Evaluating Access to Bus Stops Considering Topographical Features: A Case Study of Suburbs in the Tokyo Metropolitan Area

Naoyuki MORI[a], Kiyoshi TAKAMI[b] and Giancarlos PARADY[b]

[a] City of Yokohama, Naka-ku, Yokohama-shi, Kanagawa-ken 231-0005, Japan
[b] Department of Urban Engineering, The University of Tokyo, Bunkyo-ku, Tokyo 113-8656, Japan

Abstract

In the hilly residential areas developed since 1960s in the suburbs of Tokyo metropolitan area, not a few residents have come to find it difficult to get around due to the population aging, which requests to improve the convenience of public transportation. This study evaluated the accessibility to bus stops in Kanazawa Ward, Yokohama City, by employing the concept of metabolic conversion distance to take into account the effects of the topography and the walking speed of elderly people. As a result, it was shown that the metabolic conversion distance to the nearest bus stop was on average about 1.62 times longer than the network distance, and the standard deviation of it increased approximately 1.66 times. It was also shown that approximately 57% of the residents in the 300-m catchment area of bus stops by crow-fly distance were outside the catchment area by metabolic conversion distance. This implies that common practices to evaluate accessibility based on crow-fly distance greatly underestimate the population in areas of transportation disadvantage. Moreover, based on these results, the direction of Yokohama City's public transportation policy was discussed.

Key Words: *public transportation, accessibility, topography, metabolic conversion distances*

1. Introduction

In the Tokyo metropolitan area, suburban residential development started along railroad lines in the suburbs of the city center. However, since the 1960s, the rapid increase in population and housing demand have led to the development of residential areas away from railroad stations and on hilly land in the suburbs. In suburban residential areas with undulating terrain, residents who moved in at the time of development are aging, and they commonly face difficulties in walking up hills and stairs. Many people find it difficult to drive as they age, and the low accessibility of public transportation prevents them from going out freely, thereby reducing opportunities for hospital visits, shopping, and interaction with others, which in turn leads to social exclusion (Kenyon *et al.*, 2002). Therefore, indicators are required to establish the minimum level of public transportation standards necessary for social inclusion (Lucas, 2012).

Against this backdrop, supporting mobility in hilly areas with limited financial resources and with elderly residents has become an important policy issue for governments. However, governments lack appropriate methods for identifying transportation-disadvantaged areas based on topographical effects.

Mavoa et al. (2012) categorized public transportation accessibility indicators into three types: (1) access to public transportation stops, (2) travel time via public transportation, and (3) access to destinations via public transportation. Among these, (1) was assessed using standard walking speeds in most previous studies that did not consider the physical limitations of the elderly (Transport for London, 2010; Daniels and Mulley, 2013; Bok and Kwon, 2016; Saghapour *et al.* 2016; Hawas *et al.*, 2016). Since older adults walk slowly due to reduced physical function and under the additional physical burden of walking uphill, it is important to consider this in assessments. Sato et al. (2006) considered the differences in physical capacity due to age and the burden of inclines and stairs on the walking path, and proposed the " metabolic conversion distance " index. However, calculating the metabolic conversion distance is complex, so local governments generally don't use it to determine transportation disadvantage in public transportation planning.

In this study, we evaluated accessibility to bus stops in Kanazawa Ward, Yokohama City, by calculating the metabolic conversion distance to bus stops. We then compared this with conventional methods for identifying areas of transportation disadvantage that do not account for the effects of inclines and declines. Furthermore, the bus stop area and population within the area were calculated and compared for each crow-fly distance, network distance, and metabolic conversion distance. This allowed us to quantitatively clarify the degree of difference from the evaluation based on crow-fly distances, which are generally used by local governments. We did not find any previous studies that have attempted to do so.

The remainder of this paper is organized as follows. Section 2 reviews previous studies on accessibility a assessments considering public transportation access and topography. Section 3 describes the calculation method for the metabolic conversion distances and its application in this study.

In Section 4, for Kanazawa Ward, Yokohama City, the distance to the nearest bus stop for every 10-m mesh and the catchment area of the bus stop are calculated using GIS.. Finally, Section 5 discusses the results of this study and future prospects.

2. Previous studies

Saif et al. (2006) showed that a reasonable walking distance for public transportation is important for accessibility. Approximately 400 m (0.25 miles) or 800 m (0.5 miles) is considered a typical walking distance to a public transportation stop or station (El-Geneidy *et al*., 2010; Hess, 2009; Hsiao *et al.* Lovett *et al.*) The Japan Society of Civil Engineers (2006) states that "the distance a user can walk from his/her home to a bus stop without difficulty is 300 m for an able-bodied person."

