Measuring the Changes of Subway Accessibility Through the Service Area Territories: A Case Study of Fukuoka Subway Network

Somsiri Siewwuttanagul, Takuro Inohae, and Nobuo Mishima

Abstract The expansion of subway networks can stimulate changes of accessibility of surrounding communities. The plan of future a network needs to be evaluated to examine the effect on existing networks and the accessibility of surrounding communities in order to prepare them for the changes of spatial physical dynamics. This research focused on the plan of a new subway station in the Japanese city of Fukuoka. The new station will be located in a prime site of the city and aims to link the old and new CBDs of Fukuoka city (Tenjin station district and Hakata station district). This methodology was introduced for measuring the changes of accessibility in order to indicate how much such plans could potentially benefit surrounding buildings. In this study, 12,237 buildings in the subject area including four major usages of Public Service, Mixed Use, Residential and Commercial were considered in the analysis, which uses a Reach Index to simulate the changes of accessibility between before and after operation of new subway stations. The results can be used to compare how expanding subway accessibility is associated with surrounding buildings. The changing of service area territories indicates the influence that a new subway station has on transportation networks.

Keywords Service area territory · Accessibility · Public transportation · Land use

1 Introduction

The changing of public transport networks will always have an effect on physical urban forms and also the overall dynamic of transport networks in a given city (Miller 2004; Broitman and Koomen 2015; Dubé et al. 2013; Loo et al. 2010), especially in metropolitan areas that contain a high density of population which implies a high number of users of public transportation as well. Therefore, new

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construction projects or expansion projects of public transportation networks need to be evaluated in terms of their effect on existing transit networks and the accessibility of surrounding communities in order to prepare for the changes of spatial physical dynamics (Esch et al. 2014; Dempsey et al. 2010) which leads to changes in user's behavior (Ceder et al. 2013; Golias 2002; Guo and Wilson 2011; Hernandez and Monzon 2016). According to the current project that is focused on here, the study aimed to investigate the effects of a new subway station construction which will create a link between two highly populated (or 'centers') of Fukuoka city, Japan. The project proposed to provide better accessibility by linking two main interchange stations, one located in the Tenjin area (including interchanges linking the subway, bus center and Fukuoka city's local train system called Nishitetsu), and the other, located in the city's Hakata area (which hosts the biggest train station in the Kyushu region and an inter-region bus center). The project included a plan to build a new subway station that would link those two city centers in a very popular area of Fukuoka city that includes the largest shopping center and is also close to Nakatsu-Kawabata, which has the highest density of buildings in the city. The resulting changes of completion and subsequent operation of the new facility became a focal point of this research. The comparison of the change of accessibility due to the new subway station is subjected to investigation by the application of the specific methods of this research.

The interpretation of this research was inspired by Golias (2002) who examined the impacts on travelers' behavior and transport modes of choice following the construction of a new subway system. However, this study has applied a different approach for defining the results by using more physically spatial analysis method and using a computer-aided-analysis technique on route analysis (Wu and Chen 2012; Chen et al. 2014; Litman 2006, 2012) in order to determine the impacts of a future public transportation network. The relationship of connecting distance and public transportation service area territories was interpreted by implementing a methodology to investigate the change of a future public transportation network. Also, this framework has been developed to investigate urban development dynamics by considering physical urban configurations that work with the interaction between urban spatial construction and transportation networks (Papa et al. 2013; Papa and Bertolini 2015).

