Evaluation of Accessibility with and without Proposed Rail Transit cases in Selected Southeast Asian Cities

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Abstract:
Recently, metropolitan cities in developing countries have pursued rail transit development based on their transportation master plans. These masterplans should be developed considering the accessibility of residents in the whole cities' expanse. However, most plans have not been developed in detail based on the evaluation and analysis of public transportation accessibility. The differences in service level of public transportation in each city have been disregarded. Therefore, this study evaluated the relationship between the accessibility of public transportation (e.g., rail transit) and the impact of improvement on rail transit to access facilities (e.g., hospitals) in selected Southeast Asian cities. Firstly, results showed that the development level of the present public transportation network varies significantly among cities. Secondly, the study found that urban railway development might significantly improve accessibility, but accessibility will be low in some areas. Hence, it's essential to consider results when setting up the rail transit in the future.

Keywords: Accessibility, Rail transit, Public transportation, Southeast Asian Cities, GTFS, Hospital facilities

1. INTRODUCTION

The development of public transportation is vital in the realization of a sustainable city and plays an essential role in residents' economic and social activities (United Nations, 2012). In recent years, many metropolitan cities in developing countries have been investing in rail transit development based on public transportation masterplans. Fundamentally, it is necessary to provide equitable access to public transportation to all residents when introducing rail transit. Therefore, it is critical to firstly have a thorough understanding of the existing network before attempting to improve service levels on public transportation while working with limited resources such as human resources and budget. The evaluation of accessibility by public transportation could significantly support the management of public transportation networks and transportation masterplans.

However, when formulating these master plans, the alignments and relationships of the planned routes are not necessarily in synchronization with the urban development plan, and their impacts on accessibility are often unclear. Moreover, there has not been sufficient analysis on the accessibility of public transportation in Southeast Asian Cities.

Thus, this study aims to evaluate the accessibility of public transportation based on network analysis of General Transit Feed Specification (hereafter, GTFS) in selected four Southeast Asian cities (Bangkok, Manila, Ho Chi Minh, and Jakarta). Fundamentally, this study focuses on the changes in accessibility when new routes of rail transit are constructed. Specifically, the service areas without and with proposed rail transit cases were analyzed from the center area of each city. Furthermore, using the location of hospitals as one example for POI (Point of Interest), the proportion of reachable facilities was also calculated and compared using the without and with of proposed rail transit network cases to clarify the difference in accessibility and catchment area to access the hospitals.

In this paper, literature about the analysis of accessibility for public transportation, particularly about rail transit analysis based on GTFS data were reviewed and presented in Section 2. The data collection and the overall framework of the analysis were explained in Section 3. The results and discussion of the accessibility without and with proposed rail transit network cases were presented in Section 4. Finally, Section 5 concludes the main idea of the paper.

2. LITERATURE REVIEW

In existing studies, the various types of accessibility index have been developed and classified into some categories. For example, Geurs et al. (2004) and Benentson et al. (2011) classified accessibility indicators into four types: (1) Infrastructure-based, (2) Person-based, (3) Utility-based and, (4) Location-based. Furthermore, Papa et al. (2016) and Marcin et al. (2019) described the temporal dimension of accessibility and identified three: (1) People: Distribution of residents, (2) Transport: Change in the performance of transportation, and (3) Activities: Fluctuation of attractiveness on the temporal variation. To accurately measure and analyze the temporal fluctuation of accessibility, several past studies estimated the performance of accessibility to public transportation using GTFS data and GIS tools.

For instance, Karner (2018) analyzed the robust transit equity by using publicly available data sources such as GTFS data, which was then utilized to develop gravity-based accessibility. Goch, et al. (2018) analyzed the spatial relationship between the distribution of service area and population using GTFS data in network analysis for transportation policies in Warsaw city. Goliszek, et al. (2017, 2020) examined the potential and cumulative accessibility of workplaces in Szczecin using GIS tools based on GTFS data during peak time. This particular study clarified that residents could tolerate reaching most workplaces within 30 to 40 minutes in a medium-sized city. Bok, et al. (2016) explored the internationally comparable methodology for evaluating accessibility based on the level of rail-based transit service area and level of road-based transit service area with interoperable data sources and compatibility. This study also compared the accessibility to public transportation in several metropolitan areas by employing the FUAs (Functional Urban Areas) approach, which was defined in 2012 by the OECD (Organization for Economic Cooperation and Development) in collaboration with the EU (European Union) for international comparison. Specifically, this study explored the relationship between the TOD (Transit Oriented Development) degree and accessibility. Additionally, many other existing studies have similarly analyzed the accessibility to public transportation based on GTFS data and in terms of outputs have proposed various indicators (Fayyaz, et al., 2017, Fransen, et al., 2015, Bárta, et al., 2020, Marcin, et al., 2019, Shah, et al., 2016).