As noted above, most existing studies assess accessibility using a uniform walking speed (Transport for London, 2010; Daniels and Mulley, 2013; Bok and Kwon, 2016; Saghapour *et al.* 2016; Hawas *et al.*, 2016) that does not consider the reduced walking speed of the elderly. In addition, it is important to consider the influence of topography, because the physical load is higher in cities with undulating terrain than on flat roads.

The hiking function, which was empirically calculated by Tobler (1993), expresses the change in walking speed due to a gradient. Accessibility studies using hiking functions include accessibility assessments of healthcare centers in Mozambique and Peru (Dos Anjos Luis and Cabral, 2016; Carrasco-Escobar *et al.*, 2020).

Páez et al. (2020) showed that the minimum metabolic energy pathway differed significantly from the minimum distance and time pathways. Iseki and Tingstrom (2014) analyzed the range of bicycle trips from a station and showed that the range considering the energy consumption as a cost index was smaller than considering the crow-fly or network distances, indicating that the crow-fly and network distances were underestimated.

Considering energy costs, Sato et al. (2006) proposed the "metabolic conversion distance" index. This translates the load during walking into an increase in distance due to the metabolic energy consumed (see Section 3 for details). The metabolic conversion distance has been widely calculated and applied in studies, based on the distance to various destinations such as fresh food stores (Toriumi and Omori, 2020), convenience stores (Nakayama and Yan, 2019), central city areas (Hara *et al*., 2009; Ito *et al.*, 2020), and bus stops (Kita *et al.*, 2012; Nakahira and Matsuo, 2017; Hayauchi *et al.*, 2019).

However, in practice, local governments generally use horizontal distance as the basis for evaluation when identifying areas of transportation disadvantage; moreover, some local governments correct the horizontal distance by considering slope and height differences (Hayauchi *et al.*, 2021). However, these evaluation methods have limitations such as the lack of a basis for the correction formula and unclear threshold values for slope and elevation differences during corrections. As described above, the metabolic conversion distance has been used in many studies to appropriately evaluate accessibility to public transportation.

3. Evaluation of the metabolic conversion distance to bus stops

(1) Metabolic conversion distance

The metabolic conversion distance proposed by Sato et al. (2006) is defined as the distance calculated for each segment of an inter-OD path, incorporating the slope load (which serves as an index of metabolic energy expended during uphill walking) and the moving load (which is the reciprocal of the ratio of each age group's walking speed to the reference walking speed of 4 km/h). The metabolic conversion distance is expressed by Equation (1) with the horizontal distance denoted as .

$$L' = L \cdot \frac{r(\theta)}{r(0)} \cdot \frac{v_3}{v_j} \tag{1}$$

$r(\theta)$ Metabolic energy (kcal) when walking on a slope with gradient θ

v_j Walking speed (km/h) for age group j

v_j is as shown in **Table 1**, and $r(\theta)$ is expressed as Equation (2) based on the approximate expression for the relative metabolic rate (RMR).

$$r(\theta) = (3.113e^{4.614\theta} + 1.2) \times BMR \times W \times T \tag{2}$$

BMR, basal metabolic rate (kcal/kg/day); W, body weight (kg); T, time (days)

Table 1

Walking speed by age group (Sato *et al.*, 2006)

Age group *j*	Walking speed (km/h)
1 (5-10 years old)	2.17
2 (11-14 years old)	3.39
3 (15-49 years old)	4.00
4 (50-64 years old)	3.40
5 (65-74 years old)	2.82
6 (75 years old and above)	2.51

Sato et al. (2006) stated that the RMR has the same function for gradients above 11% and below -11%, because walking downhill on a steep gradient is loaded. However, we decided not to apply this in this study, because the evidence is unclear and it has been pointed out that the RMR may become a discontinuous function and lack affinity with the model structure (Hayauchi *et al.*, 2019).

Thus, the metabolic conversion distance is evaluated more for travel on roads with large gradients and generally at older ages than for travel on flat roads.

(2) Target area

Yokohama City, which includes the target area of this study, is characterized by convenient access to daily necessities facilities such as supermarkets and hospitals near stations and the formation of bus routes originating from stations.

