Accessibility Evaluation Considering Consumed Calories—Case Study on the Tokyo Coastal Subcenter Area

Hiroyuki ONEYAMA [a], Masami YANAGIHARA [b], Yuki KAWABE [c],

[a,b,c] *Graduate School of Tokyo Metropolitan University, 1-1, Tokyo, 192-0397 Japan*
[a] *E-mail: oneyama@tmu.ac.jp*
[b] *E-mail: yanagihara@tmu.ac.jp*
[c] *E-mail: nbszg918@yahoo.co.jp*

Abstract: We propose an accessibility index that can evaluate the amount of activity in large urban areas by considering calorie consumption. We applied the proposed method to the Tokyo coastal subcenter area, which was one of the main venues of Tokyo 2020 Olympics and is expected to be active even after the Olympics. The results of this analysis showed that the Tokyo coastal subcenter area is less accessible than the existing facilities in the city center. In addition, the amount of activity that can be performed varies significantly depending upon the attributes and conditions. Hence, to improve the accessibility of the Tokyo coastal subcenter area, it is necessary to not only improve access to the Tokyo coastal subcenter area, such as access-time reduction, but also to implement movement load reduction measures such as setting up of rest areas in railway cars, stations, and transportation hubs, and alleviate congestion in the train.

Keywords: Accessibility, Calorie consumption, Tokyo costal subcenter area

1. INTRODUCTION

Over the past few years, preparations were underway for the Tokyo Olympics and Paralympics (hereinafter referred to as the Olympic Games) scheduled to be held in 2020 (now postponed to 2021), such as the development of Games facilities and the surrounding transportation network. In addition, large-scale commercial and event facilities were constructed in the coastal subcenter area of Tokyo where the tournament facilities are concentrated. However, the Tokyo coastal subcenter area can only be reached using the limited transportation networks, i.e., “Yurikamome,” “Rinkai Line,” and “Toei Bus,” which are characterized by considerable congestion during peak hours. In other words, the “accessibility” to the land is low.

In several past instances, such as the Beijing Olympics, facilities constructed for hosting the Olympics games were not used after their conclusion, the main reason being their low accessibility. To utilize the Olympic facilities as a legacy after the games and revitalize the Tokyo coastal subcenter area, it is important to ensure accessibility by changing the utilization rate of public transportation and reducing the burden on transit. In this case, it is important to secure not only accessibility to a single facility or area but also the possibility of migration.

So far, most of the accessibility indicators consider travel time and cost. However, the differences in physical strength based on gender and attributes of a person who does the actual work must also be considered. Accordingly, in this study, we propose an accessibility index that considers the possibility in activity based on the difference in attributes and use this index to evaluate the accessibility of the Tokyo coastal subcenter. In addition, this study was aimed at identifying the cause of accessibility deterioration in the coastal area and presenting the direction of transportation measures necessary for improving accessibility.

2. LITERATURE REVIEW

Many previous studies have proposed measures to calculate accessibility. Morris et al. (1978) defined accessibility as the facility that helps people to reach a location to perform an activity. Providing a link between transportation and land-use models, accessibility can be seen as an indicator to assess transport and land-use policies, especially in urban structures. Van Wee (2013) discussed the categorization of the accessibility measures by the following four groups, such as infrastructure-based, location-based, person-based and utility-based accessibility measures. Iida et al. (1996) focused on "continuity," according to which automobiles can move from the starting point to the destination without changing trains, while public transportation, such as railways, possesses the characteristic of "discontinuity" that occurs when changing trains at stations. Oshima et al. (1996) analyzed the economic effect of introducing transfer resistance reduction equipment, such as escalators, on the increase in the movement resistance due to the increase in vertical movement caused by the deepening of the subway in metropolitan areas. Sato et al. (2002) targeted urban public transportation terminals to consider measures to reduce the barriers of the entire passenger facility with increase in the aging society; they focused on the equipment and structure of the passenger facility. Yatskiv and Budilovich (2016) proposed the method to estimate the accessibility and show the case study for Riga Transport System.

However, few studies have proposed accessibility indicators that take into account personal physical characteristics at the level of the entire metropolitan area. And then, many previous studies have focused on specific areas such as movement within stations and movements from departure points to stations. Others have calculated accessibility over a wide area, from the starting point to the nearest station or to the destination. In addition, many studies have focused only on the outbound route, while others targeted the time spent at the destination as well as the return route from the destination to departure point.

