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Estimations of Bus Stop Territories using Reachable Area Analysis Focusing on Travel Behavior of Elderly to Medical Facilities

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***Abstract*— As aging and population decline are becoming problematic, particularly in local cities, negative effects, such as reliance on automobiles, hollowing out of central urban areas, and decline in public transport, are occurring in a vicious cycle. To escape this vicious cycle, it is necessary to develop a transportation network that allows the citizens, particularly the elderly who cannot drive cars, to receive services in sustainable ways. Often, this requires the elimination of transit blank areas. In this study, we focus on medical services, which is an important service for the elderly, in Komatsu City, Ishikawa Prefecture, and perform reachable area analyses with Geographic information system to investigate the locations of bus stops for eliminating transit blank areas. By estimating bus stop territories for bus stops with high transportation accessibility to medical facilities, we examine the number of elderly people who have high transportation accessibility to medical facilities.**

Keywords*— Public transportation, bus stop, medical facilities, aged person, reachable area analysis

I. INTRODUCTION

Nowadays, local cities are facing problems such as low fertility and aging, population decline, and density decrease and spreading of urban areas. These result in negative effects, such as reliance on cars, hollowing out of central urban areas, and decline in public transport in a vicious cycle [1]. To escape this vicious cycle, it is necessary to develop a transportation network that allows the citizens, particularly the elderly who cannot drive cars, to receive services in sustainable ways [2]. Often, this requires the elimination of transit blank areas, which are usually defined either as areas where no buses are in operation or as those outside circles of some fixed radius centered around bus stops (bus stop territories). However, in reality, paths that can be traveled on foot are limited to roads. Thus, simple circuits of a fixed circuit, which do not consider the road network, are insufficient for representing transit blank areas. With the overall purpose of improving the efficiency of private transit buses and community buses, we perform a survey on public transit and a workshop to understand the usage intent of citizens in Komatsu City, Ishikawa Prefecture, with a population of approximately 100,000. Next, to eliminate transit blank areas, we estimate bus stop territories using GIS, considering the actual road network, and evaluate the number of people who live in conditions where buses can be used. Finally, we focus on medical services, which is an important service for the elderly, and by estimating bus stop territories for bus stops with high transportation accessibility to medical facilities, we examine the number of elderly people who have high transportation accessibility to medical facilities. This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. PREVIOUS WORK AND OUR CONTRIBUTIONS

A. Summary of Previous Work

Much research has been conducted using reachable area analysis for blank areas in public transport. For example, Nakahira and Matsuo [3] noted that fixed circuits for finding transit blank areas do not con-sider the actual road network and

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overestimate bus stop territories, and estimated bus stop territories that account for road conditions, such as path distance, based on the road network and road slope and for the decrease in walking distance for the elderly due to road slope.

From the viewpoint of community development rather than transportation, Hirai and Minami [4] saw a decline in shopping convenience for mobility-disadvantaged people who cannot use cars or public transportation as a problem, and estimated reachable areas from retail stores in Morioka City, Iwate Prefecture, to estimate the shopping-disadvantaged population and to understand the current scale of their problem.

Yamamoto and Hashimoto [5] surveyed elderly drivers and drivers who were returning their driver's licenses, to learn whether the respondents wished to use livelihood support services after returning their licenses, their reasons and mindsets for making such decision, and the relation between the response to this question and whether they intend to return their licenses. They found that while most people wished to go out for both shopping and medical services on foot, on bicycle, or on a pick-up and drop-off vehicle, some wanted to use assistance services; they confirmed that the people who wished to use such services were influenced by living in an inconvenient area that was far from shops and hospitals or by having difficulty moving around.

Based on the survey results, Hashimoto and Yamamoto [6] focused on residence areas, analyzing the factors that made people feel good about the decision to return their licenses and factors that led to inconvenience in their lives. Consequently, they found that, compared to people in urban areas, more people in suburban and rural areas had difficulties in their lives and that the factors that inconvenienced people differed depending on the residence areas: in urban areas, a long distance to the hospital had a large effect, whereas in suburban and rural areas, not being able to go out shopping or not having access to pick-up and drop-off services had significant effects.

