002, the national government has been requesting local governments to formulate local public transport plans.

However, it is rare for local governments to have specialists in public transport planning; in particular, local governments of small communities in peripheral areas have fewer or no full-time personnel in charge of this (Ministry of Land, Infrastructure, Transport and Tourism, 2012). Persons in charge who are not necessarily familiar with transport planning are required to formulate plans, which is not an easy task for them. This is probably why more than half of the local governments cite "how to make a plan" as necessary information (Ministry of Land, Infrastructure, Transport and Tourism, 2012).

Local public transport plans should be evaluated not by the transport services provided as the "derived demand" but by the degree of contribution to the "improvement of citizens' lives," which is the "primary demand." However, a large number of plans focus only on improving a transportation system and do not consider how it improves the lives of residents (e.g. , Takamatsu City, 2010).

The Ministry of Land, Infrastructure, Transport, and Tourism, Japan prepared a handbook for formulating local public transport plans (Ministry of Land, Infrastructure, Transport and Tourism, 2009). The key here is the importance of satisfying the trip needs of the residents. However, Tanimoto and Kita (2003) pointed out that, in rural areas, residents may adapt to the poor environment, and their trip needs may be under-formed, hence, local public transport plans should focus on activity opportunities rather than on residents' needs, where "activity opportunity" is states and/or activities, such as shopping and taking medical care that residents can achieve when they need it (Sen, 1985). Based on this idea, Kita et al. (2017) constructed a normative model for evaluating planning alternatives by focusing on the size of residents'

* Corresponding author.
E-mail address: kita@crystal.kobe-u.ac.jp (H. Kita).

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activity opportunities. However, it has not necessarily reached the stage of practical use, because it consists only of abstract logic. Hence, this study aimed to construct a practical deployable supporting method for planning local public transport services for expanding activity opportunities, in concrete, (a) to correspond resources and resource utilization ability with actual data, which were limited to abstract concepts in the previous study, (b) Once the minimum level of activity opportunity is determined, a local public transport plan to realize it can be formulated, and (c) Analysis can be performed using only open data that is easy to obtain.

The remainder of this paper is organized as follows. This section describes the background and purpose of the study. Section 2 describes the problems of needs-focused plans and the significance of focusing on activity opportunities as a key concept of this study. Section 3 reviews past studies that measured activity opportunities, methods for planning local public transport services and social choice theory. Section 4 describes the model in detail, and Section 5 presents the data for the proposed method. Section 6 presents a case analysis, and Section 7 concludes the paper.

2. Concept of the study

2.1. Expansion of activity opportunities

2.1.1. Concept of activity opportunity

In this study, "activity opportunity" is a set of feasible options of "what activities can be done where and at what time. It is objective state, comparable among individuals, and is almost the same concept as "capability" in the "capability approach" described by Sen (1985). In the context of transport, it corresponds to "being able to shop", "being able to consult a doctor", etc.

In the capability approach, what can be achieved using the goods or services of a person (e.g., shopping and taking medical treatment) are defined as "functioning," and a set of these functionings is defined as "capability," which determines a person's state or condition. The capability approach distinguishes between functionings and goods because there are differences between individuals in their ability to utilize goods.

For example, when owning a car is good, an individual who can drive a car has the mobility to get around by car; however, an individual who cannot drive a car has poorer mobility by foot. Thus, even if the same goods are given, the functioning to be realized differs depending on the ability to utilize the goods.

Therefore, the capability approach called the goods for achieving a functioning as "resources," and the ability to use the goods as "resource utilization ability," and considers that functionings are formed under resources and resource utilization ability. In this study, activity opportunity is a concept corresponding to functioning, and we considered that resources and the ability to use the resources determine their size.

2.1.2. Problems with need-oriented planning

One of the problems with needs-oriented planning is "cognitive adaptation". Local public transport plans that focus on meeting mobility needs are, in other words, plans that focus on satisfaction. Focusing on satisfaction means evaluating the contribution of public transport from the specific standpoint of welfare-oriented planning. The welfare principle consists of consequentialism, in which the goodness of something is judged solely on its consequences, and utilitarianism, in which the goodness of something is judged on the basis of an individual's subjective evaluation. Sen (1999) quotes Elster's (1982, 1983) discussion of cognitive adaptation, in which preferences are formed by adapting to one's environment, and describes the mechanism of people's needs formation as follows. "When placed in an adversity that cannot be changed by the individual, its victims will limit their aspirations to the limited things that are attainable, rather than vainly longing for the unattainable."

Individuals "unconsciously" form needs that are adapted to the environment in which they live. If the environment is poor, they form humble needs accordingly and try to maintain a certain level of satisfaction with the status quo. In quality of life studies such as Rapley (2003) and Sirgy et al. (2006), it is claimed that quality of life cannot be properly evaluated by focusing only on people's subjective evaluations. These are problems with need-oriented planning.

Tanimoto and Kita (2003) pointed out that such a situation may occur in the context of public transport. For example, they conducted a needs survey targeting the central district, where there are five bus services per day to/from shops and medical facilities, and the peripheral district, where there are only two bus services per day, and reported that residents in central districts answered that they had unsatisfied trip needs, while those in peripheral districts answered that they had no unsatisfied trip needs. Even if "no needs" is obtained, residents in peripheral districts may form limited trip needs due to cognitive adaptation and respond so. It does not mean that public transport is sufficient, and restrictions on daily life must exist. Despite this, plans that focus on needs give priority to providing services to districts where residents have a strong response to their needs. This is a problem.

In a survey conducted by Kita et al. (2001), in a village with only five round-trip bus services per day, when asked, "If you were to add one more bus service, what time would be best? Many of residents responded, "I live according to the current bus schedule, so I cannot answer that question. This is the state of people who have adapted to their environment and do not have in mind activities that cannot be realized with the current bus schedule, i.e., they have no needs.

Another problem with needs-oriented planning is "luxury preference". The size of a need is defined as the difference between the desired state and the current state. Given two residents in the same situation, the size of the needs of high-aspiration (luxury) residents is larger than those of low-aspiration (modest) residents. Considering the size of the need, public assistance is provided to extravagant rather than modest residents, which is also a problem. Tanimoto and Kita (2003) stated that it is important to focus on activity opportunities (what can be done and when and where) instead of needs, this study is in the same position.

2.1.3. Significance of focusing on activity opportunities

The purpose of transport planning is to contribute to the improvement of the quality of life and the revitalization of the community from the field of transport. People are social beings as well as living organisms, and quality of life is closely related to securing a "comfortable living environment" and a "vibrant living environment. The former corresponds to the ability to easily perform activities necessary to maintain one's life, such as shopping and going to the hospital, while the latter corresponds to the ability to easily perform activities for social participation.

People with low mobility do not have sufficient opportunities for social participation and may even experience "social exclusion" (Lucas, 2004). Activities such as "having dinner with friends," "participating in local events and talking with various people," and "going to see grandchildren" make people a little happier. People are happy when they help out in the community using the skills they developed at work when they were young, and this is also the source of their own energy. A community where this kind of activity takes place on a regular basis everywhere is full of smiles and vitality. In this sense, "community vitality" is proportional to the "total amount of social participation" in the community. Societies in Japan and other countries are aging. As people get older, their physical and cognitive functions deteriorate, making it difficult for them to obtain various opportunities to engage in activities for daily living. This not only makes it difficult to maintain one's lifestyle, but is feared to lead to gradual social exclusion.

To improve this situation, a local public transport plan should be developed as a strategic and systematic blueprint to secure the appropriate level of activity opportunities for the elderly. Focusing on "opportunities for activities" that are closely related to the quality of life, it

is understood that local public transport planning is itself only a "means" to improve the quality of life and to revitalize the community, and that it has an alternative and complementary relationship with other means that contribute to these goals. For example, in order to create a town where the elderly can live with peace of mind, it is effective to combine a town development plan that allows them to do their daily activities within walking distance with a public transport plan that enables them to go to the hospital and go shopping without depending on others. For example, a combination of delivery services for those who can shop alone but have difficulty carrying heavy items home, electric wheelchairs for those who have difficulty walking to and from work, and assistance services for those who have difficulty getting to and from work alone would be helpful.

