Analysis of Regional Disparities in Public Transportation Accessibility: A Spatial Approach to Equal-Time Job Accessibility

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Abstract
This study empirically analyzes regional disparities in public transportation service levels between the Seoul metropolitan area and other South Korean regions, offering policy implications for balanced national development. Overcoming prior research limitations like reliance on administrative boundaries or a single-transportaion mode, this study utilizes nationwide direct-link transit data to evaluate mobility and accessibility at a fine 500m x 500m grid cell resolution. Mobility is defined as reachable grid cells and accessibility, as accessible jobs, both within one hour. Analysis reveals the Seoul metropolitan and Busan-Ulsan-Gyeongnam have the highest mobility and accessibility, while Gangwon ranks lowest. Notably, dense industrial clusters show high public transport job accessibility, underscoring that improving transit access to employment centers, not just attracting businesses, is key to enhancing regional competitiveness.

Keywords : Spatial inequality, Public transportation, Disparity, Spatial coverage, Job Accessibility

1. Introduction

In modern cities, public transportation is a crucial element that ensures individuals' ease of mobility to various destinations. Notably, in South Korea, public transportation accounts for a high modal share of 32.7% (Ministry of Land, Infrastructure and Transport, 2022) when considering travel distance and ridership, thus playing a pivotal role in mobility. The competitiveness of a city is influenced by the level of public transportation services, and efficient allocation can facilitate balanced development (Shabanam et al. 2024).

Public transportation has a greater societal impact compared to private vehicle use. This is because public transportation offers high road utilization efficiency and low usage costs, making its services accessible to diverse social strata. Specifically, low-skilled and economically vulnerable populations are more dependent on public transportation than private cars, necessitating the establishment of an adequate service level to provide them with employment opportunities (Elgeziry, M, 2022). Regions with inadequate public transportation systems face limited mobility, which degrades access to employment and educational services, leading to disparities in regional development and quality of life (Stewart, 2017).

Public transportation also contributes to industrial and economic development by enhancing labor market and consumer accessibility (APTA, 2022). An efficient public transportation system in a nation increases the likelihood of attracting various industries and businesses, and induces a higher volume of commuting and business activities (Lee et al., 2023). High values in indicators of public transportation infrastructure, such as bus stop density and public bicycle usage, enable urban residents to conveniently travel to various destinations like workplaces, schools, shopping, and cultural facilities. This, in turn, enhances accessibility to living infrastructure such as housing, education, and commercial facilities, thereby revitalizing the region (Kim, 2024).

The disparity in public transportation services between regions is identified as a representative factor of imbalance in urban and regional development in South Korea (Park, 2023). The establishment of a public transportation network involves not merely road construction but also substantial budgets, compelling the nation to make cautious investment decisions. In this context, there is a clear tendency for public transportation services to be primarily supplied to the Seoul Metropolitan Area, where population and jobs are concentrated.

In fact, the widening gap in regional public transportation infrastructure has accelerated even further since the COVID-19 pandemic (Korea Research Institute for Human Settlements, 2023). The increasing closures of local terminals and reductions in intercity bus routes and frequencies have drastically degraded convenience for local residents. In stark contrast, discussions for large-scale metropolitan railway projects, such as the GTX lines and Shinansan Line, are actively progressing in the Seoul Metropolitan Area, with continuous investment being made.

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This contrasting situation in public transportation service levels between the Seoul Metropolitan Area and other regions further exacerbates the inter-regional accessibility gap, which directly translates into restricted mobility in local areas and can lead to significant problems such as an imbalance in regional revitalization and quality of life (Hwang et al., 2024).

Literature Review

Improving accessibility, a key indicator for evaluating public transportation service levels, is considered a core task for governments (Yoo et al., 2021). While various efforts are underway to enhance transport accessibility, the term "accessibility" is not uniformly defined, which can lead to ambiguity in evaluation. According to Cho (2014), public transportation accessibility can be largely categorized into three types: first, the ease of reaching public transportation facilities such as stops and stations; second, the geographical area reachable within a specific time using public transportation; and finally, the number of opportunities (e.g., medical services, education, employment) accessible via public transportation.

