wctr'04
4-8 july 2004 / istanbul-turkey

EVALUATION OF URBAN STRUCTURE FOR MORE EFFECTIVE USE OF REGIONAL SUBWAY NETWORK

Seungil Lee
Department of Urban Engineering, The University of Seoul
90 Jeonnong-dong, Dongdaemun-gu, Seoul 130-743, Korea
Email: silee@uos.ac.kr

Abstract

The paper reports on a study to conduct a measurement of regional accessibility of Seoul Metropolitan Subway in Korea with respect to geographical configuration of the subway network and the spatial distribution of land uses in the region as well as in each catchment area of the subway stations seeking for its more effective use. It can be supposed that the ineffective use of the subway network is due to the regional imbalances of jobs and housing. So the regional accessibility of Seoul Metropolitan Subway in terms of work trips should be represented by means of the population and employment which can potentially reach a station from all other stations of the network. The difference between the subway accessibility indicators means the rate of jobs-housing imbalances in the influence sphere of the network. The accessibility measuring model developed using raster GIS technique disaggregates the population and employment of a catchment area into numerous tiny raster cells and determines network travel times between raster cells using a time-oriented minimum-path algorithm. The model represents the accessibility indicators of an origin cell after calculating population and employment from all destination cells as a function of travel time.

Keywords: Accessibility; Subway; Catchment area; Jobs-housing balance; Accessibility measuring model
Topic Area: F1 Transport and Spatial Development

1. Introduction

These days public transportation oriented transport policies have been increasingly important because they can mitigate serious traffic congestion and the consequent environmental problems due to rapid increasing car ownership. From various means of public transportation subway attracts lots of interests from urban planners and transport experts because of its mass and regular transportation capability. However, it is difficult to construct a new subway network due to its enormously high construction costs. Therefore, the existing subway should be used in highly effective way.

The paper reports on a study to conduct a measurement of regional accessibility of the Seoul Metropolitan Subway in Korea with respect to geographical configuration of the subway network and the spatial distribution of land uses in the region as well as in the influence sphere of each of the subway stations seeking for its more effective use. The Seoul Metropolitan Subway consists of 468 two-way links and 410 nodes for 16 lines. It was supposed that the ineffective use of the subway network is due to the mismatch of suburbanization of workplaces with suburban spread of population. So the regional accessibility of the Seoul Metropolitan Subway in terms of work trips should be represented by means of the potential employed population for a station from all other stations of the network. Then it can assess the existing spatial distribution of the population of the region with respect to the optimal use of the subway network.

The measurement will be made with an accessibility model developed using raster GIS combined with networks coded as vectors. The model disaggregates the workplaces and the population of the influence sphere (Max. 500m) of each station into its raster cells with the size of 75 by 75m in consideration of the spatial distribution of land uses. As the accessibility of a destination cell of a station the model calculates the potential employed population which are collected from all origin cells of the other stations as a function of travel time, i.e. the attraction of a destination declines with travel time. In fact the travel time is composed of the travel time in the subway network and the access and egress time by walking within the influence sphere of each station. The model determines the network travel time using a time-oriented minimum-path algorithm which adds boarding and transfer waiting time to in-vehicle travel time as a function of service frequency of the connecting line. The entire travel time will be calculated after associating the network nodes with the station cells.

The accessibility model can represent the spatial distribution of regional accessibility of the subway network after the completion of calculating all destination cells. The result can be applied to evaluate the urban structure for the more effective use of the subway. In the paper the model specifications and the results of the accessibility measurement of the Seoul Metropolitan Subway will be presented.

2. Accessibility

2.1. Land-use transport interaction and accessibility

A general definition of accessibility is that it is the potential of opportunities for interaction (Hansen, 1959). The original Hansen's accessibility concept, rather closer to potentiality model, has been developed into the indices indicating real spatial interactions of activities after being applied to many urban simulation models like gravity models, Lowry models or Wilson's entropy models (Kim, 1987). Wegener (1996) describes precisely how the accessibility indices can be embedded in the 'land-use transport feedback cycle' (see Figure 1):

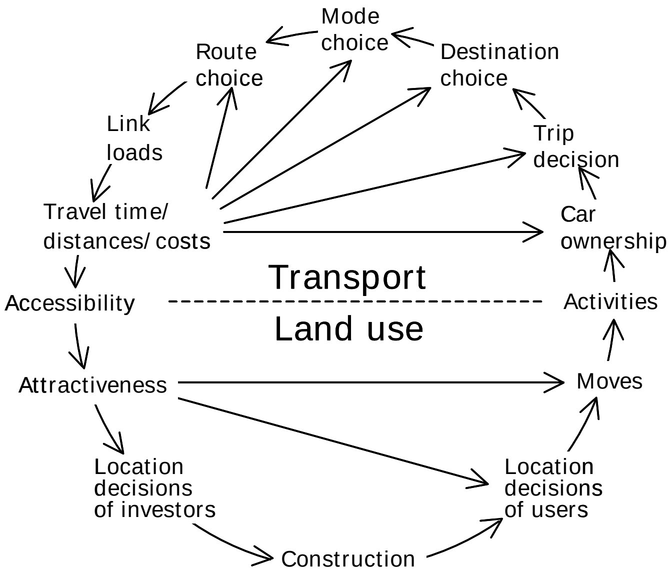

Figure 1. 'Land-use transport feedback cycle' (Wegener, 1996)

The distribution of land uses determines the location of human activities, which require spatial interactions to overcome the distance between them. These trips occur in the transport system in a sequence of choices: decisions to own a car, to make a trip and to select destination, mode and route. These decisions result in flows in the networks and congestion and increases in travel times, distances and costs. Travel times, distances and costs create opportunities for spatial interactions and can be measured as accessibility. The distribution of accessibility in space, together with other attractiveness indicators, determines location decisions and consequently conducts changes of the land-use system, which in turn determine the location of activities. In the repeating land-use transport interaction process, the changes in the transport system as well as in the land-use system result in the changes of spatial distribution of accessibility.