In this way, we can choose whether community buses, cab tickets, clinics, and convenience stores in rural areas should be provided, whether house calls and mobile vending services should be enhanced, or whether support for relocation of villages to central areas should be provided as administrative services to secure the minimum livelihood opportunities necessary for people to lead their lives. The idea is to make a choice between whether it is better to support the relocation of villages to the center of the city. In addition to the "sectoral response of public transport" the choice can be made among a wider range of cross-sectoral policies, such as "medical care" and "promotion of commerce". This would also make it possible to provide more effective services with less burden. This is closely related to the positioning of local public transport plans in the comprehensive plans of local governments, and it is important to clarify the "optimal sharing area by transport services" to determine the extent to which transport services should be shared in order to improve the quality of life of residents under tight fiscal conditions, and to identify effective and efficient transport services from among a wide range of measures. This leads to the concept of selecting effective and efficient measures from among a wide range of countermeasures.

2.2. Public transport plan created by the local community

Another distinctive concept in this study is "community-created public transport planning. The purpose of this study is "Practical and systematic support methodology for planning local public transport services for expanding activity opportunities of residents" which appears in the introduction of this paper. Who will formulate the plan? As proposed by the International Association of Transportation and Traffic Safety (2010), this paper also believes that it is the local community that should make the local public transport plan. In reality, local governments and/or councils often formulate plans; however, we believe that they formulate plans as agents of local communities. Therefore, when formulating plans, it is necessary to appropriately reflect the will of the local community, that is, "what future of society do the residents want to realize?'', and the geographical, social, and cultural characteristics of the area. This means the importance of "Target Achievement-Type Planning". There is no general-purpose and standardized plan that can be applied to any place; thus, it is necessary to formulate a realistic plan based on the characteristics of each area.

This also applies to the planning method proposed in this study. In other words, it is up to the community to decide on what kind of goals to set, on what basis to evaluate alternative plans to achieve them, how to collect the opinions of many residents, and to form a consensus of the local community. For example, many public transport plans implicitly adopt a specific value standard such as "the greatest happiness of the greatest number." This study considers that the planning body should explicitly compare and contrast multiple value standards and their effects on the evaluation of alternative plans and formulate plans that suit each community.

As described in the following chapters, the proposed methodology was constructed by introducing specific value standards, concepts, decision criteria, and indices, such as the "magnitude of activity opportunities," "social relationship function," "disparity principle," and "basic capability." This study intended that the elements of the proposed methodology should be selected and specified by the local community and are metabolites that can be replaced with other indices and value standards to construct a planning methodology. This study aimed to organize a discussion by "knowing the impact of differences in values in the selection of planning alternatives deepens the residents' understanding'' into a more comprehensive and useful reference for supporting smoother social choice in the real world. It is recommended to obtain several future figures of residents' life by replacing the above-mentioned elements, comparing them, discussing a series of actions to be taken (i.e., drafting a local public transport plan), and forming a consensus in the local community. This study proposed a methodology for this purpose.

3. Study review

3.1. Methodologies for planning local public transport services

There are various works on the methodology for supporting the formulation of local public transport plans. In the United States, Transportation Research Board (2000) lists eight indices: accessibility, mobility, economic development, quality of life, environment and resource conservation, safety, operational efficiency, system status, and behavior, which should be examined from various perspectives regarding performance. Although the overall picture is presented, it is limited to introducing the relevant data and necessary survey/analysis methods. Many guidebooks for formulating local transport plans have been published in the UK (e.g. Department for Transport, 2004), and the Sustainable Urban Mobility Plan (SUMP) (Rupprecht Consult, 2019) has been published in the EU. All of these are systematic methodologies based on accessibility as the central concept, and descriptions of rural areas are relatively substantial. Here, "Public Service" is positioned as a service necessary for a society that cannot be provided on a commercial basis by the private sector. However, no quantitative evaluation indices have been presented (Hayashi et al., 2021). In Japan, the Ministry of Land, Infrastructure, Transport, and Tourism, and the Regional Transport Bureau have issued various manuals (e.g. Ministry of Land, Infrastructure, Transport and Tourism, 2021), and recently, the viewpoint of public transport planning can be observed. However, there are rather many cases of goal setting for transport business planning, and there is little explicit recognition of social common capital. Eitoku and Mizokami (2008) proposed a method to comprehensively evaluate road policies and activity bases allocation policies using quality of mobility (QoM) indexes and proposed a methodology to evaluate transportation and land use policies using QOL indexes in a unified manner. In Hayashi et al. (2021), the intention as a planning method based on the characteristics of social common capital cannot be read. The "Bus Service Handbook" (Japan Society of Civil Engineers, 2006) and "Public Transport Plan for Local Communities" (International Association of Tranaportation and Safety Sciences, 2010) are documents for planning public transport plans and clearly describe their treatment as social common capital, however, they are not quantitative methodology.

Many supporting methods for local public transport planning have focused on the users' needs. The Ministry of Land, Infrastructure, Transport and Tourism (Ministry of Land, Infrastructure, Transport and Tourism, 2012; Ministry of Land, Infrastructure, Transport and Tourism, 2016) and Moriyama et al. (2004) have developed a method to formulate plans based on needs identified through questionnaires and interviews, and to evaluate the plans based on the number of bus users and their satisfaction. In both cases, the problems described in 2. 1.2 remain.

However, there are few studies on methodology and support methods for local public transport planning that focus on activity opportunities. Kita et al. (2015) recognized a set of activity opportunities as capability and constructed a theoretical model to evaluate public transport services from a viewpoint of capability approach.

Furthermore, Kita et al. (2017) regarded the policy in the local public transport plan as a combination of the production volume of common consumer goods and cost burden, and considered the functioning achieved by the production volume of common consumer goods and resource utilization ability of each policy (the degree of achievement of the functioning). In the same manner, we modeled the mechanism that determines the desirable policies. Here, common consumption goods (resources), resource utilization ability, and the degree of functioning achievement were used as abstract concepts. However, how the resources and resource utilization ability determines the degree of functioning achievement were not specified. Further, because the relationship between resources/resource utilization ability and degree of achievement of functions has not yet been formulated, it has not yet been practiced.

In this study, we formulated the degree of achievement of the functioning for the practical use of the model. In the next section, we review studies dealing with measurement of the size of activity opportunities and select the indices to be used in this study.

Similar to Kita et al. (2017), this study also used the disparity principle (Rawls, 1971) and social relation function (Gotoh and Yoshihara, 2013) among various social choice norms, as a procedure for finding desirable policies among the combination of the degree of achievement of functionings. The social relationship function imposes basic requirements to embody the social goal to secure all members of community the minimum capability that should be secured by the community, called "basic capability." Therefore, studies on the social choice theory is presented in 3.3.

3.2. Measurement of activity opportunity

As a measurement method based on user satisfactions, Sasaki and Tokunaga (2012), for example, evaluated various activities based on satisfaction surveys. However, satisfaction and activity opportunities are inherently different concepts (Goto, 2012).

As a measurement method based on activity performance, Yoshida et al. (2009) focused on the frequency of outings and the number of trips to measure them. However, since the opportunity to engage in an activity is the size of potential or possibility that can be accomplished, it is essentially different from the resultant activity performance, which is something that has been accomplished. Chikaraishi et al. (2012) consider the relationship between the two from the perspective of "constraints" that prevent activities and the perspective of "choices" that could have been made but were not used.

As a measurement method based on weighted averages, Inoi et al. (2004), for example, use the weighted sum of the achievability of 13 activities (shopping, hospital visits, etc.) related to outings among the elderly as an index of activity opportunities. The weighted average assumes that the activities are complementary to each other, which is different from reality.

As a measurement method using a structural equation model, Eitoku and Mizokami (2008) define the capability related to mobility as QoM (Quality of Mobility), and use structural equation models to measure QoM and evaluate the effects of transport improvements. As pointed out by Chikaraishi et al. (2012), measurement based on structural equation models has the disadvantage that "constraints" and "choices" cannot be distinguished.

As a method to overcome these issues, Goto (2013) proposes an approach to capture the degree of achievement of functionings (size of activity opportunities) by depicting the maximum realization point of functionings that can be achieved by maximizing the use of available resources and resource utilization abilities as a feasibility frontier. This study takes the same position, but no model that can be used for empirical analysis has been developed so far.

