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Activation plans of Public Transport based on Urban Network Analysis

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This study aims to analyze the changes in urban railway network centrality by introducing metropolitan express railways and analyzing the environmental benefits owing to the activation of public transportation. Interest in climate crises is emerging and interest in the environment and carbon emissions is increasing. Countries around the world, including Korea, are declaring a "Net Zero 2050" policy to make net greenhouse gas emissions in the atmosphere zero. This study analyzed the aspects of transportation plans and transportation demand management. The change in the centrality of the urban railway network with the introduction of the Great Train eXpress (GTX) was examined. Through urban network analysis (UNA), the urban railway network, before and after the introduction of GTX was compared. Owing to the Betweenness centrality analysis, the importance of Sindorim Station and Yeouido Station in the future networks has increased. The Straightness centrality analysis revealed that stations on the GTX-B route, among the GTX stops, had high path linearity. Based on the stations with high network centrality, the introduction of public transportation activation measures can lead to the conversion of means to public transportation and the resulting environmental benefits. The revitalization of public transportation and transformation of public transportation will help create more environmental benefits.

1. Introduction

Transportation is one of the major contributors to air pollution and carbon emissions. The Seoul Metropolitan Government is promoting and implementing eco-friendly transportation policies that cover the revitalization of public transportation and the establishment of green transportation promotion areas (Kwak et al., 2021). The railway provides significant environmental, economic, and social benefits, and is considered the key factor for attaining the 2050 vision of the European Green Deal, which targets cutting the net emission of greenhouse gases, achieving social equity, and ensuring the separation of economic growth from resource usage (Bencekri et al., 2021). Public transportation can play an important role in reducing Greenhouse Gas(GHG) emissions. The Great Train eXpress(GTX) is a high-speed, direct-track railway that runs on the Great Depth and runs at speeds between 180-200 km/h and a schedule speed of 100 km/h below ground level (Choong and Min, n.d.). This study analyzed the metropolitan subway network after the introduction of the current metropolitan express railway. The network characteristics and centrality of urban railroads will change with the introduction of metropolitan express railways. The benefits of reducing air pollution by reducing the traffic volume were calculated and estimated. The analysis shows that the cost-benefit of reducing air pollution by reducing the traffic volume is approximately 42.5 B KRW/y. The results confirmed that transportation demand management enables eco-friendly goals to be achieved (Ku et al., 2021). In this study, the theory used to grasp the characteristics and centrality of a metropolitan area network is the urban network analysis (UNA), based on the social network theory. UNA was used to analyze structures, such as the impact of nodes and each actor on the entire network, and the identification of relationships between each node in all the networks composed of nodes and links. Seoul's subway network is characterized by large differences in service supply by region and is disproportionately distributed. This study analyzed the benefits of future public transportation activation policies using UNA and environmental benefits. The Seoul Subway Network was established by processing the "railway route and stop information" provided by the GIS data distributed by the Korea Transport Database (KTDB) in 2020.

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2. Methodology

2.1 Framework

Data from the Korea Transport Database(KTDB) contains Train Network. The future railway network was constructed by processing data. The network was evaluated using the Network Centrality index. The framework of this study is illustrated in Figure 1

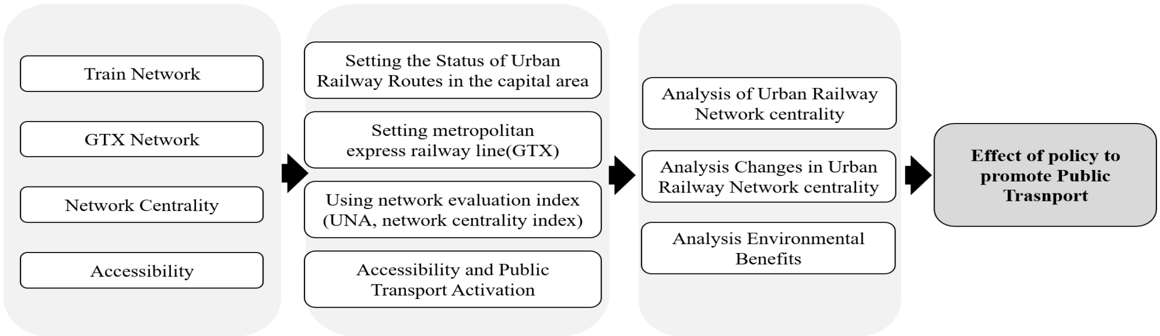

Figure 1: Framework of the study

2.2 Open data in Korea

To conduct this study, the DB was processed based on public transportation GIS data distributed by the Korea Transport Database (KTDB), as of 2019. The KTDB is a place where basic data and statistics necessary for various transportation policies are comprehensively investigated, analyzed, and managed at the national level. The KTDB distribution data were used, except for the routes, which are not currently in operation. Nodes and links corresponding to the metropolitan area were extracted from the DB provided on a national basis and used for analysis. Figure 2 shows the map of the metropolitan area and the Seoul metropolitan railway stations. In the future, the Great Train Xpress (GTX) will utilize.