However, only a few studies have evaluated the accessibility of new rail transit based on GTFS data in Southeast Asian cities due to the non-existent or slower development of rail transit and data management compared to its counterparts in the U.S. and European cities (GTFS Data Exchange, 2015). Moreover, the existing studies had rarely employed accessibility to public transportation as an indicator to compare metropolitan areas.

Thus, this study focuses on improving the accessibility to public transportation based on GTFS data. The improvement of accessibility to public transportation was analyzed based on the service area coverage and the number of reachable facilities (POI) with and without the proposed new rail transit routes in four selected Southeast Asian cities. This study showed the results of accessibility for hospitals as one example.

3. METHODOLOGY

In this study, the research methodology investigated changes in citywide accessibility with and without the proposed rail transit network cases. Two indicators were chosen to represent the accessibility in this study, the coverage of the service area from the center area of each city and the proportion of reachable facilities (e.g., hospitals) among the whole facilities by public transportation and walking. This study set the impedance as travel time, including waiting time, access, and egress time. By using travel time, it is possible to represent the difference in the operating frequencies of public transportation by considering the temporal variance. The flowchart of the analytical process of this study is shown in Figure 1, while the details of the analytical method are further explained below.

Firstly, the percentage of service area from the center area of city by walking and public transportation was identified for each travel time range (i.e., 0-30, 31-60, 61-120, 121-240, and 241-480 minutes) without and with proposed rail transit network. To include the temporal variation by different operating frequencies of public transportation, travel time was analyzed based on the GTFS data. Secondly, the number of reachable hospitals as POI from each mesh was calculated for one hour during the peak time (8–9 a.m.). In general, POI is a specific point on the map and could be expressed on the map of specific facilities. This study was showed the results of accessibility to hospitals among the various type of POI. This calculation shows how many hospitals are accessible from each mesh without and with cases. Finally, by comparing these results, the impact of the proposed public transportation plan is believed to have improved the accessibility to public transportation as a whole, and the resulting analyses were compared between the four cities.

1. Identification of service area:

- ✓ Identification of accessible area
- ✓ Presentation of reachable area from center area of each city in 1-30, 31-60, 61-120, 121-240 and 241-480 minutes by walking and public transportation

2. Analysis of accessibility for selected study areas:

- ✓ Calculation of travel time from centroid of each mesh to POI
- ✓ Evaluation of accessibility for public transportation systems to compare with existing and future cases

3. Comparison between case studies and interpterion of the results:

- ✓ Through geographical information systems (GIS), which provides spatial analysis
- ✓ Comparison as well as the visualization of results

Figure 1. Process of evaluation on accessibility for public transportation

3.1 Case Studies

This study has chosen four Southeast Asian cities (Bangkok, Manila, Ho Chi Minh, and Jakarta) as case study areas. These areas represent the developing city's characteristics, such as private modes, dependent urban structures, and insufficient development of public transportation. The spatial demographic characteristics of the selected study areas are summarized in Table 1. The cities of Bangkok and Ho Chi Minh have greater land areas and smaller population densities compared to Manila and Jakarta. In Manila, the urban structure is more aggregated compared to the other three cities, as indicated by its high population density (Average: 25,631.3 Persons/Km²).

Table 1. Characteristics of case studies (World Pop,2020)

	Study Area (Km²)	Population (Persons)	Density (per./km²)
Bangkok	2,180.0	15,020,343.0	6,890.1
Manila	562.0	14,404,808.0	25,631.3
HCMC	1,740.0	10,899,273.0	6,264.0
Jakarta	688.0	11,818,750.0	17,178.4

In order to understand the current traffic state of the study area, the modal share of each city was summarized and shown in Table 2. 40-50 % of people choose public transportation as the travel mode in Bangkok and Manila. In Bangkok, 40 % of the people use passenger cars, while in Manila, approximately 35 % of the residents select walking (included in others) as their modal choice. On the other hand, the percentage of modal share concerning passenger cars and motorcycles that were occupied was extremely high at 88.3% and 74.8% in Ho Chi Minh and Jakarta, respectively. Based on this Table, we could see that most people are still dependent on private modes such as passenger cars and motorcycles. This demonstrates the need for improvement in the public transportation systems, including rail transit.