Based on the description, accessibility is, in simple terms, a construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them (Keeble et al., 1982; Schürmann et al., 1997):

$$A_i = \sum_j g(w_j)\, f(c_{ij}) \tag{1}$$

where A_i is the accessibility of area i, W_j is the activity W, caused by allocation of land uses, to be reached in area j, and c_{ij} is the generalized transport cost of reaching area j from area i. The functions $g(W_j)$ and $f(c_{ij})$ are called activity functions and impedance functions, respectively. They are associated multiplicatively, i.e. are weights to each other. A_i is the accumulated total of the activities reachable at j weighted by the ease of getting from i to j.

However, this simple form of accessibility measurement would be varied unlimitedly, if the complicate factors for trip and location decisions in the transport and land-use system are taken into account. The most important ones mentioned here are trip purposes and mode choices in the transport system, and different activities and types of actors in the land-use system:

In the transport system, the spatial interaction formula should be trip purpose specific, because a certain type of activity determines trip, mode and destination differently under different conditions. For example, business trips tend to be more distance dependent than shopping trips. In the same manner, modal accessibility indicators may be presented separately in order to demonstrate differences in accessibility between modes. Or they may be integrated into one indicator as multimodal accessibility expressing the combined effect of alternative modes for a location (Vickerman et al., 1995; Schürmann et al., 1997). Contrary to multimodality, intermodal accessibility indicators take account of intermodal trips involving two or more modes. The calculation of intermodal accessibility indicators requires the capability of minimum path search in a multimodal network.

In the land-use system, there are a variety of actors with different requirements with respect to their location and with different sensitivity with respect to travel time, travel cost or other trip characteristics. So it may be necessary to develop different accessibility indicators for different activities and types of actors. For this task the actors should be disaggregated according to their location-related and socio-economic features. However, it is associated with the problem of enormous data requirements.

2.2. Subway accessibility

The measurement of subway accessibility, on which this study focuses, differs from that of road accessibility essentially in taking account of waiting and transfer times at stations. Generally, the travel time to enter into subway network is much longer than into road network, because there are less access and egress opportunities in subway network. In comparison with other public transport subway has various mode combinations at either end of a trip such as subway-walk-or-cycle, subway-bus-walk, and subway-car-or-taxi. In order to bring the characteristics of subway into accessibility indicators, the measurement of subway accessibility requires the capability of minimum path search in a network taking account of fixed link travel time and additional travel time components. To these components belong waiting and transfer times at stations as well as network access and egress times at either end using different modes.

In addition, subway accessibility indicators are also highly dependent on the composition of the activities located in a catchment area surrounding subway station. This isochrone accessibility approach for rail network has a long historical background (O'sullivan et al., 2000). However, the extent of the catchment area for a station is still indefinite, because it strongly depends on diverse factors such as trip purpose, socio-economic status of actors, urban traffic situation or urban structure. The distance of 10 minutes' walk is commonly acceptable. A further refinement is to classify catchment area types according to different modes to enter into subway network, that is, subway-walk (Type A), subway-bus-walk (Type B), and subway-car-or-taxi (Type C) (see Figure 2).

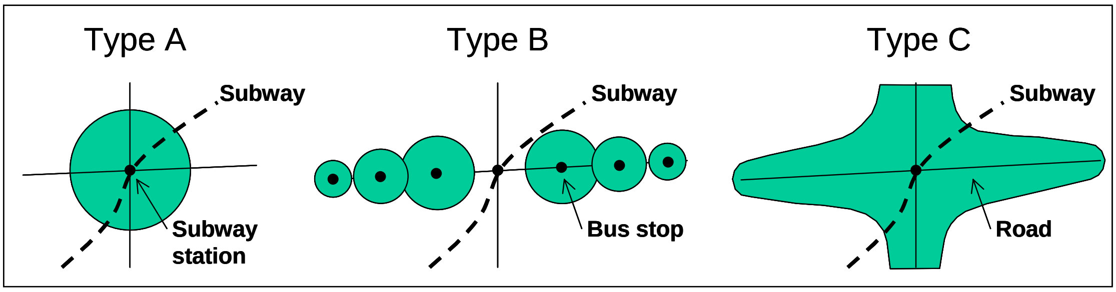

Figure 2. Three types of catchment area of subway station

To sum up, the subway accessibility indicators measured taking account of the above mentioned factors imply the ones determined by geographical configuration of a subway network or spatial distribution of activities and actors in catchment areas as well as in a city or an urban region. Therefore, changes of the subway accessibility mean new additional linkages and nodes in the network, improvements of service frequency in a line or changes of spatial distribution of land uses in an area.

2.3. Jobs-housing balance and subway accessibility

As a land-use policy, balancing jobs and housing is expected to mitigate traffic congestion and related environmental problems (Peng, 1997). The from American cities stemmed concept of geographical balance of workplaces and residences is based on the proposition that having more people closer to their jobs will reduce vehicle kilometer traveled (VKT) (Cervero, 1989). There are many researches revealed empirically the relationship between the jobs-housing ratio and urban commuting patterns in terms of VKT and trip length (Hamilton, 1982; White, 1988; Small and Song, 1992; Cervero, 1996). This concept is further developed to sustainable urban forms such as 'Compact city' and 'Decentralized concentration' (Breheny, 1992; Wegener, 1996; Lee, 2003).

