地域硏究, 第11卷 第2號
1995年 12月 pp.53~62

Subway Network Expansion and Spatial Restructuring of Accessibility in Seoul*

Keumsook Lee
Sungshin Women's University
Seoul 136-742, Korea

1. Introduction

A change in a transportation network in turn tends to generate changes in the spatial structure of accessibility and in land use patterns ultimately (Davidson, 1977). Therefore the issue of the impact of transportation changes on spatial organization has been raised frequently in regional and/or transportation related studies. The subway system in Seoul has undergone several stages, expanding at several phases, since its construction in 1974. It is likely that the accessibility of individual nodes in the subway network will be affected by the changes in the network in response to the addition of new linkages. As a consequence, the spatial structure of land values will be changed, since accessibility is a main factor in the generation of the land value. Certain centers will be advantaged by the change in the spatial structure of nodal accessibility, while others will be disadvantaged relatively. In addition, these changes will be reflected on the land use pattern and the intensity. Therefore, accessibility can be one of the most useful concept for the study of spatial structure of a region, if it can be calibrated appropriately. Various numerical indicators of the accessibility and the measurement models have been suggested in theoretical analysis and used in empirical investigation and planning. However, there are some conceptual confusion as well as gaps between the verbal definitions of the concept and the numerical indicators. It may be related with the nature of accessibility. The concept of accessibility itself is related variously to the concepts of nearness, proximity, ease of spatial interaction, potential of opportunities for interaction, or potentiality of contacts with activities or supplies (Weibull, 1980, p.54). The measurement of accessibility needs to be differentiated according to the purpose of study as well as the types of transportation systems, since the characteristics of each transport system can be significantly different.

The objective of this study is to examine the changes in the spatial structure of accessibility in Seoul which will be collateral with the expansion of subway network. A new algorithm of graph theoretic accessibility measurement developed by Lee (K. Lee, 1995) is applied on this problem. The graph theoretic analysis is appropriate for computing the nodal accessibility in a urban subway network, in which the characteristics of each link are almost uniform, and thus it is proper

* This work was supported in part by the Grant for Professors of Sungshin Women's University

to abstract the network as a graph. From this we attempt to suggest the direction of changes in the spatial structure of land value and land use pattern in Seoul.

2. Subway Systems in Seoul

1) Transformation of the subway network

The subway network in Seoul has been transformed at several phases, since it has been constructed in 1974. The Line One has been constructed in 1974. Ten years later, the Line Two has been constructed and the Line Three and the Line Four have been constructed at the following year. This subway network has been settled down as one of the major mass transits while operating for almost ten years with the partial extension. Four more lines are currently on the construction and another four lines are planned to be completed in the year of 2001. The total length of subway system in Metropolitan Seoul area would be 398km, when these lines are completed. In this study we compare the spatial structure of nodal accessibility in two phases. These two transformation phases are classified as follows : The first phase is from the construction of Line One until the construction of Line Two, Line Three, and Line Four; the second phase begins with the completion of Line Five, Line Six, Line Seven, and Line Eight.

The subway traffic volume has been increased dramatically during the first phase. And the modal share has also been increased continuously. Figure 1 and Figure 2 show the trend of changes in the subway traffic volume and the modal shares in Seoul, respectively. It is anticipated to be increased up to three quarters of the total traffic volume in the second phase.