Table 2. The modal share of each study area

	Modal Share(%)				
	Public Transport	Passenger Car	Motorcycle	Bicycle	Other
Bangkok	41.6	40.2	13.8	-	4.4
Manila	48.8	8.3	8.2	-	34.7
HCMC	6.3	5.3	83.0	2.8	2.6
Jakarta	8.2	12	62.8	-	17.0

Source: JICA (2018, 2019)

3.2 Data Collection

In order to comprehend the accessibility to public transportation that includes spatial-temporal variation, three types of data are required; (1) Public transportation network derived from GTFS data, (2) Road network data, and (3) POI. The detail of each data is explained below:

(1) Public Transportation Network

Public transportation network was made from GTFS data, including the operating frequency of each public transportation. GTFS data has been used in transit research since Google structure launched the open platform in 2008. GTFS data provides sufficient bases for efficient spatial-temporal public transportation analyses. In reality, various types of paratransit systems such as Jeepney, Songtaew, Bajaj, and TukTuk are operating throughout the city. These transportations are heavily used on a daily basis. However, they were excluded from the evaluation in this analysis since the focus is on the impact of the existing and proposed rail transit routes.

(2) Road Network

The data for road network of each city was acquired and used from Open Street Map (OSM) data. When assessing the accessibility to public transportation, this study assumed that the only mode of access and egress to public transportation stops is by walking. Moreover, the average walking speed was assumed as 4 km/h (Tipakornkiat, et al., 2012).

(3) POI

Many previous studies have evaluated accessibility through different types of POI, such as shops (Widener, et al., 2017), shopping centers (Farber, et al., 2014), medical services (Neutes, 2015), education (Allen, 2019), and workplaces (Widener, et al., 2017, Goliszek, 2017). This study explicitly adopts hospitals as the POI to be assessed in the calculation from the various types of data. One of the reasons for choosing hospitals as POI is that in Southeast Asian cities, there are many shops or factories that are integrated with the residential place, making it difficult to distinguish and evaluate the former. Table 3 shows that the total length of rail transit and roads in each city without and with cases of proposed rail transit, while the number of POI represents the number of hospitals available within the region. The Table has also shown that due to the poorly developed rail transit, the total length of the network is considered very low in all four cities.

Table 3. Overview of rail transit and road network and POI

	Total length of rail transit	Total length of rail transit	Total length of road network (km)	Number of Hospital (POI)
Bangkok	109.0	540.0	20,861.6	182
Manila	79.0	155.1	20,762.9	160
HCMC	0.0	159.0	4,467.2	100
Jakarta	170.2	274.4	16,060.5	1,172

Source: JICA (2018, 2019) and OSM

The public transportation network and distribution of hospitals in each study area are shown in Figure 2. Looking at the Figure, it is understood that the proposed rail transit network in Bangkok is located not only in the center but also around the surrounding area of the city center. Comparatively, Manila and Jakarta's rail transit network are constructed in a way that it radiates from the city center out to the suburbs. On the other hand, in Ho Chi Minh, the rail transit network is only maintained around the center. Regarding the distribution of hospitals in Ho Chi Minh, the majority of the hospitals are located in the city center. In Bangkok and Manila, hospitals exist along the routes of public transportation. In comparison, hospitals in Jakarta are distributed uniformly across the city.

