A STUDY OF MOBILITY INDICATOR FOR TRANSPORTATION EQUITY OF ROAD NETWORK IN SOUTH KOREA

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ABSTRACT

The main purpose of this paper is to develop a new indicator for regional equity analysis which is considered in transportation facility investment. At first, regional equity is defined as an index related to mobility which considers moving capability on the existing road facilities. Secondly, mobility indicator is introduced by using the performance measure of inter-regional traffic network as 'Service Quality'. Service quality is average speed by inter-region network considering modes. Mobility indicator for one origin is the sum of service qualities classified by origin. This is different from Regional Backwardness which is determined by concerning social indices such as road density, population growth and regional income. This is the only indicator when regional equity is evaluated in transportation field. In this paper, mobility indicators of road network in Korea are estimated. In comparison with Regional Backwardness, the gaps between two index ranks are found. It shows Regional Backwardness could not consider the direct impact of transport facilities. Consequently, a mobility indicator is meaningful in regional equity analysis in transportation investment, and it could be used in transportation plan properly.

Keywords: equity, mobility indicator, performance measure of network, Backwardness

1. **INTRODUCTION**

There are many methods that measure the impact of a transportation project before the project is carried out. The most famous method is a cost-benefit analysis which is based on efficiency. Most of methods in a transportation field focus mainly on efficiency and determine priority according to this criterion.

However, these methods cause the unequal distribution of impact. For instance, even though an undeveloped area is requested to be improved, the project related to this area could not be selected by the reason of having low net-benefit. This situation causes that the area remains underdeveloped, and its residents suffer from inconvenient transportation. Moreover, their disadvantages are not limited only to their mobility but also to their entire life such as job-seeking and leisure activities.

To overcome this problem, transportation equity, referred to as the distribution of impact, appeared as another indicator by which transportation projects were evaluated and prioritized. Transportation equity is dealt with benefit and cost of individuals or special groups while efficiency is concerned with only numerical value of the whole net-benefit. Although the Korean government suggests that transportation equity should be considered to prevent uneven regional development, he only uses Regional Backwardness which considers only social indicators such as road density, v/c and the rate of population growth. There is not any reasonable indicator which concerns with effect of regional road network.

The purpose of this paper is to develop an indicator which considers the regional performance of the road facilities, especially mobility as performance of inter-regional network. In this paper, Korean road networks are evaluated by a new indicator called mobility indicator and compared with a result evaluated by Regional Backwardness.

This paper is organized as follows: In the next chapter, studies and researches of transportation equity about mobility and accessibility are reviewed. Chapter 3 presents selecting proper performance measures of traffic network and making model formulation. In chapter 4, mobility indicator of Korean road network is calculated and compared with the Regional Backwardness. The last chapter summarizes conclusions and gives suggestions for further research.

2. LITERATURE REVIEW

2.1 Regional Equity in Transportation Facility Investment

Even though the pursuit of transportation is not equity but efficiency, various concepts of equity is remarked nowadays. However, there are few studies which suggest an index for regional equity and apply it to real road networks.

Litman(2007) defines several kinds of transportation equity and suggests methods which evaluate transportation plans using them. They are divided into two main groups: Horizontal equity and vertical equity. The formal deals with equity which ‘is concerned with the distribution of impacts between individuals and groups considered equal in ability and need’ while the latter deals with equity which “is concerned with the distribution impacts between individuals and groups considered differ in ability and need". According to his work, regional equity is a kind of horizontal equity. He explains that horizontal equity analysis usually has to be based on per capita comparison. Nonetheless, he focuses on the roadway cost allocation for horizontal equity after decision of investment area by the cost-benefit analysis based on efficiency.

SHI(2007) emphasizes the consideration of regional equity for balanced national development. He points out that using traditional cost-benefit analyses caused a serious problem which leads to regional discrimination. He shows China's severe unbalanced development as a result of traditional analyses. He suggests that several indexes representing Regional Backwardness be introduced from the social view. However, He considers only social indexes such as average housing expense, price index and average personal income of region. There is no direct factor which concern with conditions of transportation infrastructures.