Finally, Takatsuka, Onishi, and Yamaguchi [7] considered all of Hokkaido and estimated the number of people who were within areas covered by hospitals, assuming that medical services were accessed by cars. They anticipated that medical services were accessed by cars only, and did not consider fixed-route buses.

B. Our Contributions

Based on the previous work, we perform a fundamental spatial analysis of bus stop locations taking into account access to medical facilities, with the overall goal of improving the efficiency of fixed-route buses, which are the main public transit in the target area, in order to build a public transit network in which elderly people who have returned their driver's licenses and cannot use cars can access medical facilities without difficulty.

III. TARGET AREA PROFILE

A. Characteristics of Komatsu City and Its Public Transit

Komatsu City is located in the center of the Kaga Plain, which spreads out over the southwestern part of Ishikawa Prefecture. It is an industrial city that is part of the Hokuriku industrial area, with well-developed heavy industries, such as manufacturing of construction machinery. In addition, there are natural and cultural attractions, such as Atakanoseki, Natadera Temple, and Awazu Onsen.

The public transportation system in Komatsu City comprises 3 railway stations (Komatsu station, Awazu station, and Meihou station), 17 bus routes run by 2 operators, and 9 taxi companies.

The main public transit option is fixed-route buses. Changes in the ridership of fixed-route buses from 2009 to 2016 are shown in Figure 1, where the ridership shows an increasing trend [8]. One important initiative was the introduction of "Rakuchin passport," which is a bus pass for people aged 65 and above, disabled people, and high-school students.

By showing the pass, the rider freely takes applicable routes within the city; 15 of the 17 routes are applicable [9]. As of 2016, the breakdown of the people who purchased Rakuchin passport was 652 elderly people, 94 disabled people, and 350 high-school students, and excluding high-school students who lived outside the city, the total number of users who lived in Komatsu was 1096. In 2010, the loop route was re-organized, and in 2013, environmentally friendly EV buses, which run on electricity, were introduced. In 2014, Kibagata line was reorganized [10]. Partly due to these initiatives, not only ridership but also the fiscal burden on the city for maintaining the fixed-route buses is increasing, as shown in Figure 2. The main reasons for this are the cost of replacing buses and expanding community bus services, and the increasing cost of covering the fare due to the growth of Rakuchin passport usage

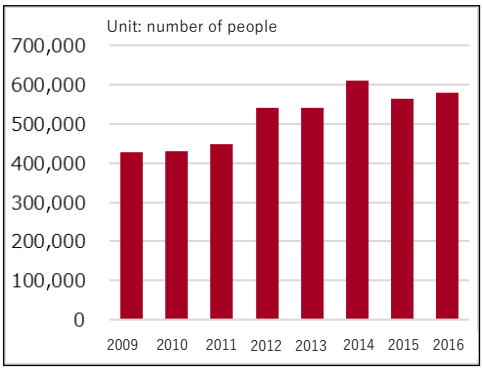

Fig. 1. Ridership of fixed-route buses over time

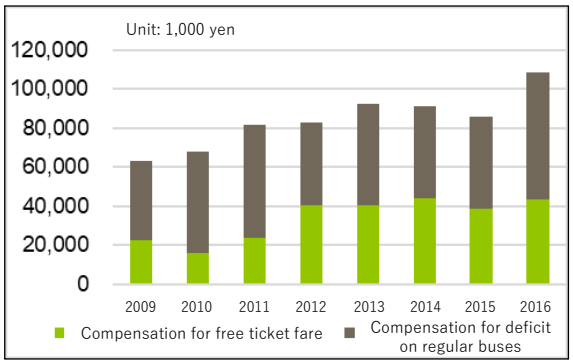

Fig. 2. Fiscal burden for maintaining fixed-route buses

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B. *Questionnaire Survey About Public Transit*

In August 2017, we conducted a questionnaire survey for Komatsu residents in order to understand their regular transit activities, usage of public transit, and their demands for improvement. The questionnaires were distributed to the general public (from 20 to 79 years old) using random sampling, and out of the 2,500 distributed surveys, there were 958 responses, with a response rate of 38%. In addition, we obtained 565 responses from questionnaires handed out at the senior citizen general consultation center and 479 responses from those handed out at high schools within the city. Thus, the sample comprises 1,523 general citizens and 479 high-school students, with a total sample size of 2,002.