The recent effective tools that are able to assist planners to examine the changes of accessibility between origin and destination were introduced by the contours catchment of Spatial network analysis for multi-modal urban transport systems (SNAMUTS) (Curtis et al. 2012) and Reach index of Urban network analysis (UNA) (Sevtsuk and Mekonnen 2012; Sevtsuk and Kalvo 2015). These tools operate the network measurement that allows planners to investigate the interaction between places and urban network within the assigned distance from one node to another which is measured using the shortest path route (Lee et al. 2017). These indicators support (Fransen et al. 2015) who introduced a function that determines the number of access options at any given time point that could be used to reach a particular destination from each community. It is also related to the use of node-place dynamics for achieving the successful development of a station area, which helps to better understand the complexity of urban systems through gathering spatial information (Bertolini 2008). This method assisted the examination of transit accessibility, with measurements taken from any activities nearby transit nodes (Lowry and Lowry 2014), such as commercial, residential, and mixed-use buildings, as well as public services and places of work including offices. To contribute to forming a new perspective on the expansion of transit networks, we have developed a methodology for determining the change of accessibility of future public transportation networks through the construction of new transport facilities. We chose Fukuoka city in Japan for this case study which involved a real-time project that was predicted to have a high impact regarding the future connection of two urban cores both considered as areas having a very high potential in the city.

2 Methodology

2.1 Overview of Data and Study Area

The procedure proposed for measuring the changes of accessibility on the existing subway's network compared with the future subway's network, which includes one new station linking the two urban cores and has been proposed as the completion of the public transportation network in Fukuoka city, Japan. Fukuoka city already provides modes of public transportation including an urban bus network and a subway network which are both operated by the same company (Nishitetsu). The network covers the area of Fukuoka city as shown in Fig. 1.

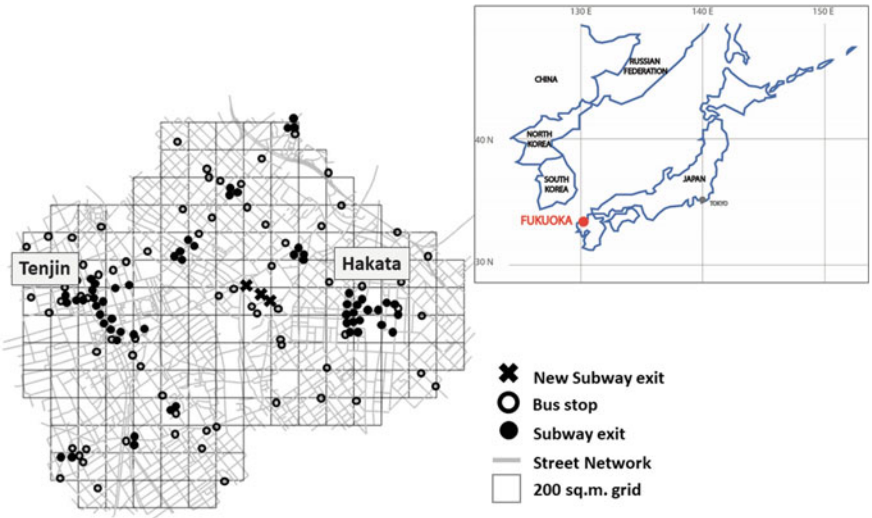

Fig. 1 The study area (Fukuoka city, Japan)