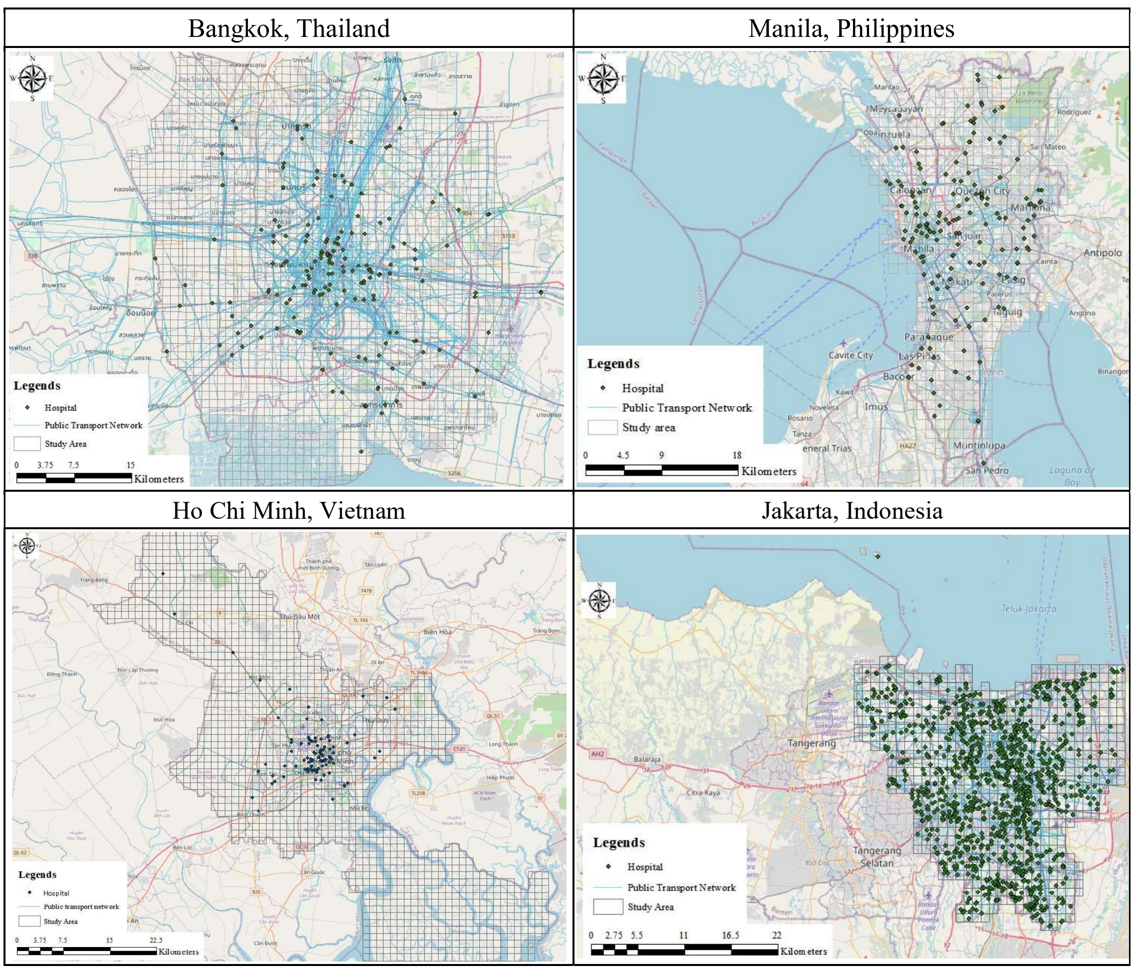


Figure 2. Public transport network and distribution of POI

3.3 Evaluation of Accessibility to Public transportation systems

In this study, the accessibility to public transportation was evaluated in three steps. The details are as follow

Step 1: Development of network dataset for evaluation of accessibility to public transportation
The evaluation was made for the accessibility to public transportation for one hour during peak time. The performance of accessibility was indicated via GTFS data utilizing the three categories of class (stops, routes, and trips) and road network data. Based on these data, the network dataset was developed by ArcGIS. Then, the travel time was calculated using this network dataset, including the time for accessing the public transportation stops and waiting time.

Step 2: Identification of a service area
Service areas created by the Network Analyst of ArcGIS Pro were used to evaluate the accessibility. The service area was analyzed based on travel time. In this study, we have set up five levels of threshold, namely 30, 60, 120, 240, and 480 minutes and then the ratio of each range with and without the proposed rail transit routes were compared to further enhance the identification of the service area.

Step 3: Understanding the proportion of reachable hospitals
The travel time from each mesh to each hospital was calculated under the without and with proposed rail transit cases by ArcGIS Network Analyst tools (Windner, et al., 2015). The calculation of travel time was based on Equation (1).

$$t_{ij} = a_{ij} + w_{ij} + TT_{ij} \tag{1}$$

where,

t_{ij} : Travel time from Origin *i* to Destination *j* (minutes)

a_{ij} : Access time to Public Transport Stops on foot (minutes)

w_{ij} : Waiting time to Public Transport Stops (minutes)

TT_{ij} Travel time between stops by public transport (minutes)

Finally, in order to make a fair comparison, the threshold was set to 60 minutes, and the percentages of reachable hospitals of each city in both cases were analyzed. As a result, it is possible to evaluate and clarify the difference in accessibility.