For those who have used the bus within the past month, we asked their purposes for using the bus. Figure 3 presents the tabulated result. Going to the hospital and shopping were the most common responses, each receiving roughly twice the responses as the next most common response, which was hobby/leisure. This may be because we had a large sample of people 60 years old and above, because of handing out the survey at the senior citizen general consultation center.

For people who had taken the bus, we asked the reasons for using the bus. The tabulated result is shown in Figure 4. "Taking the bus is the only transportation option," "The bus stop is close," and "It runs to the destination" were the three options that received maximum responses, showing that these were important factors for selecting buses as the mode of transportation.

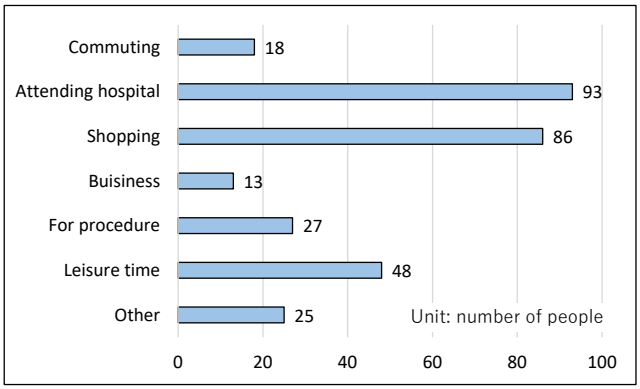

Fig. 7. Purpose of using the bus

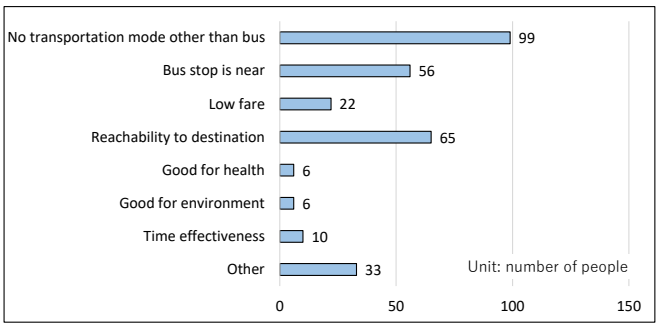

Fig. 6. Reason for using the bus

C. *Citizen Workshop on Public Transit*

To hear the residents' voices, which are important when reevaluating regional public transit, we ran a workshop for citizens at the Komatsu City Hall on December 1, 2017 (Figure 5). Many of the views ex-pressed were issues related to bus stops, such as "There are no bus stops near my house," and dissatisfaction with access, such as "The bus does not run to my destination/I need to switch buses" and "The buses are too infrequent to be useful" (Figure 6).

While there were opinions such as "I have a car and do not need fixed-route buses," there were also concerning voices, such as "I am worried about transit once I cannot physically drive or I have returned my driver's license" (Figure 7). This shows that the elderly are worried about transit after they return their driver's licenses, because they feel that the bus stops are