In transportation infrastructure investment, regional equity has not much studied except for Regional Backwardness which was developed by Korea Development Institute (KDI). It is calculated using Analytic Hierarchy Process (AHP). The factors related to Backwardness are increase of population, road density, number of car per population, ratio of land-use and financial independence. It is commonly used in even regional development in political analysis. In transportation field, several policy manuals such as the Guides for Transportation Facilities Investment Evaluation use Regional Backwardness as an equity index. Even though it deals with regional equity for transportation investment analysis, there are two weaknesses in using only Regional Backwardness: one is that the factor related to traffic network is only road density which could not consider performance of infrastructure; the other is that the effects of investment do not affect Regional Backwardness instantly and entirely.

2.2 Mobility (Accessibility)

Mobility(Accessibility) is studied in various fields including not only transportation engineering but also sociology. This concept is usually understood complicatedly. Because it has significant role in social and transportation field, many related researches have been conducted. Moreover, it is an important factor when land-use and transport strategies are evaluated (Karst T. Geurs., at al., 2004).

Kim(1987, 1995) categorizes accessibility concepts and analyzes limitation of accessibility index. Accessibility value between public facilities and users is estimated.

Kim and others (1992) examine the change of accessibility among cities on the assumption to build highways in the Plan of the Multiple Purpose Development of the Land in Korea, and calculate 'Accessibility Value (APD)' using Eq. (1) and 'Weighted Accessibility Value (AWPD)' using Eq. (2) considering road distance and time distance:

$$APD_i(ATD_i) = (\sum TC_{ij})^{-1} \quad (1)$$

$$AWPD_i(AWTD_i) = \left[\frac{\sum (T_{ij} \times TC_{ij})}{\sum T_{ij}} \right]^{-1} \quad (2)$$

where TC_{ij} is the shortest distance or travel time, and T_{ij} is traffic volume. Eq. (1) and Eq. (2) are the implicit function.

Kim and others (2006) define accessibility and mobility separately, and examine imbalance of road and rail network. Accessibility is defined as 'ability to move from i zone to the others'. It is classified into 'Spatial Accessibility (SA)' and 'Economic Accessibility (EA)'. The estimation model is suggested by modifying the model designed by Allen (1993) and Cho (2002).

$$SA_i = \frac{1}{n} \sum_{j=1}^{n} \sum_{i=1, i \neq j}^{n} s_{ij} \quad (3)$$

$$EA_i = \frac{1}{n} \left(\sum_{i}^{n} \frac{M_j}{s_{ij}} + \sum_{j}^{n} \frac{M_i}{s_{ij}} \right) \quad (4)$$

where s_{ij} is average travel time, and M_i is numbers of arriving passenger. Eq. (3) is a formula of spatial accessibility value, and Eq. (4) is the formula of economic accessibility value. Even though Eq. (3) reflects spatial restriction, it does not represent the performance of road network. Meanwhile, mobility is defined as 'ability to move from zone i to zone j'. Mobility imbalance is calculated using network density as a main factor and selecting ten paths according to k-paths algorithm. According to this process, mobility imbalance index is estimated as a form of Gini co-efficient.

2.3 Direction of Study

Regional equity in transportation facility investment has not been much studied internally and externally. Most guides of transportation policy and plan use Regional Backwardness considering transportation equity in Korea. However, Regional Backwardness is not proper because it ignores mobility of transport modes in traffic network. Mobility is one of the most important factors which are provided by transportation facilities. Hence, a regional mobility indicator is needed for evaluating performance of road network.

In this study, the concept of mobility in transportation is defined, and the relation between equity and mobility is explained. Based on this progress, a model of mobility in traffic network is established. Also, value of mobility of road network in Korea is calculated and compared with value of Regional Backwardness providing from public governmental institute. In consequence of this study, effective index for evaluating transportation facility investment could be suggested.

3. MODEL FORMULATION

3.1 Premises

In this research, the premise, 'Equity based on region is proportion to Mobility by region', is suggested. Mobility is defined as 'how fast to move from one zone to the others '. And equity is defined as 'how equitable to divide service benefit among regions'.

Figure 1 Relation between mobility and equity

As shown in Figure 1, gap of mobility indicators classified by region means gap of equity classified by region. Namely, mobility deals with performance of the existing transportation facilities. Therefore, considering regional equity in transportation facility investment project is reflected by examining mobility in regions related to the project.