2.3 Urban network analysis

UNA is a methodology, which numerically analyzes the characteristics of structural networks consisting of nodes, and links connecting each node. Network centrality measurements were conducted using social network analysis. This method can be applied to man-made networks, such as, railway and road networks. It provides insight into the importance of railway stations and road intersections (To, 2016). UNA and network analysis, identifying the important nodes is a fundamental issue. Research on network node centralization can provide a theoretical basis for planning public transportation systems (Wang and Fu, 2017). Relatively important nodes can be identified using the network centrality indicators. Evaluation of relative node importance includes various indicators, such as, Degree, Betweenness, Closeness, and Straightness. Degree centrality describes the possible movement activities that a mover can obtain at a station and Betweenness centrality describes the ability to control the movement activities of a station. Closeness centrality represents the independence or efficiency of a station. Centrality characteristic analysis is useful for urban railway management and operation tasks, and serves as the basis for network vulnerability analysis, which is important for the safety of urban railway systems (Tu, 2013). Degree centrality provides the concept of the number of connections a vector has (Agryzkov et al., 2019). The most common measure of node importance is the Betweenness centrality, which is the ratio at which the nodes act as bridges for important transmissions between the pairs of nodes along the shortest path within the network (Mahyar et al., 2018). Betweenness centrality is particularly relevant for public transportation. Stations can be used extensively because they are near important locations, however, other stations can be used much more because they serve as transfer points to multiple locations (Derrible, 2012). Betweenness centrality is a centrality index widely used in UNA and can be used to explain the importance of the corresponding node in terms of the shortest path. We measured the importance of nodes in terms of connecting with other nodes through the shortest path (Fan et al., 2019). Betweenness centrality is a measure of the importance of the nodes within a network. Nodes with a high benefit centrality affect the bottleneck of the network (Mahyar et al., 2018). Degree centrality is based on the idea that important nodes have the largest number of connections in the graph. Closure centrality measures the closeness of a node to all the other nodes along the shortest path. Betweenness centrality is the concept of a central node if it is between many different nodes, given that many shortest paths connecting the node and the node are passed. Straightness centrality is the idea that the communication efficiency between the two nodes is equal to the inverse of the shortest path length. Betweenness centrality (${C_i}^B$) of Node i and Straightness centrality (${C_i}^S$) of Node i is expressed as Eq(1) and Eq(2).

$$ {C_i}^B = \frac{1}{(N-1)(N-2)} \sum_{j,k \in G, j \neq k \neq i} n_{jk}(i)/n_{jk} \quad (1) $$

$$ {C_i}^S = \frac{1}{N-1} \sum_{j \in G, j \neq i} {d_{ij}}^{Eucl}/d_{ij} \quad (2) $$

n_{jk} is the number of shortest paths between j and k, $n_{jk}(i)$ is the number of shortest paths between j and k including Node i. ${d_{ij}}^{Eucl}$ is the Euclidean distance between nodes i and j along a straight line (Crucitti et al., 2006). In this study, Betweenness and Straightness are used as indicators to evaluate the network of metropolitan urban railways. Betweenness centrality was used to identify the stations that are the intermediaries of the shortest paths in the network, and straightness centrality was analyzed to determine the path efficiency of the stations and routes. A common approach to the preferred path between two points on a network is to define an impedance (or generalized cost) for every link and minimize the total impedance (cost) (McDaniel et al., 2014). In this study, the length of the link was applied as impedance.

2.4 Benefit and green effect in mode change

A fuel life cycle scenario analysis was performed to assess the environmental benefits of the "road-to-rail" policy, with 2017 as the base year. All "road-to-rail" scenarios achieved energy savings and emissions reduction compared to that freight transport (Tong et al., 2021). Major roads were treated as route sources by presenting a study on the effects of traffic emissions on the air quality in Lisbon. Road emissions were calculated based on the average daily traffic volume and emission factors were classified by different road classes and vehicle types (Borrego et al., 2000). The environmental benefits of the new PM-only(Personal Mobility only) road were estimated using the mean conversion and traffic allocation methods. Benefits were calculated by reducing pollutant emissions owing to a decrease in passenger car traffic (Choi et al., 2021). In view of the global efforts for new vehicle technologies, a review of the expected environmental and traffic noise impacts of this type of vehicle when introduced in the market and road traffic was provided (Kopelias et al., 2020).