Tanimoto et al. (2009) also construct an index to evaluate the diversity of time choice of activities by counting the feasible time allocations under a given public transport service based on the concept of the spatiotemporal prism proposed by Hägerstrand (1970). Kita et al. (2015) extended the accessibility index by Tanimoto and Kita (2003) by taking physical constraints such as walking ability to bus stops and time frame in which residents can go out into consideration as the resource utilization ability.

These are indices that consider spatiotemporal constraints that should be focused on in public transport planning, and indices that can distinguish choices and constraints from the spatiotemporal aspect. This study uses the model by Kita et al. (2015) as a measurement model of activity opportunities.

3.3. Social choice theory

The proposed methodology evaluates the activity opportunity of each resident realized under each alternative plan and selects the most desirable plan for the community. Such procedures for summarizing each resident's preference for the alternative plan as a community consensus have been studied as social choice theory (Arrow et al., 2002).

Arrow and Hurwicz (1960) proved that there is no social welfare function that satisfies the four conditions of independence from unrelated choices, non-dictatorship, non-restrictiveness of the domain which is indispensable for democracy, Pareto principle, with satisfying the rationality (completeness, transitivity) of the preference relation in case that the number of options is three or more.

The social welfare functional by Sen (1985) and the social relation function by Gotoh and Yoshihara (2013) are attempts to relax Arrow's impossibility theorem. Rawls (1971) also proposes the "disparity principle," which states that "it is desirable to maximize the expected benefits of those in the most disadvantaged positions in society.

Kita et al. (2017) constructed a social choice model by combining the disparity principle and the concept of social relational functions. Specifically, they assume a society in which there are individuals who are below their basic capability, and the individual with the largest gap between his or her basic capability and each individual's capability is the most disadvantaged individual. Based on the disparity principle, the policy that minimizes the gap is considered optimal. Since this study intends to develop a planning methodology of local public transport for residents with many restrictions on their activities, such as the elderly in rural areas, this study also follows the idea of Kita et al. (2017), which focuses on the activity opportunities of the most disadvantaged residents.

4. Model

4.1. Practical application

Kita et al. (2017), built a methodology focusing on activity opportunities. However, it is still an abstract level, and does not specify resources and resource utilization ability nor formulate the size of activity opportunities. It prevents the practical use of this methodology. This study is to overcome these problems and develop a practical methodology for planning.

This section specifies resources and resource utilization ability, and proposes a practical planning methodology using the activity opportunity measurement method of Kita et al. (2017). In addition, we attempt to use GIS as a means of presenting information on alternatives prepared in advance by planners to residents.

4.2. Focused areas and residents

In this study, we focused on rural areas, where there are not necessarily facilities for activities in residential areas; however, there are facilities in central districts away from residential areas. The assumed situation was "a situation in which residents used public transport to move to their activity bases and performed activities that are essential to their lives, such as shopping and going for medical treatment."

The proposed methodology can take into account a wide range of residents, but it is particularly concerned with the elderly. Municipalities have recognized mobility restrictions for the elderly and disabled as an issue related to local public transport (Ministry of Land, 2012), and from the perspective of normalization, they should be a central target in local public transport planning.

4.3. Overview of the model by Kita et al. (2017)

The model by Kita et al. (2017) consists of two parts: an activity opportunity measurement model for state description and a social choice model of alternatives. The latter is a normative two-stage model consists of a capability frontier derivation model and a social evaluation model.

In the activity opportunity measurement model, "the extent to which a resident can go to an activity base (a facility where functioning k can be performed) when they want to'' is described by the size of the activity opportunity related to functioning k (the degree of achievement of functioning k). However, it is not possible to determine whether functioning k can be achieved only by arriving at the destination. For example, even if a patient can arrive at a hospital, receiving a medical examination cannot be achieved if the hospital does not have an appropriate department. To improve this situation, it is necessary to formulate a plan that functionally combines public transport and regional medical plans. However, to avoid divergence of discussion, in this study, we focused on the sizes of activity opportunities from the viewpoint of public transport planning, and define the size of an activity opportunity related to functioning k as "the extent to which residents can go to the activity bases when they want to."

The capability frontier derivation model assumes a situation in which there are no activity base in the residential area and they are located in the central area far from the residential area. Residents are assumed to use the bus service to move to the center and achieve two kinds of functionings such as shopping and medical care. This bus service is a common consumption good that is shared and consumed by multiple residents, while the medical care and shopping are private goods that are paid and consumed by each residents. As shown in Fig. 1 (a), each resident divides his/her own budget into common consumption goods and private goods. The quantity of common consumption goods and the quantity of private goods obtained through each cost function is the quantity of resources in the capability approach.

The degree of achievement of a resident's functioning k is determined by the resources "common consumption goods production volume'' and "private goods production volume for functioning k", and the resource utilization ability", "resource utilization ability related to communal consumption goods" and "private consumption goods". It is defined by the "resource utilization capacity for the target goods". The function that relates them is called the achievement level function of the functioning, and is shown in Fig. 1 (b). Then, each individual's capability is derived from the combination of the achievement levels of functionings.

In the social evaluation model, a combination of the output of a joint consumption good and its cost for each individual is considered as an alternative plan, and the capability of the residents that each alternative brings is measured. The social evaluation model ranks the alternatives by using the social relation function (Gotoh and Yoshihara (2013) and the disparity principle (Rawls, 1971) as social evaluation. However, Kita et al. (2017) do not identify communal consumption goods and private goods (resources). Also, the functional achievement function, which relates resources and resource utilization ability to the degree of achievement of functionings, is not specified. Thus, there are still issues to be solved for practical use.

4.4. Specification of the model

In order to develop practical applications of the proposed methodology, the following factors should be specified.

The first factor to be specified is the type of functioning k. The type of functioning k that should be focused on in planning varies from community to community. In this study, we generalize function k ($k = 1, \ldots, K$), and take the idea of selecting it by the local community. Table 1 shows eight items of daily living for the elderly, which Nitta and Takebayashi, 2010) organized with reference to the ICF (International Classification of Functional Factors in Living).

The second factor is the activity bases. We identified the activity base with the largest activity opportunity for each functioning k in each residence location. This does not impair the generality of the model, and it can be easily extended to multiple sites, even if there are multiple activity bases where functioning k can be achieved.

The third factor is the degree of achievement of the functionings. Capability (a set of degrees of achievement of functionings) is defined by resources (volumes of common and private goods) and resource utilization ability. However, Kita et al. (2017) did not formulate a functioning that relates them. Unlike Kita et al. (2017), who assumed a

Table 1
Activities supported by local transport.

Conservation of life	shopping, hospital visit
Maintenance of life	business at public/financial institutions, barber/beauty, working/volunteer
Promotion of health and cultural activities	visiting relatives/friends, education/learning, walking/hiking,

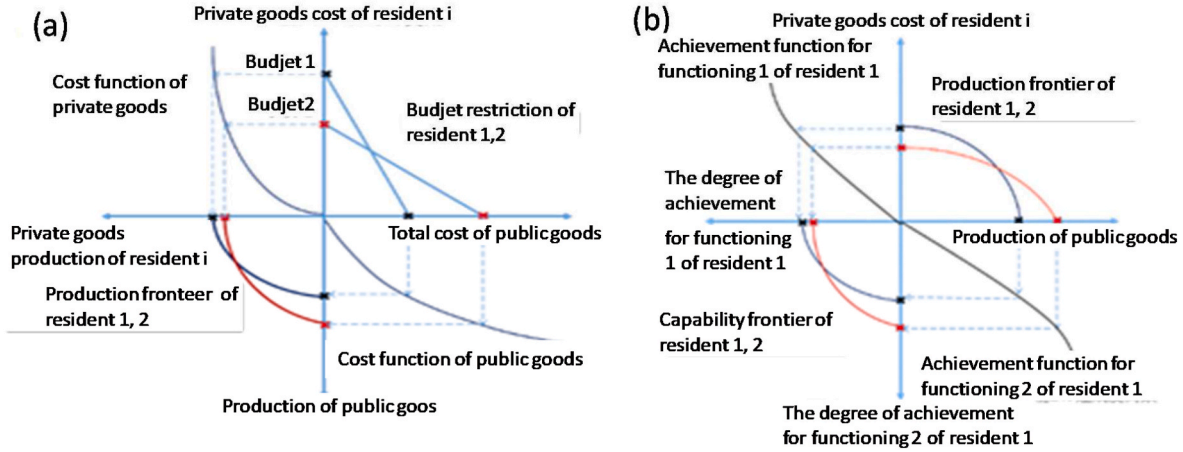


Fig. 1. Capability frontier of residents 1and 2.

society consisting of two residents, this study assumes a practical planning for each municipality with many residents. Although it is possible to set budget constraints and cost burdens for each resident, this study rather simplified the model to facilitate understanding of the overall picture of the model and did not consider these factors. A model to measure activity opportunities realized under given resources and resource availability was constructed using the measurement model developed by Kita et al. (2014). However, the model is structured in such a way that each resident's ability to use resources, including budget constraints as an individual, can be incorporated into the model as needed. It is possible to ascertain the resource utilization ability of residents in various ways, such as tax-exempt households, disability certification, and certification for those requiring long-term care, and it is rather desirable to take these into account in a more detailed manner during the implementation and operational phase of the plan.