In this study, we define accessibility as the number of opportunities reachable by public transportation, specifically focusing on employment opportunities. The reason for prioritizing employment among various opportunities in a city is that commuting is the primary purpose for citizens using public transportation (Korea Transport Institute, 2014). In this context, the distance between one's workplace and residence is directly linked to life satisfaction; shorter commute times are associated with higher job satisfaction and quality of life for workers (Han.L, 2022).

ITF-OECD (2023) evaluated the level of public transportation infrastructure in the Seoul Metropolitan Area, comparing the number of accessible jobs when using a car versus public transportation. The analysis revealed no significant difference in the number of accessible jobs by mode in the central urban areas of the capital and some areas adjacent to railway lines. However, in most suburban areas with high commuting demand to Seoul, public transportation accessibility was found to be severely low, leading to high car dependency. Despite its insights, this study had limitations in clearly identifying the accessibility of public transportation itself, as it primarily examined the service level of public transportation relative to private vehicles.

Beyond Korea, studies in major U.S. metropolitan areas and recent EU cities highlight that a lack of private vehicle accessibility and inadequate public transportation services pose significant barriers to employment access and retention (e.g., Cervero et al., 2002; Korsu and Wenglenski, 2010; Sanchez et al., 2004). Fransen et al. (2019) confirmed that possessing a driver's license positively influences job accessibility. In the case of the Flanders region in Belgium, a positive correlation was observed between driver's license ownership and high job accessibility, suggesting relatively low job accessibility via public transportation. Furthermore, the importance of public transportation in the labor market is underscored by the significant negative correlation between job accessibility and the probability of long-term unemployment. However, this study indirectly revealed the high accessibility associated with private vehicle ownership rather than directly presenting job accessibility through public transportation. This limits its ability to ascertain the clear impact of public transportation.

Elgeziry (2022) revealed that job accessibility through public transportation has a greater impact on vulnerable populations. Through a case study in San Bernardino, California, the research analyzed the effect of affordable and convenient public transportation access on employment opportunities for low-skilled and economically vulnerable residents. The findings indicated that despite the availability of jobs for economically vulnerable and low-skilled residents, the existing public transportation system did not adequately cover their work hours and job locations, severely limiting job access. While this study is highly contributory due to its consideration of operating hours based on workers' job locations, its limitation lies in analyzing the mobility of specific social strata, making it difficult to grasp the overall effect of public transportation. Bastiaanssen (2022) confirmed that in urban areas of the UK (excluding London), employment elasticity showed a positive value when public transportation accessibility increased at the census tract level. This had a greater impact on people without cars and low-income individuals. This study is significant for using employment probability as a dependent variable to measure people's actual opportunities, but it has limitations in quantifying the number of opportunities.

Research Contribution and Differentiation

Previous studies evaluating public transportation accessibility based on the number of accessible jobs have primarily focused on the job accessibility levels of specific social strata or compared travel ranges within the same time using private vehicles. This approach has made it difficult to conduct a direct, region-by-region comparison of public transportation as a standalone mode. Therefore, this study aims to analyze job accessibility via public transportation for all citizens, not just specific groups, to understand the service level across all social classes. Furthermore, the analysis will focus exclusively on public transportation, excluding private vehicle use.

The key questions guiding this research are:
Within a given urban area in South Korea, what is the geographical range that can be reached by public transportation within a specific timeframe?
What are the disparities in the number of accessible jobs within the same timeframe across different regions?

This study will empirically analyze the regional differences in public transportation accessibility across South Korea, measured by the number of accessible jobs. We will also identify the number of jobs reachable by public transportation (Ma L. et al., 2021), which can serve as a metric for urban competitiveness. Understanding the number of jobs accessible in each region can help identify areas where public transportation needs improvement and contribute to establishing economic hubs by forming central transportation axes when planning new cities. Ultimately, this research will provide crucial foundational data for developing policies that foster balanced development and strengthen inter-regional cooperation.