3. Results

3.1 Urban network analysis

The Betweenness centrality (${C_i}^B$) of Node i is defined as the number of nodes in the path connecting two randomly selected nodes. Therefore, in the subway network, the station, which is the center of the most global transfer, has a large mediation centrality. In addition, the station with the highest betweenness centrality has the greatest impact on the entire network if it is paralyzed or fails to function properly owing to any natural disaster. Therefore, stations with high betweenness centrality are the most important stations in the subway network. The results of analyzing the Betweenness centrality based on the existing metropolitan area network and stations are as follows.

Table 1: Top 5 station in Betweenness centrality

Rank	Station	${C_i}^B$	Standardized ${C_i}^B$
1	Sindorim	89,164	4.80
2	Guro	80,628	4.25
3	Dongdaemun History & Culture Park	79,718	4.19
4	Euljiro 3(sam)ga	77,838	4.07
5	Express Bus Terminal	74,154	3.83

In the current metropolitan urban railway, the central areas of Seoul have a high Betweenness centrality value. On the map, the higher the value is, the closer it is to red. Stations on Line 1, such as Sindorim, Guro, City Hall, and Onsu, are located at the top. Stations on Line 2, such as Dongdaemun History and Culture Park and Eulji-ro 3-ga, are located at the top. In addition, when divided by line, Seoul Lines 1 and 2 were found to have a high Betweenness centrality value. In addition, the values at some stations on the Gyeongui Jungang Line, Line 9, and Line 5 were high.

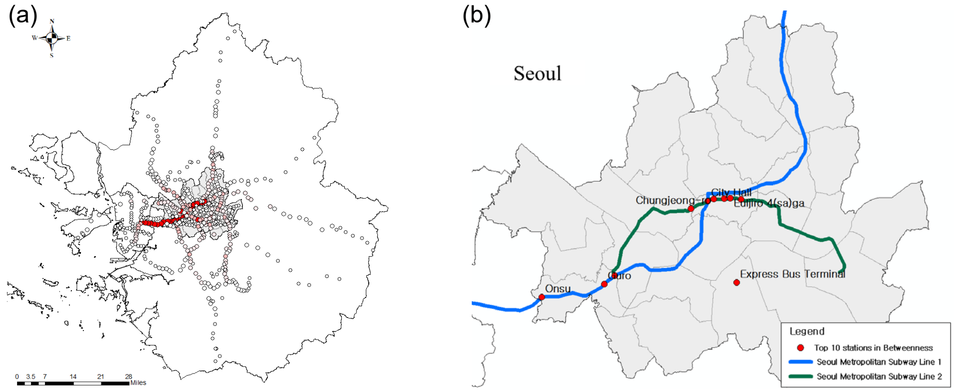

Figure 2: (a) Distribution of Betweenness in Seoul metropolitan area and (b) Top stations in Betweenness centrality

The Straightness centrality ($C_i{}^S$) of Node i has a higher value as the linearity of the network connected to the node increases. This refers to a station where the distance loss of the network is relatively small. Smaller the distance loss, lower is the environmental loss owing to fuel usage. Gyeongwon Line was a suspended route. Stations on Lines 1, 2, 7, and 8 had high-strength centrality values. On the map, higher the value is, closer it is to yellow.

Table 2: Top 5 Station in Straightness centrality

Rank	Station	$C_i{}^S$	Standardized $C_i{}^S$
1	Pyeongtaek	519.40	2.48
2	Sangbong	518.41	2.42
3	Sindorim	517.25	2.39
4	PyeongtaekJije	516.48	2.12
5	Mangu	511.17	2.12

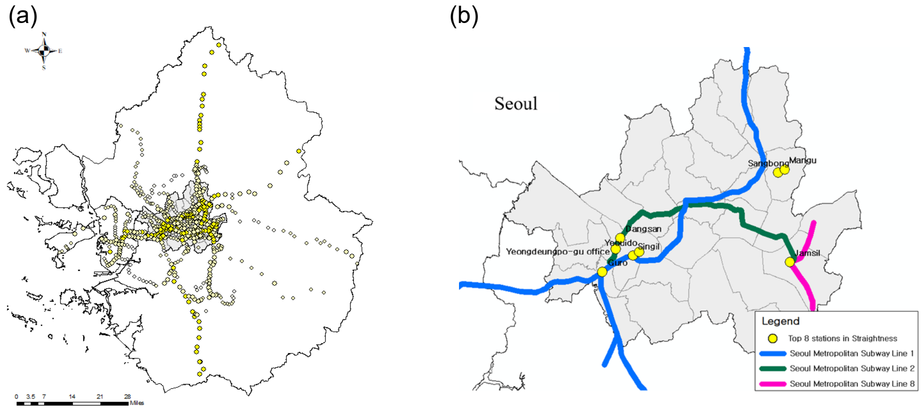

Figure 3: (a) Distribution of Betweenness in Seoul metropolitan area and (b) Top stations in Betweenness centrality

3.2 UNA introduction of GTX

With the introduction of the metropolitan express urban railway, there have been many changes in the value of Betweenness centrality. Yeouido Station saw a significant rise in the value of Betweenness centrality after the introduction of the metropolitan railway GTX. The values before the introduction of the top 5 stations and metropolitan urban railroads are listed in Table 3. Larger the difference value, higher is the importance of the inverse.