In a broad sense, jobs-housing balance is to be related with accessibility, because spatial distribution of residences and workplaces is to measure accessibility taking account of potential interactions between them. If an area is designated with a feeble difference between the accessibility of employable residents and that of workplaces, the area is to be defined as ‘balanced’. Furthermore, if the accessibilities are measured by means of public transport, the meaning of the accessibility becomes closer to that of jobs-housing balance.

In this study the accessibility, into which the concept of jobs-housing balance is adopted, will be applied to evaluate spatial distribution of population and employment in catchment area of subway stations as well as in an urban region serviced by a subway network seeking for more effective use of subway. For the purpose, the difference between the accessibility of employed population and that of employment should be calculated after separately measuring the accessibility indicators:

$$\Delta A_i = \left| A_{pop\,i} - A_{emp\,i} \right| \tag{2}$$

where ΔA_i is the difference between the accessibility of employable population $A_{pop\ i}$ and the accessibility of employment $A_{emp\ i}$ in area i.

2.4. Accessibility measuring model

The accessibility measuring model developed for this study is based on the assumption that the attraction of a destination increases with size and declines with travel time. Therefore, both size and distance of destinations are taken into account. The activity function is here linear: the size of a destination W_j is represented by employable population or employment in the destination j. The impedance function is however nonlinear: a negative exponential function is here applied in which parameter β indicates that nearby destinations are given greater weight than remote ones. A generalized cost c_{ij} denotes travel time between origin i and destination j.

$$A_i = \sum_j W_j \exp(-\beta c_{ij}) \tag{3}$$

In order to apply the accessibility function in a subway network of an urban region, the model requires two main modules of calculation processes: one is for land-use system, the other is for transport system (see Figure 3).

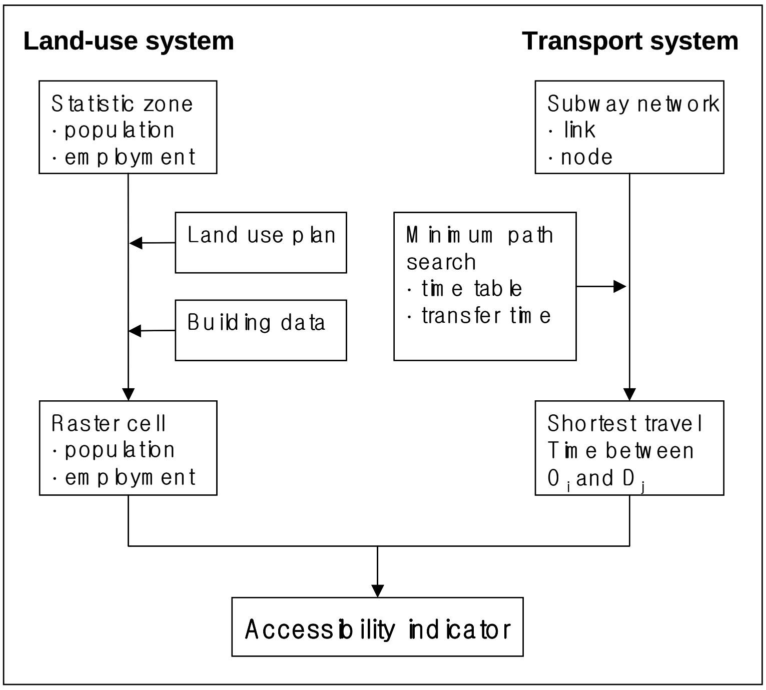

Figure 3. The accessibility measuring model

The module for land-use system is to allocate the aggregate activities of statistic zones to identical small spatial divisions. For this task the model uses raster GIS technique in which the size of a spatial division, a so-called raster cell, is defined as 75x75m. The smaller is the size of a raster cell, the more accurate travel times between them can be calculated, but on the other hand, the demand of data becomes greater. As a function of building ground area weighted by land-use types, the model calculates the population and employment in the catchment area (maximum radius 500m) of a subway station from those of the statistic zones to which it belongs (see Figure 3 and Equation (4)). In this process GIS transforms buildings into the corresponding rasters which contain their own portions of the activities.

$$P_i = P_k \cdot \frac{GBA_i \cdot w_i}{\sum_{i \in k} GBA_i \cdot w_i} \tag{4}$$

where P_k and P_i denote the population and employment in statistic zone k and those allocated to building i located in the zone. GBA_i, weighted with land-use type factor w_i, indicates the ground building area of building i.

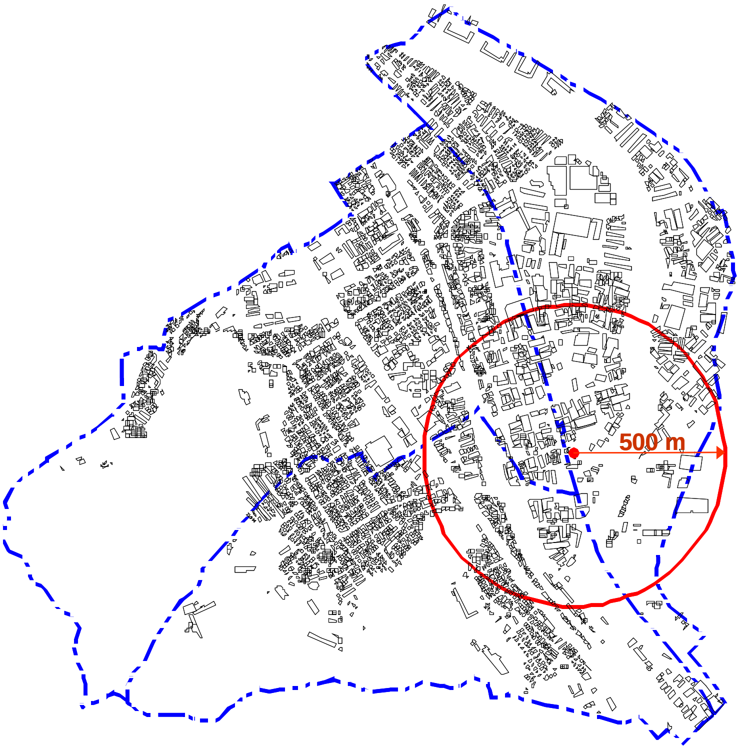

Figure 4. Disaggregation of activities according to building area

The module for transport system is to calculate the shortest travel time for any combination of origin and destination cells located in catchment areas of subway stations. The model requires subway network coded as vectors between station nodes. The network is linked to the raster representation of activities by associating each station node with a raster cell as reference. The travel time between an origin and a destination cell is composed of network travel time and access-and-egress time by walk within catchment area (see Figure 5).