In particular, the topography of Kanazawa Ward, Yokohama City, has large undulations (**Fig. 1**), many suburban residential areas with hills, and an aging population that settled during periods of rapid economic growth. Because buses run on arterial roads, people are often forced to travel up hills from residential areas to bus stops. The buses are connected in front of the stations of the railway, which runs through Kanazawa Ward, and the bus routes start from these stations, as described above. Based on these characteristics, Kanazawa Ward, Yokohama City was selected as the target area.

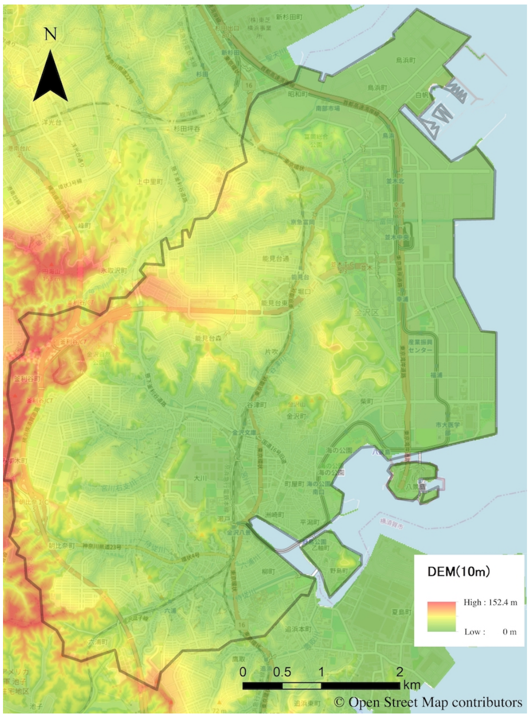

Fig. 1 Elevation in Kanazawa Ward, Yokohama

(3) Calculation method for the metabolic conversion distance in this study

According to Sato et al. (2006), the route between the ODs is divided by contour lines every 1 m, and (1) is applied to each section to evaluate the metabolic conversion distance. However, if this method is applied to an entire administrative area, the number of calculations required increases significantly. Therefore, we reduced the computational cost by evaluating the metabolic conversion distance for each road link constituting the inter-OD path. An example of a simple road network is shown in **Fig. 2**.

The target area was divided into 10-m meshes; the nodes (1-9) included in each mesh were given 10-m mesh elevation values, and the metabolic conversion distance of each link calculated based on these values was given as the link cost. In this study, the target population was elderly people aged 75 years or older who were most likely to have mobility impairments.

The walking speed for people aged 75 years and above is 2.51 km/h from **Table 1**, and the metabolic conversion distance of link is given by Equation (3).

$$L' = L \cdot \frac{r(\theta)}{r(0)} \cdot \frac{v_3}{v_6} = L \cdot \frac{3.113e^{4.614\theta} + 1.2}{3.113 + 1.2} \cdot \frac{4.00}{2.51} \tag{3}$$

The metabolic conversion distance of the path to the bus stop was then calculated for each centroid of the 10-m mesh. For example, when evaluating centroid A, we created node a on the nearest line and calculated the path with the minimum metabolic conversion distance from node a to the bus stop and the metabolic conversion distance at that time.

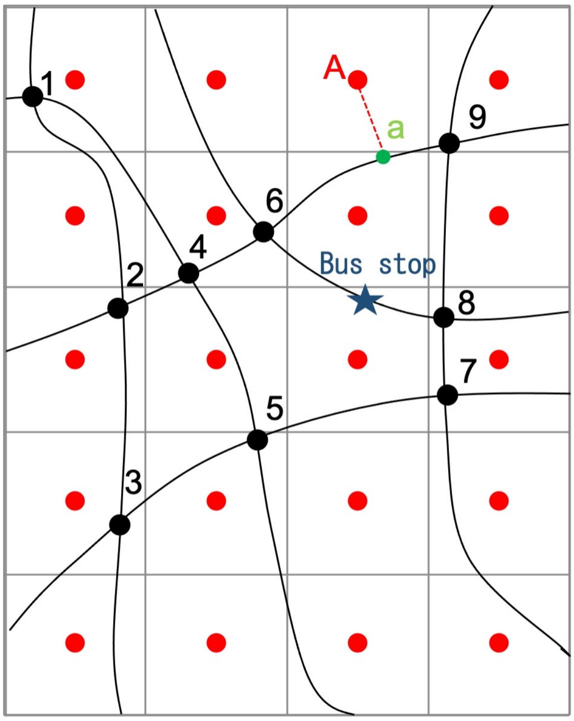

Fig. 2 Example of 10-m mesh and road network

The data required for the calculations were (1) road GIS data (using Open Street Map), (2) 10-m mesh elevation data, and (3) bus stop point data. Based on these data, links and nodes were created using the spatial analysis function of GIS. To reduce the computational cost, only the centroids included in the buffer 10 m from the road line were evaluated. We confirmed that approximately 91% of these centroids were located in urbanized areas. As there is a possibility that some of the centroids in the ward boundaries may use roads and bus stops outside Kanazawa Ward, roads and bus stops wider than Kanazawa Ward were also included.