Table 3: Top 5 Station with large difference for introduction of GTX

Rank	Station	GTX C_i^B	C_i^B	Difference
1	Bucheon Stadium	51,842	10,804	41,038
2	Yongsan	34,162	4,646	29,516
3	Yangjae	48,904	32,860	16,044
4	Samseong	19,472	3,702	15,770
5	Seoul	22,656	6,942	15,714

Accessibility should be improved based on the corresponding stations to activate public transportation. In addition, the operational efficiency and stability of the links around the nodes should be maximized. This is because these stations can adversely affect the railway network when a bottleneck occurs. With the introduction of the metropolitan express urban railway, there was an insignificant change in the value of Straightness Centrality. It is difficult to change the linearity of an existing station because a new line is created. Accordingly, in this study, the value of Strength centrality for stations on the GTX route was analyzed. Among the stations on the GTX route, the linear efficiency of the GTX-B route was found to be high.

3.3 Environmental benefits

It is important to analyze the possibility of reducing carbon emissions from urban railway traffic (Zhang et al., 2019). It can be meaningfully applied to network reconstruction and expansion (Porta and Scheurer, 2006). From the perspective of nodes and links, which will be constructed in the future, public transport activation policies for stations could bring additional environmental benefits from the Energy efficiency movement in cities as well as the transition to public transport. Policies that improve access to stations can contribute to the revitalization of public transportation. Accessibility and connectivity have a significantly greater indirect effect on public transportation choices (Papaioannou and Martinez, 2015). Using accessibility and connectivity, better means prediction results were obtained when identifying the captive users (people with essential public transportation) (Beimborn et al., 2003). Therefore, a scenario analysis was conducted on the ratio of improving accessibility to important roles obtained because of UNA. For most multimodal trips, the ratio (access and egress time as a proportion of total trip time) falls within a modest range of 0.2-0.5 (Krygsman et al., 2004). The access time for the transit time was considered. The amount of method conversion was analyzed by considering the transfer distance and transfer distance when improving accessibility. The analysis was conducted by assuming a degree of improvement in accessibility (0.2-0.5) in the ratio of access time to the total travel time. It was confirmed that the traffic volume of passenger cars decreased and the traffic volume increased. As the vehicle traffic decreases, environmental benefits occur. The amount of pollutant reduction is calculated based on these criteria. Because the safe speed of 5030 is currently in operation nationwide, the annual pollutant reduction from 10 km/h to 50 km/h was calculated accordingly. The Safe speed speed of 5030 means a law that lowers the speed limit of all roads in the city to within 50km/h to 60km/h and the speed limit of the back road to within 30km/h. Lower the speed, higher is the amount of pollutant reduction. The average traffic speed in the Seoul metropolitan area is 23-25 km/h, which was analyzed to be able to reduce carbon dioxide emissions from 991,028 t/y to 1,263,172t/y.

Table 4: Air pollutants reduction (Unit: t)

Speed	CO	NOx	VOC	PM2.5	CO_2
10	7,585	2,964	753	100	1,912,991
20	4,018	1,909	352	50	1,263,172
30	2,863	1,507	201	50	991,028
40	2,260	1,256	151	50	834,312
50	1,909	1,105	151	50	730,036

4. Conclusions

According to this analysis, The introduction of the Great Train eXpress(GTX) served as a factor affecting the centrality of the Seoul metropolitan area network. The GTX changed the centrality of the metropolitan urban railway network in Seoul. UNA results showed that Yeouido, Sindorim, and Sangbong Stations play an important role in the future network of the metropolitan area. In the future, stations with higher Betweenness Centrality will act as bridges on the network, so they should be activated while also paying close attention to operations and management. The consideration should be made not only for stations with large differences but also for stations with large values even if the amount of change is small. Among future GTX routes, GTX-B's strength centrality was high. In addition, by applying the public transport activation scenario (improvement of accessibility) based on the stations, which will become important in the future, the results of the approximate environmental benefits were obtained. The effect of the public transportation activation policy on the achievement of Net-zero 2050 is shown from the perspective of subway stations. The government-led policy on revitalizing public transportation can contribute positively to reducing carbon emissions. The government's implementation of public transportation activation policies, which consider the network characteristics of urban public transportation, can contribute to the development of eco-friendly transportation and green cities.

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