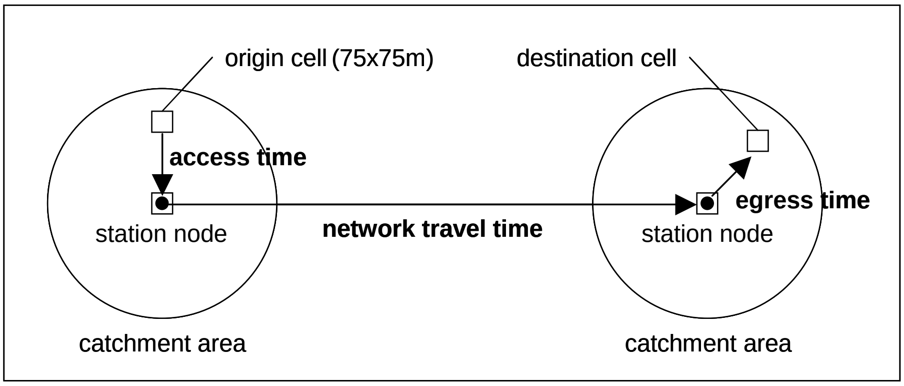

Figure 5. Calculation of travel time

From the two travel time components the network travel time is decisive in determining the shortest travel time between two cells. Because there are many alternative routes for a pair of origin and destination in a subway network, the model should search all alternative routes between two cells and select the shortest one from them. Moore algorithm is applied for this task (Wegener, 1974; 1983). The model determines the shortest network travel time between two cells ij using a time-oriented minimum-path algorithm which adds boarding time t^{boarding} and transfer waiting time t^{transfer} to in-vehicle travel time $t^{\text{in-vehicle}}$ as a function of service frequency of the connecting line. The number of transferring times n increases transfer waiting time multiplicatively. The total travel time t^{total} is to be calculated by associating the network nodes with the station cells:

$$t_{ij}^{total} = t_i^{access} + \min(t_{ij}^{boarding} + t_{ij}^{in-vehicle} + n \cdot t_{ij}^{transfer}) + t_j^{egress} \tag{5}$$

Based on the two main computing processes, the model measures the accessibility of a cell in an urban region with the potential employable population and employment collected from all destination cells as a function of travel time. In this study the accessibility measuring model is applied for Seoul Metropolitan Subway to investigate its ineffective use.

3. Seoul Metropolitan Subway

3.1. Spatial development of Seoul Metropolitan Area

The City of Seoul which has in 2000 a population of 9.9 million in a land area of 606 km^2 is surrounded by the province of Kyonggi which has a population of 11.35 million in a land area of 11,164 km^2 (see Figure 6). The City of Seoul and the Province of Kyonggi together comprise Seoul Metropolitan Area (SMA).

In terms of socio-economic dependency the Province of Kyonggi is firmly associated with the City of Seoul as its hinterland. The hinterland which occupies 94.9 percent of SMA's land area lies within more than 50 km from the center of the city. The City of Seoul with high population density of 16,342 persons/km^2 has continuous problems of land and housing scarcity which result in continuous outflow of its residents to outer suburbs.

SMA has since 1997 gained a net influx of 548,136 people, bringing the total number of its residents to 22.63 million, or 46.9 percent of the nation's total population, as of 2002. It is still predicable that people will continue to migrate to SMA in coming years seeking better opportunities for jobs, education and housing. Despite SMA's continuous influx of population, the City of Seoul has reported an outflow of residents since 1990, as many people left the city to seek cheaper residences in newly-built residential towns and other cities in the hinterland (Mugavin, 2003) (see Table 1).

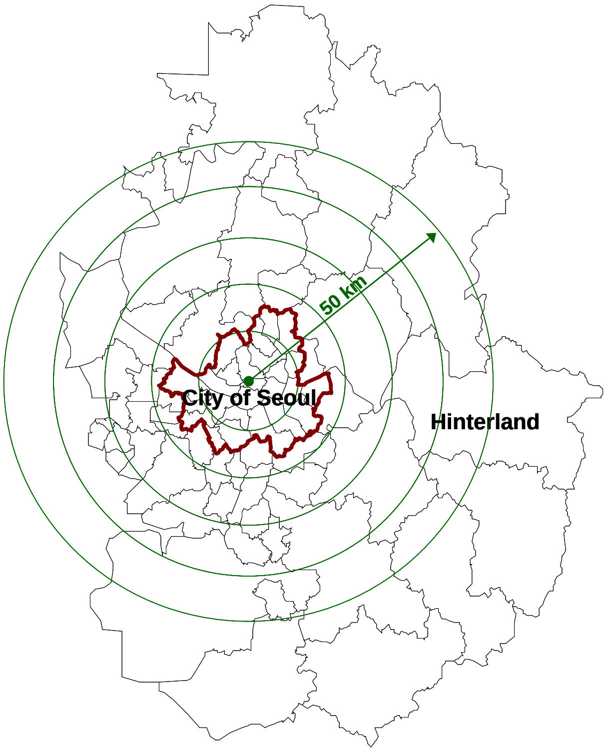

Figure 6. Seoul Metropolitan Area

Table 1. Population changes(Units: persons, %)