4. RESULTS

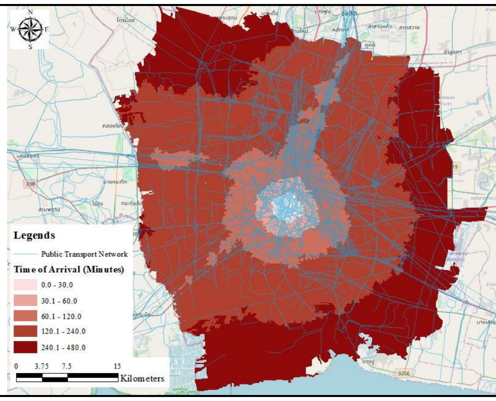
Table 4 and Figure 3 illustrate the results of the service area calculation in each city. The result reveals that 75 % of the area is reachable with more than 120 minutes of travel time from the city center in the case. In Bangkok, the opening of proposed rail transit routes would increase the service area that could be reached significantly by approximately 1,646.4 km² (75.5%) within 120 minutes. Furthermore, the opening of the planned rail transit route has shown that the area of 1,013.2 km² (46.5%) from the center could be reached in less than 60 minutes. In the transport masterplan of Bangkok, rail transit routes are planned to be constructed not only in the city center but also around the city's outskirts. Therefore, the improvement of the citywide accessibility has noticeably increased the service area. Likewise, it could be seen that there is a similar tendency in Jakarta, where the service area that could be reached within 120 minutes has increased by 379.8 km² (55.2%) with the construction of new rail transit. In the case of Manila, the reachable area that could be reached within 60 minutes increased by approximately 126.7 km² (22.6%), indicating that the accessibility in the city center has improved by a significant amount. In the case of Ho Chi Minh, the area that could be reached in 61 to 120 minutes has increased by about 205.1 km² (11.8%). The results have also shown an increased number of people who are utilizing the service of public transportation. Taking the case of Bangkok, the introduction of proposed rail transit has densified the public transportation network in the city. As a result, public transport has improved the service areas of the whole city. Additionally, this could also lead to a modal shift from private modes (Motorcycles and Passenger Cars, etc.) to public transportation.

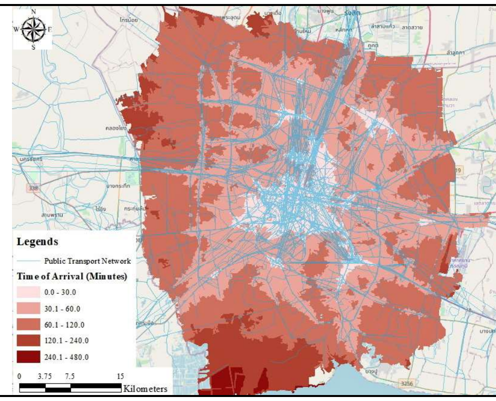
Table 4. Service area under without and with the rail transit network cases

		Range			
	(Unit: Km²)	0-30 minutes	31-60 minutes	61-120 minutes	121-480 minutes
Bangkok	Without Case	15.7 (0.7%)	48.9 (2.2%)	257 (11.8%)	1,858.4 (85.3%)
	With Case	173.2 (7.9%)	840 (38.5%)	954.8(43.8%)	211.9 (9.7%)
	Difference	157.5(7.2%)	791.1(36.3%)	697.8(32.0%)	-1,645.6(-75.5%)
Manila	Without Case	11.2 (2.0%)	23.9 (4.3%)	103 (18.3%)	423.9 (75.4%)
	With Case	13.3 (2.4%)	113.4 (20.2%)	108.9 (19.4%)	326.4 (58.1%)
	Difference	2.1 (0.4%)	89.5 (15.9%)	5.9 (1.1%)	-97.5 (-17.4%)
Ho Chi Minh	Without Case	18.6 (1.1%)	64.7 (3.7%)	207.8 (11.9%)	1,448.9 (83.3%)
	With Case	46.7 (2.7%)	158.4 (9.1%)	518.1 (29.8%)	1,016.8 (58.4%)
	Difference	28.1 (1.6%)	93.7 (5.4%)	310.3 (17.8%)	-432.1 (-24.8%)
Jakarta	Without Case	12.1 (1.8%)	36.9 (5.4%)	142.9 (20.8%)	496.1 (72.1%)
	With Case	14.5 (2.1%)	74.3 (10.8%)	482.9 (70.2%)	116.3 (16.9%)
	Difference	2.4 (0.4%)	37.4 (5.4%)	340.0 (49.4%)	-379.8 (-55.2%)

