DEVELOPMENT OF ACCESSIBILITY INDEX USING CLOSENESS CENTRALITY

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Abstract: The Cost-Benefit analysis is a worldwidely applied methodology to verify the validity of the transportation SOC project. But in general the indices included in the analysis are insufficient to measure various effects because there exists many difficulties to measure various qualitative benefits. In this research it is proposed that the closeness centrality can be utilized as a accessibility index. The closeness centrality is a index to measure the centrality of some node or region in social science area. We verify the suitability of the index with a small size network and suggest the application of the index on the feasibility study of the transportation SOC project.

Key Words: Accessibility, Closeness centrality, Index development, Transportation network

1. INTRODUCTION

The Cost-Benefit analysis is a worldwidely applied methodology to verify the validity of the transportation SOC project. In Korea, benefits are estimated by mobility index - the valuation of travel time savings, environmental index - the valuation of environmental costs savings, and safety index - the valuation of the traffic accident cost savings. Even though those factors are covering major part of benefits, it is insufficient to measure various qualitative benefits from the project.

The accessibility is one of those benefits unmeasured, but it is only included as a benefit index in German and British research. As Litman(2003)'s study mentioned, it is necessary to include
the accessibility factor as a benefit of transportation project.

Todays, developing accessibility index is a international research subject and many researches are performed. But we have not yet found any standard accessibility index widely applicable. FTIP(Federal Transport Infrastructure Plan)'s research in 2003 in Germany, propose the straight line distance as a accessibility index. But the limit is that it can not reflect the network size and shortest path, thus it is not suitable to use as a accessibility index in transportation area.

In this research it is proposed that the closeness centrality can be utilized as a accessibility index. The closeness centrality is a index to measure the centrality of some node or region in social science area. We verify the suitability of the index with a small size network and suggest the application of the index on the feasibility study of the transportation SOC project.

2. ACCESSIBILITY AND CLOSENESS CENTRALITY

2.1 Accessibility

2.1.1 The Concept of Accessibility

The accessibility is a concept defined by many researches in various field as transportation, urban planning, geography, sociology and so on. It was considered as the same concept of the mobility in early researches, but the limitation is that it simply defines the accessibility as the transportational effect of land-use, as it defines the traffic demand as the transportational effect of land development. (Moore, W.T., 1975)

According to Lim's study(1992), the accessibility implies the possibility of a passenger's participation to a specific activity and is utilized as a factor of traffic demand forecasting model. And in transportation geography field, the accessibility is utilized as a index of transportation network structure analysis. So it measures the connectivity between two nodes of a transportation network which is composed by nodes and links. (Taaffe, E.J., 1973)

The accessibility is also defined as the number of shortest path from one node to another node in Shimbel's study(1953) and the shortest path is variously calculated from the time, distance and cost variables in Alber et. al's study(1971).

2.1.2 The Accessibility model

There are many studies about the accessibility model composed by many researchers. Hansen(1959) proposed the accessibility model to forecast the spatial distribution of population. In his study, the employment accessibility defines the spatial distribution of population and it generalize the concept of accessibility as a theory.

\[ A_i = \sum_{j=1}^{n} E_j D_{ij}^\beta \]  

where,

- \( A_i \) : Accessibility of area i
- \( E_j \) : Number of employer in area j
- \( D_{ij}^\beta \) : Distance from area i to area j
\[ \beta : \text{Constant (} \beta > 0) \]

Transportation network and graph theory is applied to the accessibility model in Shimbel's study (1953). In this model, the accessibility is measured from the sum of link cost variable.

\[ A_I = \sum_{j=1}^{n} C_{ij} \]  

(2)

where,

- \( A_I \) : Accessibility of node I
- \( C_{ij} \) : Cost from node i to node j
- \( n \) : Total number of nodes

2.1.3 The applications of the accessibility

In German case, the accessibility is already utilized as a measure of effectiveness of a transportation project. In this case, the accessibility is measured by linear equivalent speed between the centroid of the area and the direct influence sphere on base year.

\[ \text{Accessibility} \ V_e = \frac{S_{SP}}{t_{open}} \]  

(3)

where,

- \( V_e \) : Linear equivalent speed
- \( t_{open} \) : Travel time between the centroid and the direct influence sphere at the opening
- \( S_{SP} \) : Shortest path between the centroid and the direct influence sphere

In British case, the passenger's public transport accessibility called PTAL (Public Transport Accessibility Levels) is utilized. It is calculated by measuring walk times including average waiting time from certain area to every public transportation node, i.e. bus stop and railway station. The reliability factor is also considered to calculate the final approaching time to the service area.