Therefore, in this study, we propose an accessibility index that considers personal physical characteristics using calorie consumption. In addition, we consider round-trip travel time, transfer resistance, and staying time at the destination, that is, the amount of activity.

3. ACCESSIBILITY INDEX FOCUSING ON CONSUMED CALORIES

3.1 Overview of Proposed Accessibility Index

In this section, we propose an accessibility index that focuses on calories burnt as the amount of activity that can be achieved owing to differences in attributes. Specifically, the amount of activity in the target area is evaluated by calculating the time required for traveling and calories burned. We considered calorie consumption because it can be used to evaluate the subject according to the differences in attributes such as gender, age, and special situations.

In this study, we proposed the following three accessibility indicators.

a) Available time for activities

This is the time at which the activity is possible at the destination area. In addition, assuming that the daily activity time, the "stayable time" is defined as the difference in the daily activity time and the time required for round-trip travel. Similarly, "surplus energy" is defined as the difference in the daily average calorie consumed over the daily activity time and the calorie consumed for the round-trip travel. The activity time for activities, such as shopping with this surplus energy, was calculated; compared with the stayable time; and the minimum among these is defined as the "available time for activities" at the destination. The daily activity time is a parameter and can be set based on the estimation conditions. In this study, 8 h, which is usually set as the working hours per day, was set as the daily activity time.

b) Average available time for activities per person

To evaluate the amount of activity in the entire target area, the available time is multiplied by the population of the area, and the average is calculated. This will evaluate how much each person can work at the destination.

c) A proportion of people who can perform activities for *T* hours or more

This indicator is defined as the proportion of the population living in the area with an active time of *T* hours or more to the total population. This value is an index to evaluate how many people can reach their destination quickly and travel around as many facilities as they can without becoming tired. In this study, *T* was set to 4 h, considering the time required for a cohesive sightseeing activity.

3.2 Accessibility calculation method

As the area to be analyzed, accessibility evaluation was conducted from the entire metropolitan area to the Tokyo coastal subcenter, and the daytime on holidays was considered as the research target time zone. Then, to calculate accessibility, the railway network created by Ando et al. (2019) was used. Figure 1 shows the conceptual graph of the train network, in which the shortest route between arbitrary stations can be calculated, considering the transferable stations, by adding the travel time at the time of transfer, waiting time including operation frequency, fare, etc., to the specific link of transfer, the travel speed, and operation frequency.

To calculate the accessibility to the destination station from any location, Japan 4th mesh, with a rectangular dimension of approximately 500 m × 500 m, was used. Each mesh is connected to several nearest train stations, and the traverse time is calculated according to the straight-line distance. Figure 2 shows the entire train network and the boundary of the mesh. In total, 2,331 train stations (counted as different stations for different lines, even for the same station); 46,019 links; 18,797 nodes; and 79,583 meshes were included in the study area.

In order to calculate the calorie consumption in detail and accurately, it is necessary to consider the detailed walking route in consideration of the gradient and so on. However, in this study, calories are estimated by focusing on boarding time and transfer in order to calculate macro accessibility for the entire mesh-based urban area. Refinement and verification of calorie calculation are issues for the future.