The fourth factor is resource utilization abilities. To measure activity opportunities in practice, it is necessary to associate these concepts with available data. As this study focused on the spatio-temporal aspects of residents' activities as elements of local public transport planning, the resources of bus services are no facilities, but routes, timetables, and location of bus stops. Benches at bus stops and the number of seats in vehicles can also be considered as resources; however, we leave them in the current modeling to be considered in future expansion. Regarding the ability to utilize resources, there is a wide range of physical abilities, cognitive abilities, time constraints, and economic constraints associated with using public transport, all of which can constrain activity opportunities. However, rather than trying to build a measurement index that takes everything into account, it would be more practical to model basic capabilities and introduce additional abilities that are deemed necessary for each community. Therefore, in this study, we focused on the ability to walk to the bus stop and time windows for the activity and built them into the model.

The fifth factor is the planning alternatives. Kita et al. (2017) ranked each policy based on the social relationship function (Gotoh and Yoshihara, 2013) and disparity principle (Rawls, 1971). Specifically, we first focused on the size of activity opportunities for those who have the least opportunity for activities (the most unfavorable residents) based on the social relationship function and then selected the planning alternative with the highest level based on the disparity principle. However, in rural areas, such as those applied in this study, many residents had no activity opportunities by using public transport only. If there are residents without activity opportunities in each planning alternative, the size of activity opportunities for the most disadvantaged will be the same, and the optimal planning alternative cannot be uniquely determined. Therefore, in this study, we extended the model of Kita et al. (2014) and built a model that prioritizes planning alternatives by focusing on the number of the most disadvantaged residents when the size of activity opportunities of the most disadvantaged persons is the same.

In the following sections, we explain the third point, the activity opportunity measurement model, and the fifth point, the evaluation of the alternative planning model.

4.5. Measurement model of activity opportunity

4.5.1. The measurement model by Kita et al. (2017)

The situation considered in this model was as follows. Walk for h_{n1} hours in section 1 from home to the nearest bus stop, and then take the bus for T hours. Arrive at the nearest bus stop to the destination at time a_k. Then, walk section 2 from the bus stop to the activity base for h_{n2} hours. Start an activity at the facility at time t_s and continue until time t_e. Walk section 2 again from the activity base to the bus stop for h_{n2} hours, take the bus departing at time d_j for T, and arrive at the bus stop nearest the home. From there, walk for h_{n1} hours to return home.

The size of the activity opportunity achieved by public transport is defined as "the extent to which a resident can go to the activity base where he/she wants to perform the activity", and the number of combinations (t_s, t_e) of the feasible activity starting at time t_s and ending at time t_e was selected as the index of the diversity of time choice. As mentioned earlier, resources related to public transport consist of journey time, timetables, and distances to bus stops, and resource utilization ability consists of walking speed and the size of the time window.

First, we explain the relationship between bus schedules and the size of the activity opportunity. The number of combinations of (t_s, t_e) determined by destination arrival time $a_k (k = 1, 2, \ldots, K)$ and destination departure time $d_j (j = 1, 2, \ldots, J)$, depending on the bus schedule, is described in Eq. (1).

In the case of a round trip per day (bus stop arrival time a_1, bus stop departure time d_1), residents can only engage in activities at their destination between time a_1 and time d_1, as shown in Fig. 2. Thus, (t_s, t_e) does not depend on the boarding time because the times considered are those on the destination side.

$$\sum_{j=1}^{J} \int_{d_{j-1}}^{d_j} \sum_{k=1}^{K-1} \int_{a_k}^{\min(t_e, a_{k+1})} dt_s dt_e \tag{1}$$

Considering the walking time from the bus stop to the activity base, h_{n2}, and the business hours of the activity base $T_a = [\underline{T}, \overline{T}]$, eq. (1) can be expressed as Eq. (2).

$$\sum_{j=1}^{J} \int_{\max\left(d_{j-1}-h_{n2}, \underline{T}\right)}^{\min\left(d_j-h_{n2}, \overline{T}\right)} \sum_{k=1}^{K-1} \int_{\max\left(a_k+h_{n2}, \underline{T}\right)}^{\min\left(t_e, a_{k+1}+h_{n2}, \overline{T}\right)} dt_s dt_e \tag{2}$$

Activities can be executed within this time frame. However, if the arrival and departure times of the bus and the start and end times of the activity are different, there is a waiting time. Therefore, Kita et al. (2014) introduced an attenuation function based on the waiting time. The waiting time is $\left(d_j - t_e + t_s - a_k - 2h_{n2}\right)$. The attenuation function A_1 for waiting time is described in Eq. (3), where γ is a parameter.

$$A_1 = e^{-\gamma\left(d_j - a_k - t_e + t_s - 2h_2\right)} \tag{3}$$

In addition, the fatigue attributed to the walking time to the bus stop and the fatigue attributed to the bus ride time were also considered by introducing attenuation function A_2 and damping function A_3, respectively.

$$A_2 = e^{-\alpha w} \tag{4}$$

where α is a parameter, and w is the total round-trip walking time. Age and grade were considered by incorporating the metabolic equivalent distance (Sato et al., 2006) into the total walking time. The gradient of each section is the average gradient of the section. When the gradient of section 1 of the outward trip is θ_1 and the slope of section 2 is θ_2, the

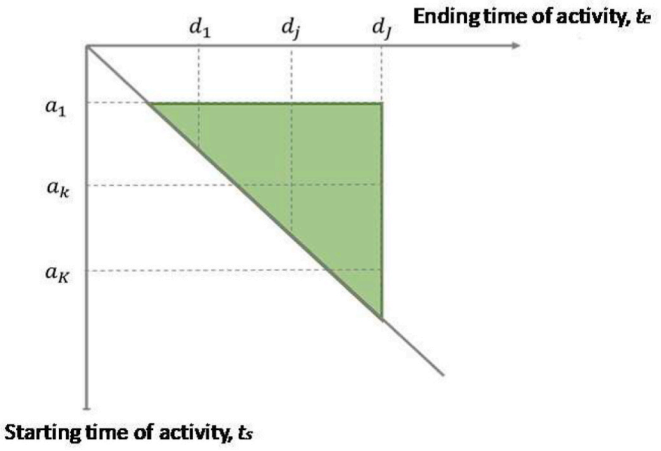


Fig. 2. The size of activity opportunities as variety of time choices.

gradient of section 1 of the return trip is $-\theta_1$ and the gradient of section 2 is $-\theta_2$. The total walking time considering age and gradient is described in Eq. (5).

$$w = h_{n1}\left(\frac{r(\theta_1)+r(-\theta_1)}{r(0)}\right)+h_{n2}\left(\frac{r(\theta_2)+r(-\theta_2)}{r(0)}\right) \tag{5}$$

$r(\theta)$ is a set described as follows (Sato et al., 2006).

$$r(\theta)=\begin{cases}1.2+3.113e^{4.614\theta} & \text{if} \quad \theta \geq -11(\%)\\ 1.2+3.113e^{-4.614\theta} & \text{otherwise}\end{cases} \tag{6}$$

An attenuation function was introduced for the bus boarding time T and walking time, too. An attenuation function A_3 is described in Eq. (7). β is a parameter.

$$A_3 = e^{-\beta \bullet 2T} \tag{7}$$

The time constraint was considered by the resident's available time period for going out, $T_p = \left[\underline{t_p}, \overline{t_p}\right]$, as shown in Eq. (8). The time constraint was formulated by multiplying the probability p_{kj} that a resident can use the k-th outbound bus and the j-th inbound bus.

$$p_{kj} = Prob\left(\underline{t_p} < a_k, \overline{t_p} > d_j\right) \tag{8}$$

Therefore, the index for determining the size of activity opportunity A was obtained using Eq. (9).

$$A = A_2 A_3 \sum_{j=1}^{J} \int_{\max\left(d_{j-1}-h_{n2},\underline{T}\right)}^{\min\left(d_j-h_{n2},\overline{T}\right)} \tag{9}$$

4.5.2. Activity opportunity measurement model used in the proposed methodology

This study used the activity opportunity measurement model proposed by Kita et al. (2014). There are some requirements to be considered when applying this model to rural areas, such as the subject area of this study.

