Korean Journal of Geomatics
Vol. 4, No. 2 / December 2004
pp. 53~57

Analyzing Public Transport Network Accessibility

Chulmin JUN*

Abstract

Due to the traffic congestion and public-oriented transportation policies of Seoul, public transportation is receiving attention and being used increasingly. However, current transport routes configuration is showing unbalanced accessibility throughout the city area creating differences in time, expenses and metal burden of users who travel the same distances. One of the reasons is that transport route planning has been partially empirical and non-quantitative tasks due to lack of relevant methods for assessing the complexity of the transport routes. This paper presents a method to compute the connectivity of public transport system based on the topological structure of the network of transport routes. The main methodological issue starts from the fact that the more transfers take place, the deeper the connectivity becomes making that area evaluated as less advantageous as for public transport accessibility. By computing the connectivity of each bus or subway station with all others in a city, we can quantify the differences in the serviceability of city areas based on the public transportation. This paper is based on the topological interpretation of the routes network and suggests an algorithm that can automate the computation process. The process is illustrated using a simple artificial network data built in a GIS.

Keywords : *Public transportation, Accessibility, Transfer, GIS*

1. Introduction

Traffic congestion in large cities in Korea leads to public-oriented transportaiion policy that encourages use of public transportation rather than privately-owned cars. However, there are criticisms that public transportation means have shown over- or under- supply due to less systematic routes planning and operations. As a result, differences in accessibility to other areas from bus stops or subway stations cause differences in time, expenses and metal burden of users who travels the same distances. Current limitations in public transport planning call for robust methodology to assess the accessibility or serviceability of the transport routes.

On the other hand, space syntax is the technique that has been used to derive the connectivity of urban or architectural spaces (Hillier 1996). The theory has primarily been applied in the research areas that seek to find the movement of human beings among indoor spaces or pedestrian paths and it has helped to compute the connectivity of the network of built environment quantitatively based on the topological structure of spatial links (Hillier 1984). Some attempts are found in recent cases that apply the theory to GIS area to automate the process to compute the connectivity (Jiang *et al.* 1999), but none can be found in practical transportation network analysis.

This paper proposes a method to evaluate accessibility of public transport network based on its topological structure. The author sees a transfer of vehicles as a connection node that links two different routes, and the more transfers take place, the deeper the connectivity becomes making that area evaluated as less advantageous as for public transport accessibility. The paper presents an algorithm to show how geometric accessibility based on the connectivity of pubic transport routes, rather than their physical distance, can be computed. In order to automate the assessing process, transport data including routes and stops were built in a GIS and relational database and the

*Associate Professor, Dept. of Geoinformatics, University of Seoul, Seoul Korea (E-mail : cmjun@uos.ac.kr)

The manuscript for this paper was submitted for review on November 30, 2004 / accepted on December 20, 2004

algorithm was programmed in C# language. An artificial data set is used to illustrate the proposed algorithm.

2. Hierarchical Network Configuration

Human movement is frequently described in an abstracted form using its topology. Topological description allows researchers to focus on the structural relationship among units of movement while disregarding the details of phenomena. For example, pedestrian movement can be described using network of simple lines without considering the details such as sizes of forms, number of people and speed of movement. Such network configuration is also referred to as graph, which is a way to represent a network by a set of vertices and a set of edges that connects pairs of vertices. Fig. 1 illustrates how meandering streets can be mapped to a graph. As shown in this figure, spaces are first broadly perceived as discrete components, for instance, linear lines, and then are combined forming a continuous network.

When spaces are mapped to a graph, the hierarchical relationship of component units is obviously captured. All this is best illustrated using Fig. 1. Line 2 is accessible from line 1 by one turn, whereas line 4 is accessed by two turns. In other words, the relationship of 2 and 3 is called symmetrical with respect to 1 whereas the relationship of 4 to 1 is asymmetrical. In the literature of space syntax theory, this relationship is described thought a variable called depth (Bafna 2003). If one were to represent each component with a node and a turn with a link connecting their respective nodes, one could then describe the hierarchy from each node as shown in Fig. 2. Fig. 2 shows the hierarchy from node (or street) 1.