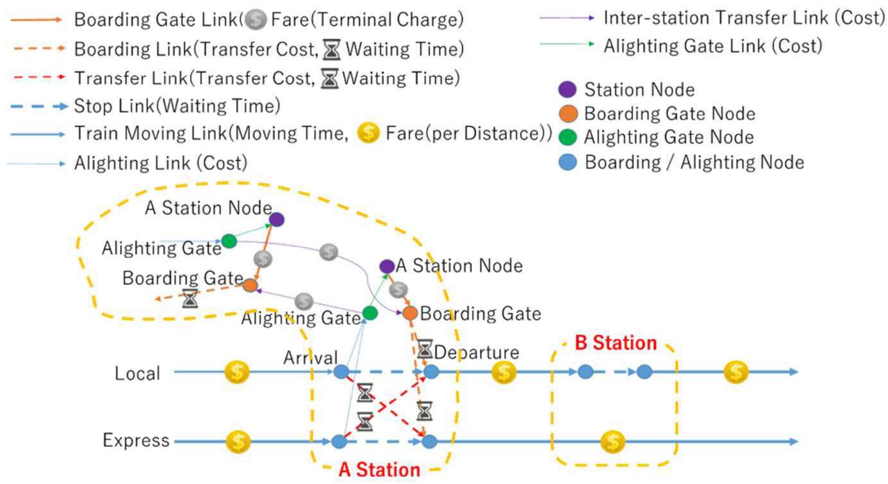


Figure 1 Conceptual graph of train network

Figure 2 Study area including train network and meshes

For calculating the amount of activity, we first set the destination station of the migration target area and defined the cost for searching the minimum path from every station in the research area to the destination station. In this study, time and calorie were considered as the minimum path-search costs. (Hereafter, we term these factors as "the minimum time route" and "minimum calorie route," respectively.) In this study, we focused on the calculation of accessibility indicators only for the shortest cost route. When reflecting the degree of congestion due to differences in route traffic, or when calculating the average calorie consumption considering the selection behavior of multiple routes, it is desirable to consider route selection of multiple routes, which will be examined in the future.

Then, the time and calories consumed for the round trip on each shortest path were calculated. In addition, assuming that the daily activity time is 8 h, the “stayable time” is calculated as the difference between the daily activity time and time required for a round-trip travel. In addition, the surplus energy is calculated as the difference between the daily average calorie consumption for 8 h and the calorie consumption for a round-trip travel. Then, this surplus energy was used to calculate the activity time for shopping, which was compared with the stayable time, and the smaller of these was calculated as the “available time for activities” at the destination.

In addition, to evaluate the amount of activity in the entire target area, the “average available time for activities per person” was calculated by multiplying the activity time of the area population. Next, we calculated and evaluated the population by using an activity time of ≥4 h, i.e., “The proportion of people who can perform activities for 4 h or more.”

The calculation of calorie consumption of travelers with different attributes is reflected as a difference in parameters. To consider the difference in the basal metabolism and calorie consumption due to the differences in the attributes of the subjects, the three attributes, i.e., adult males, elderly males, and women with children, were considered, including in the situations with normal movement and crowded trains. Accessibility was calculated by considering these two movement patterns.

Table 1 shows the difference in coefficients depending on the attributes used in the analysis.

Table 1 Coefficients used during the analysis

	adult males	elderly males	woman with child
average weight(kg)	65	58	52
walking speed(m/s)	0.8	0.8	0.7
average consumed calories in 8 hours (kcal)	900	750	650
consumed calories on board in train (kcal/h)	123	110	95
in congestion	1.5 times consumption of calories on board in train		
with baby car			41kcal/30min

3.3 Analysis Case Settings

In the above-mentioned shortest-path search, the accessibility index was calculated and evaluated considering the migratory behavior in the Tokyo coastal subcenter area. For the case study of migratory activities in this area, two destination stations, namely “Ariake-tennis-no-mori station” in Yurikamome Line and “Tokyo Teleport station” in Rinkai Line, were considered, which refer to the cases of migration toward the Olympic and commercial facilities, respectively. In addition, as comparison target areas, two destination stations in the Tokyo city center, namely the “Kokuritsu-Kyogijo (Japan National Stadium) station” in Toei Oedo Line and “Ueno station” in JR Lines, were selected, which refer to the cases of traveling around the Japan National Stadium area and around the famous and popular sightseeing spots in Tokyo, respectively. Figure 3 shows the locations of these four stations.