For mobility indicator modelling, two models are necessary. One is the performance measure of inter-region traffic network, which considers ability to move from one region to others. The other is aggregating the network performance measure of inter-region network by origination region. The former is named 'service quality' or 'SQ', the latter is named 'mobility indicator' or 'MI'.

3.2 Service Quality by Inter-Regional Network

Service quality (SQ) is defined as performance measure of inter-regional network. Network performance measure is a scalar value for indicating the states of operating traffic network (Park, 2007). The factors of performance measure of traffic networks are attributes of link (location, length, distance between nodes, and number of lines, mode, type, capacity, and directness), travel time, volume, connectivity, reliability etc.

In this paper, distance between regions and travel time by mode are selected. Distance is spatial restriction between regions. Travel time means performance of traffic network.

$$SQ_{ij} = f(D_{ij}, T_{ijk}) \tag{5}$$

where,

SQ_{ij} : Service quality between regions

D_{ij} : Distance of zone between regions

T_{ijk} : Travel time between regions by mode k

T_{ijk} , travel time by mode k, is average travel time by mode k from among various travel time values, because of being considered multiple paths between region i and j. It is obtained in free flow state in that the performance of network to itself is considered. D_{ij} , distance of zone between regions, is a straight line distance between centres of regions from among various distance values, because shortest path distance and average path distance are changeable in case of adding or removing links.

Based on factors above described, the concept of average speed is suggested. This concept means that distance between regions is overcome and that performance of network is emphasized to itself. Eq. (6) is a mathematical model for SQ.

$$SQ_{ij} = \sum_{k=1}^{n} \frac{\alpha_k D_{ij}}{T_{ijk}}, \qquad i \neq j \tag{6}$$

where,

SQ_{ij} : Service quality between zone i and j

D_{ij} : Straight distance between centres of zone i and j

T_{ijk} : Average travel time between zone i and j by mode k

α_k : Weight coefficient by mode k, $0 \le \alpha_k \le 1, \quad \sum \alpha_k = 1$

Present traffic network is operated multiply by various modes. Hence, travel time between regions needs to consider a kind of mode. α_k is suggested as weight coefficient by mode. It is influenced by many attributes in region or network: traffic volume by mode, a number of connections, dispatch interval of public transportation mode and average travel time according to mode.

3.3 Mobility Indicator by Region

3.3.1 Basic Mobility Indicator Model

Mobility indicator (MI) is based on SQ, performance measure of inter-regional network. It indicates how fast to move from one area to the others. Namely, MI is calculated by accumulating SQ. For modelling, average method is suggested as basic model. It points that all destination have equal weight for origin.

$$M_i = \frac{\sum_{j=1, i \neq j}^{n} SQ_{ij}}{n-1} \tag{7}$$

where,

M_i : Mobility Indicator by zone i

SQ_{ij} : Service quality between zone i and j

However, there are two considerations of using basic mode. At first, if distance between origin and destination is under 30km(average distance between zones based on Korea administrative district), average speed could be high. Therefore, destinations which locate within 30km boundary from origin are excluded for estimating MI because their SQs could be overestimated depending on centroid location of their zones. Secondly, only 40 points are determined as a destination, which means that these points are primary cities in Korea. These points are defined as 'prime area'. MI model is considered with these two considerations below.

3.3.2 Mobility Indicator Model with considerations

Mobility indicators (MI) are based on SQ, performance measure of inter-regional network. They indicate how fast to move from one area to the others averagely. Namely, MI is calculated

There is a condition of grouping target destination regions which are prime area. In a political view, it may be unreasonable that all destination regions have equal weight. Therefore, SQs which are linked to some particular regions which have the indicators representing heavy traffic condition such as high GRDP, high income, high population and central place in province are aggregated for calculating MI. Eq. (9) is the formula of MI model.

$$M_i = \frac{\sum_{j=1, i \neq j}^{n} SQ_{ij}\delta_{ij}}{\sum_{j=1}^{n} \delta_{ij}} \tag{9}$$

where,

M_i : Mobility Indicator by zone i

SQ_{ij} : Service quality between zone i and j

δ_{ij} : $\begin{cases} 1 : D_{ij} > k \ and \ SQ_{ij} \in I_j \\ 0 : otherwise \end{cases}$

I_j : Set of service quality in destination zone j

4. **RESULT**

4.1 Data

In this research, road network is only analyzed except for rail road and airline network. Therefore, α_k, weight coefficient by mode, is not considered. Target road network is based on Korea Transport Database (2009) except islands including Jeju-island. Total 245 traffic zones are analyzed. Average travel time in road network is examined using Emme/2 program. VDF functions are suggested in Standard Guidelines for Preliminary Feasibility Studies (2009). Weight coefficient ignores toll fee.