<table>
<thead>
<tr>
<th>PTAL</th>
<th>Range of Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a(Low)</td>
<td>0.01 - 2.50</td>
<td>Very poor</td>
</tr>
<tr>
<td>1b</td>
<td>2.51 - 5.00</td>
<td>Very poor</td>
</tr>
<tr>
<td>2</td>
<td>5.01 - 10.00</td>
<td>Poor</td>
</tr>
<tr>
<td>3</td>
<td>10.01 - 15.00</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>15.01 - 20.00</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>20.01 - 25.00</td>
<td>Very good</td>
</tr>
<tr>
<td>6a(High)</td>
<td>25.01 - 40.00</td>
<td>Excellent</td>
</tr>
<tr>
<td>6b(High)</td>
<td>40.01+</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
2.1.4 Issues and Improvements

It can be easily analyzed the accessibility with the graph theory on the transportation network simply composed with nodes and links. But the limit is that it cannot reflect the properties of nodes and links. In other words, nodes cannot reflect the scale and the characteristic of the city and links cannot reflect the traffic volume and the traffic speed. And these limitations propose the necessity of modified model which contains the time value and the distance value.

2.2 Closeness Centrality

The closeness is a basic concept in topological space in the area of Topology and related mathematical area. It can be intuitively said that two sets are "close" when the one is near to the other. It is naturally defined in metric space with the concept of "distance", but there is not exist any method to measure the "distance" in topological space.

In the graph theory, the closeness centrality is a centrality index of a vertex on the graph. The vertex closer to the other vertices has higher closeness centrality. It is considered as the average shortest distance in network analysis. If the vertex is more centrally situated in network, it has higher closeness centrality. It also has positive correlation between the closeness centrality and the degree.

In the network theory, the closeness centrality is one of the centrality indices, and it is calculated from the average shortest distance between the point and every other accessible points. The closeness centrality contains also the meaning of the information transfer time between two vertices.

\[ C^c = \frac{\sum_{t \in V \setminus v} d_G(v, t)}{n - 1} \]  

where,

- \( d_G(v, t) \): geodesic distance between a vertex \( v \) and other vertex \( t \)
- \( n \): size of the network's connectivity component \( V \) reachable from \( v \) (\( n \geq 2 \))

According to Dangalchev's study(2006), the closeness centrality can be modified to measure the network vulnerability and applied to the unconnected graph. Total closeness centrality can be easily calculated as follows.

\[ C^t(v) = \sum_{t \in V \setminus v} 2^{-d_G(v, t)} \]  

3. DEVELOPMENT OF ACCESSIBILITY INDEX

3.1 The Premise of model

In this study, the accessibility represents the accessibility from a node(\( node_1 \)) to the other node(\( node_2 \)).

Considering traffic flow concept, the closeness centrality can be represented by access time to
a certain node. (Borgatti, 1995) In other words, the closeness centrality refers how easily it can access to the node, namely the accessibility of the node. Higher closeness centrality the node has, easier and faster the passenger access. And it is also shown from the concept of the accessibility above. Thus, the accessibility can be measured by utilizing the closeness centrality.

The original concept of closeness centrality is a index based on the distance between nodes. When the concept of management of the infrastructure is grafted to the original, the link cost can be generalized to the accessibility index of transportation network (Yang, 2009). In that case, link cost refers travel time, properties of the link, traffic volume and so on.

3.2 Development of the Accessibility Model

3.2.1 The Application of Weight of the Link

The original closeness centrality does not contain the weight of the link, so it can not properly reflect the resistance between nodes. As a supplement, we generalize the weight of the link with average resistance value. Dijkstra algorithm(1959) is utilized to decide the shortest path, namely the least resistance path.

![Figure 1 Travel time and trip distance between nodes](image)

Average resistance value = \( \frac{(20+10+40+10)}{4} = 20 \)

Generalized resistance weight of link = \( \frac{\text{Resistance value of the link}}{\text{Average resistance value}} \)

The diagram below is weighted network graph realized with generalized resistance weight of link.
3.2.2 Consideration of Every Connected Links

In general, connecting path to certain node is not a single but more than two. In that case, it is necessary to consider every links connected to the node. In diagram 4, node A is linked with 3 other nodes and node B is linked with 4 other nodes. But it is not easily said that node B has better accessibility than node A because node A is connected with lower resistance links and node B is connected with relatively higher resistance links. In other words, highly resisted links has long link travel time and the accessibility of the link should be measured low. In this study, the every connected links are considered with its resistance weight to develop the accessibility index.

3.3 Development of Accessibility Index

There are several steps follow to develop the accessibility index considering multiple weighted links connected. At first, the average cost of the connected links should be calculated. As mentioned above, the link cost can be various. It can be from the changeable (or can be mentioned as “manageable”) variables as the German and the British case and from the fixed (may be the hard-to-change) variables as the Hansen’s and Dangalchev’s. In this study the travel time on the link, which is changeable as the German and the British case, is adopted as the link cost. So the average link cost ($C_{avg}$) is calculated from the travel time of the link as follows.
\[ C_{avg} = \frac{\sum_{i=1}^{n} X_i}{n} \]  
Where, \( X_i \) = travel time on the link \( i \) heading to the object node, link cost 
\( n \) = number of links connected to the object node

Generalized link cost \( (X'_1, X'_2, \cdots, X'_n) \) is calculated as the concept of generalized resistance weight of the link.

