Transit network expansion and accessibility implications
A case study of Gwangju metropolitan area, South Korea

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ABSTRACT

Densely populated metropolitan areas require a well-functioning transit system to serve the travel demands in the area. Because of this, transit networks have evolved with the growth of the metropolis and this has entailed changes in the network's accessibility. This study aimed to explore the changes in accessibility following major transit network expansions in the Gwangju Metropolitan Area. The time distance based accessibility was calculated at three different transit provision stages. The global accessibility measure indicated that the construction of subway line 1 would improve the transit accessibility significantly, but the second line would not have as much impact as line 1. The spatial distribution of accessibility changes appeared to deliver a similar message. However, our findings contradicted with the criticism of the current subway line 1, whose modal share has stayed quite low since its operation, and the expectation of the planned subway line 2. This might be due to the limitations of our definition of accessibility, but it also could be understood that the under-use of subway line 1 hindered the realisation of accessibility impacts in reality.

1. Introduction

Public transit is a crucial element of urban transportation systems. It enables people to move around in a densely developed area, and therefore enhances the interactions between various economic actors. Also, it is recognised as a social tool that alleviates social exclusion by providing mobility to deprived groups or communities who need affordable modes of transportation (LeRoy and Sonstelie, 1983; Martin et al., 2008; SEU, 2003). Moreover, improved transportation networks can make a certain region more attractive and draw in people and businesses, leading to growth in the region (Lakshmanan et al., 2009). As such, public transit induces various effects and those effects are usually realised through improvements in accessibility.

Accessibility is a widely used concept and its improvement has been an aim of transportation planning (Geurs et al., 2012). Accessibility has been defined and operationalized in various forms (Geurs & van Wee, 2004; Páez et al., 2012) and a few studies used the accessibility measure to address various transit issues. For instance, Lovett et al. (2002) measured the bus accessibility to general practitioners presuming 800m as an acceptable walking distance limit. They found that 13% of the East Anglian population could not visit their GP using the local bus services and that remote rural areas faced a worse situation than urban areas. Foth et al. (2013) determined that Toronto developed an equitable public transit system during the 1996–2006 period, which benefitted socially disadvantaged people. In their study, job accessibility and transit travel time were used to assess the transit equity for each census tract. Lee et al. (2012) did a case study of the Seoul metropolitan area and used two separate accessibility measures for buses and subways. The densities of bus stops, given the administrative area, were used to measure bus accessibility, and subway accessibility was defined as the proportion of subway influence spheres, 500 m each, in a unit area. Also, Lee et al. evaluated the accessibility changes after an expansion of the subway network in Seoul by using the travel time recorded on the smart card.

This study aimed to evaluate the accessibility impacts following major investments in a metropolitan area's public transit. In order to measure the transit accessibility, a new algorithm was developed and applied to a case study area and the spatial distribution and its implications were examined.

2. Case study

2. 1 Study area

The study site was Gwangju Metropolitan Area (hereafter Gwangju), which is located about 300 km south of Seoul, the capital of South Korea, as shown in Figure 1. Gwangju is the sixth largest city in South Korea with 1.5 million people residing inside and has functioned as a political, economic, and cultural centre of the southwestern part of the country.

<Figure 1> Gwangju Metropolitan Area

Gwangju was selected as the case study for two reasons: 1) the heavy use of public transit; and 2) its plan for subway network expansion in a few years. Almost 40% of passenger movements have been made by public transit in the last 10 years, which indicates that an improved system can make a difference for many people. Also, the subway expansion plan gave us an opportunity to evaluate its impacts based upon the detailed network changes.

The most frequently used travel mode in Gwangju was the private car in 2015, but until the early 2010s, the local buses accounted for the largest share of passenger journeys (Table 1). The increasing use of private cars can be explained by the spatial pattern of new residential areas within the city along with improved living conditions. The city has grown outwards by developing new residential districts on the fringes of city boundaries. These new districts were constructed with a broad new road network that surrounds the city and people moved to them. However, the public transit networks did not respond to such movements promptly, and this left no other travel options than private cars for those living in the newly developed districts.