4. Analysis results

(1) Metabolic conversion distance to bus stop

Figs. 3 and **4** show the results for the metabolic conversion distance to the nearest bus stop for the elderly using the method described in the previous section and the results for the shortest flat network distance without considering the gradient, respectively. **Table 2** summarizes the results of the network distance and metabolic conversion distance calculations, and **Fig. 5** shows the frequency distributions of the network distance and metabolic conversion distance.

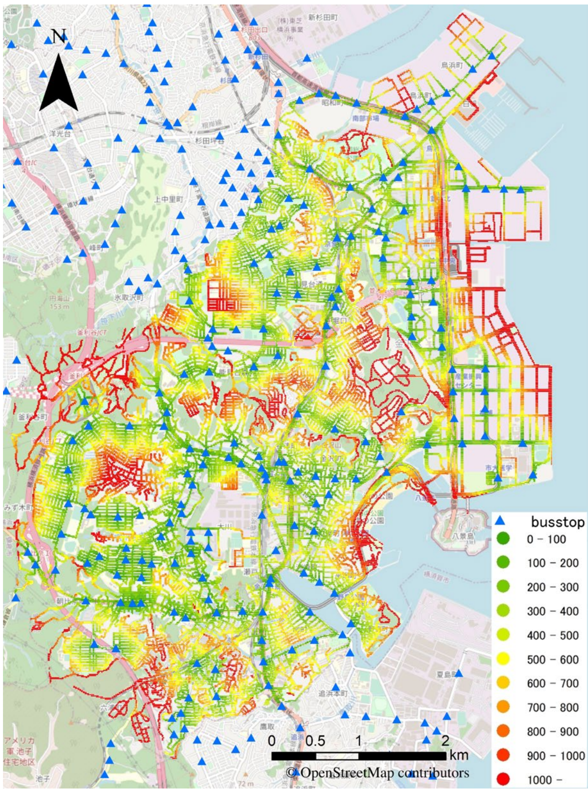

Fig. 3 Metabolic conversion distance to the nearest bus stop (m)

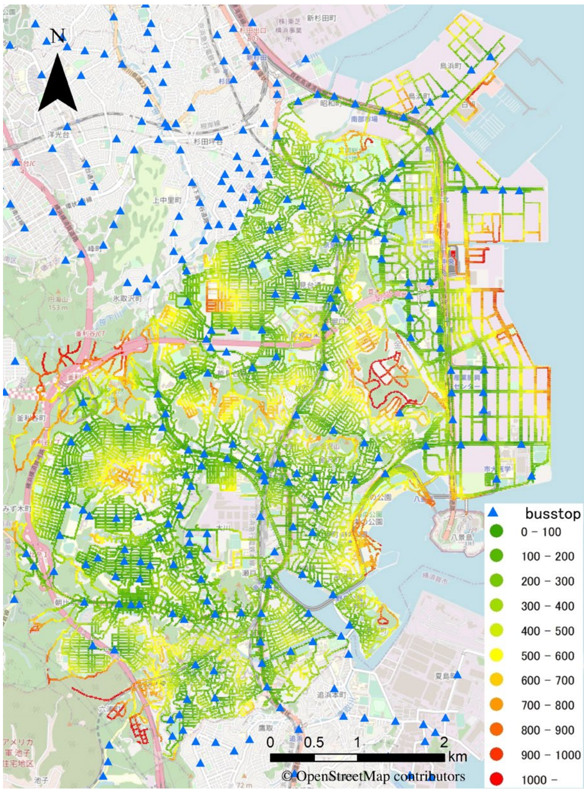

Fig. 4 Network distance to the nearest bus stop (m)