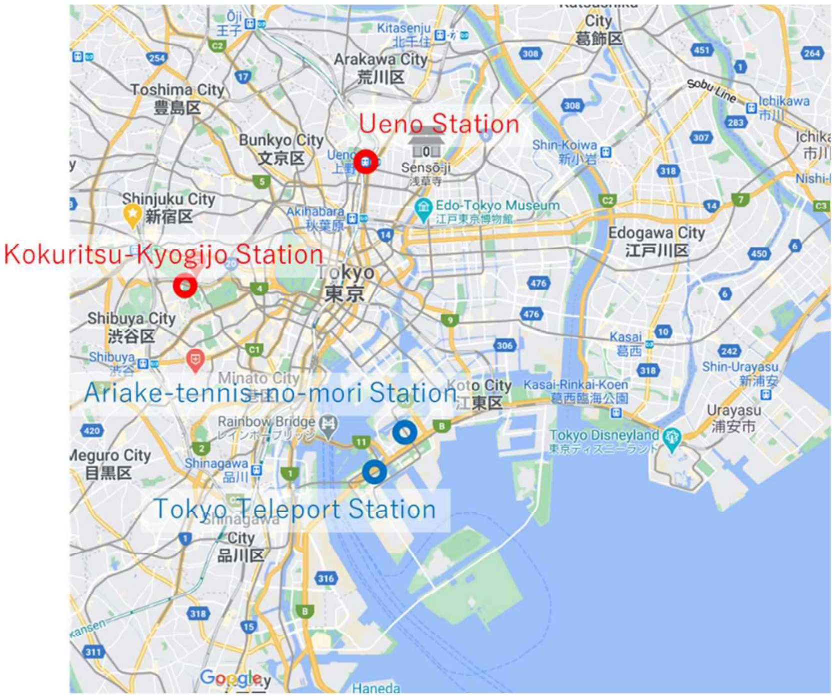


Figure 3 Locations of the four target stations

4. ANALYSIS RESULTS

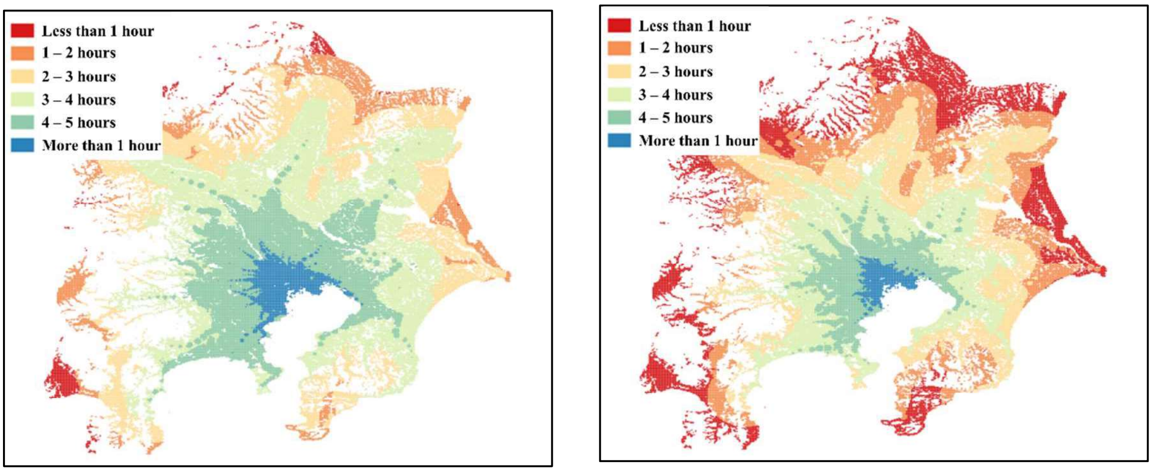
4.1 Analysis of Maximum Active Time

4.1.1 Available Time for Activities on the Minimum Time Route

First, the active time was calculated on the network using the minimum time route. Table 2 shows the results of the accessibility calculations for each pattern. The results showed that the Tokyo coastal subcenter area, Ariake-tennis-no-mori station, and Tokyo Teleport station, have low accessibility in terms of all indicators than those of the comparison area, i.e., Kokuritsu-Kyogijo and Ueno stations. In addition, the available time for activities is significantly lower in people with low physical strength, such as elderly men and women with children, than in adult males and in congested situations. Figures 4 and 5 illustrate maps of adult males and females with children in the case of Ariake-tennis-no-mori station.

Table 2 Total available time for activities based on the minimum time route [10^3 h]

Destination Station		Adult male		Elderly male		Woman with child	
		Not congested	Congested	Not congested	Congested	Not congested	Congested
Tokyo Costal Sub-Center Area	Ariake-tennis-no-mori	136.6	137.6	128.3	110.7	112.6	73.7
	Tokyo Teleport	140.3	137.3	131.8	114.0	115.8	78.5
Tokyo City Center Area	Kokuritsu-Kyogijo	162.1	157.2	151.3	126.4	133.5	88.0
	Ueno	197.1	191.6	183.9	164.1	165.4	126.4



Not congested congested

Figure 4 Time–space frequency distribution of available time for activities using the minimum time route (Destination: Ariake-tennis-no-mori Station, Adult male)