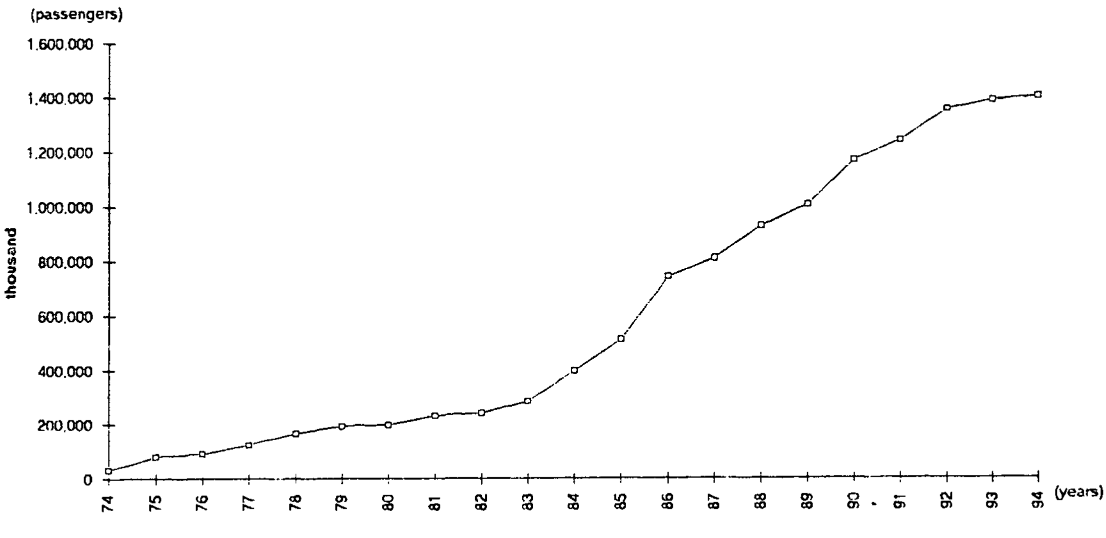

Figure 1. Trend of Subway Traffic Volume

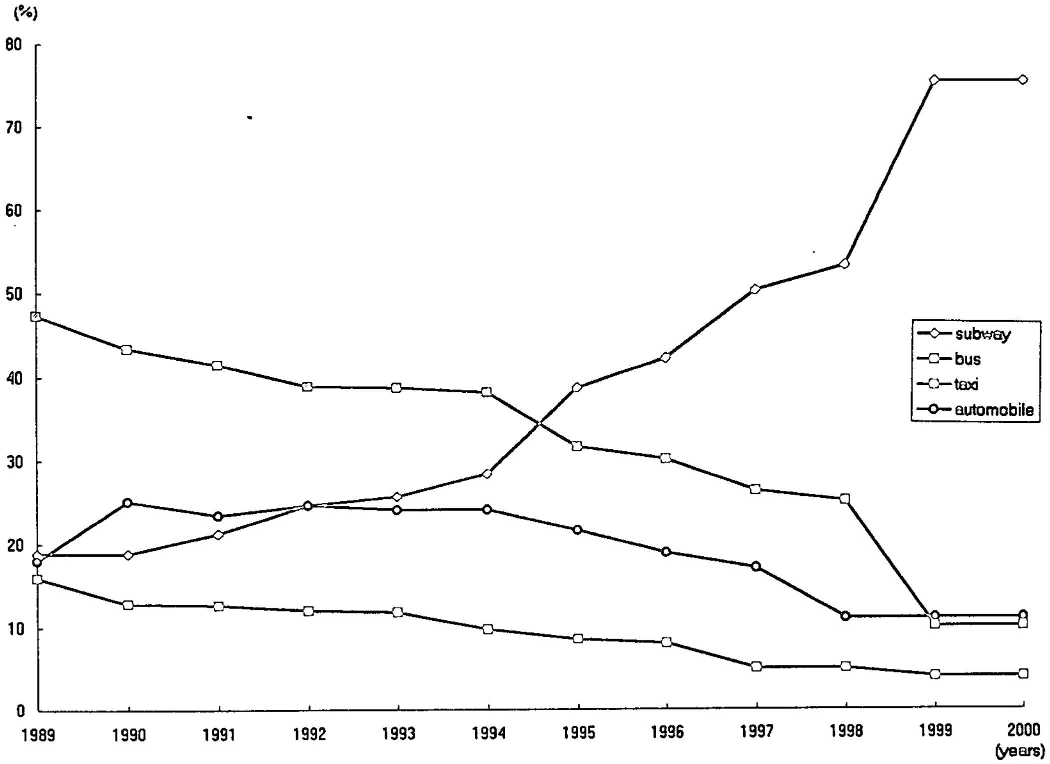

Figure 2. Trend of Modal Shanes in Seoul

2) The behavioral characteristics of subway traffic

Accessibility concerns physical and temporal constraints on behaviour of individuals and thus is an aspect of the freedom of action of individuals (Weibull, 1980). Actually travelling behavior shows quite different patterns in accordance with transport systems. Therefore, the identification of the characteristics of a particular transport system is needed in accessibility measurement modelling. A number of studies (Koenig, 1978, p.1; see also Vickerman, 1974; Koenig, 1977) pointed out that the concept of accessibi-lity is associated with appreciation of the type and quality of transport systems as well as appreciation of the availability of satisfactory potential destinations with respect to a given need (e.g. looking for an employment place, shopping, leisure, etc.), which can be reached from a location using a particular transportation system (Burns and Golob, 1976, p.175; see also Karlvist, 197 ; Black and Conroy, 1977). The configurations of such characteristics may be reflected on the behavioral responses of people for the particular transport system and affected by such attributes of a transport system as route distance, travel time, travel cost, supply capacity, assortment, operation hours, congestion, queuing time, and location in relation to other activities or supplies.

In order to investigate the characteristics of intra-urban subway traffics, we have performed a questionnaire survey on 450 persons in this study. The most important factor they consider to take subway is time. The number of stations between the origin and the destination does not affect particularly the decision making for taking subway. This propensity appears prominently when they are alined on the same line in particular. On the other hand, most respondent manifested quite big psychological strain imposed on transfer to different lines. The majority of respondent give score around 70 as the weight for the psychological strain imposed on transfer to other lines. People may not take only the shortest paths between nodes, when they take intra−urban subway. Therefore, Shimbel's method (Shimbel, 1953), which excluded all other paths except the shortest one, may not be appropriate for the calibration of nodal accessibility in an intra-urban subway network. These two characteristics of subway traffic should be taken into account in modelling the the accessibility measurement scheme in a subway network.

3. Nodal Accessibility Measurement Scheme in Subway Networks

Since the characteristics of each transport system will be significantly different, the measurement of accessibility may need to be differentiated according to the type of transportation systems. When examining a transportation network for evidence of the spatial organization of an area, therefore, we need an appropriate accessibility measurement which is available to account the traffic characteristics of the particular transportation system. A large number of numerical indicators of accessibility have been suggested in various research fields with different purposes.