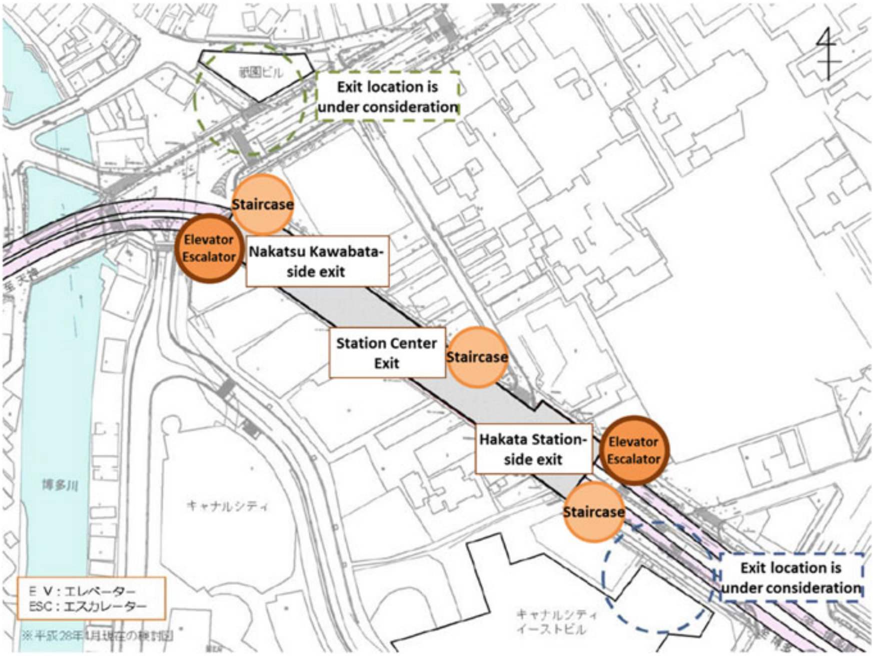

Fig. 2 The master plan of new subway exits (Chuukan station) (Fukuoka City 2016)

According to the new plan, Fukuoka city decided to construct a future subway network which will have one new station called Chuukan Station along the Nanakuma line, which will be extended by 1.4 km and aims to link the old and new CBDs of Fukuoka city (Tenjin station district and Hakata station district). The station was proposed to include five exit gates (see Fig. 2) and would be connected to the largest department store in Fukuoka named Canal City. The area also includes a convention hall and a high-end hotel located in the heart of Fukuoka's main business area.

2.2 *The Setting of Origin and Destination*

The scope of analysis has been divided into (1) the origin point, which uses building data; and (2) the destination point, which uses nodes of public transport for observing the impacts of the future subway network that affects the level of accessibility with regards to both qualitative and quantitative elements. The total subject area covered is 6,240,000 m^2 with 12,237 buildings categorized into four groups of major usage, namely Public Service, Mixed Use, Residential and Commercial; these are used as the origin points to access the destination (nodes). Following this, the destinations are divided into two parts. The first part uses only on the subway's gates to compare the accessibility of the existing and future networks. The second part uses the subway's gates as well as bus stops in the area; this is then analyzed using the same methods as the first part.

2.3 The Details of Index

According to a review of accessibility conducted by Geurs and Wee (2004), the relationships between components of accessibility illustrated the association of land-use and transport component which relied on the location and characteristics of origin and destination that could refer to transit nodes and building locations in this study. This study classified infrastructure-based measurements on transport component perspectives in order to investigate the changes of accessibility due to the promoted plan of the new subway station in the prime site of Fukuoka city. To compare the effect of the new subway station, potential measure (Bhat et al. 2002; Hansen 1959; Vickerman 1974) in order to measure the changes of accessibility of surrounding buildings to the subway station. In a direct relationship to (Bhat et al. 2002), this study operated centrality tool assay, using the Reach Index (Eq. 1) in Urban Network Analysis (UNA) toolbox in order to simulate the impacts on accessibility due to the operation of a new subway station in Fukuoka city. The Reach Index was introduced by Sevtsuk and Mekonnen (2012) and Sevtsuk and Kalvo (2015) in their centrality analysis technique of urban network analysis (UNA). The Reach Index measured the number of accessible nodes of public transport within the designated search radius. This study set every building contained within the study area as the Origin point (i) and public transport nodes, such as a subway gate or a bus stop as a Destination point (j) in order to examine the number of nodes that each building has access to, as defined within the study.

$$Reach[i]^r = \sum_{J \in G-\{i\}, d[i,j] \le r^{W[j]}} \quad (1)$$

Variations in the length of street segments were difficult to define in terms of the territories of zoning; accordingly, to solve this issue, the study designed a set of cell grids (Nedovic-Budic et al. 2016), each covering an area of 200 m^2, in order to identify the subjected observation areas (see Fig. 1). Also, the variations of the accessible distances and street networks in each subject area that could be affected by the expansion of the public transport service area, as well as the facilitation of the public transport network in Fukuoka city, were all monitored, too.