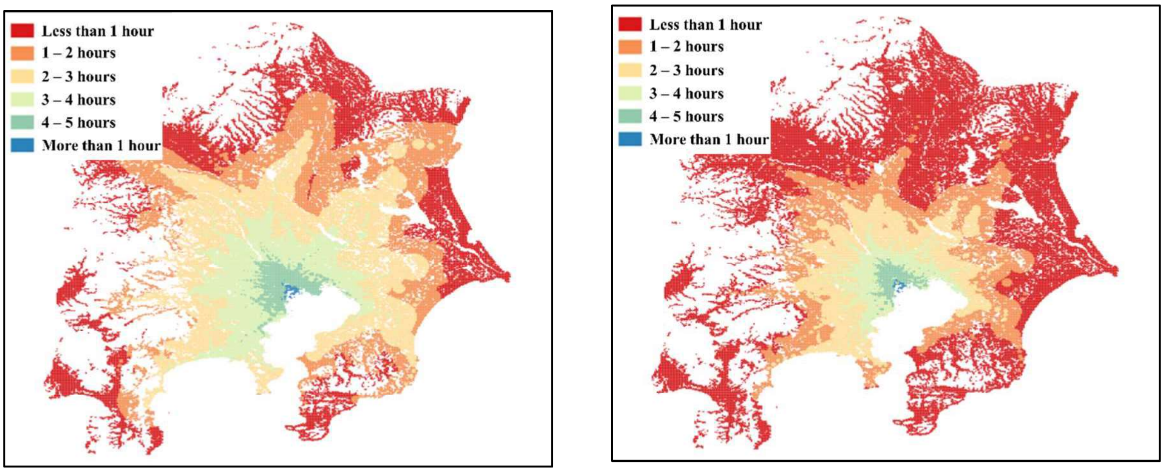


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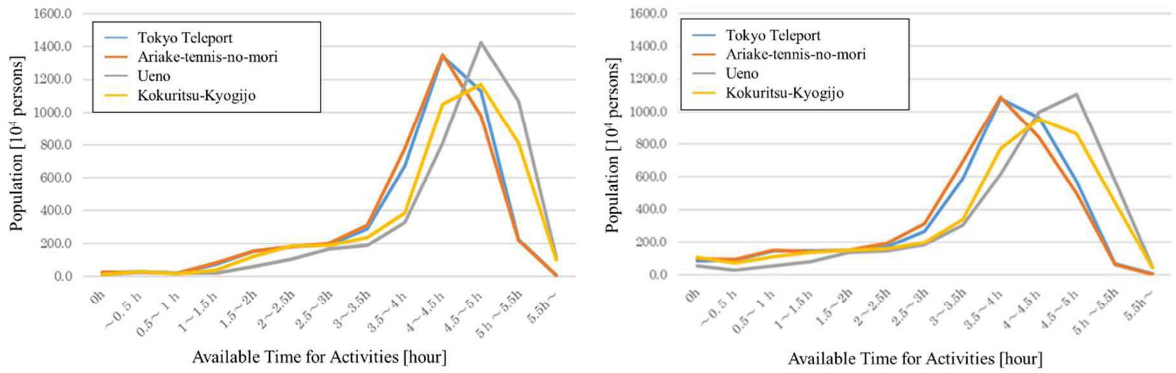
Figure 5 Time–space frequency distribution of available time for activities based on the minimum time route (Destination: Ariake-tennis-no-mori Station, Woman with child)

Accordingly, we found that the spatial distribution in the area where the available time is high is closely related to the stations connected along the inflow and outflow stations. Therefore, the available time can be improved in a wider area by improving the convenience of the line passing through the station with many connecting lines.

Figures 6 and 7 show the population distribution based on the available time for activities. The population distribution map shows a difference of approximately 1 h in the peak available time for activities between the facility in the city center, Kokuritsu-Kyogijo station, and Ueno station, than the time required for activities in the Tokyo coastal sub-center area, Ariake-tennis-no-mori station, and Tokyo Teleport station. Moreover, it is possible that the peak times for adult males and women with children differ by approximately 2 h.



Not Congested Congested

Figure 6 Population distribution of available time for activities in the case of an adult male