Fig. 3. Workshop

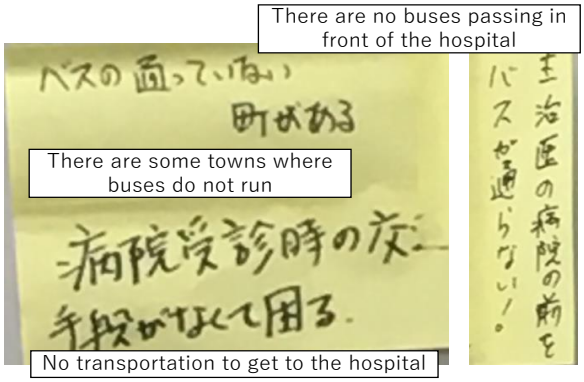

Fig. 4. Opinions concerning access to medical facilities

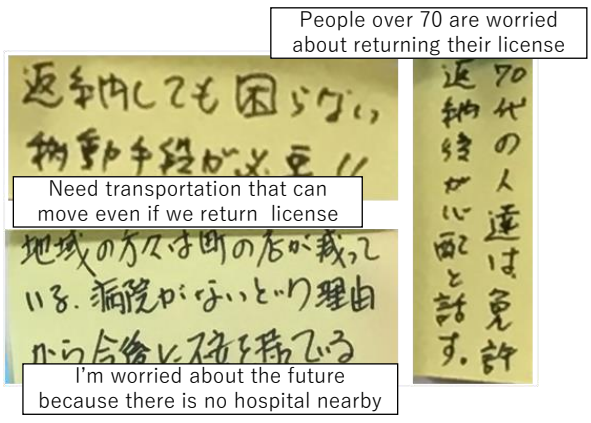

Fig. 5. Opinions expressing concern about getting around in the future

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far away and the buses do not run to the medical facilities. Therefore, there is a need for fixed-route buses that allow the elderly who have returned their driver's licenses to go to medical facilities without difficulty.

IV. REACHABLE AREA ANALYSIS WITH A FOCUS ON THE ELDERLY

A. Analysis Summary

As it became clear in the survey and the workshop, the elderly are worried about their transit after re-turning their driver's licenses. Thus, there is a need for fixed-route buses that the elderly can take to medical facilities without difficulties. One minimum requirement for this is a usable bus stop within walking distance for the elderly. Accordingly, we performed a reachable area analysis using the Network Analyst tool for ArcGIS—created by Esri Japan Corporation, to estimate bus stop spheres, which are areas reachable on foot from each bus stop by taking the shortest path possible—and attempted to visualize transit blank areas.

Here, we considered people living in a bus stop territory as being covered by the bus stop, and calculated the number of people covered by a bus stop as the number of people who can go to the bus stop and take the bus. Finally, by calculating the coverage rate as the ratio of covered people as a fraction of all elderly people in Komatsu City, we ascertained how many of the elderly living in Komatsu City are in an environment where they can use buses.

B. Analysis Parameters

From a study of tolerable walking distances, by age group, from home to train stations and bus stops [12], most people 50 years old and above consider distance within a 10 min walk to be tolerable (Figure 8), and as the average walking speed for the elderly is known to be roughly 60 m/min, we considered the area within 600 m(=10 min × 60 m/min) by path distance to be the bus stop territory. For estimating the population aged 65 and older living in bus stop territories, we used the population data of 250 m grid cells, obtained in the 2015 census. To reproduce the population density at a higher resolution than the 250 m grid, we distributed the population over the building data and tabulated the number of people who were distributed to buildings within the bus stop territories. We used the building data from "ArcGIS Data Collection Detailed Maps," where we excluded facilities such as schools and hospitals to extract housing, and calculated the area of each building on the GIS. In the Basic Plans for Housing [13], the "minimum standard for living floor space" is defined as the "standard regarding necessary and essential housing area as the basis for a wholesome and cultural state of living, depending on household size," and is given as at least 25 m2 for a one-person household, so we excluded the data for buildings be-low 25 m2. Finally, we also excluded data that were separated by at least 3σ from the mean area for the remaining building data.

As a result, we extracted 46,406 data points that satisfied 25 ㎡ ≦[Area] and [Area]≦663.5683 ㎡. We set the number of people living in each building by distributing the grid population data equally into the buildings within the grid.