\[ X'_i = \frac{X_i}{C_{avg}} \]  
(7)

Then the probability of the choice of a link \( (P(X'_i)) \) is calculated with generalized link cost by logit model. Finally, the accessibility index is obtained by multiplying the probability and the utility, the exponential value of the reciprocal of link cost \( X'_i \).

\[ P(X'_i) = \frac{1}{\sum_{i=1}^{n} e^{X'_i}} \]  
(8)

\[ ACC = \sum_{i=1}^{n} P(X'_i) \times e^{X'_i} \]  
(9)

4. APPLICATION OF THE MODEL

4.1 Data and Analysis

At first, nine zones are selected to simply apply the model. The zones are categorized into three categories; zones easy to access, hard to access, and the medium. Then the link travel time is obtained from Seoul metropolitan area OD and network data by Emme/3, a transportation simulation engine. The model we developed is applied to this data set and finally the accessibility indices of nine zones are obtained. The profitability of these accessibility indices to the categories is analysed. Selected nine zones are as following;

<table>
<thead>
<tr>
<th>Accessibility</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Jongro, Kangnam, Jamsil</td>
</tr>
<tr>
<td>Medium</td>
<td>Myunmok-dong, Balsan1-dong, Bongcheonbon-dong</td>
</tr>
<tr>
<td>Low</td>
<td>Ssangmoon1-dong, Daejo-dong, Sekok-dong</td>
</tr>
</tbody>
</table>
4.2 Results

The accessibility indices of the nine zones are as following.

Table 3 Accessibility index value of the zones

<table>
<thead>
<tr>
<th>Zones</th>
<th>JR</th>
<th>MM</th>
<th>SM1</th>
<th>DJ</th>
<th>BS1</th>
<th>BCB</th>
<th>KN</th>
<th>SK</th>
<th>JS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>1.0682</td>
<td>1.0586</td>
<td>1.0522</td>
<td>1.0512</td>
<td>1.0420</td>
<td>1.0562</td>
<td>1.0763</td>
<td>1.0601</td>
<td>1.0763</td>
</tr>
</tbody>
</table>


Then the categories of the zones and obtained accessibility index value of the zones are compared.
Table 4 Comparison of the Model and Actuality

<table>
<thead>
<tr>
<th>Accessibility</th>
<th>Actuality</th>
<th>Obtained from Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Jongro, Kangnam, Jamsil</td>
<td>Jongro, Kangnam, Jamsil</td>
</tr>
<tr>
<td>Medium</td>
<td>Myunmok-dong, Bongcheonbon-dong</td>
<td>Myunmok-dong, Bongcheonbon-dong, <strong>Sekok-dong</strong>, Balsan1-dong</td>
</tr>
<tr>
<td>Low</td>
<td>Ssangmoon1-dong, Daejo-dong, <strong>Sekok-dong</strong></td>
<td>Ssangmoon1-dong, Balsan1-dong, Daejo-dong</td>
</tr>
</tbody>
</table>

The model shows high accessibility index values for the three zones on high accessibility category. For the medium accessibility category and the low accessibility category, two zone for each have the expected result; two zones, Myunmok-dong and Bongcheonbon-dong, on the medium accessibility category equivalently have the medium level of accessibility index value, and another two zones, Ssangmoon1-dong and Daejo-dong, on the low accessibility category have the low level of accessibility. But the accessibility index value of Sekok-dong and Balsan1-dong are different. Expected accessibility of Sekok-dong is low but the result is medium, and for Balsan1-dong expected accessibility is medium but the result is low. These differences could be produced from the reason that the categories we divided first are not based on the quantitative values. Those are socially agreed ranks in a degree, but for medium levels, some confusing could be occurred. But in a broad view, it can be understood that the model reflects the accessibility tendency.

5. CONCLUSIONS

The Cost-Benefit analysis is a worldwide applied methodology to verify the validity of the transportation SOC project. But the limit is that the methodology can not measure every effects produced because they are not quantified, and the accessibility is one of these unmeasured effects. Thus, the concept of closeness centrality, which is a measure for the centrality of a node or area, is adopted to develop accessibility index in this study.

In the study, we generalized the link cost on weighted network with traffic volume. Then the link choice probability is calculated with generalized link cost by logit model. Finally the accessibility index is obtained from the probability and the utility of the link. The model is applied to 9 major nodes in Seoul, and the relative rank of the accessibility index of the nodes are highly similar.

It is possible to calculate the accessibility of the node with the developed index of the study. With this index, backward regions with low transportation SOC supply can be properly considered on the planning policies.

If further researches are performed, the accessibility improvement of the area can be measured with the index, and it allows to monetarize the effect of a project. Surely the study on the monetarization of the index value is a premise. And the accessibility index also could be utilized on the zonal studied.

This study has its limitation on the analysis that it is performed on the small part of the metropolitan area road network. If the analysis on bigger network could carried out, the reliability of the study could be much higher and it should be possible to find out the relations between the accessibility and the benefit quantification.
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