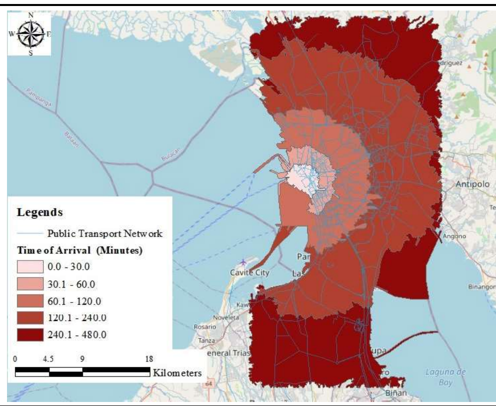
Without case	With Case

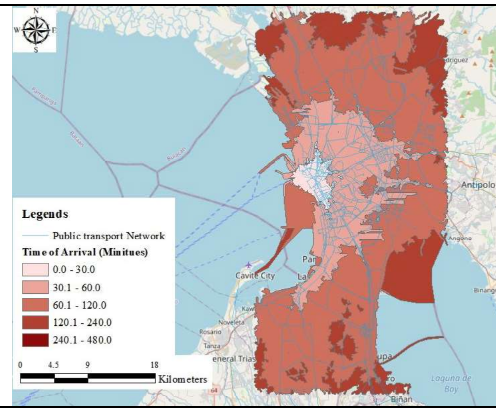
Bangkok



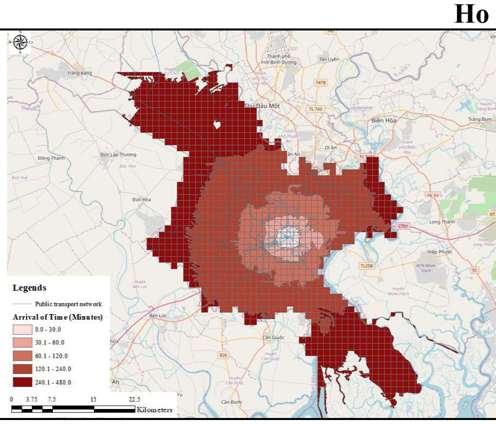


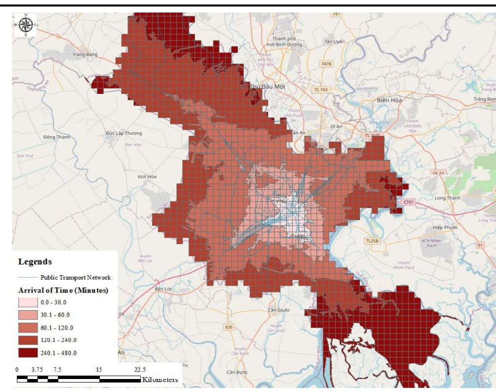
Manila



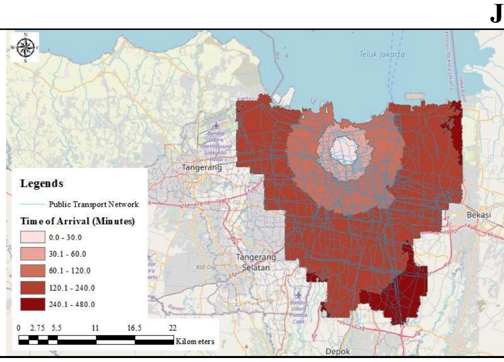


Ho Chi Minh





Jakarta



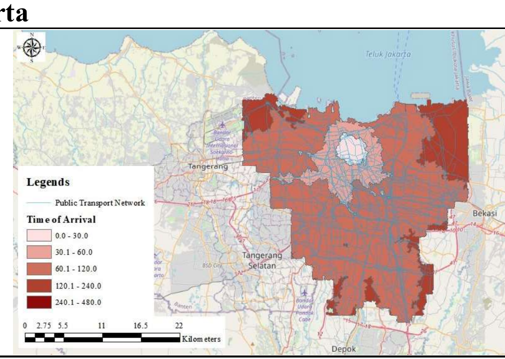


Figure 3. Comparison service area without and with proposed transit network cases

The proportion of the number of reachable hospitals within 60 minutes from each mesh's centroid was calculated for each city under the without and with cases of proposed rail transit. The results are shown in Table 5 and Figure 4. Within 60 minutes without case, 95 % to 100 % of the mesh could reach only 0% to 20% of hospitals in three cities (Bangkok, Ho Chi Minh, and Jakarta). On the other hand, in Manila, 70% of the mesh could only reach 0-20% of the hospitals within the same periodic constraint. Compared to the other cities, it was 25-30% lower, and this was mainly because the area of Manila is much smaller than other cities, and the distribution of hospitals in Manila is concentrated in the center area of city. On the contrary, after introducing the railway network, the same area in Manila where only 0-20% of hospitals could be reached decreased to 274 km² (48.8%), and the area in Bangkok decreased to 1429 km² (65.6%). As mentioned above, the number of hospitals that could be reached is increasing due to the small scope of analysis for Manila, while in Bangkok's case, the massive development of the newly planned railway network has significantly improved the accessibility of public transportation throughout the city.