The first requirement considered was the transfer waiting time. There is a high possibility that transfers occur when moving to the activity bases, particularly in rural areas. Therefore, when applying the model to a rural area, Kita et al. (2014) introduced an attenuation function A_4 described in Eq. (10) with respect to the transfer waiting time t.

$$A_4 = e^{-\gamma \bullet 2t} \tag{10}$$

The second requirement was the non-compensatory relationship between fatigues due to walking, boarding, and waiting times. When the bus stop is far from home, residents with low physical ability, including the elderly, are likely to give up using the bus regardless of how well the bus schedule is. Kita et al. (2014) evaluated the attenuation function for waiting, boarding, and walking times as a compensatory relationship, this study introduced a threshold, L(m), for the non-compensating and compensating functions for walking distance. If the distance to the nearest bus stop is longer than L, residents cannot perform the activity (there is no activity opportunity).

$$A_2^{'} = \begin{cases} e^{-\alpha w} & 0 \leq l_1 \leq L \\ 0 \text{ otherwise} \end{cases} \tag{11}$$

Based on the above discussion, the activity opportunity measurement model for determining the size of the activity opportunity, A′, used in this study was formulated as shown in Eq. (12).

$$A^{'} = A_2^{'} A_3 A_4 \sum_{j=1}^{J} \int_{\max\left(d_{j-1}-h_{n2},\underline{T}\right)}^{\min\left(d_j-h_{n2},\overline{T}\right)} \sum_{k=1}^{K-1} \int_{\max\left(a_k,h_{n2},\underline{T}\right)}^{\min\left(t_e,a_{k+1}+h_{n2},\overline{T}\right)} A_1 p_{kj}\, dt_s dt_e \tag{12}$$

4.5.3. Parameters

Threshold L between the uncompensated and compensated functions in Eq. (11) was set to L = 800 m, referring to the estimation result of 800 m obtained by Moriyama et al. (2005).

For the waiting time in Eq. (3), this study adopted a value of 1.814 for γ, estimated by Tanimoto et al. (2009), based on a questionnaire survey conducted in Yonago City, Tottori, Japan. Parameter α of the attenuation function for walking time and parameter β of the attenuation function for boarding time were calculated using an equivalent time coefficient. The equivalent time coefficient converts the psychological and physical burdens in all modes of transport into time and evaluates them in a unified manner. This study used the values listed in Table 2 for seating, walking, and waiting times on buses based on Do and Nitta (1997).

The equivalent time coefficients used in this study were seated, walked, and waited on the bus and were created based on a study by Do and Nitta (1997) (see, Table 2). In this case, for example, 10 min of fatigue while walking was equivalent to 10 × 3.33 = 33.3 min of fatigue while sitting on a bus. Table 3 summarizes the parameters used in this study.

4.6. Evaluation model for planning alternatives

Kita et al. (2017) ranked the planning alternatives by evaluating the combination of functionings achieved under each alternative using a social relationship function (Gotoh and Yoshihara, 2013) and the disparity principle1 (Rawls, 1971). In particular, they calculated the degree of achievement f^{ik} of functioning k (k = 1, 2) of resident i (i = 1, 2) under each planning alternative, and evaluated the capabilities $\left(f^{11}, f^{12}, f^{21}, f^{22}\right)$ by combining them. This study extended this to a function k (k = 1, 2, …K) of resident i (i = 1, 2,…, I). As the size of an activity opportunity described in Eq. (13) depends on the residential location of the resident and the location of the activity bases, where function k can be achieved. This study considers that the size of activity opportunity A′ in Eq. (12) is considered to be the degree of achievement of the functioning f^{ik}. The capability of resident i to planning alternative x is denoted as $C_i(x)$.

$$C_i(x) = \left(f^{i1x}, f^{i2x}, \ldots, f^{ikx}, \ldots f^{iKx}\right) \tag{13}$$

Under each planning alternative, the residents with the lowest degree of achieving functions below their basic capabilities were identified as the most disadvantaged residents under the alternative. If denotes the degree of achieving functioning k, secured as the basic capability as f_0^k, the basic capability BC of the functioning k (k = 1, 2, …K) is described as

$$BC = \left(f_0^1, f_0^2, \ldots, f_0^k, \ldots, f_0^K\right) \tag{14}$$

Here, we note that the planner does not set a level of basic capability. The basic capability is the level determined by the community or the local government as the agency of the community, and the level varies depending on the kind of activities and the extent to which a society secures residents.

The difference between resident i's achievement f^{ikx} of functioning k under planning alternative $x(x = 1, 2, \ldots X)$ and basic capability f_0^k is called deviation from basic capability. The deviation from the basic capability, r^{ikx}, is denoted as

$$r^{ikx} = \begin{cases} f_0^k - f^{ikx} & \text{if } f_0^k > f^{ikx} \\ 0 \text{ otherwise} \end{cases} \tag{15}$$

Table 2
The equivalent time coefficient.

seating on bus	walking	waiting
0.986	3.283	1.814

Table 3
Parameters.

boarding time (β)	walking time (α)	waiting time (γ)
0.986	3.283	1.814

Next, find the maximum value r^x of the deviation r^{ikx} from the basic capability under each planning alternative x. r^x is the deviation from the basic capability of the most disadvantaged resident i under the planning alternative x and is given as

$$r^x = \max_i \left(\max_k \left(r^{ikx} \right) \right) \tag{16}$$

Since this model aims to maximize the activity opportunities of the most disadvantaged, planning alternative x^* with the smallest r^x is considered the optimal planning alternative, where X is the set of all the alternatives.

$$x^* = \underset{x}{\operatorname{argmin}} (r^x | x \in X) \tag{17}$$

In rural areas, the optimal planning alternative x^* with the smallest r^x is not always uniquely determined. This occurs when no planning alternative can improve the dissociation of all the most disadvantaged populations (maximizing the activity opportunities of the most disadvantaged). In such cases, we used a two-stage model that focuses on the number of the most disadvantaged population as the second-best measure and selected the planning alternative that minimizes the number of the most disadvantaged residents as the optimal alternative. Specifically, if alternatives cannot be ranked using Eq. (17), the alternative x^{**} that minimizes p^x is selected as the optimal planning alternative.

$$x^{**} = \underset{x}{\operatorname{argmin}} (p^x | x \in X^*) \tag{18}$$

where X^* is the set of planning alternatives that minimizes r^x. Because each planning alternative for public transport is provided collectively, the community basis optimum planning alternative for each route or section in a route can be selected by the alternative evaluation model shown above.

Next, in the local public transport plan, it is necessary to consider which route should be implemented first and the priority of the implementation of the planning alternative. Therefore, in this method, each optimal alternative x^*, x^{**} for each section or route $y (y = 1, 2, \ldots, Y)$ was redefined to alternatives y. Then, alternatives y were ordered and prioritized using the alternative evaluation model. Alternative x in Eqs. (15)–(18) was replaced with alternative y, and priority was considered in ascending order of r^y or in descending order of p^y.

Public transport services, which are constituent variables of the activity opportunity measurement model, are operational variables determined by planners and can be visually displayed on a GIS as a planning alternative. In addition, displaying the estimated values of activity opportunities in each functioning on a GIS will facilitate the understanding of local government officials and residents. On the contrary, some factors, such as the content of basic capability, are determined by the community. An overview of this methodology is shown in Fig. 3.