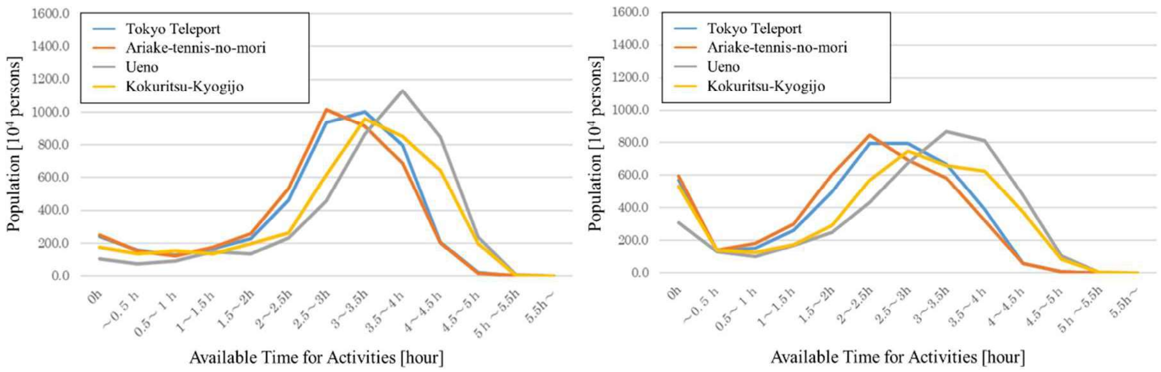


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Figure 7 Population distribution of available time for activities in the case of women with children

4.1.2 Available Time for Activities based on the Minimum Calorie Route

Next, the available time for activities was calculated in the network using the minimum calorie route. The results are shown in Table 2. Similar to the analysis results of the minimum time route, the results showed that the Tokyo coastal subcenter area was inferior in accessibility for all indicators than those of the comparison area. However, there is a difference in the numerical values when compared with the minimum time path. Figures 8 and 9 show the activity-based time–space distribution for each pattern.

Table 2 Total available time for activities based on the minimum calorie route [10^3 h]

Destination Station		Adult male		Elderly male		Woman with child	
		Not congested	Congested	Not congested	Congested	Not congested	Congested
Tokyo Costal Sub-Center Area	Ariake-tennis-no-mori	136.6	137.6	128.3	110.7	112.6	73.7
	Tokyo Teleport	140.3	137.3	131.8	114.0	115.8	78.5
Tokyo City Center Area	Kokuritsu-Kyogijo	162.1	157.2	151.3	126.4	133.5	88.0
	Ueno	197.1	191.6	183.9	164.1	165.4	126.4