<Table 1> Mode share in Gwangju

	2010	2012	2015
Private Car	31.7	36.4	40.3
Taxi	15.6	15.2	13.8
Bus	38.0	36.3	35.0
Subway	2.5	2.7	3.3
Others	12.2	9.4	7.6

Source: Gwangju Metropolitan City, 2015 & 2016

In Gwangju, the transit users that use either the bus or the subway can transfer from one to another for free within a certain amount of time. If a bus user transfers to the subway, it should be within one hour after boarding a bus if they do not want to make any additional payments. For a free transfer from the subway to the bus, the user should board a bus within 30 minutes after alighting from the subway. For between-buses transfers, a one-hour restriction is set, counting from the time of boarding to the first bus. To claim such a free transfer, a smart card should be used. As of 2012, over 88% of transit users make the payment through the smart card while the proportion of car users is still increasing. Therefore, the Gwangju transit system can be treated as an intermodal system.

In Korea, there are 5 subway systems in operation and Gwangju has one of them. In Gwangju, the subway operates with a 20 km single line and currently carries about 50,000 passengers per day on a normal day, which accounts for approximately 3% of modal share. This is the lowest share of all 5 subway systems in Korea (Table 2). Gwangju obviously has the shortest network length, but Daejeon, whose population and network length are similar to Gwangju, shows a 30% higher mode share than Gwangju. This low usage of the subway network can be explained by its current route that links the old Central Business Distrct (CBD) area in the east, the new CBD area in the middle, and the transportation hubs in the west. This straight line deflects the most populous areas in the north and north-western areas and major trip generating points such as universities and the express bus terminals (Goo and Song, 2016). In order to promote the use of the subway system, and to improve the quality of the public transportation service in general, an expansion of the subway system has been planned and the new line will penetrate high-demand districts in the metropolitan area. This addition is expected to raise the subway's modal share over 15% (KDI, 2010).

<Table 2> Mode share in selected metropolitan areas in Korea

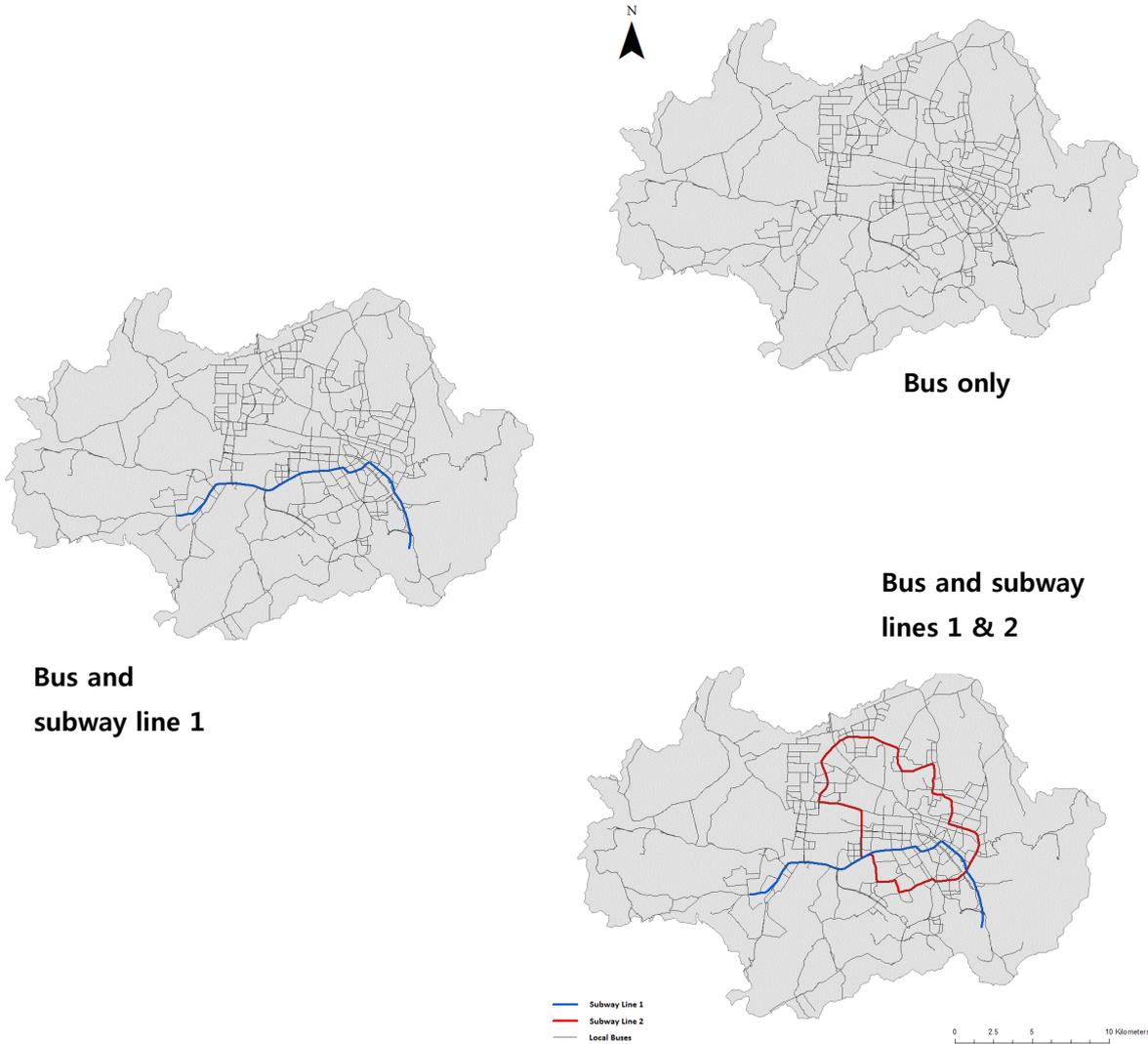|	Subway		Mode share (%, in 2013)				
	Operation begins	Total length	Bus	Subway	Private car/van	Taxi	Others
Busan	1985	132 km	25.6	17.1	31.6	13.2	12.5
Daegu	1997	81 km	21.1	7.9	49.4	11.5	10.1
Daejeon	2006	23 km	22.1	3.8	58.9	10.0	5.2
Gwangju	2004	20 km	36.6	2.7	37.9	14.7	8.1
Seoul	1974	332 km	27.4	38.2	23.1	6.9	4.4
Korea	-		25.9	3.0	53.6	10.4	8.0