Table 2

Comparison of network distance and metabolic conversion distance

	Network distance	Metabolic conversion distance
Number of points to be evaluated	98,307 locations	
Mean	322 m	523 m
Minimum	0.003 m	0.006 m
First quartile	164 m	263 m
Second quartile	275 m	443 m
Third quartile	437 m	712 m
Maximum	1,628 m	7,025 m
Standard deviation	214 m	356 m

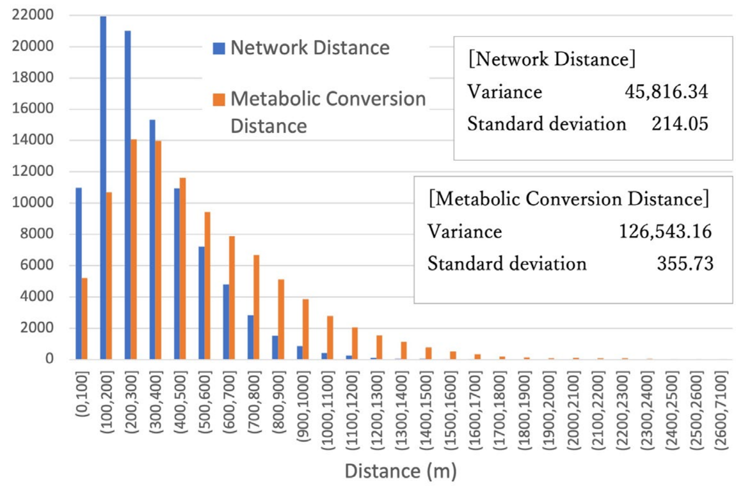

Fig. 5. Histogram of network distances and metabolic conversion distances

Comparing the mean values, the metabolic conversion distance was approximately 1.62 times longer than the network distance. The standard deviation of the metabolic conversion distance was approximately 1.66 times larger than that of the network distance, indicating that the metabolic conversion distance varied more than the network distance.

There were five points in the mountains where the metabolic conversion distance exceeded 7,000 m. Excluding these points, the maximum distance was 2,564 m.

(2) Comparison of the catchment area by three different distance indices

Next, using the network analysis function of GIS, we calculated the bus stop access areas in Kanazawa Ward for each of the following distances: crow-fly, network, and metabolic conversion. Referring to the aforementioned description by the Japan Society of Civil Engineers, **Fig. 6** depicts the areas where both bus stop access and egress are within 300 m (300-m bus stop catchment area) at each distance. In this study, the 300-m bus stop catchment area based on metabolic conversion distance represents the bus stop catchment for elderly individuals aged 75 and above, whose travel load is equivalent to that of the base age group (15-49 years old) walking 300 m.

Figs. 3 and **6** show that the increase in the metabolic conversion distance and the reduction in the catchment area tend to be larger in the inland area, which has more undulations than the east side of Kanazawa Ward.

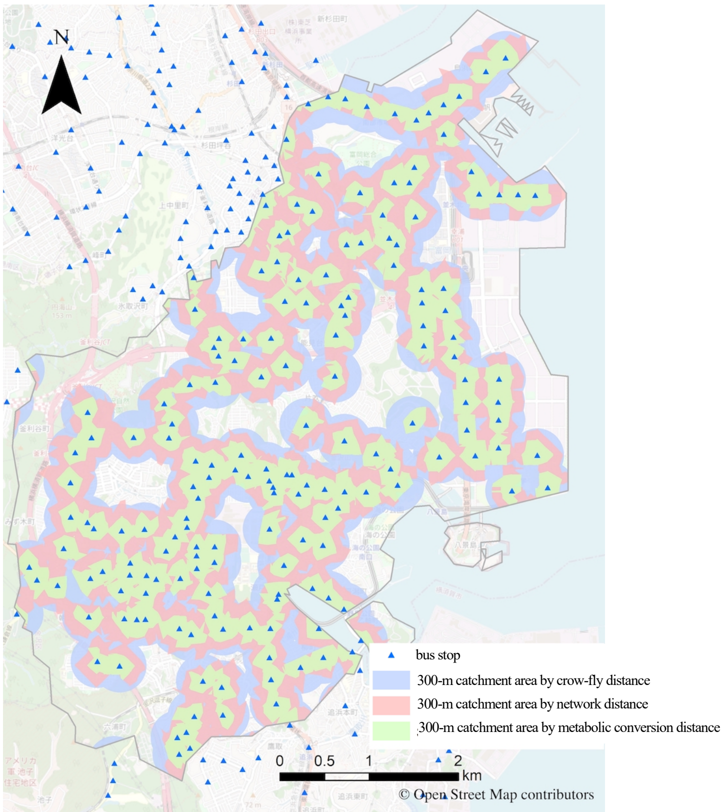

Fig. 6. The 300-m catchment area of bus stops

Next, the 300-m catchment area was calculated for each indicator, and the area coverage rate for the 30.9 km^2 area of Kanazawa Ward is summarized in **Table 3**. The area covered by crow-fly distance , a common administrative index, covers 73.0% of Kanazawa Ward, but only 55.5% by network distance, and 30.2% by metabolic conversion distance.