C. Bus Stop Territory Estimation

The grids with residents within Komatsu City and bus stop territories for all bus stops (228 locations) in Komatsu City, estimated by taking path distance into account, are shown in Figure 9. There are transit blank areas in some parts, but the 600 m ranges from bus stops cover a wide area, which are areas where buses can be used. In addition, 25,337 of the 28,772 elderly citizens of Komatsu City are covered, and the coverage rate is approximately 88.1%. Thus, about a tenth of the elderly living in Komatsu City may not have a bus stop within walking distance.We also calculated the coverage rate for the latter-stage elderly (75 and older) and non-elderly (below 65), but the values were roughly the same.

V. REACHABLE AREA ANALYSIS WITH TRANSIT TO MEDICAL FACILITIES IN MIND

A. Analysis Summary

In the previous chapter, we calculated the coverage rate by estimating all bus stop territories in the city. However, in reality, each bus stop differs in how it connects to different routes and how far it is from major medical facilities. Therefore, transit convenience from each bus stop to major medical facilities is not uniform. Accordingly, in this chapter, we create

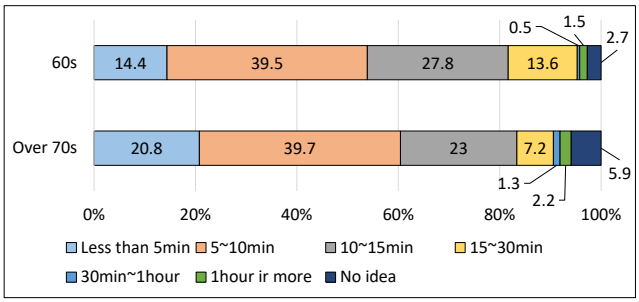

Fig. 8. Reason for using the bus

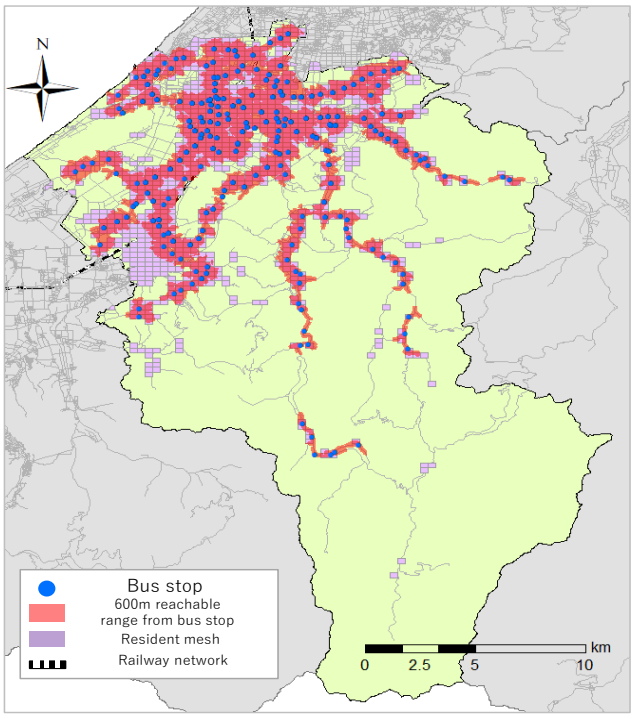

Fig. 9. Bus Stop Area of Influence (All bus stops)

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an indicator for each bus stop that represents the ease of transit to a medical facility, and by calculating the coverage rate with only those bus stops that satisfy some condition, we consider how many of the elderly are in an environment with high transit convenience to a medical facility using buses in Komatsu City.

In selecting the major medical facilities, note that specialty clinics for internal medicine, dentistry, ophthalmologist, orthopedics, etc., which are common destinations for the elderly, are interspersed within Komatsu City, and many of the elderly often go to the nearby specialty clinics. However, for more sophisticated medical treatment, they visit a larger general hospital rather than a specialty clinic. As general hospitals contain multiple departments, it is possible to narrow down the destination without specifying the specialty that the person is visiting. For this reason, we chose general hospitals within Komatsu City, particularly the four facilities that are secondary emergency hospitals and larger in scale, as the target.