Depth of one node from another can be directly measured by counting the number of steps (or turns) between two nodes. The greater the depth of two nodes, the greater the hierarchical difference between them. The depth of a node (or a street) is defined by the number of nodes distant from a given number of steps to that node. If we take the example of Fig. 2, the depth of node 1 for immediate neighbors (eg. step 1 nodes) is 2 since there are two nodes that can be accessed by one turn. On the other hand, the depth of node 1 in 2 steps distance is 4 since there are two nodes that can be reached by two turns, that is, 2 (nodes) × 2 (steps). Thus, the total depth from a node to all other nodes can be measured by summing the product of the level of step and the number of nodes in that step as given by:

$$TD_i = \sum_{s=1}^{m} s \times N_s \qquad (1)$$

, where

TD_i : the total depth of node i

s : the step from node i

m : the maximum number of steps extended from node i

N_s : the number of nodes at step s

The mean depth then is given by the total depth divided by k − 1, where k is the total number of nodes in the graph (Hillier 1984). This means the average depth of a particular node. Fig. 3 shows extreme cases from node 1 in a network of same number of nodes. One case contains a node that extend to the maximum number of steps, which is k − 1 with the rest of nodes, one in each of intervening steps (case b in Fig. 3), and the other contains only neighboring nodes to node a (case a in Fig. 3).

In the case a, completely symmetrical structure, in Fig. 3, MD is computed as follows,

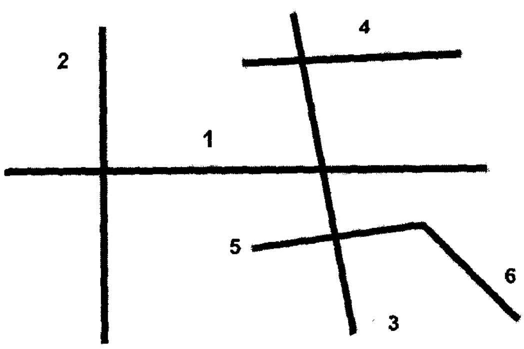

Fig. 1. Topological description of streets network.

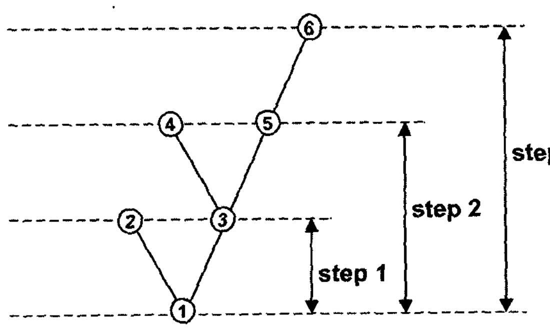

Fig. 2. Hierarchical structure described from a street.

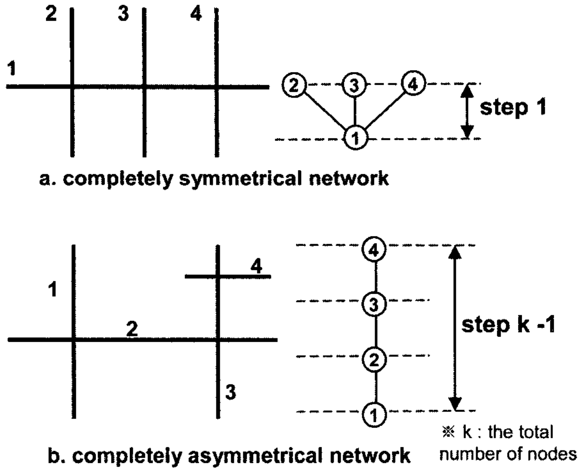

Fig. 3. Depths of two extreme cases.

$$MD = \frac{1+2+...+(k-1)}{k-1} = \frac{(k-1)k/2}{k-1} = \frac{k}{2}$$

whereas MD of the case b is computed by

$$MD = \frac{k-1}{k-1} = 1$$

Here, $1 \le MD \le \frac{k}{2}$ is derived. Therefore, MD is normalized as follows:

$$0 \le \frac{2(MD-1)}{k-2} \le 1 \qquad (2)$$

Now, using the normalized depth (ND), the depth from a node in a graph can be represented by a number ranging from 0 to 1. Using ND values makes it possible to compare depths of nodes from graphs with different number of nodes.

3. Applying to Public Transportation

The hierarchical description in the previous section primarily targets the abstraction of free movement of people mostly in built spaces rather than the movements in the public transportation which take place along fixed routes. However, we can derive the similarity of these two problems. Hierarchical network structure focuses on turns of spaces which are the basis for computing the depth of a certain space to others, while the public transportation generally entails transfers between vehicles. Thus, we can map turns of spaces to transfers between transportation means. In the hierarchical network description, the deeper the depth from a space to others, the more relatively difficult it is to move from that space to others. On the other hand, in public transportation, cost generally increases as the number of transfers between different modes increases. In this case, the cost can be either total fares or time taken in transfers, or it can even be seen as the mental burden that a traveler feels when he or she moves to or waits for the next vehicle in transfer areas.