Similarly, the population within the 300-m catchment area and the coverage rate to the population of Kanazawa Ward were calculated. For population data, we used the 100-m mesh population data. These data were derived by proportionally distributing the 2015 Census 500-m mesh population based on 100-m mesh total floor space data. The population within each catchment area was then calculated for each 100-m mesh using the area coverage rate of the respective catchment area. Specifically, the populations aged 65-74 years and 75 years and above were calculated. It should be noted that this method, which calculates the population within a catchment area by area proportion, assumes a uniform population distribution within each 100-m mesh.

Table 3

The 300-m catchment area of bus stops

	Area (km^2)	Coverage rate(%)
All of Kanazawa Ward	30.9	(100.0)
Catchment area by crow-fly distance	22.6	73.0
Catchment area by network distance	17.1	55.5
Catchment area by metabolic conversion distance	9.3	30.2

The metabolic conversion distance in this study focuses first on the population aged 75 years and above, as they are most likely to experience mobility impairments. **Table 4** shows the population coverage rate for the population within the 300-m catchment area of bus stops and for the Kanazawa Ward (population of 24,373). The population coverage rates were 85.8% for the crow-fly distance, 68.3% for the network distance, and 36.5% for the metabolic conversion distance. In terms of population, 20,923 people were covered in the catchment area by crow-fly distance, whereas only 8,904 people were covered in the catchment area by metabolic conversion distance, indicating that approximately 12,000 people were outside the catchment area. Thus, approximately 57% of the residents in the 300-m catchment area by crow-fly distance were outside the catchment area by metabolic conversion distance .

Next, we focused on the 65- 74 age group. This age group will reach 75 years of age within the next 10 years and will face impaired mobility. Then, as shown in **Table 4**, 25,471 people will be covered in the catchment area by crow-fly distance, but only 10,978 people will be covered in the catchment area by metabolic conversion distance , indicating that approximately 14,500 people will be outside the catchment area.

Table 4

Population in the 300-m catchment area of bus stops

	Population aged 65-74 years (people)	Population aged 75 years and above (people)	Population coverage rate of aged 75 years and above (%)
All of Kanazawa Ward	29,594	24,373	(100.0)
Catchment area by crow-fly distance	25,471	20,923	85.8
Catchment area by network distance	20,401	16,636	68.3
Catchment area by metabolic conversion distance	10,978	8,904	36.5

Table 5 summarizes the differences in the area coverage for the population aged above 75 years using the three distance indices. The coverage rate decreases in order for the crow-fly, network, and metabolic conversion distances, but the decrease in the population coverage rate for "crow-fly distance to metabolic conversion distance" and "network distance to metabolic conversion distance" is higher than that for the area coverage rate. This indicates that the population density of areas within the catchment area by crow-fly or network distance, but outside the catchment area by metabolic conversion distance, is higher than the average population density of Kanazawa Ward.

Table 5

Difference in coverage rate of the 300-m catchment area of bus stops (%pt)

	Difference from all of Kanazawa Ward	Difference from the catchment area by crow-fly distance	Difference from the catchment area by network distance
Catchment area by crow-fly distance	-27.0 (-14.2)	—	—
Catchment area by network distance	-44.5 (-31.7)	-17.5 (-17.5)	—
Catchment area by metabolic conversion distance	-69.8 (-63.5)	-42.9 (-49.3)	-25.3 (-31.8)

Left: difference in area coverage; Right (in parentheses): difference in population coverage for those aged 75 years and above

5. Conclusion

This study focused on the accessibility to public transportation stops as a public transportation accessibility indicator and evaluated the accessibility to bus stops considering the topography and walking speed of the elderly using the metabolic conversion distance. First, the metabolic conversion distance from the centroid of each 10-m mesh to the bus stop was calculated, and the network distance and metabolic conversion distance were compared. Next, the catchment area analysis was conducted to calculate and compare the area and population within each of the crow-fly, network, and metabolic conversion distances. Approximately 57% of the population within the catchment area by crow-fly distance was outside the catchment area by metabolic conversion distance. Many municipalities use crow-fly distances to evaluate access to public transportation, which may overestimate the catchment area for the elderly. This study reaffirms the need to evaluate access to public transportation in a manner that is appropriate to the current situation.