The graph theoretic analysis has been utilized frequently as a measurement scheme of the nodal accessibility in a transportation network (Garrison, 1960; Nystuen and Dacey, 1961; Berge, 1962; Kansky, 1963; Muraco, 1972; Murayama, 1994). It is possible to describe and analyze the spatial organization of a transportation network in using graph theory. In particular, the graph theoretic analysis is appropriate for the accessibility measurements of track transportation network, such as rail and subway networks of which the characteristics of each link are almost uniform and thus proper to abstract as a graph and represent by a matrix. In determining nodal accessibility by the graph theoretic analysis procedures, the distance matrix is topological, andr thus distance is defined as the number of linkages between nodes. Taaffe and Gauthier (1973) claimed this definition of distance is reasonable when the concern is strictly with the structural properties of a network, or when one has only a minimum amount of information available about that network. In particular, this definition of distance is reasonable for intra-urban subway network. The resulting accessibility matrix of the network does not alter structural relationships between nodes compare to nodal accessibility calibrated by the valued graph analysis in intra-urban subway network, because the lengths between stations are almost even in urban subway networks and the characteristics of each link are almost identical.

A new algorithm of graph theoretic accessibility measurement developed by Lee(1995) is utilized in this study. Two new concepts are introduced in this algorithm, which allow to consider the characteristics of intra-urban subway traffics. The first one is the concept of inconvenience of transfer which is one of the most influential factors in intra-urban subway traffics. All nodes have been treated identically in the existing graph theoretic accessibility measurements. As mentioned above, most respondents felt quite big psychological strain in transferring to different lines. This indicates that the mobility can be reduced, if the passenger have to transfer the subway line on the way to the destination. Thus it should be noticed that transfer nodes give significantly different influence on the traffic behavior in an intra-urban subway system. In order to take into account such transfer influence of a sequence of linkages, an weighting method is introduced in this model, which is in sharp contrast with existing graph theoretic accessibility measurement models: In the latter, all nodes were treated identically. The second one is the selective inclusion of some indirect connection paths in determination has been pointed out to be the major shortcoming of graph theoretic accessibility measurements. In the other extreme, therefore, Shimbel (1953) introduced the shortest path procedure to eliminate counting of all redundant paths. However, in an intra-urban subway network, it is not expected to be proper to count only the shortest path between nodal pairs or to account indirect connection via the scalar-weighted multiplication procedure. Passengers are usually involved more than the shortest path between nodal pairs in using surface transportation modes, particularly in taking the intra-urban subway. It is thus desirable to take into account probable paths selectively in the calibration of nodal accessibility. Namely, in the determination of nodal accessibility, some indirect connection paths should be included, while others should not be. The new algorithm is programmed to include effective indirect connections paths efficiently during the matrix multiplication procedure.