2.4 The Setting of Boundary

The study measures infrastructure-based accessibility by observing the changes of accessibility of each building along the subway network. The buildings subjected to consideration in this study are all within the public transit node's pedestrian catchment areas (PCAs) according to Jun et al. (2015). Not only the walking distances were considered but also the urban development density, urban form, and interstation length which caused PCAs shorter than 800 m. The study applied Reach index to investigate the buildings that access the subway station with standard catchment area as 800 m (Jun et al. 2015; O'Sullivan and Morrell 1996; Sherwin and Parkhurst 2010) to observe the boundary of the subway station's service area of Fukuoka city. This initial analysis shows that the urban development agglomeration of Fukuoka is clustered within 500 m from the subway station (Fig. 3).

According to initial analysis and the review of Jun et al. (2015), this study proposed the boundary for observing changes of accessibility which were presented 500 m in radius from each related subway station and 200 m in radius from each bus stop which connects the two central business districts (CBDs), namely Tenjin area and Hakata.

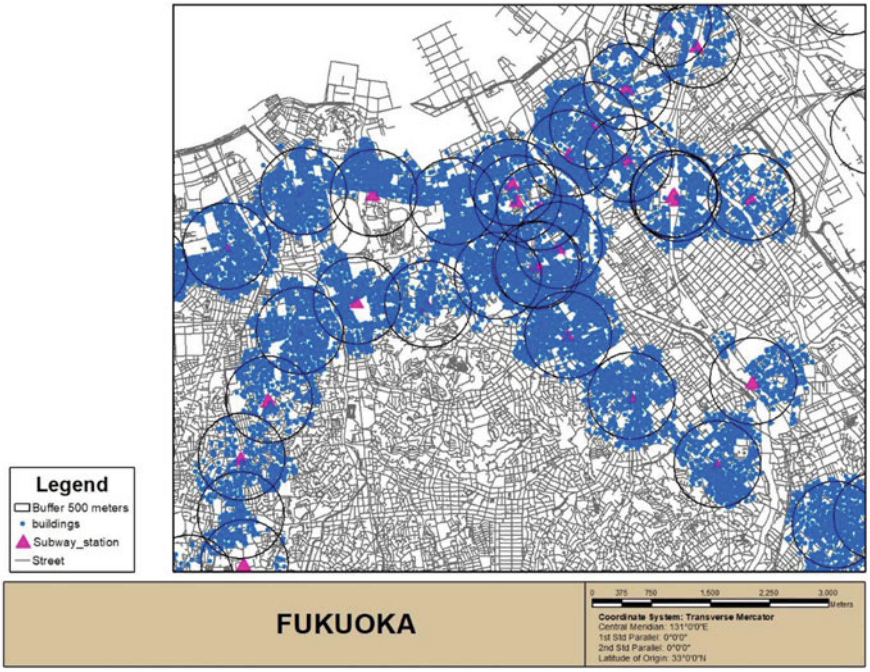

Fig. 3 Building accessibility to subway station within 800 m radius

2.5 Definition of Terms

This study has investigated the changes of transit node accessibility on the expansion of a public transport network, comparing the existing network and the future network of Fukuoka, which had one new subway station constructed in a prime area of the city. Then, the study divided the dataset into four parts in order to create a comparison between the subway network and the whole public transportation system with regards to accessibility change. Therefore, this part gives the relevant definitions which have been used in this study as:

SE A Subway's exit in the existing network; the number of nearby buildings able to access subway's exit within the study area (9 stations in total) at a 100, 200, 300, 400 and 500 m radius from each subway exit.

SF A Subway's exit in the future network; the number of nearby buildings able to access subway's exit within the study area (10 stations in total) at a 100, 200, 300, 400 and 500 m radius from each subway gate.