The straight distance is calculated as a Euclidean distance between centroid between zones. The coordinates of centroid are in KATECH (TM128) coordinate system which is used commonly car navigation programs. 40 primary regions are selected by population and central position in provinces: Seoul, Pusan, Daegu, Inchon, Ulsan, Gwangju, Daejun, Chuncheon, Cheongju and Mokpo etc. For calculating SQ and MI, Microsoft Access 2007 is used with SQL (Structured Query Language).

4.2 Computational Result

4.2.1 Service Quality by inter-Regional Network

Total 56780 OD pairs are examined and the same numbers of SQ are calculated. Figure 2 shows distribution of SQs. As can be seen, about 96% of SQs are in the range between 50km/h and 80km/h. In addition, SQs between 60km/h and 70km/h are occupied about 65 %. In cases of lower 60km/h, it is speculated that travel time is relatively long in comparison with straight distance between regions. In these OD pairs, origins and destinations are almost small area in metropolitan city, as 'gu'.

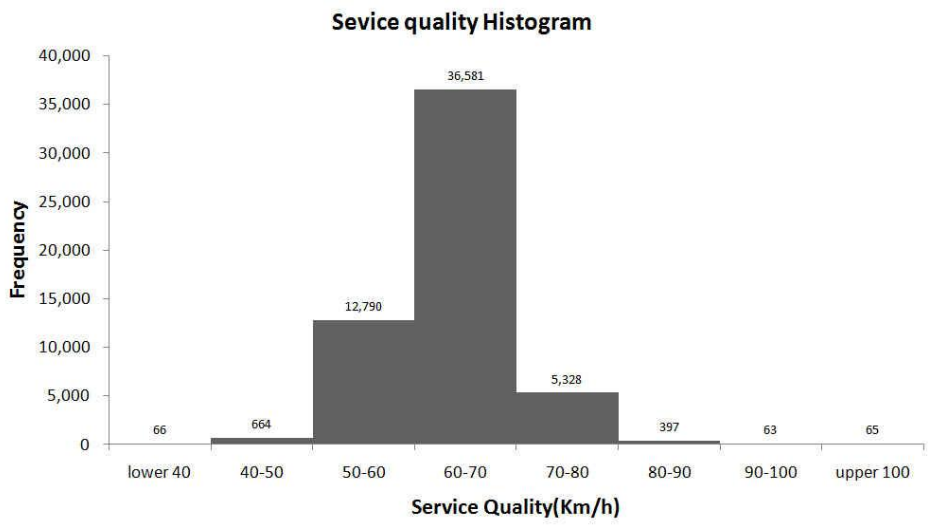

Figure 2 Service quality distribution diagram

4.2.2 Mobility Indicator by Region

MIs of 245 regions are calculated on the basis of SQs by regions twice: the first estimation is for 245 destinations and the second one is for only 40 destinations. Figure 3 show the results and difference between two mobility indicators.