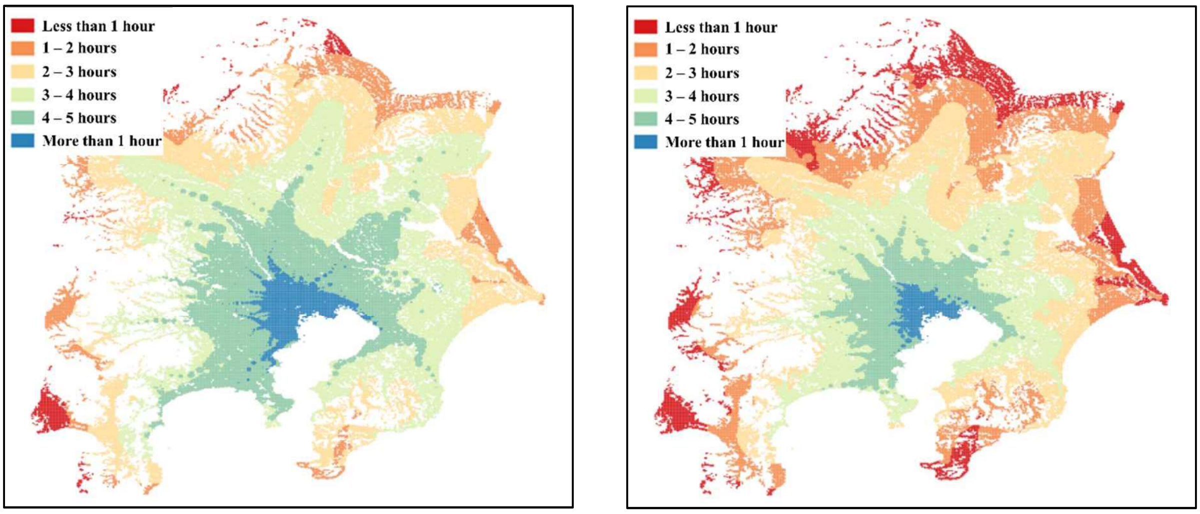

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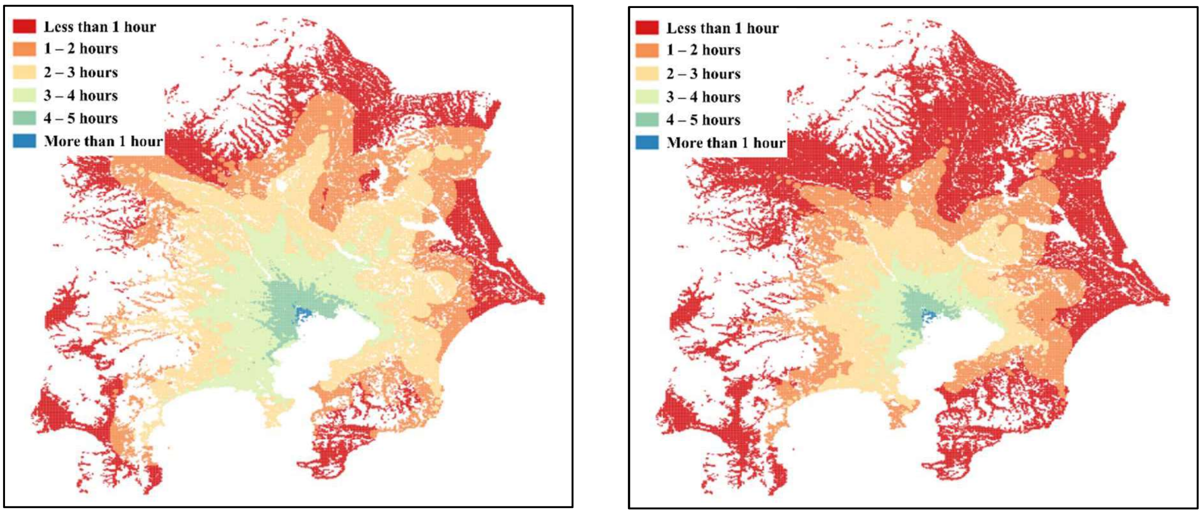
Figure 8 Time–space frequency distribution of available time for activities with respect to the minimum calorie route (Destination: Ariake-tennis-no-mori Station, Adult Male)



Not Congested Congested

Figure 9 Time–space frequency distribution of available time for activities with respect to the minimum calorie route (Destination: Ariake-tennis-no-mori Station, Women with children)

4.2 Comparison by Accessibility Index

From the calculated active time, the accessibility index based on the maximum active route was calculated. Table 3 shows the average available time for activities per person, and Table 4 shows the proportion of people who could perform the activities for 4 hours or more.

These tables show that the average available time for activities per person in the Tokyo coastal subcenter area differ from that in the city center by approximately 0.4–0.6 h. In addition, it is established that compared to adult males, women with children, who have the most severe conditions, have about 30% less active time during busy times.

Next, regarding the proportion of people who can perform activities for 4 hours or more, the results showed a difference of nearly seven times in the tennis forest between adult males and women with children when the area is congested. These results show that accessibility is considerably poor with respect to calorie consumption in the Tokyo coastal subcenter and a certain solution is necessary.

Table 3 Average available time for activities per person [hour]

Destination Station		Adult male		Elderly male		Woman with child	
		Not congested	Congested	Not congested	Congested	Not congested	Congested
Tokyo Costal Sub-Center Area	Ariake-tennis-no-mori	3.9	3.7	3.5	3.0	3.0	2.5
	Tokyo Teleport	3.9	3.7	3.5	3.1	3.1	2.6
Tokyo City Center Area	Kokuritsu-Kyogijo	4.3	4.1	3.8	3.5	3.4	2.9
	Ueno	4.6	4.3	4.1	3.7	3.7	3.2

Table 4 Proportion of people who can perform activities for ≥4 h according to the minimum time route

Destination Station		Adult male		Elderly male		Woman with child	
		Not congested	Congested	Not congested	Congested	Not congested	Congested
Tokyo Costal Sub-Center Area	Ariake-tennis-no-mori	62.6	57.2	44.7	23.7	20.9	9.0
	Tokyo Teleport	65.1	61.7	49.1	27.6	23.5	10.6
Tokyo City Center Area	Kokuritsu-Kyogijo	73.2	70.5	63.4	42.1	39.3	25.1
	Ueno	78.3	76.8	72.7	53.9	51.4	32.2

4.3 Comparison by Route Selection Method

Next, we compared the difference in the proportion of active people between the minimum time route and minimum calorie route. Table 5 shows the proportion of people who can perform activities for 4 h or more based on the minimum calorie route; the result was compared with the result of the minimum time route (Table 3). As shown, no change was observed in the active population in the minimum time route and minimum calorie route in the noncongested case for adult males. However, in other cases, the proportion of people who could perform activities based on the minimum calorie route was higher than that on the minimum time route.