In addition to these two new concepts, the distance decay relationship is also introduced into the analysis. The weighting procedure for discounting indirect connections, which was introduced by Garrison (1960), is modified in this model. A major difficulty in the scalar-weighted multiplication procedure is how to determine the appropriate value of the scalar. In the Garrison study, the value 0.3 was chosen arbitrarily, without justification. However, this value is apparently too small for the intra-urban subway traffic, where the number of stations between nodes is not an important factor and the distance-decay effect is not so high. We thus adopt the value 0.7 for the scalar, which is the result of the questionnaire survey.

The calibration procedure of the generalized accessibility measurement of an intra-urban subway networks is the following: To determine nodal accessibility, the subway network abstracted as a graph, and information on the relationship between pairs of nodes is recorded in a matrix. Since the cell entries of the matrix may be information on the presence or absence of linkages between a nodal pair, zero or one is assigned ($C_{mn}=1$, or 0 according to whether there is direct connection between node m and node n). There may exist several routes with different linkages between node m and node n., if there exist several other nodes li in between. This can be taken into account by writing the connection between nodes m and n in the form:

$$C^{(k)}_{mn}, = \sum_{l_1, l_2, \ldots l_{k-1}}{}' C_{ml_1} C_{l_1 l_2} C_{l_2 l_3} \cdots C_{l_{k-1} n} t^{p}$$

where p is the number of transfers along the route and t is a scalar$(0 < t < 1)$ measuring the ineffectiveness of a transfer. There are restrictions in the summation: $l_i \neq m$, $l_i \neq n$, and $l_i \neq l_j$ for $i \neq j$. This scheme is different from the existing graph theoretic analysis in which successive matrices are derived by multiplying the original connection matrix. In this way the redundant paths such as loops can be excluded. Accordingly, the total connectivity between nodes m and n may be expressed as

$$T_{mn} = \sum_{k=1}^{k_{\max}} s^{k} \; C^{(k)}_{mn},$$

where s is a scalar $(0 < s < 1)$ measuring the distance decay effect. Thus the factor s^k represents the decrease of connectivity with the number k of nodes on the path; k_{max} denotes the diameter of the network.

Finally, the accessibility of node m can be obtained by summing the total connectivity T_{mn} over all n:

$$A_m = \sum_n T_{mn}$$

This expression takes into account indirect connections of relevance as well as all direct ones between the nodes of the network, and gives the accessibility of a given node with respect to other nodes in the network. The larger the value of the row sum, the greater the accessibility of the node. Such a large value imply high accessibility in the structural sense that the node has a high level of centrality in the network. Although this measurement of accessibility depends only on the presence or absence of connections between nodal pairs, it is sensitive to the presence of spatial clustering of nodes in the network.

4. Comparison of Spatial Patterns of Nodal Accessibility

Using the formula developed in the preceding section, we compute the the nodal accessibility in the subway network of Seoul for the two phases and analyze the spatial structure in this section. is calculated for two phases of the subway network in Seoul and the spatial structures are analysed in this study. For the estimation of intra-urban accessibility, the whole subway network extended into the metropolitan Seoul area is considered. The inclusion of such a large area in the analysis is necessary, since the subway network is connects these surrounding regions. We assume that the rest of the elements such as land use policy, housing policy, and other transport related policies are deliberately kept unchanged for the period of this study, to provide a *cetris paribus* character to the analysis. This method thus allows to evaluate the accessibility difference among places and across time periods. The larger the value for a place, the more advantageous its position, not only for subway transport but also for efficient economic activity. It is a more favourable place to which to make business trips, with which to exchange information, and to which to deliver goods. It is also possible to estimate the land value growth in any zone, if the relationship between the land value and accessibility is known. Examining the changes in the spatial structure of accessibility due to the proposed subway network, we can also forecast the direction of changes in the structure of intra-urban land use.