2.2 Data

Road and bus network data were acquired from the Korea Transport Database (KTD) and the Gwangju City Bus Information System (GCB). The subway line 2 was digitized by our research team based on the coordinates of each station provided by KTD and Gwangju Metropolitan City. Further transit information such as headways was collected from the Gwangju Metropolitan Transit Corporation.

3. Accessibility analysis

3.1 Three stages of the transit networks

As previously delineated, there are two transit systems operating in Gwangju: bus and subway. Local buses currently cover most of the metropolitan areas though their service levels differ by the areas. Along with the buses, a subway line is operating, and an additional line is planned to be constructed by 2025.

<Figure 2> Three hypothetical stages of transit service provision

With the currently operating bus network and subway line as well as the planned subway line 2, three stages of transit service provision were hypothetically defined in this study: 1) bus network only; 2) bus network and subway line 1; and 3) bus network and subway lines 1 & 2. The first stage has never existed by itself, but was included in order to figure out the accessibility impacts of the subway line 1. The second stage is the current transit system in

Gwangju and the third stage is the future scenario, unless no significant reforms of bus networks are to be implemented. These hypothetical stages are mapped in Figure 2.

3.2 Accessibility measurement

The expansion of public transportation networks usually requires a large investment (Song et al., 2010) and the financial investment is often made by public funding bodies such as the government or public agencies. Therefore, the public expects positive impacts from the new or improved transportation infrastructure. In principle, the improved public transportation networks lower the travel time and cost of the passengers by providing better accessibility and they also enable deprived groups to move around at a reasonable cost (Lakshmanan and Anderson, 2005; SEU, 2003; Lucas, 2006). The subway network in Gwangju is not an exception.

It has been argued that access or accessibility is the most appropriate measure to assess the benefits and/or impacts from transportation, although it should not be considered as a solely perfect measure (Martens 2012; Mavoa et al., 2012). Also, transit accessibility is becoming more important as it is closely related to equity issues as well as the reduction of the detrimental effects of high auto-dependency (Mavoa et al., 2012).

The network accessibility of each bus stop or subway station can be measured using the time distances between the node pairs. Various distance measures can also be used to quantify the accessibility.   Time distance was also chosen, as it is a more relevant measure when space is in consideration and urban travel behaviour is heavily affected by the time distance (Burnett, 1978; Louf and Barthelemy, 2014).