2. Methodology

Previous studies on public transportation accessibility have faced several methodological limitations. For instance, Han Dae-ho (2016) evaluated public transportation levels in Seoul based on administrative dong units. However, these units often fail to reflect actual population distribution or area differences. In contrast, this study measured transport accessibility at a more granular spatial unit by employing a 500m x 500m grid-based analysis. This approach is advantageous for evaluating public transportation services based on actual residential areas.

Furthermore, studies by Yoo Kyeong-sang et al. (2020) and Jeong Yong-il (2021) utilized grid units but were limited to specific cities like Seoul or Cheongju, North Chungcheong Province, hindering the generalizability of their findings. This study overcomes this limitation by conducting a nationwide analysis. By classifying regions based on urban area categories officially announced by the government (Committee for Balanced National Development, 2023), rather than simple administrative districts, we enhanced the policy applicability of our research.

Finally, most existing studies primarily considered single modes of transportation like buses or subways (Rural Service Standards, 2023) and failed to incorporate actual public transportation usage characteristics such as transfer possibilities. To address this, our study attempted a more realistic assessment of public transportation accessibility by conducting a network analysis that considers integrated approaches across various transportation modes and transfer routes.

The data used for this analysis, as of December 2024, includes:
- GTFS direct section data for national regional buses, express/intercity buses, trains, subways, aviation, and maritime transport from TMAP.
- 500m x 500m grid SHP files from SGIS, along with population, household, business, and employee count data.
- Province and city/county shapefiles from the National Geographic Information Institute.

The direct section data can be considered as links connecting nodes (origin and destination). These nodes are spatially mapped onto the 500m x 500m grid files, transforming movement between stops into movement between grids.

Table 1: Example of Direct Section Data

Area	Agency Type	Route Name	Stop ID 1	Stop ID 2	Stop Name 1	Stop Name 2	Distance (m)	Time (sec)	Oper_ Count	First Depart	Last Depart
Gangwon	Express Bus	Express Bus : Gang-neung-Goyang	300070	300006	Gangneung Terminal	Goyang Terminal	184,663	10,200	5	7:00:00	19:40:00

For transfer calculations, a threshold distance of 800m was defined as the walkable range for transfers (Streb. M, 2022), assuming a walking speed of 1.2 m/s. Waiting times were also factored into the total travel time: 450 seconds for intra-regional movement and 900 seconds for inter-regional movement.

The analysis target area was set nationwide, and the spatial unit was structured based on a 500m x 500m grid cell system. Out of a total of 418,637 grids, 185,216 grids that actually contained population were selected for analysis to ensure relevance from a service perspective.

Table 2: Public Transportation Direct Section Data Structure (Grid-to-Grid Travel)

Agency Type	GRID ID 1	GRID ID 2	Dist (m)	Time (s)	Speed (km/h)	Oper Count
Transportation	Start	End	Distance	Time	Speed	Oper per day

· Spatial coverage
This study aims to analyze public transportation service levels within major metropolitan areas from the perspective of spatial accessibility. To achieve this, we evaluated public transportation-based mobility by combining the spatial range reachable within a set time (1 hour) via public transportation with the population size within that range.

For the mobility assessment, we adopted an accessibility analysis method based on travel time between origin and destination. This allowed us to quantitatively calculate the actual travel range provided by the public transportation network. For grids where a population exists, we evaluated the connectivity between all grids reachable within a maximum of 60 minutes using public transportation, starting from the public transportation stops located within each grid.

The public transportation direct section data used for this analysis totaled 5,772,986 records, from which 3,646,722 grid pairs reachable within 60 minutes were derived. To ensure the validity of the reachable range, cases where the destination grid had no population were excluded. This process resulted in the removal of 166,770 direct sections based on origin and 165,865 direct sections based on destination. Ultimately, only significant travel routes were extracted, and the range of movement possible within one hour was calculated for a total of 67,323 grids. For spatial analysis, this study categorized the entire nation into seven major metropolitan areas: the Seoul Metropolitan Area, Gangwon Region, Daejeon-Chungcheong Region, Jeonbuk Region, Gwangju-Jeonnam Region, Daegu-Gyeongbuk Region, and Busan-Ulsan-Gyeongnam Region. Within each of these wider metropolitan areas, we analyzed public transportation accessibility and population distribution characteristics.