The spatial patterns of nodal accessibility in two phases are fairly different. Figure 3 and Figure 4 show the spatial structures of nodal accessibility for two phases illustrated in three dimension. The nodal accessibility values in the second phase are increased dramatically overall as compared with those in the first phase. There exist even more than ten times increase in the highest nodal accessibility, even though the increase tend to decline as one moves outward from the center.

The future linkages of intra-urban subway network would greatly be greatly different from the existing linkages. The spatial structure of nodal accessibility in the first phase is revealed to draw an almost concentric pattern, spreading from the center toward the north, southwest, and southeast. Nodes centrally located in the subway network generally demonstrate

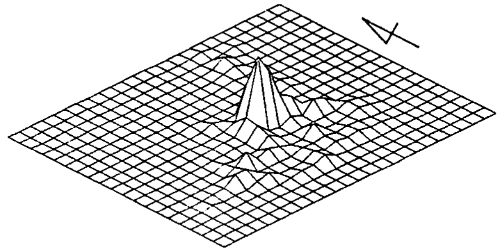

Figure 3. Spatial Structure of Nodal Accessibility in the First Phase Subway Network

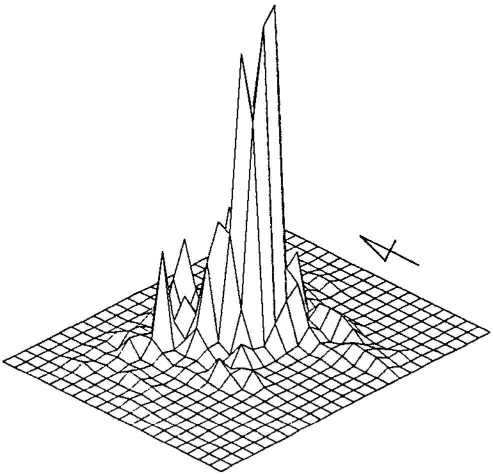

Figure 4. Spatial Structure of Nodal Accessibility in the Second Phase Subway Network

high accessibility in both phases. These features become consolidated in the second phase subway network. However, high accessibility in both phases. These features become consolidated in the second phase subway network. However thescope of central area having high accessibility values is to be extended significantly compared with the existing subway network. Although the absolute value of nodal accessibility in the southern part of the Han River also increases much, the increase in the northern part is remarkable. This may contribute markedly to the economic growth of the northern part of