The accessibility is calculated following Equation 1. *K* is a scaling constant used for better readability and can be any number suitable for analysis results. The following inverse distance sum was used:

$$A_i^{node} = k \sum_{j, i \neq j}^{N} \frac{1}{t_{ij}} \qquad \text{equation (1)}$$

where N : Number of subway stations and bus stops (N = 1 to n)
k: Scaling constant,
t_{ij}: Network-based time distance between station/stop i and j

To compute the accessibility, it is necessary to compute the time distance between all origin-destination pairs. The calculation of time distance between Origin-Destination (O-D) pairs was based on Park and Lee (2015), who developed a thorough methodology that measures time distance based upon the graph theory and the shortest distance algorithm. Park and Lee (2015) used actual travel time obtained from the smart card transaction database, but no such data existed for Gwangju. So, the travel time was calculated using the average travel time of each bus line and subway line.

Also, it is important to note that people can transfer between lines and/or modes at a low or very minimum cost. Thus, transfers were also considered in the calculations. Passengers can transfer to buses on-site, i.e. at the same bus stop, or at a nearby bus stop. Also, as previously noted, they can transfer between modes, and this normally requires movement over a certain distance. Therefore, it became necessary to have a clear boundary within which passengers are willing to transfer. The boundaries were determined using the definition of the subway station catchment area and the bus stop catchment area. If a person transferred from a bus to the subway, the search area was given a 500 m radius (Kim et al., 2002; Lee et al., 2012). Also, the transfer between buses or from the subway to a bus was set to a 400 m radius following Kittelson & Associates (2002). In the accessibility calculations, transfer had two impacts: people could reach broader areas at the same or similar financial costs, but they needed to spend more time than direct movements. Therefore, a transfer penalty should be set to 8 minutes and 3 seconds at each transfer, which was the average transfer time in Gwangju (Yang, 2015).

4. Results and discussion

Accessibility at a global level has increased with the provision of the subway network, as presented in Table 3. This result can be taken for granted as our hypothetical networks expanded without a single stop or a line closing while the bus networks remained the same throughout the stages.
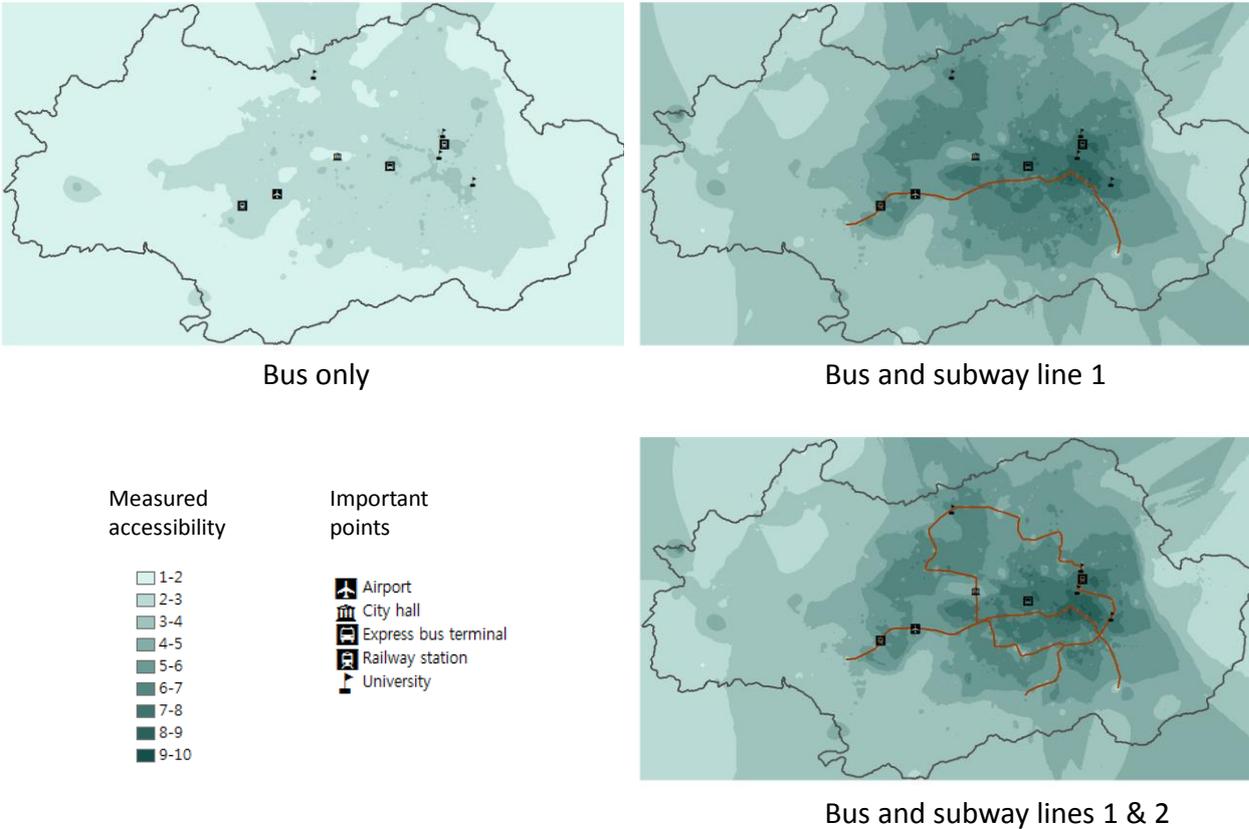
<Table 3> Global accessibility