3 The Changes of Accessibility

The results illustrated the spatial accessible area of the existing subway network (SE) and the future subway network (SF) which has one new station with 5 exits. The spatial map shows the new station helps filling the transit desert of the study area and made surrounding buildings more highly accessible for public transport networks, by connecting adjacent public transportation nodes along with the public transport network. Future network accessibility was investigated in terms of the most accessible area in a 100 m radius with 10 access choices to the public transport network and the highest accessible area is within a 500 m radius of which there were indicated 59 access choices to the public transport's nodes.

The impact of the new subway network has increased the accessibility in the area surrounding the subway station. The future subway network (SF) exhibited a shift in access potential, in particular the area which is illustrated in Fig. 4 by two large gaps between the existing and future subway from the access point possibility of 6 choices to 9 choices. The study shows that the access points of 6 and 7 in the existing subway network in a 100 m radius from new subway station have shifted to 7, 8, 9, 10, 11, and 12 choices in the future subway network as indicated by the distribution rates of 39.6%, 5.3%, 23.7%, 7.7%, 16.1% and 7.6% respectively.

In addition, the existing subway's network provided a 3.9% subway accessible score for the total area when considered within a 100 m radius from each subway's gates. The pedestrian catchment area has expanded according to the service radius from subway's station as follows: the accessible area in a 200, 300, and 400 m radius is generated as 13.9%, 29.2%, and 47.4% respectively. In a 500 m access radius, an outstanding accessibility ratio is represented as 66.4% of total area in terms of subway accessibility.

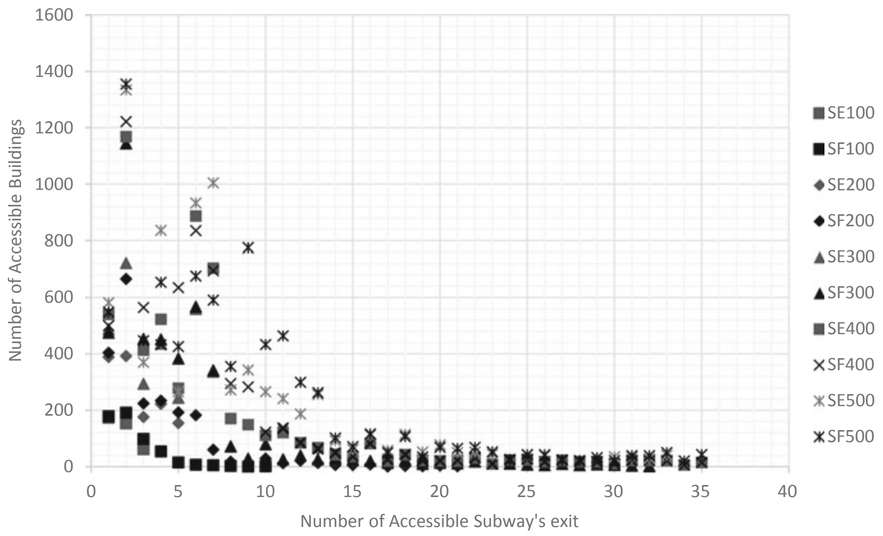

Fig. 4 The changes in accessibility between existing network and future network

Figure 5 illustrates that a 300 m radius access distance shows the highest expansion of subway accessibility as a + 4.29% increase from the existing network. This is followed by a + 3.84% increase at 400 m, a + 2.88% increase at 500 m and a + 2.687% increase at 200 m. Within a 100 m search radius, the new subway station influences the subway network with an increased expansion at only + 0.8% (as shown in Fig. 6).

To consider the distance of the subway's accessibility around the Chuukan station area, Table 1 shows that the new subway network can shorten the subway's exit accessibility distance by 80% in a 100 m radius, from 500 m (in the existing network) to less than 200 m (in the new network) and also shorten the accessibility distance by 25% of buildings which are located within 300 m from new station, since at a 400 m distance from the new station the accessibility was found to be at the same level as existing network due to the intersection of the surrounding subway's service area. In other words, if we consider access distance as the time spent to reach the network measured at a walking speed of 4 km per h, the new network can save 1.5–6 min in terms of the access time within a 300 m area surrounding the new station.