	1980	**1990 (*1990-1980*)**	**2000 (*2000-1990*)**
The City of Seoul	8,350,616	10,603,250 (*27.0*)	9,895,217 (*-6.7*)
	62.9	*57.1*	*46.3*
The Hinterland	4,930,335	7,970,687 (*61.7*)	11,459,273 (*43.8*)
	37.1	*42.9*	*53.7*
Sum	13,280,951	18,573,937 (*39.9*)	21,354,490 (*15.0*)
	100.0	*100.0*	*100.0*

(Source: STAT-Korea)

Table 2. Employment changes(Units: jobs, %)

	1993	**1997 (*1997-1993*)**	**2000 (*2000-1997*)**
The City of Seoul	2,945,848	2,663,184 (*-9.6*)	2,466,373 (*-7.4*)
	62.8	*58.1*	*53.9*
The Hinterland	1,670,081	1,921,927 (*15.1*)	2,112,827 (*9.9*)
	36.2	*41.9*	*46.1*
Sum	4,615,929	4,585,111 (*-0.7*)	4,579,200 (*-0.1*)
	100.0	*100.0*	*100.0*

Remark: Firms with 4 or more employees are surveyed.

(Source: STAT-Korea)

The process of suburbanization can also be found in employment: the City of Seoul loses constantly its workplaces to the hinterland (see Table 2). Like the migrated residents firms also seek inexpensive lands and buildings for their productive activities. Especially, service sectors are moving remarkably to outer suburbs following the residents settled in newly-built residential areas (Lee, 2003).

However, most of workplaces are concentrated in the city center of Seoul and the centers of inner suburbs. The imbalance of residences and workplaces in the urban region generates much more traffic in the city center and inner and outer suburbs as well as on their connecting road network (see Table 3). In special, the traffic loads on the connecting networks increase very rapidly.

Table 3. Changes in work trips(Units: trips/day, %)

	1980	**1990 (*1990-1980*)**	**2000 (*2000-1990*)**
Within Seoul	1,884,518	3,138,785 (*66.6*)	3,314,508 (*5.6*)
	65.2	*55.3*	*41.6*
From Seoul to Hinterland	112,586	253,525 (*125.2*)	390,399 (*54.0*)
	3.9	*4.5*	*4.9*
From Hinterland To Seoul	170,674	570,736 (*15.1*)	914,038 (*9.9*)
	36.2	*41.9*	*46.1*
Within Hinterland	720,765	1,716,843 (*138.2*)	3,356,112 (*95.5*)
	25.0	*30.2*	*42.1*

(Source: STAT-Korea)

3.2. Ineffective use of Seoul Metropolitan Subway (SMS)

The total length of Seoul Metropolitan Subway (SMS) amounts to 475.8 km in 2000. About 70 percent of the subway network are located in the City of Seoul. SMS is extended to the outer suburbs with its six main extension lines (see Figure 7).

SMS has been extensively constructed in a short time period (see Table 4). In comparison with urban spatial development of SMA the subway network is however not so widely extended. The extension of the network leans mainly to the City of Seoul.

Nevertheless, SMA is, compared to other cities in Asia, with very high utilization of rail and bus transport. However, the utilization of SMS is not higher than that of car (see Table 5). During last six years the situation of SMS was not remarkably changed, while the rate of car use was continuously on the increase.

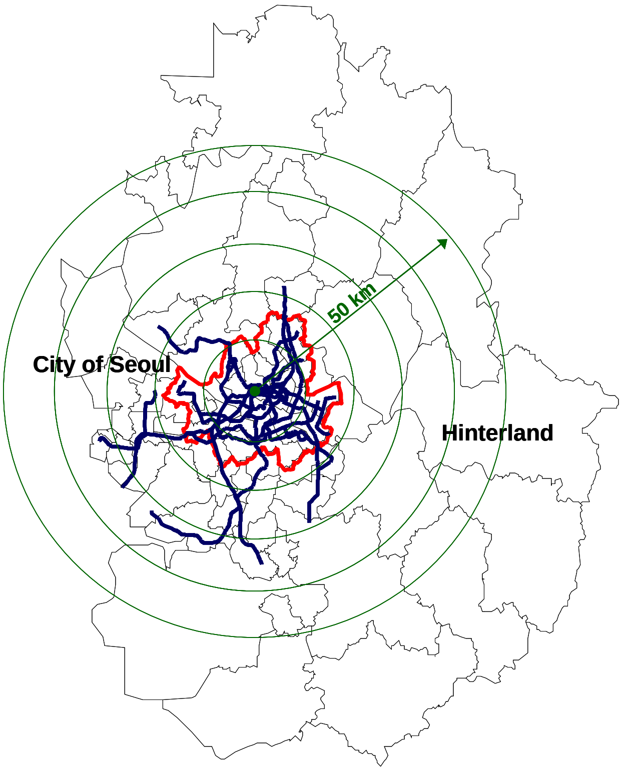

Figure 7. Seoul Metropolitan Subway

Table 4. Extension of the subway network(Units: km, %)

	1985	1990 (*'90-'85*)	1995 (*'90-'85*)	2000 (*2000-'90*)
The City of Seoul	54.7	58.8 (*7.7*)	125.7 (*113.8*)	338.0 (*168.9*)
The Hinterland	43.7	68.6 (*60.0*)	87.1 (*27*)	137.8 (*58.2*)

(Source: STAT-Korea; Ministry of Construction and Transport; KORAIL)

Table 5. Trips by modes(Units: thousand trips/day, %)

	Total	Car	Bus	Subway	Taxi	Others
1996	41,408.8	12,123.4	13,571.2	8,552.4	4,211.5	2,950.4
	100.0	*29.3*	*32.8*	*20.7*	*10.2*	*7.0*
2002	47,789.7	15,740.9	13,864.6	11,254.9	4,000.1	2,929.2
	100.0	*32.9*	*29.0*	*23.6*	*8.4*	*6.1*

(Source: The City of Seoul)

There are three viewpoints to understand the ineffective utilization of SMS:

The first one is due to the insufficiency of the subway extensions to the hinterland to which many people moved seeking cheaper residences. The suburbanization of residences and workplaces in SMA has been more progressive than the extension of subway network to the hinterland. Therefore, the residents have no other choice except cars for their work trips to the city of Seoul.