· Job Accessibility
In this study, accessibility is defined as the total number of jobs located within all destination grids reachable from a given origin grid within one hour, using the direct sections converted from grid-to-grid movements. We will then calculate the average number of reachable jobs per grid for each urban area to compare regional differences.

To compare regional accessibility, we will utilize the metric proposed by Allen et al. (2019), which is derived from the number of jobs reachable within a specific time in each region. The formula is as follows:

$$A_{ij} = \sum_{i=1}^{J} O_j f(t_{ij})$$

A_{ij}= Accessibility at location i

0_j= Number of opportunities at location j

$t_{i,j}$= Travel cost (time or distance) from location i to j

$f(t_{ij})$= Decay function based on travel cost

T = Threshold (travel time)

A_{ij} is a measure of accessibility for location i. 0_j is the number of opportunities at location j. 0_j can be interpreted as the attractiveness or gravity of location j. $f(t_{ij})$ is a decay function of travel cost t from i to j and threshold (T) for travel time or the number of transfers is set, meaning it is reflected if it is below the threshold and excluded if it exceeds it.

To understand the relationship between the level of public transportation service establishment and jobs, a correlation analysis was conducted between internal grid data (population, number of households, number of businesses, number of jobs) and the number of public transportations stops to enhance justification. The correlation analysis results, transformed into log values, showed a correlation coefficient of 0.35-0.38 between the number of stops and the intra-grid data. The number of stops has a significant correlation with socioeconomic indicators, and it can be seen that this should be considered when assessing public transportation service levels.

Table 3: Number of Stops within Grids

Metric	Value
count	71,830
mean	2.72
std	1.94
Min	1
25%	2
50%	2
75%	3
Max	27

Table 4: Population within Grids

Population	Grid
0	233,421
1-10	73,411
11-100	86,363
100-1,000	14,064
1,000-10,000	11,211
10,000+	166

3. Results

Spatial Coverage

We examined the percentage of grids reachable within 1 hour by public transport relative to the number of populated grids in each urban area. The Seoul Metropolitan Area showed the highest proportion at 47.2%, demonstrating its well-established transfer system, including bus-subway connections. Following Seoul, the Busan-Ulsan-Gyeongnam area (BUK area) also exhibited a high level of public transport service, likely due to its inclusion of two metropolitan cities and their larger populations.

Conversely, the Gangwon region had the lowest proportion at 27.1%, indicating that the spatial reach of public transport is significantly limited there. The Daejeon-Chungcheong, Jeonbuk, and Gwangju-Jeonnam regions showed similar proportions. Further analysis of factors like population and job numbers in these areas is necessary to determine if their current public transport distribution is adequate.

Table 5: Ratio of 1-Hour Reachable Grids to Populated Grids by Urban Area

Metropolitan Area	SIDO	Number of Populated Grids	Grids Reachable Within One Hour	Percentage
Seoul Metropolitan Area	Seoul Incheon Gyeonggi	30,069	14,195	47.2
Gangwon Area	Gangwon	18,529	5,029	27.1
Daejeon Chungchung Area	Daejeon Sejong Chungnam Chungbuk	38,023	13,453	35.3
Jeonbuk Area	Jeonbuk	15,688	5,561	35.4
Gwangju Jeonnam Area	Gwangju Jeonnam	24,620	8,731	35.4
Daegu Gyeongbuk Area	Daegu Gyeongbuk	31,229	10,273	32.8
Busan Ulsan Gyeongnam Area	Busan Ulsan Gyeongnam	23,525	8,696	37.0

Job Accessibility

When analyzing by urban area, the Seoul Metropolitan Area consistently had the highest number of jobs reachable by public transportation. This region recorded more than twice the number of employees and businesses compared to the next highest-ranking area. Following the Seoul Metropolitan Area, the Busan-Ulsan-Gyeongnam area (BUK area) showed the next highest accessibility. The average number of reachable jobs in other regions was found to be similar across them.