	Av. Acc.[*]	Av. Acc. Bus	Av. Acc. Subway	Total
Bus only (n=2254)	2.292	2.292	-	5165.81
Bus + Subway line 1 (n=2274)	5.585	5.612	2.495	12699.63
Bus + Subway lines 1 & 2 (n=2318)	5.599	5.685	2.544	12977.67

[*] Av. Acc. means average accessibility.

It is interesting to note that the addition of the subway line 1 more than doubled the global accessibility while subway line 2 did not have as much of an impact on increasing the accessibility level in general. The large increase in the transit accessibility level between stages 1 and 2 can be explained by different characteristics between the bus and the subway. Subway line 1 is a single line that stretches for only 20 km, but it can be over 40% faster than the bus and go under the major roads where many local buses pass. So subway line 1 can significantly reduce the time distances between the O-D pairs on the subway line, regardless of the modes of transit. As a result, the average accessibility of bus stops more than doubled, indicating that the huge jump in transit accessibility comes from the buses and not from the newly added subway stations. Subway line 2 also helped to improve the transit accessibility, but its impact was not as impressive as line 1.

The local accessibility of each bus stop and subway station was mapped by stages, as shown in Figure 3. As the bus stops and subway stations are depicted as points, the

accessibility information was saved as point data, which is difficult to visualise .Therefore, surface maps were generated using the Inverse Distance Weighted (IDW) function.

Bus only

Bus and subway line 1

Measured accessibility

Important points

- 1-2
- 2-3
- 3-4
- 4-5
- 5-6
- 6-7
- 7-8
- 8-9
- 9-10

✈ Airport
🏛 City hall
🚌 Express bus terminal
🚉 Railway station
⚲ University

Bus and subway lines 1 & 2

<Figure 3> Changes in local accessibility

As illustrated in Figure 3, the high accessibility areas expanded as the subway network was added over time. The construction of subway line 1 indeed increased the transit accessibility where the line went through, and it also increased accessibility to its northern and south-eastern areas, which was quite noticeable and unexpected. Moreover, an additional subway line that was planned to be a circular line with a tail did not seem to change the accessibility pattern. This unexpected result can be explained by the bus network in Gwangju. Many bus routes were designed to pass where the stations of subway line 1 are located. But the circular line covers areas with fewer bus routes and bus stops as the majority of line 2 stations are located at newly developed residential areas underserved by the bus network. Subway line 2 was designed to provide better transit accessibility to residential areas on the fringes of the metropolitan area and trip generating points. Thus, the construction of subway line 2 was highly expected to enhance the transit accessibility of those areas. However, it turned out that subway line 1 already achieved this and the impacts of the second line turned out to be minimal. This unexpected result was due to the definition of accessibility based upon time distance and our assumption of travel behaviour, i.e. shortest distance. On the other hand, our results indicate that the current transit network can provide a more enhanced accessibility without the help of an additional subway line if the subway is fully and effectively utilised by potential passengers.

5. Conclusions

The construction or expansion of a transit network in an urban area is expected to benefit the general public by enhancing accessibility and providing mobility. The public transit is often presumed to benefit people with less means of private transportation. Thus, it is particularly important to evaluate its impacts. This study attempted to discover the benefits of expanding a transit network in a metropolitan area by using the concept of accessibility. Our analysis results suggested that the current transit system has significantly improved the accessibility based upon the time distance, but the planned new line would not induce such a huge jump of accessibility at both global and local levels. This unexpected finding can be seen as a limitation of our approach, i.e., the usage of time distance calibrated with the assumption of the shortest distance journey makings, and as unrealised benefits that could materialise once people began to use the current subway network more frequently.

This study can be seen as a valuable addition to existing literature, especially in the fields of urban planning and transportation studies as the intermodal transit systems were taken into account at the same time.

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