Figure 4 shows the proportion of reachable hospitals from the centroid of each mesh within 60 minutes, with and without cases. The Figure shows that the darker shadings represent higher accessibility to hospitals from each mesh. In Bangkok, it could be seen that the including of proposed network for urban railway network will improve accessibility not only in the city center but also along with this network. It could also be seen that accessibility has not improved in some northwestern and southern regions. Hence it is necessary to prioritize such areas when proceeding with rail transit development plans in the future. Similar trends are seen in other cities, and these Figures show that from the perspective of public transport fairness, it is necessary to prioritize the development of blank areas with low accessibility.

Table 5. Total area for percentage of reachable hospital without and with cases

		Range				
	(Unit: Km²)	0-20%	21-40%	41-60%	61-80%	81-100%
Bangkok	Without Case	2,070 (99.5%)	10 (0.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	With Case	1,429 (65.6%)	256 (11.5%)	229 (10.6%)	212 (9.8%)	54 (2.5%)
	Difference	-641 (-32.9%)	246 (11.0%)	229 (10.6%)	212 (9.8%)	54 (2.5%)
Manila	Without Case	404 (71.9%)	92 (16.4%)	66 (11.7%)	0 (0.0%)	0 (0.0%)
	With Case	274 (48.8%)	89 (15.8%)	86 (15.3%)	110 (19.6%)	3 (0.5%)
	Difference	-130 (-23.1%)	-3 (0.6%)	20 (3.6%)	110 (19.6%)	3 (0.5%)
Ho Chi Minh	Without Case	1,678 (96.4%)	34 (1.9%)	21 (1.2%)	7 (0.4%)	0 (0.0%)
	With Case	1,595 (91.7%)	41 (2.4%)	24 (1.3%)	70 (4.0%)	10 (0.6%)
	Difference	-83 (-4.7%)	7 (0.5%)	3 (0.1%)	63 (3.6%)	10 (0.6%)
Jakarta	Without Case	688 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	With Case	548 (79.7%)	136 (19.8%)	4(0.5%)	0 (0.0%)	0 (0.0%)
	Difference	-140 (20.3%)	136 (19.8%)	4 (0.5%)	0 (0.0%)	0 (0.0%)