B. Transit Convenience from Each Bus Stop to a Medical Facility

We created indicators for each bus stop, indicating the transit convenience to a medical facility, and ranked them. First, we took into consideration the four facilities mentioned in the previous section, assuming that bus users travel from each bus stop to one of the four facilities, using a bus that reaches the destination fastest in the morning schedule. Next, we accounted for the expected waiting time (if the bus runs once every 30 min, 30/2=15 min) for a bus that travels to the facility at the bus stop in the morning (7:00–12:00); added travel time; and if a transfer is needed, the transfer waiting time, and then, converted it to a monetary value at 40 yen/min. By adding fare to this, we calculated the generalized cost, and gave this as the transit convenience to the medical facility. We ranked the bus stops according to the calculated generalized cost, and categorized the bus stops into "low-cost," "medium-cost", and "high-cost" bus stops. Here, low generalized cost implies high convenience, while high generalized cost implies low convenience. We call the group of all bus stops group A, the group of low- and medium-cost bus stops group B, and that of low-cost bus stops only group C, and performed analysis for the three bus stop groups (Figure 10).

C. Visualizations of Bus Stop Territories and Coverage Rate

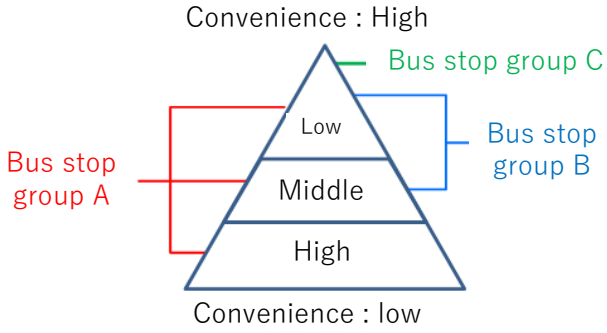

Fig. 10. Classification patterm

For bus stop groups A, B, and C, visualizations of bus stop territories, as well as coverage rates of 65 and older coverage rates, by elementary school district are shown in Figures 11–13.

From bus stop group A to B to C, as the cost requirement becomes stronger, relatively inconvenient bus stops in the suburbs move outside the scope of analysis and convenient bus stops become limited to the central urban area. In addition, the coverage rate fell strikingly for areas far from the central urban area; many areas have 0% coverage with bus stop group C, but there are also areas that fell to 0% with bus stop group B. Meanwhile, there are also areas where the coverage rate is below 50% even with bus stop group A, suggesting that there is a disparity not only in the transit convenience to medical facilities on buses but also in the number of bus stops and their locations. In particular, there is a large difference be-tween the north and south of Komatsu City. Finally, looking at the entire Komatsu City, 65 and older coverage rates are 88.1% for group A, 74.9% for group B, and 49.8% for group C; there is a sharp decline from B to C, and we observe little coverage outside the central urban area.

D. Relation to the Residents' Mindset

Looking at the relation between 65 and over coverage rate in each elementary school district, obtained from the analysis of each bus stop group, and the average response to the survey question "Is the public transit system adequate? (on a 5-point scale, where the highest score is 5 and the lowest score is 1)" in each elementary school district (respondents are only 65 and older, with a sample size of 728), we found a positive correlation between the coverage rate and evaluation of public transit adequacy. The correlation coefficient was 0.744, and the scatterplot of the elementary school districts is shown in Figure 14.

VI. CONCLUSIONS

This study targeted Komatsu City, Ishikawa Prefecture, where aging and the increase in fiscal burden for fixed-route buses are problematic and elucidated the factors that affect bus usage from a questionnaire survey. Next, we conducted a citizen workshop to investigate issues and needs that cannot be grasped easily through a survey, by hearing citizen voices directly. Through the questionnaire and the workshop, we confirmed the importance of securing the means of transportation to medical facilities after elderly people become unable to drive or return their driver's licenses. Furthermore, to understand whether the elderly can access medical facilities without difficulty from the viewpoint of bus stop locations, we performed reachable area analyses using GIS and confirmed the presence of transit blank areas. We then calculated the 65 and older coverage rate, estimating the number of elderly people who can use a bus stop within walking distance. As a result, the 65 and older coverage rate was less than 90%, suggesting that slightly more than 10% of the elderly may not have a bus stop within walking distance.