The second one is related with car ownership. The rapidly growing rate of car ownership according to increasing income results in an intensive use of cars for all travel purposes within the City of Seoul and also from the hinterland to the City of Seoul and vice versa. Until now the rapid suburbanization process has been strongly reinforced by the construction of new roads together with the increasing car ownership.

The last one has a concern with jobs-housing balance. The decentralization of residences and workplaces to the hinterland has taken place mismatched in terms of job-housing balance. The mismatch causes more travel costs in using SMS, i.e. ineffective use of the subway. In this case the utilization of car is more effective. This study focuses mainly on this viewpoint.

4. Implementation of the Accessibility measuring model

4.1. Generation of input data

In order to investigate the ineffective use of SMS with respect to the spatial distribution of residences and workplaces with a given subway network the accessibility measuring model developed for this study was applied. For an implementation of the model two sets of input data were prepared: land-use data and transport data.

To the land-use data belong population, employment, buildings, land-use plans, road network, and statistical zones. For the disaggregate representation of the land-use data SMA was subdivided into about 785,000 raster cells each representing an area of 75 by 75m. The model allocated the land-use data to the raster cells. Population and employment data for 2000 were extracted from census statistics based on ‘Dong’ by Korea National Statistical Office. Dong is the smallest statistic zone which is identical to traffic zone. With smaller statistic zones the errors by allocating to raster cells can be reduced with higher accuracy. SMA has 1,129 Dongs as of 2000. From them 661 Dongs are linked to the catchment areas of SMS which were considered to measure the accessibilities of the subway network. Based on the land-use plans and the topographies of SMA the aggregate population and employment were distributed into the raster cells (see Equation 4). The buildings located in the Dongs of the catchment areas amount to about 1.25 million. The ground building areas of each building were computed to allocate population and employment into the raster cells representing buildings. Because the population data are classified by 5 year age groups, the employable population from 20 to 60 years old were used. The disaggregate data of the raster cells can be re-aggregated to arbitrary spatial divisions. Table 6 presents the employable population and employment re-aggregated for the spatial divisions of city center, inner suburbs and the hinterland. The results imply that the employable population of SMA are more decentralized than the employment.

Table 6. Spatial distribution of activities in SMA(Units: persons, jobs, %)

	Employable population		Employment	
	Dong	**Catchment area**	**Dong**	**Catchment area**
City center	323,315	184,441 (*57.0*)	665,468	570,426 (*85.7*)
Inner suburbs	5,289,688	2,698,999 (*51.0*)	2,688,148	1,618,318 (*60.2*)
The hinterland	2,711,012	898,932 (*33.2*)	1,251,803	455,772 (*36.4*)

Remarks:

1) Employable population means the persons ranging from 20 to 60 years old.

2) Firms with 4 or more employees are surveyed.

To the transport data belong the subway network information. The subway network of SMA consists of 410 nodes and 468 links including those for transfer. The subway network information for the model is contained in a single network file which consists of a link part and a line part. For each link the information such as link type (rail link and transfer connection for walking), from-node and to-node, link length in km, and link travel time in minute were coded. For 16 subway lines for SMS list of nodes and peak-hour headway were coded. Especially, for 76 transfer connections walking transfer times were surveyed and coded with 13 categories of 0.5 minutes intervals (Maximum 6.5 minutes). Walking and waiting times for transfer play a critical roll to determine a shortest travel time route. For example, some transfer times amount to over 10 minutes which are equivalent to 5 link travel times.

4.3. Results of accessibility measurement

The accessibility measuring model calculated two accessibility indicators of the employable population and employment in the catchment areas of SMS based on the given subway network. The results can be represented both graphically and tabularly. There are three kinds of graphical outputs: accessibility indicators of employable residences and workplaces (see Figure 8) and the differences between two accessibility indicators (see Figure 9). From each accessibility indicator the spatial distribution of activities under the given geographical configuration of subway network can be evaluated. For example, the areas of higher residences accessibility in the city center are narrower than those of workplaces accessibility. This means that The employable population are more decentralized than the employment, because the residents living in the hinterland can hardly reach the city center from the increasing travel time. In addition, some nodes which show lower accessibility indicator just near the higher ones result from longer transfer walking and waiting time for those subway lines.

The difference between two accessibility dA_i indicators can more apparently represent the spatial distribution of the accessibility indicators.

$$dA_i = \frac{|AW_i - AR_i|}{AR_i} \tag{6}$$

where AR_i denotes accessibility indicator of residences and AW_i indicates that of workplaces in raster cell i.

Figure 9 indicates that the catchment areas on the connection axes at the right side of the city center have a lot of imbalance between jobs and housing. The reason can be also found in a poor subway connectivity between the city center or inner suburbs and outer suburbs.

To evaluate the whole subway network in the urban region with respect of jobs-housing balance two methods were introduced: a weighted average and a GINI coefficient. The weighted average rate of employment accessibility to population accessibility indicates the regional balance of jobs and residences. A GINI coefficient is used to measure the inequality in jobs-housing balance between the catchment areas. A GINI coefficient of zero indicates that the balanced residences and workplaces accessibility in an area is evenly distributed. A GINI coefficient close to one indicates that the distribution of balanced accessibility is highly polarized, i.e. few centers of the hinterland have a very high balance of residences and workplaces accessibilities.