In an aging society, identifying areas with transportation disadvantage and providing mobility support are critical issues. Evaluation using metabolic conversion distances can calculate accessibility by considering topography, and thus enables a more precise evaluation than crow-fly or network distances, which have been used as indicators by local governments. Furthermore, by combining the metabolic conversion distance with population density and aging rate in GIS, we can identify transportation-disadvantaged areas where population aging is progressing. Thus, accurately identifying transportation-disadvantaged areas that are relevant to the current situation will enable a precise understanding of regions requiring government support, thereby contributing to the improvement of transportation policies.

In this study, only the distance to the bus stop was considered for accessibility evaluation, and the accessibility from the bus stop to the destination was not considered. To accurately evaluate the accessibility to destinations, "travel time" could be considered as an evaluation index, taking into account "bus waiting time" and "boarding time." In this study, accessibility to bus stops was evaluated based on the assumption that daily necessities facilities are located near stations and that people use buses to reach stations to access these facilities. Therefore, accessibility to daily necessities facilities located in the neighborhood but inaccessible by bus was not taken into account. This is a limitation when considering only the accessibility to existing bus stops. In addition, although the method used in this study can identify transportation-disadvantaged areas through relative comparisons, there's a lack of knowledge regarding the threshold of the metabolic conversion distance needed to determine these areas. Therefore, it's not possible to make an absolute determination of transportation-disadvantaged areas. Further empirical studies are required to address these issues.

The views expressed in this paper are not those of the authors' organization, and all responsibility for their content rests with the authors.

NOTE

This paper is an English translation of a part of "Mori, N., Takami, K., Parady, G.: Evaluating Access to Bus Stops Considering Topographical Features: A Case Study of Kanazawa Ward, Yokohama City, Journal of Japan Society of Civil Engineers, Vol. 80, No. 2, 22-00336, 2024."

REFERENCES.

Bok, J. and Kwon, Y.: Comparable measures of accessibility to public transport using the general transit feed specification, *Sustainability*, Vol. 8, No .3, p.224, 2016.

Carrasco-Escobar, G., Manrique, E., Tello-Lizarraga, K. and Miranda, J. J.: Travel time to health facilities as a marker of geographical accessibility across heterogeneous land coverage in Peru, *Frontiers in public health*, Vol. 8, p. 498, 2020.

Daniels, R. and Mulley, C.: Explaining walking distance to public transport: The dominance of public transport supply, *Journal of Transport and Land Use* Transport and Land Use, Vol. 6, No. 2, pp. 5-20, 2013.

Dos Anjos Luis, A. and Cabral, P.: Geographic accessibility to primary healthcare centers in Mozambique, *International Journal for equity in Health* Vol. 15, No. 1, pp. 1-13, 2016.

El-Geneidy, A. M., Tetreault, P. and Surprenant-Legault, J.: Pedestrian access to transit: Identifying redundancies and gaps using a variable service area analysis, *paper presented at TRB 89th Annual meeting*, No. 10-0837, 2010.

Hara, T., Ishizaka, K. and Ohashi, Y.: Evaluation of residential area from a point of elderly people's walking accessibility in local center city, *Journal of architecture, planning and environmental engineering*, Vol.74, No.635, pp.129-135, 2009.

Hawas, Y. E., Hassan, M. N. and Abulibdeh, A.: A multi-criteria approach of assessing public transport accessibility at a strategic level, *Journal of Transport Geography*, Vol. 57, pp. 19-34, 2016.

Hayauchi, G., Nakamura, F., Ariyoshi, R., Tanaka, S. and Miura, S.: A study on the influence of topographical factors to mode choice, *Journal of the Japan Society of Civil Engineers, Ser. D3 (Infrastructure Planning and Management)*, Vol. 75, No. 5, pp. I_565-I_574, 2019.