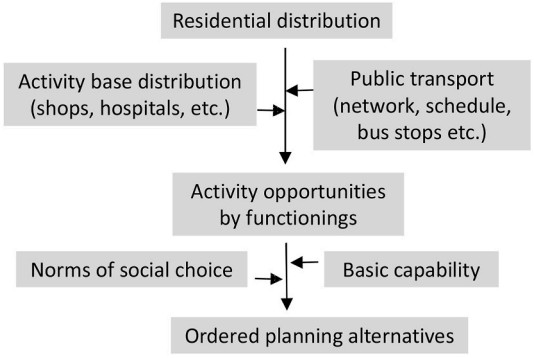


Fig. 3. The structure of the methodology.

5. Data required for analysis

5.1. Measurement of activity opportunities in mesh units

The activity opportunity measurement model can measure the size of activity opportunities on an individual basis; however, there are some aspects to consider when obtaining data on an individual basis. For example, it is not easy to obtain personal information, such as address and age because of privacy, and it is also difficult to specify the time window when an individual can leave. In addition, since public transport services are provided collectively, it is useful to determine the effects of services by district and section in a route as information for planning public transport.

Hence, this method measures the size of activity opportunities in the mesh units. Thus, by considering elderly people with low resource utilization ability, it is possible to identify areas that are inconvenient for elderly people. In addition, by assuming various resource utilization abilities, such as non-elderly people and those who can go out only in the morning, the inconvenient areas for residents with each attribute can be identified. In this study, since the maximum distance to access the bus stop was set to 800 m, the availability of the bus stop can be determined, and the data described later can be analyzed using a 500-m mesh or a 250-m mesh. A 500-m mesh was used because the more detailed the mesh, the more hidden the data in rural areas due to privacy.

5.2. Data preparation

The proposed method can only be used with open data that are easily available in any area. It was desirable to obtain coordinate data because a GIS was used. The data necessary for the analysis were classified into "geographic and demographic data", "public transport data", and "activity bases data," as explained below.

Geographic and demographic data necessary for planning consisted of coordinates of the residential locations, population, aging rate, altitude, walking distance, gradient from the residential location to the nearest bus stop. The walking distance was determined by obtaining a straight-line distance between the coordinates of the residential location and the nearest bus stop from the analyzing function of GIS and multiplying it by a conversion coefficients obtained by Koshizuka and Kobayashi (1983) and Morita et al. (2014), e.g. in the analysis presented in the next chapter, of 1.29.

Public transport data include bus schedules, routes, bus stops, length of boarding times, and waiting times for transfers. Based on a timetable, the bus schedule determines the destination arrival time a_k and destination departure time d_j for each route and destination. Coordinate data were required to display route and bus stop data on a map using a GIS. If a local government does not have this data, it can be obtained from the National Land Numerical Information Download Service (Ministry of Land, Infrastructure, Transport and Tourism, 2023), or similar one.

Activity base data are coordinates of activity bases (destination coordinates) that can achieve functioning k, business hours of activity bases, walking distance between destination coordinates and bus stop, and gradient from departure point to nearest bus stop.

6. Case analysis

6.1. Purpose of case analysis

To demonstrate that an optimal alternative can be selected by applying this method, we conducted a case analysis focusing on a municipality in rural areas.

6.2. Target area

The target area for the analysis was Maniwa City, Okayama Prefecture, Japan. Maniwa City is located in the north-central part of Okayama Prefecture, adjacent to Tottori Prefecture. As of 2015, the population was 46,124, and the aging rate was 36.6%. In Maniwa City, the population is expected to decrease to 40,298 by 2025, and the aging rate will increase to 41.0%. Most of the areas in the city are mountainous, and the road network maintained along the valley connects activity bases (Maniwa City 2015).

For public transport, there was a Maniwa City Community Bus operated by Maniwa City Government to cover this area, with 3 trunk lines and 34 branch lines. The number of round trips on the main line was approximately six per day, and the number of round trips on the branch line was approximately one round trip per day. In the future, it is expected that the elderly will change their mode of transport from private cars to community buses; therefore, it will be more important to secure opportunities for elderly people to perform activities through public transport. Improvement of the public transport service is recognized as an important issue. Hence, it is considered to be a suitable region for the application of the method.

6.3. Preparation for analysis

6.3.1. Condition setting

The situations assumed in this study were: 1) walking from the departure point to the nearest bus stop, 2) getting on the bus to the activity base where functioning k can be achieved, 3) performing the activity at the base, 4) getting on the bus again, and 5) walking back to the departure point. To simplify, the functioning k to be analyzed were shopping ($k = 1$) and hospital visits ($k = 2$), which are indispensable in daily life, although the proposed model has a structure to deal with three or more functionings. When there were multiple activity bases where functioning k can be achieved, we assumed that residents go to the base with the largest activity opportunity.

Public transport included 36 Maniwa City community bus routes (the Yubara-Hiruzen route was excluded because it overlapped with the Hiruzen-Kuze route). Because the demand-type Yatsuka and Kawakami routes were connected to the Hiruzen-Kuze route, which was the trunk line, it was assumed that the ride time was added to 30 min, and the Hiruzen-Kuze route was used.

The departure point was considered as a 500 m mesh. The base for shopping ($k = 1$) was the Maniwa City Hall bus stop, which was located in the central area of the city, where some supermarkets surrounded it, and was the only base in the city where these bases are concentrated. The bases for medical care ($k = 2$) were the Maniwa City Hall bus stop and the Yubara Onsen Hospital bus stop. Both bus stops were located near general hospitals (Fig. 4).

For simplicity, we did not specify the facility as the activity base and assumed that once residents reached the Maniwa City Hall bus stop or Yubara Onsen Hospital bus stop as the destinations, they could go shopping or go to the hospital at any of the surrounding facilities. The distance from the bus stop to the facilities was assumed to be 0 m.

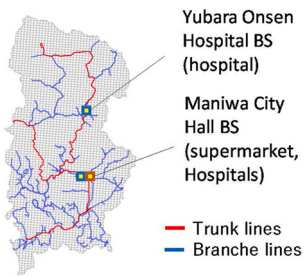


Fig. 4. Activity bases and bus routes.

Because the community bus was operated from 7:00 to 18:45, the business hours of the facility were set from 7:00 to 19:00 (hereafter, [7, 19]) when they can be used.

The level of basic capability was set by the local government as the agent of the community. Here, we set the basic capability of functioning k ($k = 1, 2$) for analysis as follows. Shopping ($k = 1$) was an activity with higher frequency. We believe that it was desirable to have many trips even if the boarding time was long; therefore, we set a minimum of 40 min for boarding time, 400 m walking distance, and two round trips, one in the morning and one in the afternoon. Then we set it as $f_0^1 \fallingdotseq 2.80 \times 10^{-3}$. Assuming that the frequency of hospital visits ($k = 2$) was lower and that residents with physical disabilities desired short distances to travel, the minimum travel time was 20 min, walking distance was 400 m, and there were at least two round trips in the morning and one round trip in the afternoon. The limit was set as $f_0^2 \fallingdotseq 4.03 \times 10^{-3}$.

6.3.2. Measurement of activity opportunities

To measure the value of activity opportunity, the maximum value was normalized to 1, and is shown as a value of [0, 1]. The maximum value was obtained when the walking time was 0 h, the boarding time was 0 h, the activity at the base was from 7:00 to 19:00, and the waiting time was always 0 h, which is equivalent to a high-frequency bus service or mostly private car use.

We analyzed the cases in which the walking speed of the elderly was 2.82 km/h (Sato et al., 2006), and the resident were able to go out during [7,19] to determine areas where the activity opportunity was poor.