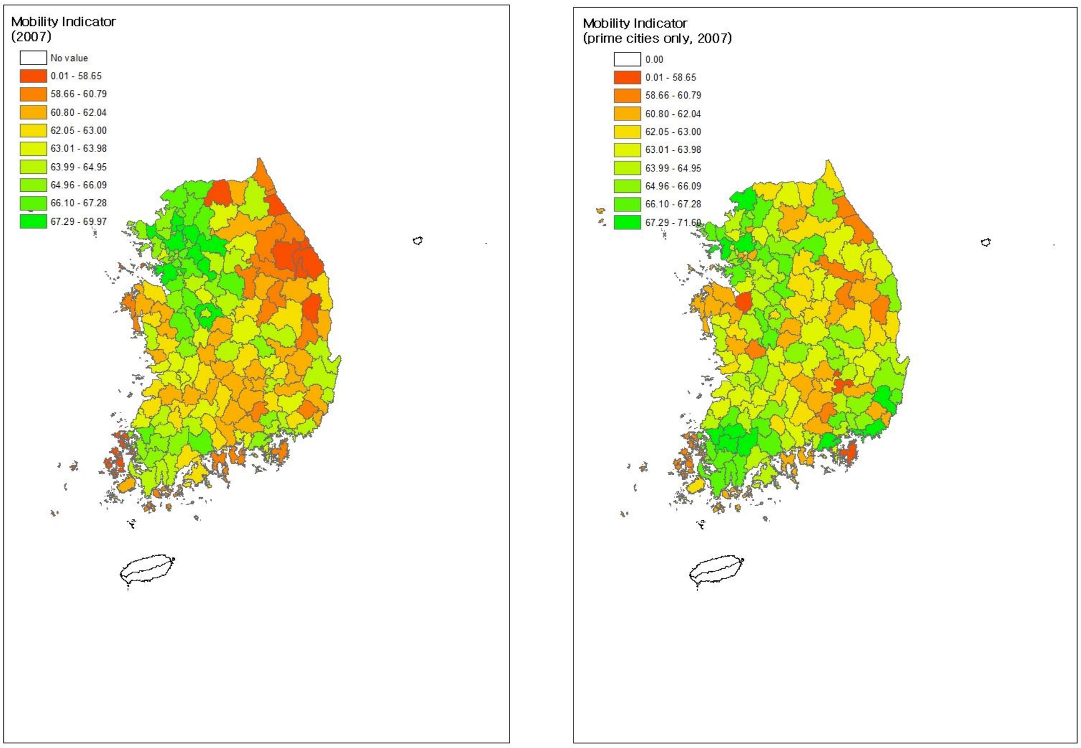

Figure 3 MI distribution map (245 destinations vs. 40 destinations)

In Figure 3, it is found increase of MI in specific regions. Based on results above, it is certain that highway interchanges located in those regions. It may be due to well constructed transportation facilities in prime areas. The second MI model with 40 destinations can be used as transportation policy criterion because this is more reasonable to evaluate the mobility between origins and main areas in nation.

4.3 Comparison with Regional Backwardness

4.3.1 Problems of Regional Backwardness

Regional Backwardness is a representative index for regional investment equity analysis. It is used in several government plans and investment guides. The region in lower rank has better socio-economic indices. Figure 4 shows distribution of Regional Backwardness rank, which is developed by KDI in 2009. This data is based on the situation in 2005. That index is a common factor of regional equity analysis in the pre-feasibility analysis of transportation facility investment project. As can be seen in Figure 4, north-western and south-eastern parts such as Seoul-Pusan line are relatively developed areas.