Table 7. Spatial distribution of subway accessibility

	Weighted average rate of employment acc. to population	**GINI coefficient**
City center	0.704	0.00100
Inner suburbs	0.702	0.00289
The hinterland	0.702	0.00641

Table 7 shows the application results of the two indicators. The area of city center which indicates a slightly higher weighted average rate and the lowest GINI coefficient is easily reachable for both jobs and residences from everywhere in SMA using SMS. On the other hand, the catchment areas in the hinterland denoting the highest GINI coefficient indicate that only few centers of outer suburbs are balanced in regional accessibility of jobs and residences using SMS. In order to enhance the utilization of SMS in those areas either the network configuration should be improved to reduce travel times or new workplaces should be settled in that area or in the areas reachable with less travel costs by subway.

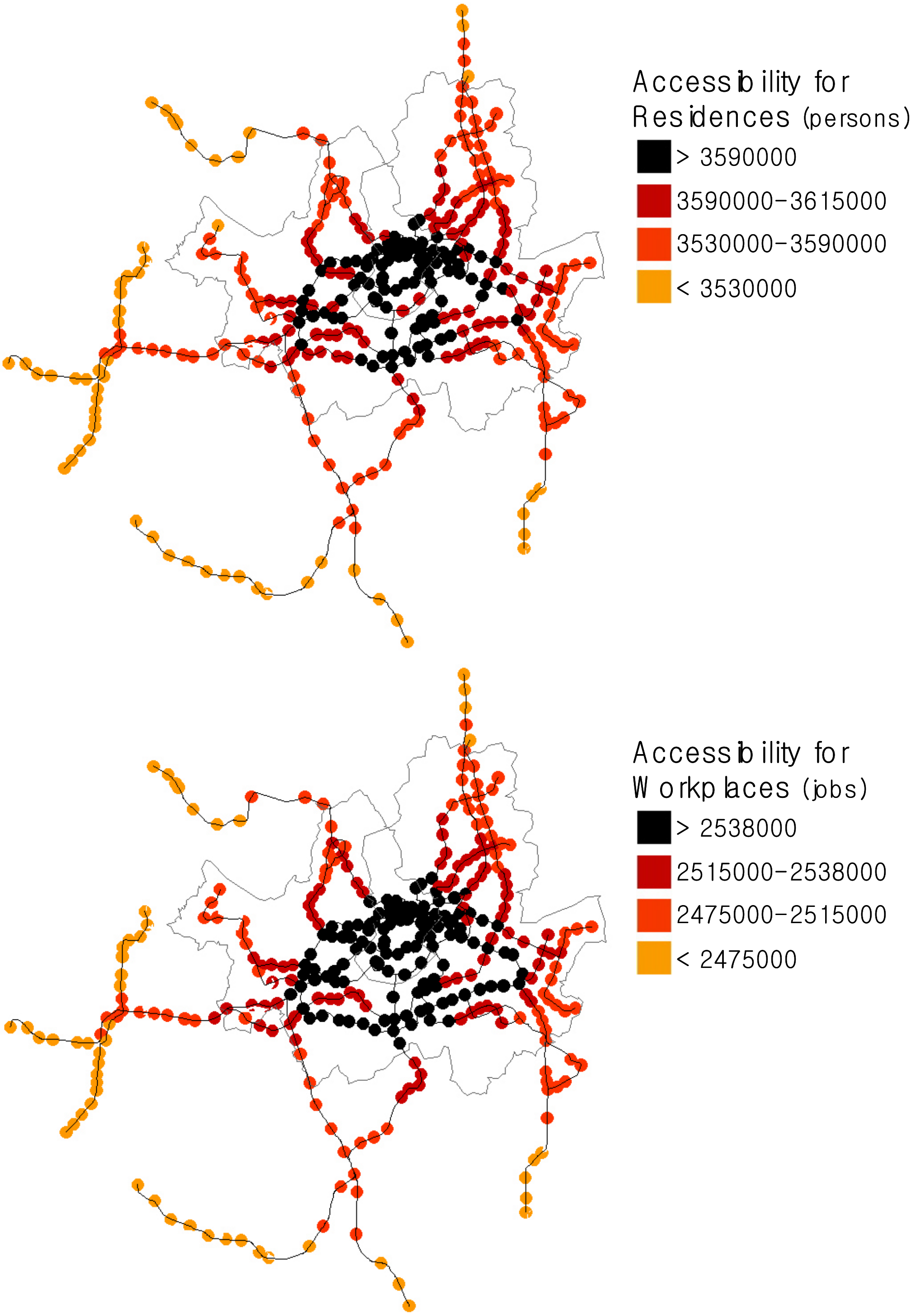

Figure 8. Accessibility indicators of residences (top) and workplaces (bottom)