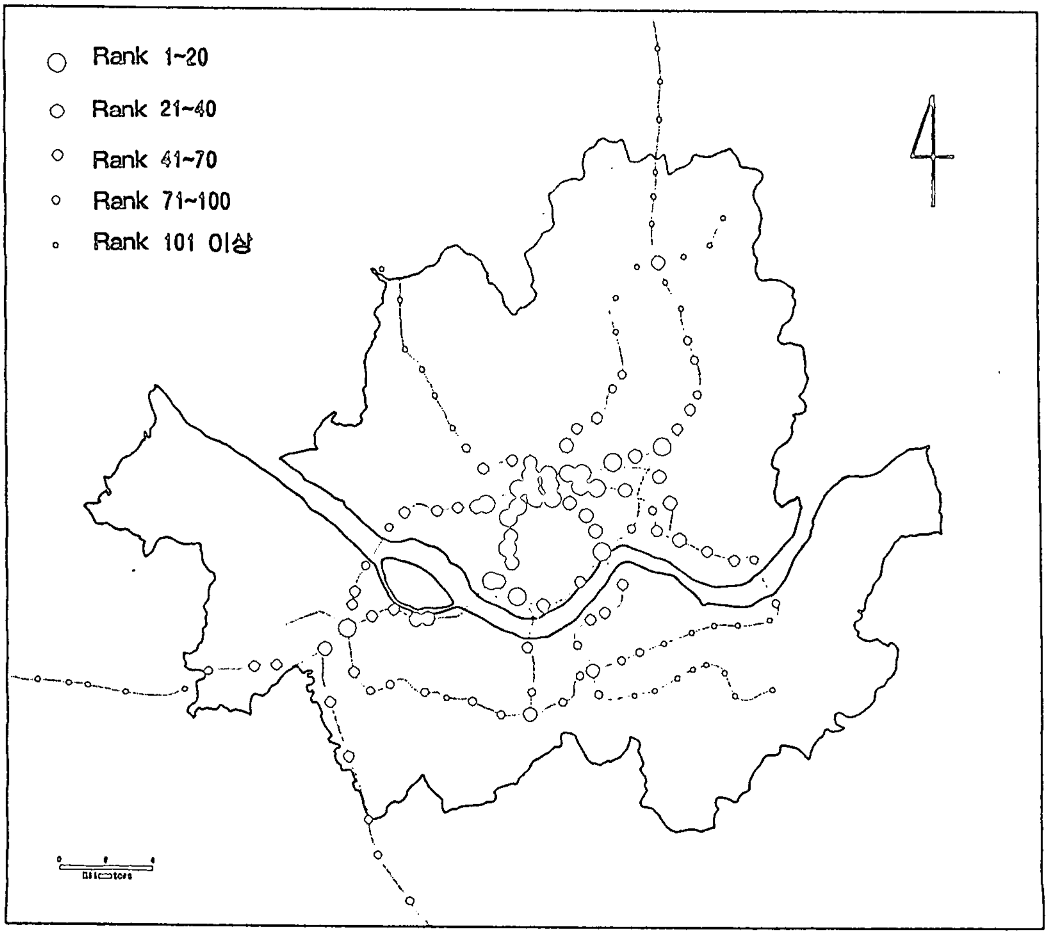

Figure 5. Accessibility Rank Map in the First Phase Subway Network

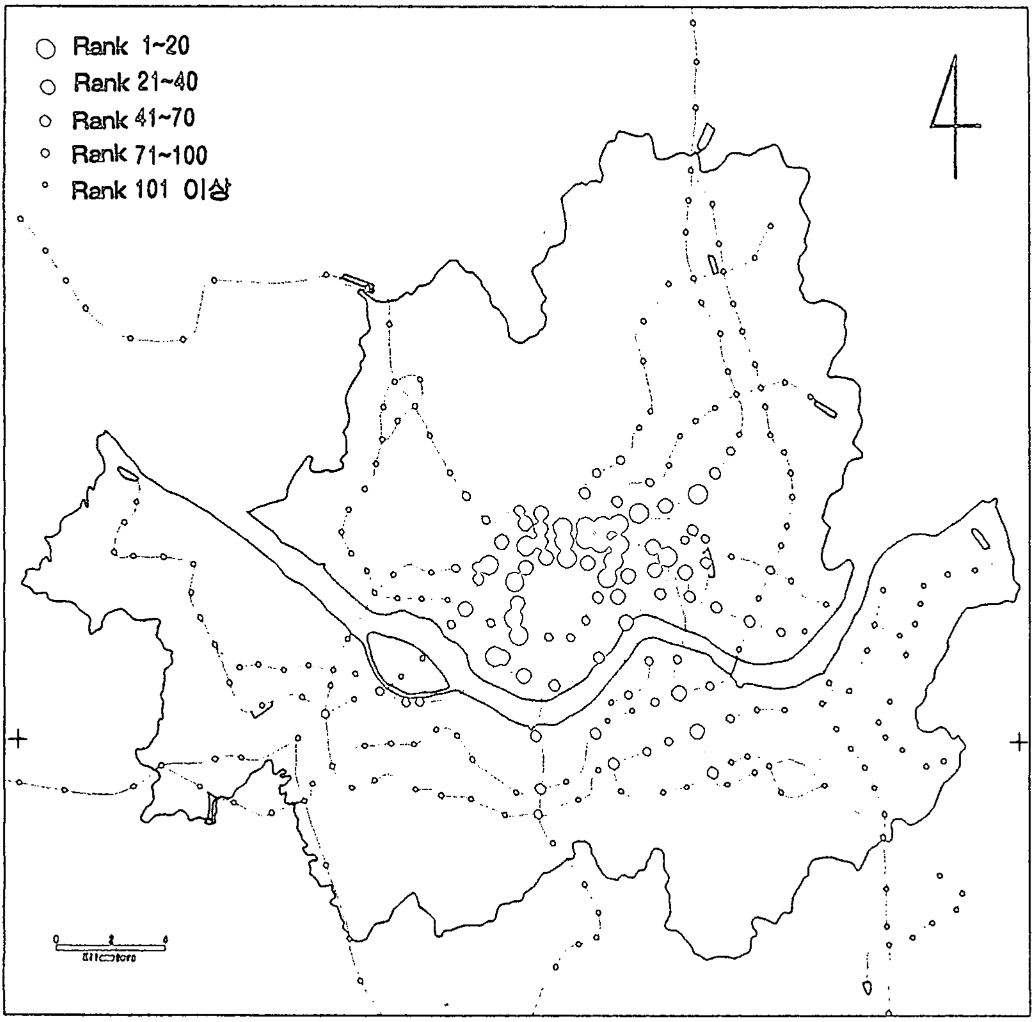

Figure 6. Accessibility Rank Map in the Second Phase Subway Network

the city in the future. This feature is also exposed in the accessibility rank maps (see Figures 5 and 6).

Whereas the concentration of high rank nodes in the central area, located in the north of the Han River, is reinforced in the second phase subway network, the nodes in the southern part are relegated to lower ranks relatively.

5. Conclusion

It is necessary to explore the accessibility structure in intra-urban planning when changes are expected in the transportation network, since a change in transport network, of itself, tends to generate changes in the spatial structure of accessibility and ultimately in the land use pattern.

Therefore, accessibility can be the most useful concept for the study of spatial structure of a region, if it can be calibrated appropriately. Through the use of the newly developed accessibility measurement scheme, the nodal accessibility in the subway network of Seoul has been calculated for two phases and the spatial structure has been analyzed. In particular the new scheme takes into account the transfer influences of a sequence of linkages and the selective inclusion of paths between nodes. It has been found that the spatial patterns of nodal accessibility in two phases are rather different: For example, the nodal accessibility in the proposed subway network displays dramatic increase on the whole. The highest nodal accessibility in the network is expected to increase more than ten times, even though such increase tends to be weakened for nodes located away from the center. Thus the future linkages of the intra-urban subway network are expected to be quite different from the existing linkages.