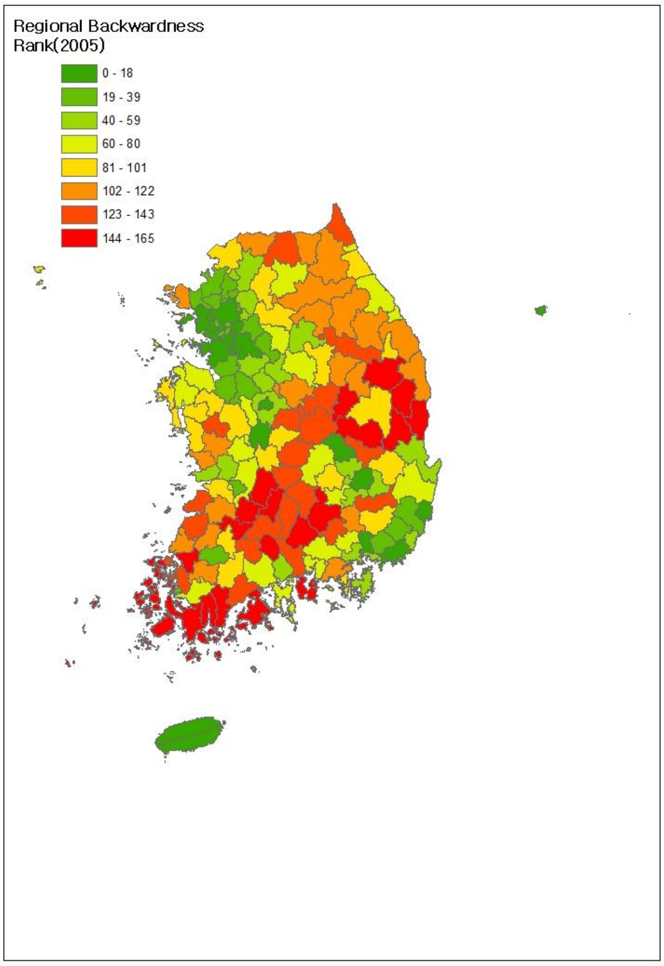

Figure 4 Regional backwardness rank map, KDI, 2005

4.3.2 Comparison with Regional Backwardness

In comparison obtained results with Regional Backwardness, the difference of the rank is shown in Figure 5. The left map shows the distribution of MI rank. The right map represents the gap of rank (Backwardness rank minus MI rank) remarkably. Brown and orange areas have lower rank than Backwardness rank, which means that the areas overrated as compared mobility. Namely, those areas need to be invested for transportation facilities (especially road network), but they are acknowledged as enough developed regions according to Regional Backwardness. On the other side, dark green and blue areas have upper rank than Backwardness rank. These areas are underrated as compared mobility. It means that those areas had enough transportation facilities in spite of high Regional Backwardness. The existence of many brown or blue areas indicates that MI has important role as regional equity in transportation investment.

Practically, a new highway (ex: Seohaean highway) is being built in south-western parts in Korea. However, it is not considered by Regional Backwardness. There are less transportation facilities in north-eastern parts because of the Taebaek Mountains.

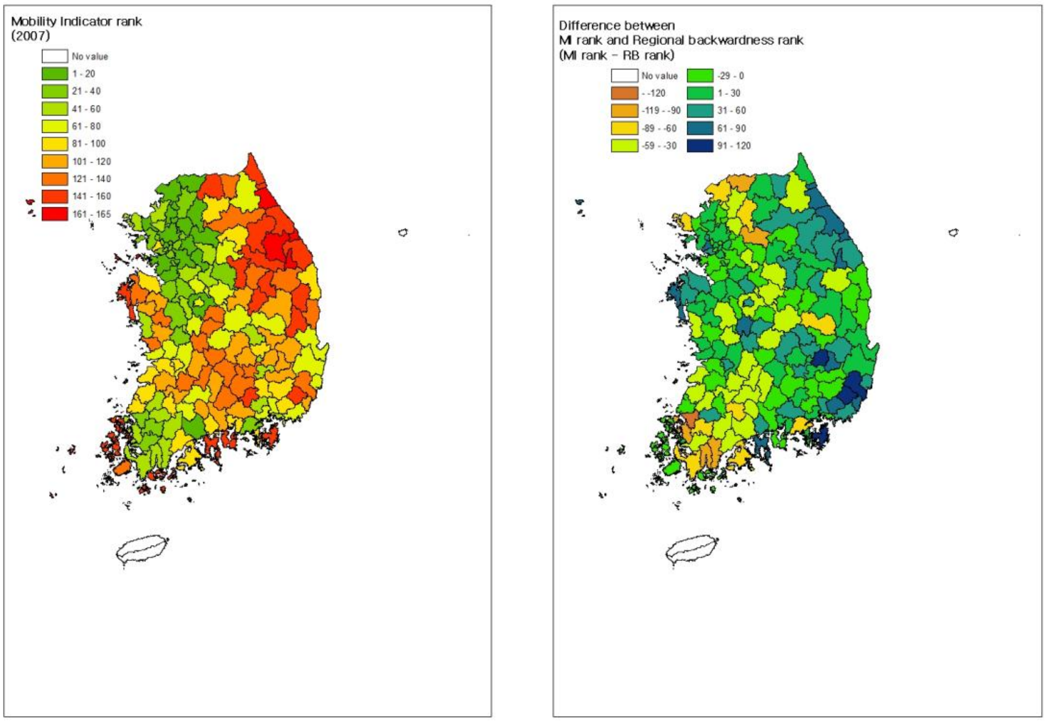

Figure 5 Differences between MI and Regional Backwardness (256 destinations)