The maximum value of activity opportunities when using public transport services should be equal to the number of activity opportunities when using a private car. The relative value R^k described in Eq. (19) was obtained by dividing the activity opportunity f_B^k when using public transport for functioning k by the activity opportunity f_C^k when using a private car. It can be said that this relative value is the service level of public transport measured by the size of activity opportunities.

$$R^k = f_B^k \Big/ f_C^k \tag{19}$$

6.4. Analyses of the current situation and planning alternatives

6.4.1. Analyses of current situation

Under the conditions described above, we measured the size of activity opportunity, f^k, and relative value, R^k, for the current Maniwa City community bus services. The measurement results are presented in Fig. 5 and Table 4 for locations A through D. Regarding the size of activity opportunity for shopping, f^1, and those for hospital visits, f^2, both the highest values are the same in both types at 0.396, and the lowest values are the same at zero. The relative value of activity opportunity for shopping, R^1, and those for hospital visits, R^2, both the highest values are the same in both types at 0.050, and the lowest values are the same at

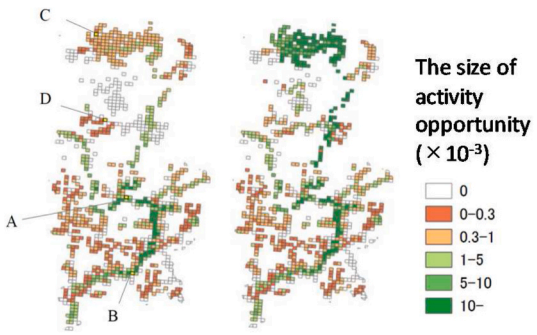


Fig. 5. Current size of activity opportunity. (left: shopping, right: hospital visit).

Table 4
Result of analysis for shopping (current).

Location	Activity opportunity (× 10–3)	Relative Value (× 10–3)	Bus service (round trip/day)	Boarding Time (min.)	Walking Distance (m)
A	39.59	49.89	8.5	11	35
B	5.20	12.07	6.0	40	488
C	0.81	6.79	4.5	101	203
D	0.05	0.29	1.0	80	672

zero. The difference between the trunk and branch lines was remarkable in both activity opportunity and relative value.

It is possible to examine planning alternatives using various approaches by focusing on activity opportunities and their relative values. For example, if the size of activity opportunity is small and the relative value is low, it can be interpreted that the level of public transport service is low and the disparity between private car and public transport users is large. Such areas can be judged as areas where the enlargement of activity opportunities can be expected by raising the level of public transport services.

However, when the opportunity for activity is low and the relative value is high, it can be interpreted that it is difficult to expand the activity opportunity by only improving public transport services. This indicates the limitation of increasing activity opportunities by only improving public transport services. Thus, by comparing activity opportunities and relative values, it is possible to estimate the range to which activity opportunities can be enlarged by improving public transport services. Using cross-sectoral comparison, such as which is more advantageous, development of activity bases, or improvement of public transport services, becomes possible.

In this analysis, the area along the branch line corresponds to the former, and northern part of the city (Hiruzen area) corresponds to the latter. Along the branch lines, there are many problems, such as no round-trip services in a day and no bus stops although the route is within 800 m. In the Hiruzen area, long travel times to activity bases were observed. The necessity of planning alternatives, including facility layouts, was noted in addition to improving public transport services.

6.4.2. *Analysis of planning alternatives*

Based on the results of the case analysis in the current situation, we analyzed the planning alternatives for the Hiruzen-Kuze route, which has many areas with low activity opportunities. Planning alternatives x to be analyzed were: three more bus services (x = 1), a limited express service that connects the Hiruzen area and Maniwa City Hall bus stop within an hour (x = 2), and shopping facility placed at the Yubara Onsen Hospital bus stop with two fewer bus services ($x = 3$). As this analysis does not consider the cost of alternatives, we assumed a situation in which only one of the alternatives could be implemented and considered the situation in which the alternative was adopted.

6.4.3. *Alternative evaluation by route*

The basic capability was set to $\left(f_0^1, f_0^2\right) = (0.0028, 0.0040)$, and the optimal alternative was adopted for each route using the alternative evaluation model. Because the divergence r^{kx} between the size of the activity opportunity for functioning k and basic capability is different for each alternative, we evaluated the alternatives by comparing this divergence. Fig. 6 shows the smallest activity opportunity and basic capability for each functioning and alternative. Table 5 lists the deviations r^{kx} from the basic capability. As presented in eqs. (16) and (17), the optimal alternative is Alternative 4, which minimizes gap r^x from the most disadvantaged individual's basic capability and maximizes the size of activity opportunities. The maximum values of deviation r^x under each alternative were $r^1 = 2.21$, $r^2 = 1.95$, $r^3 = 1.05$.

Alternative 3, which minimizes the maximum value of deviation,

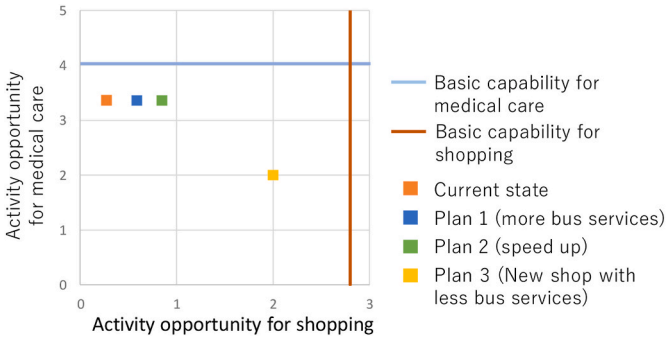


Fig. 6. The size of activity opportunity and basic capability in each functionings.

Table 5
Evaluation of planning alternatives.

Planning Alternatives, x	Measures	Deviation from basic capability rkx (× 10–3)	
		$k = 1$	$k = 2$
$x0$	Status quo	2.53	0.67
$x1$	Higher frequency	2.21	0.67
$x2$	Express service	1.95	0.67
$x3$	New shop (lower frequency)	0.80	1.05

was adopted as the optimal alternative to maximize the size of activity opportunities of the most disadvantaged residents.

Furthermore, we compared the size of activity opportunity f^{1x} for shopping in each alternative (Fig. 7) and confirmed the difference between the conventional plan focusing only on public transport services and plan based on the proposed method. Increasing the number of bus services does not increase the size of activity opportunities in areas where the distance to the activity bases is quite long.

This is the result of a planning support method that focuses on the residents' activity opportunities (what they can do), and a plan that focuses only on public transport services, such as the number of bus services, cannot completely capture the quality of life of the residents.

6.5. *Results*

In the case analysis, we set planning alternatives for the issues extracted from the analysis under the current situation and determined the optimum alternative for each route. It was confirmed that, if the local government sets the level of basic capability (what type of activities and to what extent the community should be secured to the residents), it is possible to formulate a local transport plan that can realize it. We believe that this result will be useful for formulating local public transport plans. Moreover, it was confirmed that it is possible to formulate a plan for improvement of residents' quality-of-life that was overlooked in the previous plan that focused only on public transport



Fig. 7. The size of activity opportunity for Plan 1-3.

services.

In this study, we considered only the physical ability of the elderly and time-frame during which they could go out as a resource utilization ability. By analyzing other factors and dividing them into various attributes and comparing the results, it is possible to determine whether residents with what type of resource utilization ability live in what type of area will reduce the size of activity opportunities. It is also possible to analyze how this can be enlarged.

The proposed methodology focuses on activity opportunities that are difficult for local government officials and residents to understand. Therefore, in the case analysis, the effects of the planning alternatives are output as visual information on GIS and presented together with concrete examples of the results of the analysis, as summarized in Table 4. By presenting both visual information on GIS and concrete examples of results in this manner, local government officials and residents can understand the results based on activity opportunities. Such information must contribute to building consensus among local residents.

7. Conclusions

7.1. Findings

In this study, we constructed a practical model to quantify the size of activity opportunities for residents in rural areas, and proposed a method to support the planning of local public transport services based on the evaluation results.

The proposed methodology consists of (a) an activity opportunity measurement model that measures the sizes of activity opportunities based on a given resource and resource utilization ability and (b) an alternative evaluation model that determines the optimal alternative among multiple planning alternatives based on social relationship function and disparity principles. We constructed a practical deployable planning support methodology by matching the resources and resource utilization ability, considering abstract concepts in the model developed by Kita et al. (2017), with actual data.

Through case analysis, we demonstrated that if a community or a local government, which acts as its agent, sets the level of basic capability (the type of activities and extent society should be secured to local residents), it is possible to formulate a transport plan that can realize it. In addition, we also showed the possibility of formulating a local transport plan based on the lives of residents supported by the transport, which was overlooked in previous planning that focused only on the public transport service itself. This methodology assumes that government officials in charge of transport planning formulate the plan; therefore, it can be analyzed using open data only that is easy to obtain. The results of the analysis were visualized using GIS. We believe that visual information can help extract problems and build a consensus in the community.