The spatial structure of nodal accessibility in the proposed subway network exhibits an almost concentric pattern, while it displays spread patterns from the center toward the north, southwest, and southeast directions. Nodes located close to the center of the network in general demonstrate high accessibility in both subway networks, which becomes consolidated in the proposed subway network. The scope of such central area having high accessibility value is to be extended significantly, compared with the existing subway network. Improvement of accessibility in the northern part of the Han River is noticeable in the proposed subway network, which may contribute markedly to the economic growth of the northern part of the city in the future. The concentration of high rank nodes in the central area which is located in the north of the Han River is reinforced in the proposed subway network. On the other hand, the nodes in the southern part are relegated to relatively lower rank.

This study helps to provide insight on the direction of urban development, and highlights the potential of areas in relation with the urban development. It is of relevance to examine the changes in the spatial structure of accessibility for the purpose of forecasting the direction of changes in the spatial structure of accessibility for the purpose of forecasting the direction of changes in the structure of the intra-urban land use, since the accessibility of a place affects directly the land use. The results of this study may be useful in estimating the spatial structure of land values and in anticipating the intra-urban land use pattern with proposed extension of the subway system.

References

Black, J. and Conroy, M., 1977, "Acc-essibility measures and social evaluation of urban structure," *Environment and Planning A*, Vol. 9, pp. 1013-1031.