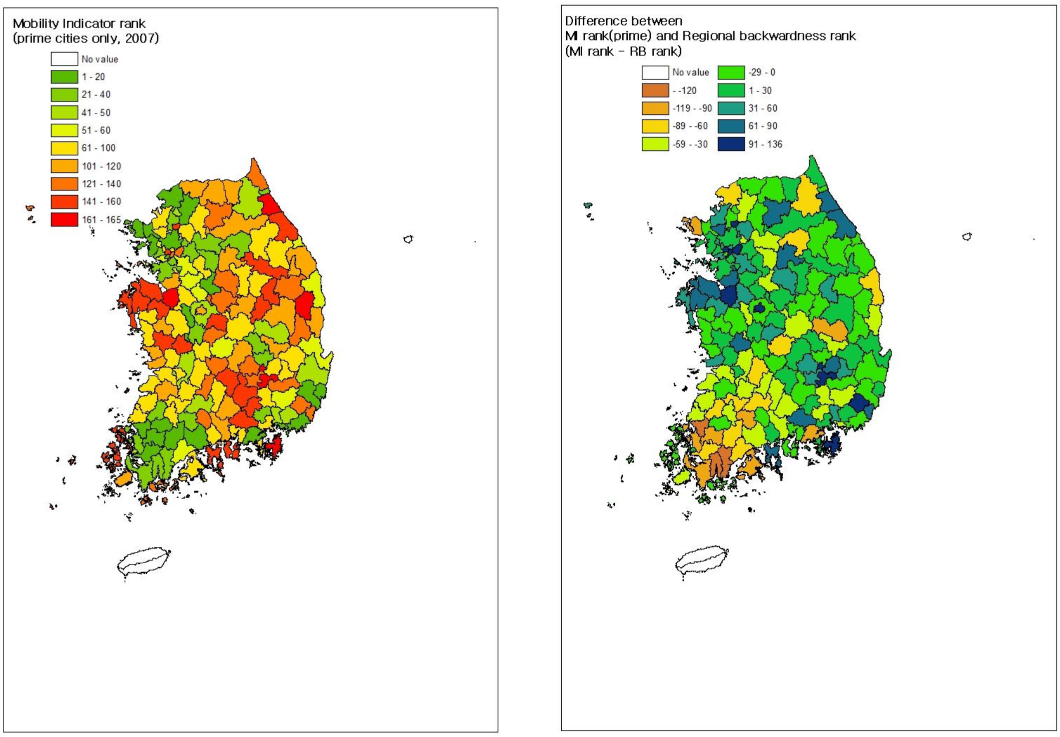

Figure 6 Differences between MI and Regional Backwardness (40 destinations)

Figure 6 describes a comparison between Regional Backwardness and MI with 40 destinations. It provides a slightly different result from the result above. More brown and orange areas are founded including south-western part in Korea. It could explain that specific areas are evaluated as an undeveloped area due to social indices even though they have proper traffic infrastructures. Because south-western part shows lower population and income compared to other areas in Korea.

5. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The contribution of this study is development of new indicator considering regional equity for making priority or feasibility analysis in transportation facility investment. This indicator is based on performance of inter-regional network instead of social indices of region. In comparison with Regional Backwardness, this indicator of road network in Korea shows slightly but meaningful difference. While Regional Backwardness concerns with life quality of region which takes the form of a monetary unit, a mobility indicator deals with direct benefit from transport facilities. In transportation political view, this indicator will be used effectively. For example, city planners need to determine projects to carry out in several projects which have nearly equal efficiency. They consider various factors for choosing them. Mobility indicator, one of direct factors for transportation equity, is essentially considered instead of regional backwardness.

However, mobility which considers only speed between points is one of strong alternatives among various factors which are related to regional transport situation. To achieve regional equity, adequate factors should be considered according to characteristic of transportation projects, when priority of projects is determined. There are various candidates which represent conditions of road network. Moreover, the target of this study is limited to road network. Therefore, more study about development mobility index is needed.

As for further study, it may be desirable to develop more realistic MI considering various factors and modes including public transportation network such as bus, rail and air network. Through further study, complementary indicators considering Regional Backwardness, MI and others in regional equity analysis could be suggested for transportation policy.

ACKNOWLEDGEMENTS

This research was supported by SNU SIR Group of the BK21 research Program and Engineering Research Institute in SNU.

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