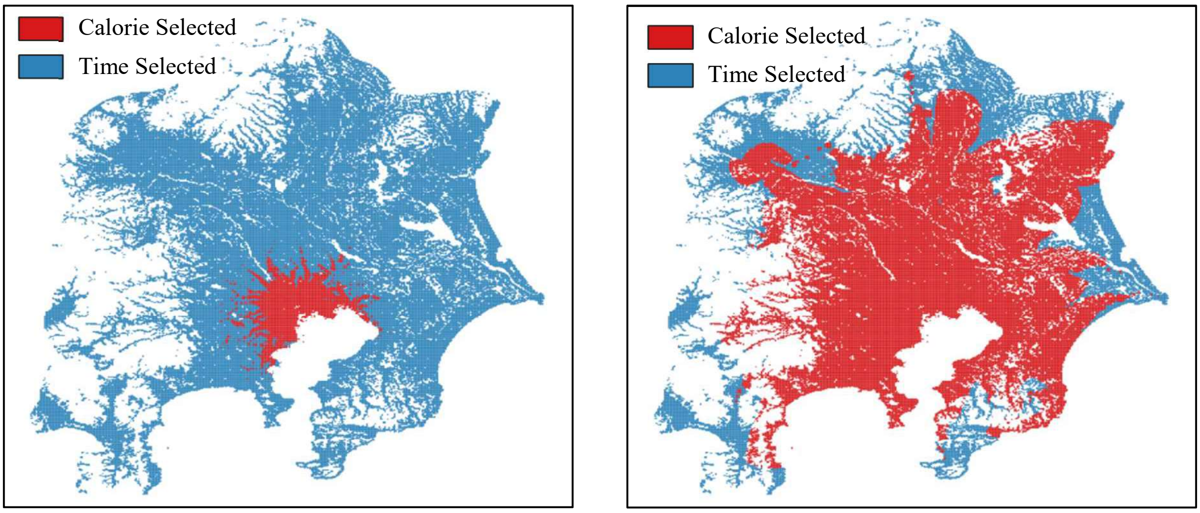
In addition, Figure 10 shows the available time for activities, stayable time considering round-trip (indicated as “Time selected” in the figure), or the activity time for shopping that can be calculated using this surplus energy (indicated as “Calorie selected”). These figures show that adult males choose the available time for stay in many areas, while women with children choose available time based on surplus energy in many areas. Therefore, while adult men have time constraints when considering their active time, calories are a constraint for elderly people and women with children who are physically handicapped.

5. CONCLUSION

In this study, we proposed an accessibility index that can evaluate the amount of activity by considering the attributes of the subject. Then, using the proposed index, we compared the Tokyo coastal subcenter area with the existing facilities concentrated in the city center and compared them by attribute.

Table 5 Proportion of people who can perform activities for ≥4 h based on the minimum calories route

Destination Station		Adult male		Elderly male		Woman with child	
		Not congested	Congested	Not congested	Congested	Not congested	Congested
Tokyo Costal Sub-Center Area	Ariake-tennis-no-mori	62.6	59.9	47.9	25.4	22.5	10.7
	Tokyo Teleport	65.1	63.9	52.6	30.3	26.0	13.3
Tokyo City Center Area	Kokuritsu-Kyogijo	73.2	72.5	52.6	45.7	42.1	27.9
	Ueno	78.3	78.1	75.0	56.6	54.7	35.7



Adult Male Woman with Child

Figure 10 Available time for activity according to calorie burned and time taken

From this analysis, it was found that the Tokyo coastal subcenter area is less accessible than the existing facilities in the city center, and the improvement in the available migration time is closely related to the stations connected along the inflow and outflow stations. It was also established that the amount of activity that can be performed varies significantly depending upon the attributes and conditions.

In addition, in comparison to the route selection method, it is clear that the active time increases when the minimum time route is selected for adult men, while the active time increases when the minimum calorie route is selected for those who are physically handicapped.

Therefore, we conclude that to improve the accessibility of the Tokyo coastal subcenter area, it is necessary to not only improve access to the Tokyo coastal subcenter area, such as access time reduction, but also to implement movement load reduction measures such as setting up of rest areas in railway cars, stations, and transportation hubs, and alleviate congestion in the train.

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