Burns, L. D. and Golob, T., 1976, "The role of accessibility in basic transportation choice behavior," *Transportation*, Vol. 5, pp. 17-42.

Burton, I., 1962, "Accessibility in Northern Ontario: An Application of Graph theory to a regional highway network," *Report for Ontario Department of Highways.*

Davidson, K. B., 1977, "Accessibility in transport/land-use modeling and assessment," *Environment and Planning A*, Vol. 9, pp. 1401-1416.

Garrison, W. L., 1960, "Connectivity of the interstate highway system," *Papers and Proceedings of the Regional Science Association*, 6, pp. 121-137.

Garrison, W. L. and Marble, D., 1964, "Factor-analytic study of the connectivity of the transportation network," *Papers of the Regional Science Association*, 12, pp. 231-239.

Haggett, P. and Chorley, R., 1970, *Network Analysis in Geography*, St. Martin's Press, New York.

Hansen, W. G., 1959, "How accessibility shapes land use," *Journal of American Institute of Planners*, Vol. 25, pp. 73-76.

Jones, S. R., 1981, "Accessibility measures: a literature review," *TRRL Report* 967, Crowthorn.

Kansky, K., 1963, *Structure of Transport Networks*, Department of Geography Research Papers 84, University of Chicago.

Karlquvist, A. 1975, "Some theoretical aspects of accessibility based location models," *Dynamic Allocation of Urban Space, edited by* A. Karlqvist, et al., Lexington.

Lee, K., 1995, "Generalized accessibility measurement in urban subway networks," presented in the Ninth European Colloquium on Theoretical and Quantitastive Geography (September 9-13, Spa, Belgium).

Lineker, B. J. and Spence, N. A., 1992, "Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain," *Environment and Planning* A, Vol. 24, pp. 1137-1154.

Muraco, W. A., 1972, "Intra-urban ac-cessibility," *Economic Geography*, Vol. 48, pp. 388-405.

Murayama, Y., 1994, "The impact of railways on accessibility in the Japanese urban system," *Journal of Transport Geography* 2(2), pp. 87-100.

Nystuen, J. and Dacey, M. 1961, "A graph theory interpretation of nodal regions," *Papers of the Regional Science Association* 7, pp. 28-42.

Prie, G. H., 1979, "Measuring acc-essibility: a review and proposal," *Environment and Planning* A, Vol. 11, pp. 299-312.

Konig, G., 1975, "A theory of urban accessibility: a new working tool for the urban planner," *SETRE*, Ministere de l'Equipement, Paris, France.

Reed. W., 1970, "Indirect connectivity and hierarchies of urban dominance," *Annals of the Association of American Geographers* 60, pp. 770-785.

Rho, J. H. and Kim, T. J., 1989, "Integrated land use-transportation model: Implementation of a nonlinear programming model for the Chicago region," *The Korean Journal of Regional Science*, Vol. 5, pp. 49-69.

Shimbel, A., 1953, "Structural parameters of communication networks," *Bulletin of Mathematica Biophysics*, 15, pp. 501-507.

Smith, D. M., 1981, *Industrial Location: An Economic Geographycal Analysis*, John Wiley & Sons, Inc., New York.

Taaffe, E.J. and Gauthier, H.L., 1973, *Geography of Transportation*, Prentice-Hall, Inc., Englewood Cliffs.

Vickerman, R. W., 1974, "Accessibility, attraction and potential: a review of some concepts and their use in determining mobility," *Environment and Planning A*, Vol. 6, pp. 675-691.

Weibull, J. W., 1980, "On the numerical measurement of a ccessibility," *Environment and Planning* A. Vol. 12, pp. 53-67.

ABSTRACT

Changes in transport are reflected in the accessibility of a place, which is denoted as the inherent advantageous characteristic of a place with respect to overcoming spatial friction, and affect the land use ultimately. A composite accessibility measurement scheme is developed and applied to the subway network in Seoul, which has been expanded at several pheses since it has been constructed in 1972. Changes in the transport network are reflected in the spatial structure of accessibility and affect ultimately the land use pattern. Therefore, it is of relevance to examine the changes in the spatial structure of accessibility, which allows to forecast the direction of changes in the land use pattern.