If we map the components using nodes and links in the previous section to a public transport network, a node (or a street in Fig. 1) can be seen as a stop, regardless of bus or subway, whereas a link between two nodes can be mapped to a transfer between two vehicles. This relationship is illustrated in Fig. 4.

If a person moves from stop 1 to stop 2, 3 or 4, he or she does not need to transfer because these stops are on the same route, subway line 1. However, if the traveler wants to go to stop 5 or stop 6 from stop 1, he or she has to transfer in the area A since stop 1 and stop 5 are not on the same route. Similarly, if the origin is stop 1 and the destination is stop 7 or 8, one transfer is needed in area B and, if the destination is stop 9, he or she has to transfer two times, one in area B and then in area C. One transfer from a transportation mode to another is the 'spatial transfer' which becomes one depth between spaces. If this network were that of pedestrian streets, when a person were to move from point 6 to point 7, he or she needs two turns, which means these points are two depths away from each other. However, in case of using pre-laid transport routes, the existence of a route that connects two points is first taken into account in computing the depths. Therefore, no transfer is needed in case of moving from

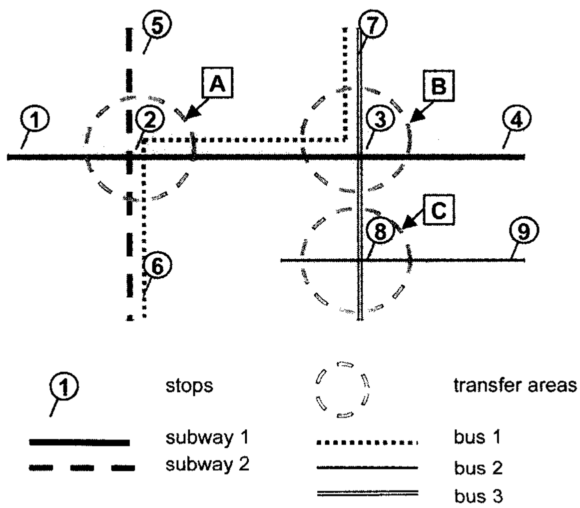

Fig. 4. Public transport network.

stop 7 to 6 because there is a direct line connecting these two points.

The relationship of stops via routes is described in Fig. 5. The connectivity from each stop to all others is hierarchically mapped to a graph. The procedure for generating a graph is iterative, starting with a stop and then progressively identifying the next neighboring stops until the entire stops are covered. The procedure first identifies the stops that are directly accessible from an origin using one route (step 1), then among these stops finds those stops that are belonged to transfer areas. Then, it looks for the routes that share these stops in the transfer areas. Next, it finds those stops that can be reached using the identified routes (step 2). It again looks for the stops belonged to the transfer areas. It continues iteratively in this manner.

Here, we can assume extremely symmetrical and asymmetrical cases as we did in the previous section

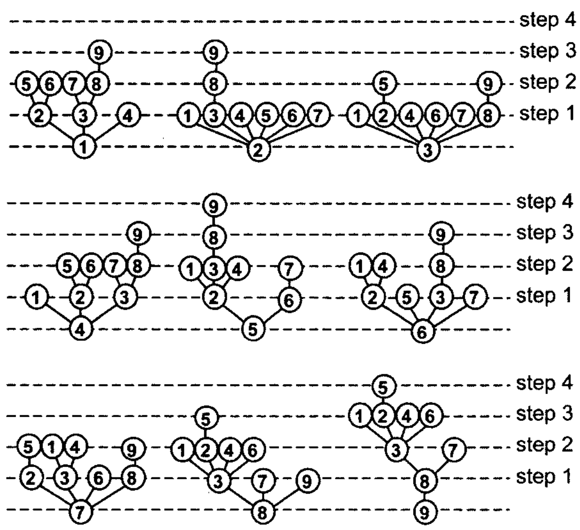

Fig. 5. Mapping schematic route connectivity onto a graph.

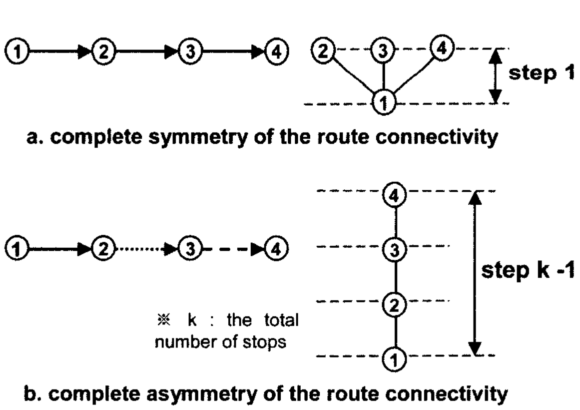

Fig. 6. Symmetry and asymmetry of the route connectivity.