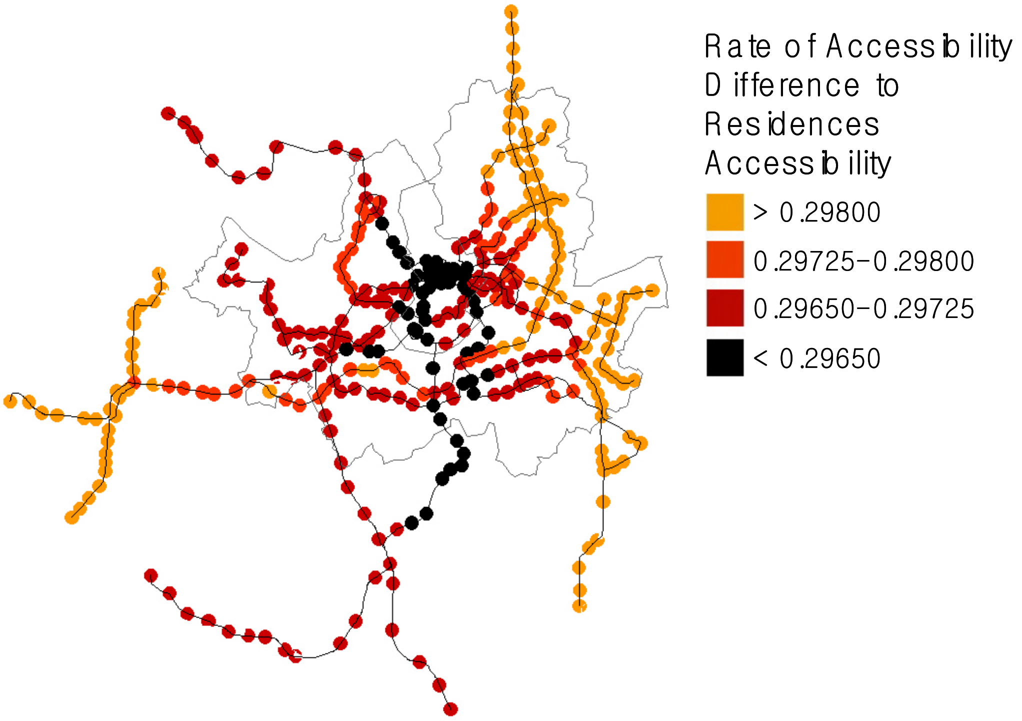

Figure 9. Difference between two accessibility indicators

5. Conclusion

This paper proposed a model that can be used to measure regional accessibilities for residences and workplaces with respect to more effective utilization of subway. The result implies that there are two alternative strategies applicable to improve the use of subway for work trips. The one suggestion is that the geographical configuration of a subway network should be improved to reduce total travel times. The other suggestion is that new workplaces or residences should be settled in the area to be improved in accessibility or in the areas reachable to the area with less travel costs by subway. The two different strategies is not to be separated because land-use system and transport system for an urban system interact mutually in a tight relationship. Therefore, the approach of land-use transport interaction is appropriate for the purpose of the study.

However, this study does not means that reducing the accessibility difference in an urban region always enhances the utilization of subway which is related to many other aspects such as monetary travel costs, life style, comfort and safety, . The land-use policy of jobs-housing balance is only a necessary condition for more effective use of subway. But it is one of the most important conditions.

The accessibility measuring model developed in this study can also be applied to monitor the changes in accessibility that result from the growth of cities and from the relocation of activities, and also to evaluate the consequences of alternative land-use and transport plans for metropolitan areas. However, the model requires a lot of improvements in future. First of all, the model can handle the other types of subway catchment area with respect to the mode combinations in that area, i.e. bus and car or taxi. Furthermore, the model can be also applied for other trip purposes effectively.

References

Breheny, M.J., 1992. Sustainable development and urban form: An introduction. In: Breheny, M.J. (Ed.): Sustainable development and urban form. European Research in Regional Science 2. London: Pion, 160-181.

Cervero, R., 1996. Jobs-Housing balance revisited: Trends and Impacts in the San Francisco Bay Area. American Planning Association Journal Autumn, 492-511.

Cervero, R., 1989. Jobs-Housing balancing and regional mobility. American Planning Association Journal Spring, 136-150.

Hamilton, B.W., 1982. Wasteful commuting. Journal of Political Economy 90, 1035-1053.

Hansen, W.G., 1959. How accessibility shapes land use?. Journal of the American Planning Association 25 1, 73-76.

Keeble, D., Owens, P.L. and Thompson, C., 1982. Regional accessibility and economic potential in the European Community. Regional Studies, 16, 419-432.

Kim, K.S., 1987. Concepts and Measures of Accessibility. Journal of Transportation Research of Korea 5(1), 33-46.

Lee, S., 2003. Reconnaissance of environmentally sustainable urban structure. International Journal of Urban Sciences 7(2), 148-168.

Mugavin, D., 2003. Compact city: some aspects and lessons from Singapore. International Journal of Urban Sciences 7 (2), 180-192.

O’sullivan, D., Morrison, A. and Shearer, J., 2000. Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. International Journal of Geographical Information Science, 14(1), 85-104.

Peng, Z., 1997. The jobs-housing balance and urban commuting. Urban Studies, 34(8), 1215-1235.

Schürmann, C., Spiekermann, K. and Wegener, M., 1997. Accessibility Indicators. Berichte aus dem Institut für Raumplanung, SASI Deliverable D5. Report to the European Commission. Dortmund: Institut für Raumplanung Universität Dortmund.

Small, K.A. and Song, S., 1992. Wasteful commuting: A resolution', Journal of Urban Economics 28, 277-286.

Vickerman, R., Spiekermann, K. and Wegener, M., 1995. Accessibility and Economic Development in Europe, Paper presented at the ESF/EC Euroconference on European Transport and Communication Networks: Policies on European Networks, Espinho.

Wegener, M., 1996. Reduction of CO2 emissions of transport by reorganization of urban activities. In: Hayashi, Y. and Roy, J. (Eds.): Transport, Land-use and the Environment. Dordrecht, Boston, London: Kluwer, 103-124.

Wegener, M., 1983. Description of the Dortmund Region Model. Arbeitspapier 8. Dortmund: Institut für Raumplanung.

Wegener, M., 1974. Polis: Simulationsmodell für die Stadtentwicklungsplanung: Routensuchalgorithmen. Battelle-Institut (unpublished paper).

White, M.J., 1988. Urban commuting journeys are not wasteful. Journal of Political Economy 96, 1097-1110.