Hayauchi, G., Nakamura, F., Ariyoshi, R., Tanaka, S. and Miura, S.: A study on evaluation of topographical factors in current urban transportation plans in Japan, *Journal of Japan Society of Civil Engineers, Ser. D3 (Infrastructure Planning and Management)*,

Vol. 76, No. 5, pp. I_1001-I_1011, 2021.
Hess, D. B.: Access to public transit and its influence on ridership for older adults in two US cities, *Journal of Transport and Land Use*, Vol. 2, No. 1, pp. 3-. 27, 2009.
Hsiao, S., Lu, J., Sterling, J. and Weatherford, M.: Use of geographic information system for analysis of transit pedestrian access, *Transportation Research Record*, Vol. 1604, No. 1, pp. 50-59, 1997.
Iseki, H. and Tingstrom, M.: A new approach for bikeshed analysis with consideration of topography, street connectivity, and energy consumption,. *Computers, environment and urban systems*, Vol. 48, pp. 166-177, 2014.
Ito, Y., Imai, K. and Honma, K.: Evaluation and Improvement of Accessibility in Hilly Residential Areas in Nagasaki city -Street network analysis Ito, Y., Imai, K. and Honma, K.: Evaluation and Improvement of Accessibility in Hilly Residential Areas in Nagasaki city -Street network analysis-, *Journal of the City Planning Institute of Japan*, Vol.55, No.3, pp.428-434, 2020.
Japan Society of Civil Engineers: *Bus Service Handbook*, pp. 341-342, 2006.
Kenyon, S., Lyons, G. and Rafferty, J.: Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility *Journal of Transport Geography*, Vol.10, No.3, pp.207-219, 2002.
Kimpel, T. J., Dueker, K. J. and El-Geneidy, A. M.: Using GIS to measure the effect of overlapping service areas on passenger boardings at bus stops, *URISA Journal*,Vol. 19, PP.5-11, 2007.
Kita, H., Ono, Y. and Kishino, K.: Development of the accessibility index considering physical performance in public transport use, *Journal of the Society of Civil Engineers, Ser. D3 (Infrastructure Planning and Management)*, Vol.68, No.5, pp.I_983-I_990, 2012.
Lovett, A., Haynes, R., Sünnenberg, G. and Gale, S.: Car travel time and accessibility by bus to general practitioner services: a study using patient registers and GIS, *Social science & medicine*, Vol. 55, No.1, pp.97-111, 2002.
Lucas, K.: Transport and social exclusion: where are we now?, *Transport policy*, Vol. 20, pp. 105-113, 2012.
Mavoa, S., Witten, K., McCreanor, T. and O'sullivan, D.: GIS based destination accessibility via public transit and walking in Auckland New Zealand, *Journal of transport geography*, Vol. 20, No. 1, pp. 15-22, 2012.
Nakahira, Y. and Matsuo, K.: GIS analysis of defining method of bus stop territories in consideration of road condition and physical ability, *Studies in regional science*, Vol. 47, No. 2, pp. 207-224, 2017.
Nakayama, S. and Yan, W.: The package redelivery problem, convenience store solution, and the delivery desert: a case study in Aoba Ward, Yokohama. *Journal of Urban Management*, Vol. 8, No. 3, pp. 355-363, 2019.
Páez, A., Anjum, Z., Dickson-Anderson, S. E., Schuster-Wallace, C. J., Ramos, B. M. and Higgins, C. D.: Comparing distance, time, and metabolic energy cost functions for walking accessibility in infrastructure-poor regions, *Journal of transport geography*, Vol. 82, 102564, 2020.
Saghapour, T., Moridpour, S. and Thompson, R. G.: Public transport accessibility in metropolitan areas: A new approach incorporating population density, *Journal of Transport Geography*, Vol. 54, pp. 273-285, 2016.
Saif, M. A., Zefreh, M. M. and Torok, A.: Public transport accessibility: a literature review, *Periodica Polytechnica Transportation Engineering*, Vol .47, No. 1, pp. 36-43, 2019.
Sato, E., Yoshikawa, T. and Yamada, A.: Investigation of converted walking distance considering resistance of topographical features and changes in physical strength by age: Model for location planning of regional facilities considering topographical condition and aging society part 1, *Journal of architecture, planning and environmental engineering*, Vol.71, No.610, pp.133-139, 2006.
Tobler, W.: Three presentations on geographical analysis and modeling, 1993.
Toriumi, S. and Omori, H.: Analysis of mobile supermarket for people in food desert area in Hitachi city, *Journal of the City Planning Institute of Japan* Vol.55, No.3, pp.443-450, 2020.
Transport for London.: Measuring Public Transport Accessibility Levels, 2010.