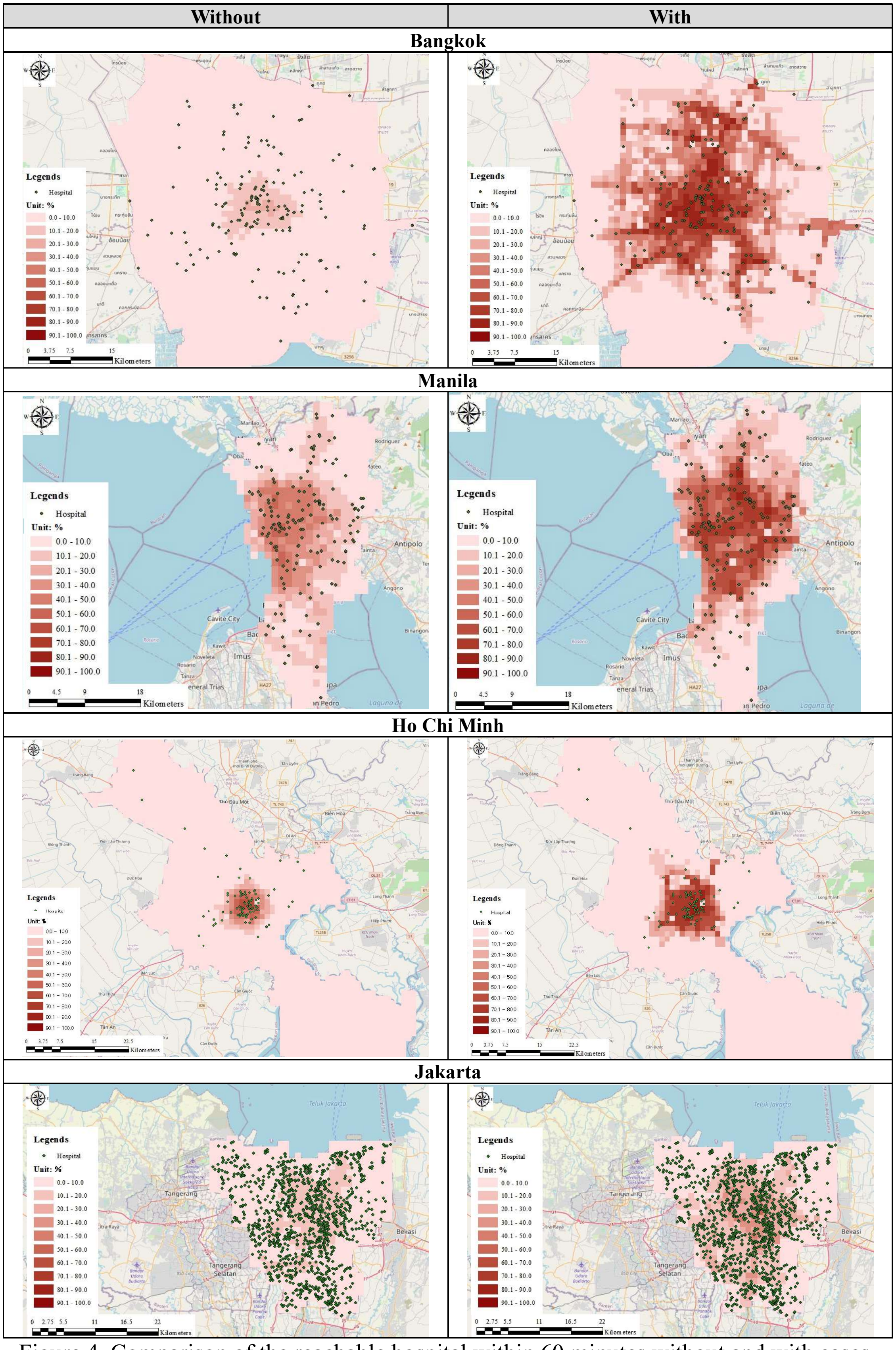


Figure 4. Comparison of the reachable hospital within 60 minutes without and with cases

5. DISCUSSION AND CONCLUSION

In this study, the accessibility of public transportation without and with proposed rail transit network cases was evaluated based on GTFS (General Transit Feed Specification) data in the selected four Southeast Asian Cities. The evaluation of accessibility was done based on two indexes: the coverage of service areas from the center area of city and the number of reachable facilities. This study has selected the hospitals as POI and presented the result. The result of the analysis of service area found that the accessibility to public transportation is very low under the current state of the public transport network in all cities. This analysis also demonstrated that by introducing the proposed rail transit routes, the accessibility of public transportation dramatically improved in Bangkok and Manila. However, in the case of Ho Chi Minh, even with the introduction of proposed public transportation routes, public transportation might be insufficient. There are many paratransit systems, such as Bajaj, Motorcycle taxis, etc., in Jakarta compared to the other cities. In this analysis, the access mode was only set as walking. Nevertheless, the service area in Jakarta is so large.

Furthermore, from the analysis of the number of reachable hospitals in each city, it was possible to understand the distribution relationship between citywide accessibility and public transportation network. The construction of the planned rail network has revealed that the improved rail network will significantly improve the accessibility of public transport not only in the center of the city but also in the areas along the routes. The analysis of reachable hospitals is related to the distribution of POI (e.g., hospitals) data. In Ho Chi Minh, these were only concentrated in the central part of the city and resulting in low accessibility in the outskirts area. This may indicate that there is still room for development in the area along planned railways. Moreover, compared to the other three cities, Jakarta has an enormous number of hospitals and is more widely distributed. This analysis showed that the distribution of facilities to be set as POI has a significant impact on accessibility.

This study assumed the access and egress modes from/to the stops of public transportation systems by foot. In future studies, in order to promote the use of public transportation, it is necessary to plan the public transportation master plan while considering the last mile by foot or paratransit and the multimodality of travel in each city. Therefore, it would be better to include the various types of paratransit mode, then evaluate and compare the accessibility of public transportation in detail. From an analysis of the reachable facilities (e.g., hospitals), the distribution of POI is a significant impact on the results. Many existing studies set the POI for various data types such as schools, workplaces, supermarkets, among others. It is then necessary to evaluate these data and compare their results in totality for the appropriate assessment of proposed rail transit routes.

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