Table 1. Computing depth from each stop in Fig. 4.

Stop No.	TD	MD	ND	ND^{-1}
1	14	1.750	0.214	4.67
2	11	1.375	0.107	9.33
3	10	1.250	0.071	14.00
4	14	1.750	0.214	4.67
5	17	2.125	0.321	3.11
6	13	1.625	0.179	5.60
7	12	1.500	0.143	7.00
8	14	1.750	0.214	4.67
9	21	2.625	0.464	2.15

(Fig. 6). The first case is when all stops are accessed from an origin via only one route. On the contrary, the other case is when all stops and routes are laid such that every stop is accessed by different means from the previous means. The former one is the completely symmetrical case, and the latter is completely asymmetrical one. Therefore, we can conclude that Eqs. (1) and (2), which were defined for space connectivity, hold true for public transport network. We can then compute TD, MD and ND as shown in Table 1.

Note that the reciprocal of ND is also calculated. These values help intuitive interpretation about the relationship between the graph and the accessibility. That is, higher values of nodes indicate that the stop is less deep on an average from all other stops and, in other words, shows better accessibility to other stops on an average. As one may easily expect, stop 3 shows the highest accessibility, 14, followed by 9.33 of stop 2. Note that stop 7 ranks third. It's because stop 7 has the routes that pass transfer areas, which makes it possible for a traveler to go to any other stops from stop 7 by only one transfer.

4. Integrating Into GIS

In order to apply the procedure proposed here to real problems, we should consider utilizing GIS capabilities. However, public transport network data are either not yet available in GIS format or, even if they are, they have limitations in reflecting the information which are necessary for the computation process suggested in this study. In most cases, a GIS data is composed of geographical feature data and the table data each record of which reflects its corresponding geographic feature. Thus, currently used GIS data structure alone can not capture the complex relationship of characteristics

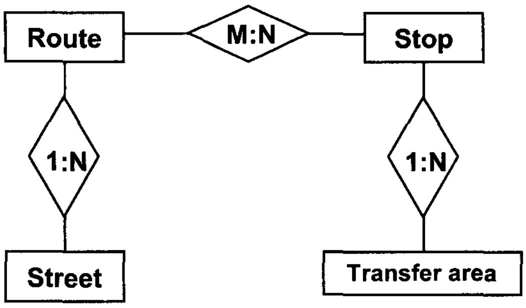

Fig. 7. E-R diagram for public transport network.

existing in public transportation.

The relationship among streets, routes, stops and transfer areas can be abstracted into an entity-relationship model in a relational database as shown in Fig. 7. The procedure begins by defining a relation for each entity. One street section may contain more than one bus or subway route. Therefore the relationship between streets and routes is one to many (1:N). On the other hand, the relationship between routes and stops is many to many (M:N) because a route may include many stops and a stop may be shared by more than one route. We also need information about transfer areas for the computation process. Since one transfer area may contain more than one stop, the relationship of these two entities is one to many (1:N). The entities included in the E-R model are classified into two types; ones are those that are built as the attribute tables of GIS data and the others are separately built tables. The former case includes Street, Route, and Stop entities and the latter Transfer Area. Also, the intersection entity generated from M:N relationship is also has to be created as a separate table. Since the data are constructed using such different formats, we cannot use macro languages provided as a subsidiary function of a proprietary GIS package. Thus, the author used C# language to implement the proposed algorithm. As a preliminary study, a test version was constructed using artificial networks similar to the one illustrated in Fig. 4. The author is currently testing the algorithm on the public transport network of Seoul.

5. Conclusions

This paper presented a method to assess accessibility of public transport network by defining the network relationship onto a graph. It derived an analogy between the concept of depths in pedestrian network and the accessibility of network of transport routes. The author developed an algorithm to automate the computing process and also demonstrated how the process can be incorporated into GIS by using relational model of entities in the routes network. If the procedure is applied to a city, we can quantify the difference in the serviceability of city areas based on the public transportation.

Acknowledgement

This study was supported by the Korea Science & Engineering Foundation (R01-2002-000-00328-0).

References

1. Bafna, S., 2003. Space syntax: a brief introduction to its logic and analytical techniques, *Environment and Behavior*, 35(1): 17-29.
2. Hillier, B., 1984. *The Social Logic of Space*, Cambridge University Press.
3. Hillier, B., 1996. *Space is the Machine*, Cambridge University Press.
4. Jiang, B., C. Claramunt and M. Batty, 1999. Geometric accessibility and geographic information: extending desktop GIS to space syntax, *Computers, Environment and Urban Systems*, 23: 127-146.