Then, focusing on medical services, we calculated the generalized cost from each bus stop to one of the four major medical facilities, as a proxy for transit convenience. Evaluating the relative transit convenience, we performed analyses by categorizing bus stops into three groups. As a result, we found that only about 50% of the elderly are in an environment where they can use a bus stop that has high convenience, which are concentrated in the central urban area in northern Komatsu City, with large disparities from other areas.Furthermore, we confirmed that, among elementary school districts, there is a positive correlation be-tween 65 and

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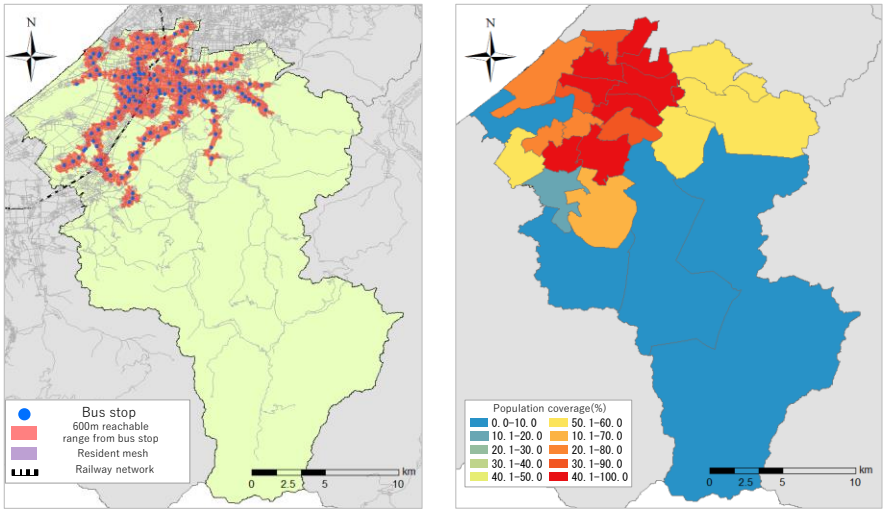