4 Conclusion and Discussion

The overall purpose of the construction of Chuukan station is mainly for the expansion of the subway's network. The difference between the pair of relationships (SE&SF) indicates that the new subway station is affected in terms of its expansion of accessibility, which provided a greater area and more potential for users to engage with

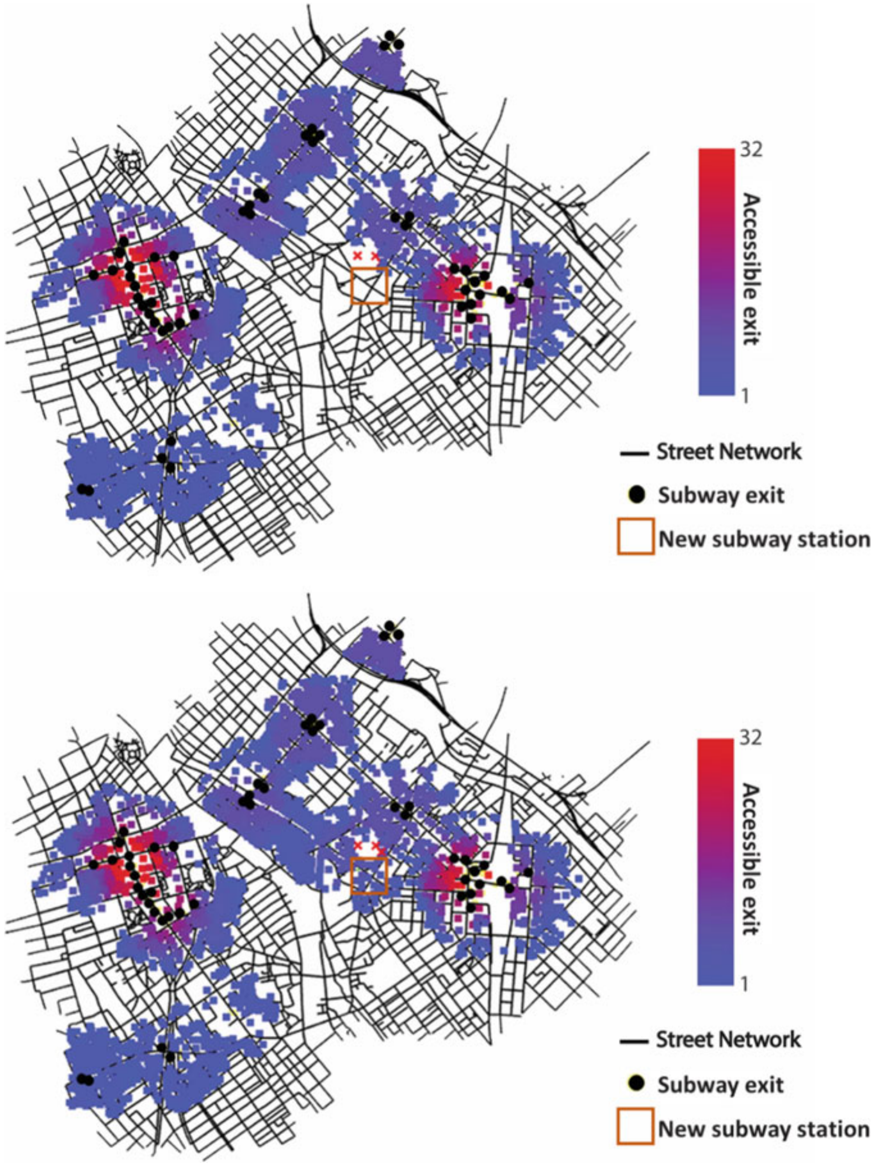

Fig. 5 The subway accessibility maps between the existing subway network (upper) and future network (lower) in a 300 m search radius