Although the explanation on the model construction and case analysis focus on the elderly, it is of course possible to quantify the size of activity opportunities for residents of various demographics, including youth and children. For example, by comparing the size of activity opportunities for young people with those for the elderly in a certain area, it may be found that an area that is easy for young people to live in is rather difficult for the elderly to live in. It is also possible to take into account differences in residents' time constraints, such as residents who are only allowed to go out when their children are not home.

The method is designed so that it can be analyzed using only readily available open data, such as the location of activity bases and the time of day when services are provided, distance and height differences between points, bus and train schedules, etc. Therefore, if we assume that people's physical abilities, such as walking speed and metabolic energy, are almost the same regardless of region and nation, the method can be applied to any region and nation. If physical ability differs from region to region, it is possible to adjust the parameters according to each region to make an evaluation that is more in line with the actual conditions of each region. On the other hand, there is basically no open data on the time of day when individual residents can go out or their physical ability to go out. We envision that the plan will first be formulated based on the standard values obtained from the statistics such as National Survey of Hours of Living, and then presented to the local public transport councils or so for community discussion. As described in Section 5, the values of activity opportunity indicator can basically be calculated using open data. National land survey data on topography, land use, school districts, population concentration areas, public facilities, etc. are provided by the Ministry of Land, Infrastructure, Transport and Tourism (2023) in Japan. For transportation data, more than 10,000 transportation companies in 100 countries have been developing GTFS (General Transit Feed Specification) (GTFS, 2023), which provides information the locations of stations and bus stops, routes, operation schedules, transfer information, fares, etc. For exercise strength, the METs table is reported by Ainsworth et al. (2011). The NHK Broadcasting Culture Research Institute conducts periodic surveys on people's daily lives and reports them (NHK Broadcasting Culture Research Institute, 2020). As for commercial facilities, "Department Store Locations" and "List of Supermarkets in Japan" are provided on a regular basis by the Japan Department Stores Association (Japan Department Stores Association, 2023) and Shokuhin Bulletin Inc., 2023. Google and other search engines also provide the locational data of the activity bases (Google, 2023).

Another feature of this method is that the evaluation results of analysis can be visualized on a GIS. Visual information facilitates the problem findings for planners and the consensus building of local residents. Fig. 8 shows an activity opportunity map of Takarazuka City, Hyogo Prefecture, Japan. This map shows that there is a large disparity

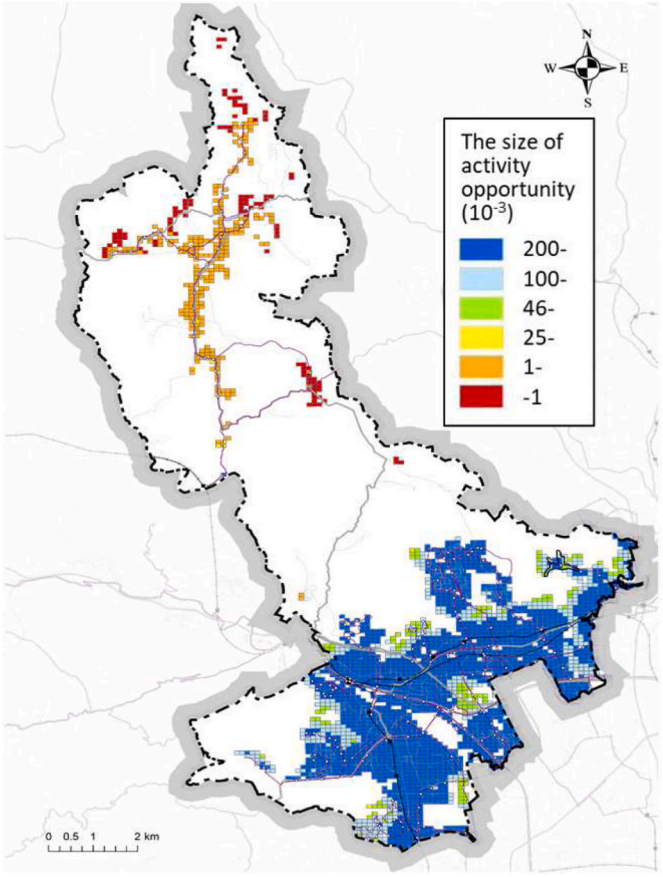


Fig. 8. Activity opportunity map in Takarazuka city, Japan (Takarazuka City, 2023).

in the size of activity opportunities between the northern and southern areas of the city. This has led to the formation of a consensus among citizens that it is desirable to focus on improving the northern area of the city, rather than to improve services that are widely and thinly spread throughout the city. In addition, the activity opportunity maps drawn for each of improvement alternative plans of public transport service assisted in the selection of the best improvement alternative for citizens. Kita et al. (2023) describes the process of developing a local public transport plan of Takarazuka City, Japan, which was developed through discussions with citizens and stakeholders by using the proposed methodology (Takarazuka City, 2023).

7.2. Further studies and perspectives

Three issues should be considered when using this method to plan local public transport.

First, the measurement of the size of activity opportunities should include an evaluation of activity bases. It is assumed that activities can be conducted when the activity base can be reached; however, surgical treatment cannot be performed at a clinic of internal medicine for example, because the accessibility to the activity base does not necessarily match the activity opportunities. It is necessary to measure the availability of desired activities at the activity base by considering the extent of the variety of services at the activity base, including the product line-up at shopping facilities and the number of medical departments at hospitals. See Ishimaru and Kita (2021) for an extended model on the degree of diversity of services at activity sites and how to incorporate this diversity into activity opportunity evaluation indices.

The second related to the above is that multiple functionings are currently evaluated independently. As shown in the case analysis, creating a base that can provide two functionings at the same base and one-stop services is a useful measure for expanding activity opportunities. To consider the actual situation more accurately, it is necessary to loosen the premise of this independent evaluation in the basic model. We are developing separate models to evaluate this effect quantitatively. Because the proposed planning methodology has a structure that can incorporate this model, we would like to build in a newly developed model in the proposed methodology in the next step.

The third is the discussion of cost sharing. The logical structure of this entire planning methodology is “local communities choose the combination of benefits and burdens,” in which each resident first compares his or her own benefits (size of activity opportunities) and burdens (share of improvement and operation costs allocated to each person) for each planning alternative, and then chooses the best combination for each person. For example, “rich activity opportunity and high cost”, “poor activity opportunity and low cost”, etc. The public transport service, however, is a community-based service. Only one public transport service can be provided in a community, the choices made at the individual resident level will not be realized as they are. Theoretically, each resident expresses the results of his or her choice as an opinion, which is then aggregated for all residents to select a planning alternative to be implemented. This is “social choice. Voting is one such method. The author has completed the basic institutional design of the related social choice methods and the planning methodology that integrates them. However, it is beyond the scope of this paper to describe them. Since this study limits the target system to a scope that does not include costs in order to improve the prospects for discussion, it is not possible to discuss the relationship between operating costs and resources (public transport services) or the relationship between the secured size of activity opportunities and the cost burden on residents, but we would like to introduce the integrated model at another occasion.

From these issues mentioned above, conversely, we can look forward to future planning directions based on the proposed methodology. The first point, measuring the size of activity opportunities by incorporating the evaluation of activity bases, provides useful information for considering whether a large shopping center in the distance or a small retail store nearby should be developed, for example. The second point, the consideration of multiple activity sites, leads to a more accurate evaluation of daily activities such as going shopping after visiting a medical facility. These results indicate that the proposed activity opportunity index can be a useful evaluation index in the integrated planning of activity bases locations and transport systems. To overcome the third point, an extension of the methodology of local public transport planning is on-going that considers both the cost burden and the size of the activity opportunity, based on the framework of “local communities choosing the combination of benefits and burdens”. Sawai and Kita (2021) discusses the evaluation process of the planning alternatives by taking cost into account and the framework of social choice.

CRediT authorship contribution statement

Hideyuki Kita: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Satoshi Komoda:** Software, Data curation. **Rizumu Ozaki:** Visualization, Validation.

Data availability

The authors do not have permission to share data.

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