Fig. 11. Reason for using the bus

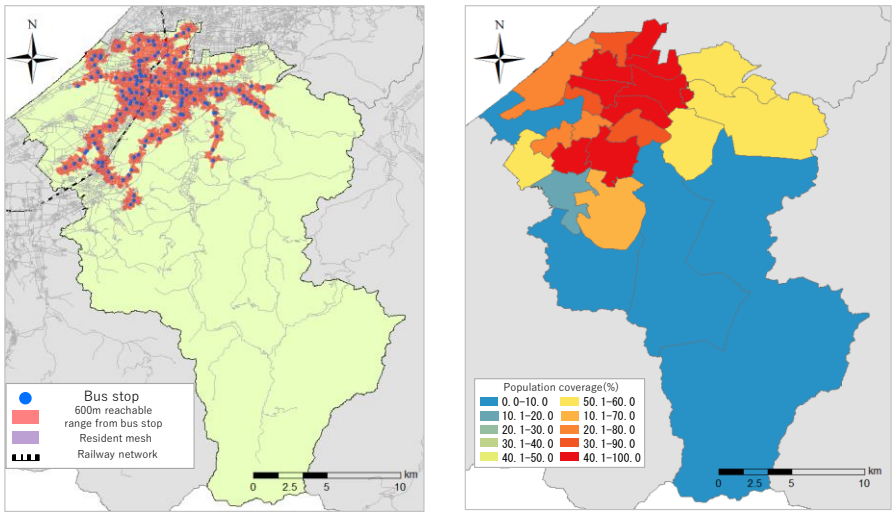

Fig. 12. Reason for using the bus

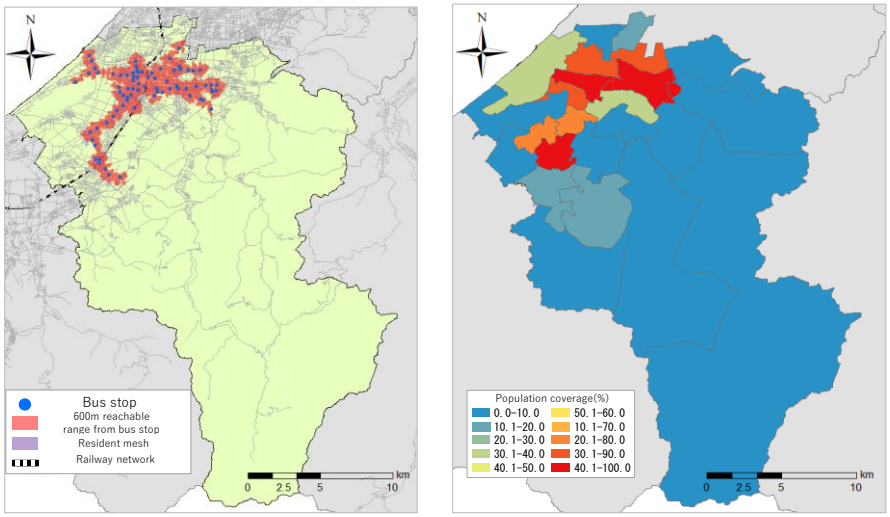

Fig. 13. Reason for using the bus

older coverage rate and the evaluation of public transit adequacy. Based on these findings, it is necessary to consider bus stop locations that can cover more of the population, so that more of the elderly can access medical facilities without

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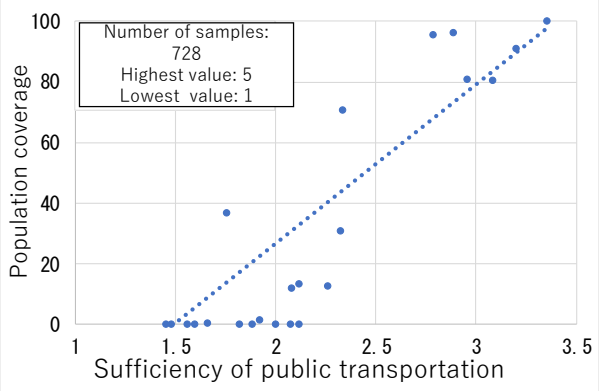

Fig. 11. Relationship between Population caverage rate for over 65 years and sufficiency of public transportation

difficulty. Finally, it is necessary to consider not only whether there is a bus stop within walking distance but also an overhaul that includes fares and schedules for fixed-route buses. We raise the following four issues as questions for future research.

First, we limited the number of medical facilities under consideration in this study, but by increasing the number of facilities, we may be able to represent the ease of going to a medical facility using buses more realistically.

Second, we assumed in this study that bus users take buses that take them to a major medical facility in the shortest amount of time, but in reality, it is impossible to choose just one set of buses, there being numerous possible combinations. While it is difficult to consider all these combinations, it may be possible to calculate the generalized cost more rigorously by storing the bus schedules in a database. By solving these issues, we can evaluate the accessibility from bus stops to medical facilities.

Third, when we estimate reachable areas, we do not take into account impassable areas, such as rivers, ponds, and factories, and are likely overestimating bus stop territories. Thus, we should be able to estimate bus stop territories that are closer to reality by performing the analysis after setting up barriers in areas that are usually impassable for people.

Fourth is the issue of setting the maximum walking distance to a bus stop for the elderly. There are individual differences in the maximum walking distance to a bus stop, and especially if we are thinking about the elderly going to a medical facility, it is necessary to set this value by taking age, medical conditions, sex, and physical abilities into account. We, therefore, believe that another study involving an experiment, or a survey is needed.

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