Table 1 Average number of accessible subway exits

Distance from each radius (m)	Average number of possibly accessible subway exit									
	Buildings at 100 m radius		Buildings at 200 m radius		Buildings at 300 m radius		Buildings at 400 m radius		Buildings at 500 m radius	
	SE	SF	SE	SF	SE	SF	SE	SF	SE	SF
100	0.0	0.9	0.0	2.6	0.0	4.0	0.0	5.0	1.0	6.0
200	0.0	0.2	0.0	1.5	0.0	2.9	0.2	4.5	2.8	7.8
300	0.0	0.1	0.0	0.2	0.3	1.9	2.9	5.7	5.2	9.7
400	0.0	0.0	0.3	0.4	2.8	3.1	4.2	5.7	6.0	9.0
500	0.2	0.2	1.2	1.2	2.4	2.4	4.4	4.9	8.1	9.7

the subway network. Chuukan station clearly fills the subway's desert of the prime area of Fukuoka city due to the location of the new subway station located between two central business districts (CBDs) of Fukuoka city which were never linked by a railway system. Even though the new subway station improves the accessibility of the subway network, it does not significantly affect the whole public transport network (including impacts on bus stops and subway gates) and also does not affect the existing highest accessible area. This suggests that the area in which the new subway station is located was already providing a full service area within a 200 m radius. Besides, the impacts on travel demand apparently show the same tendency as the impacts on node accessibility, which can be seen to identify the clear territory of the new subway station effects on the urban form of the chosen study area.

This study shown the access distance scale of the analysis for introducing the methods in order to measure the impacts of the construction of new transport facilities. The methodology of this study was used to detect the effective distances to access transport facilities by comparing the changes of subway accessibility conditions within 500 m radius areas which were represented by the average value taken at every possible choice of accessing each particular node of subway's exit. Following this step, the change of the accessible building was investigated and the number of accessible choices which related to the distance that was required to reach any particular node of public transport was interpreted. The methodology used in this study proposes the measurement of accessibility between land-use and transportation. The study selected Reach index which measures the accessibility from the origin location to the destination location along with the street network. Reach index measures the urban network in a direct way of field surveying which measures the actual distance between two subject locations within a given search radius but it has an advantage in saving more time than manually recording data. This tool allows urban planners and related researchers to measure a larger scale within a shorter time. This research discusses the subway catchment that was observed from 100 to 500 m radius with 100 m interval. If we re-scaled the simulation with more frequencies of distance, then we could find the movement of effect in any access distance. Notwithstanding, in this discussion we have not been able to illustrate the change after applying a smaller scale of distances within this analysis; however, we still insist that the results at a 500 m distance will be the same, even though, for example, the results of accessible buildings at a 500 m radius compared between before and after operating the Chuukan station probably show some things that are slightly different due to the resolution of details. However, the actual walking distance and speed are dependent on various factors such as the length of walking distance which could be influenced by such factors as weather, physical condition, or attractiveness of places nearby, etc. Subway's exits take passengers in different directions depending on the street segments they were located in. Regardless of this statement, the analysis result can be seen as being more reliable due to the fact that no matter which exit a user takes to access the subway system, they will eventually reach the same platform and thus are able to choose the direction of transit which is connected inside the underground station where one does not need to take a detour to reach the platform. Moreover, any transfer to other routes or modes of mass transit, rather than using the subway itself, is already considered as part of the same public transport system. For the future research agenda, this research leads to the development of the evaluation methods on spatial accessibility which interacted between public transport network and surrounding land-use in urban area. The development of accessibility indicator use which assists planners assesses the effect of changes of accessibility around relative transit nodes and communities. Moreover, the assessment of the other relative variables that could affect the transit station accessibility such as climate condition, infrastructure's level of service, and the attractiveness of the surrounding attractions could also help to develop its methods according to the proposed methodology of this study.

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