Table 6: Average Number of Reachable Jobs and Businesses within 1 Hour per Grid by Urban Area

SIDO_NM	Number of job	Number of Businesses
Seoul Metropolitan Area	1202.4	265.3
Gangwon Area	200.6	60.4
Daejeon Chungchung Area	298.1	86.7
Jeonbuk Area	230.8	68.6
Gwangju Jeonnam Area	250.2	70.2
Busan Ulsan Gyeongnam Area	527.9	145.5
Daegu Gyeongbuk Area	266.2	77.5
Jeju Area	283.8	85.5

The Seoul Metropolitan Area shows high accessibility to jobs via public transportation. In most grids, it's possible to reach over 400 jobs within an hour. Specifically, areas like Yongsan-gu, Jung-gu, Gangnam-gu, Songpa-gu, Seocho-gu, and Yeongdeungpo-gu in Seoul demonstrate the highest accessibility, with over 5,800 jobs reachable per grid. Outside of Seoul, areas such as Bundang-gu in Seongnam City (including Pangyo Techno Valley), Suji-gu in Yongin City (home to a semiconductor cluster), Yeongtong-gu in Suwon City, and Giheung-gu in Yongin City also offer access to a relatively large number of jobs. This indicates that the presence of large industrial complexes or business districts near a grid leads to a high number of reachable jobs.

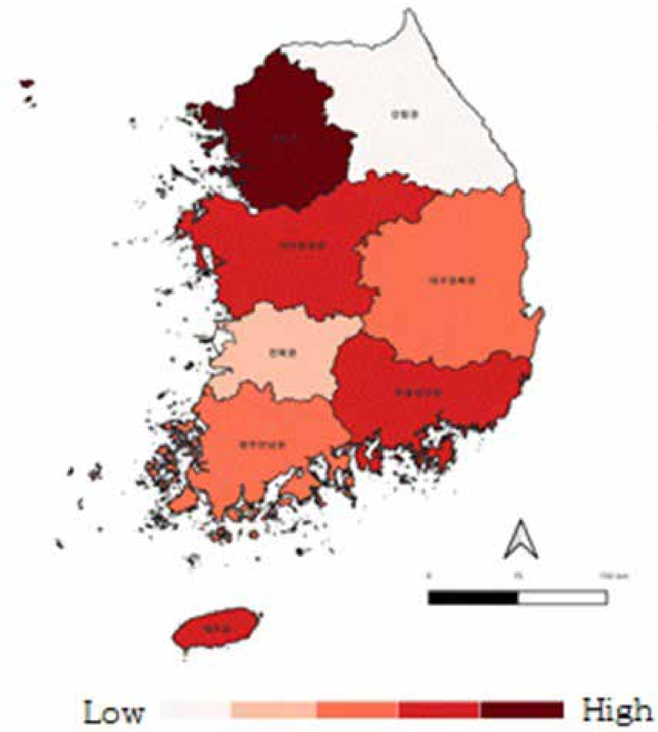


Figure 1: Average Number of Reachable Jobs per Grid within 1 Hour by Urban Area

In the Gangwon region, only Chuncheon City, Wonju City, Gangneung City, and Donghae City have grids where the number of reachable jobs exceeds 500. Most areas in Gangwon show limited accessibility via public transportation. This reflects the challenges posed by the Taebaek Mountains, resulting in insufficient public transportation infrastructure, and the lack of a proper industrial ecosystem development since the decline of mining.

The Daejeon-Chungcheong region also exhibits varying levels of job accessibility. Areas around Cheonan City's Seobuk-gu and Dongnam-gu, where Seoul Subway Line 1 passes, and Cheongju City's Heungdeok-gu, Seowon-gu, and Sangdang-gu, around Osong Station, have grids where approximately 1,000 jobs are reachable. Sejong City, with its active BRT system, also has grids where over 1,000 jobs are accessible via public transportation. Daejeon emerged as the region with the best job accessibility, largely due to its well-established public transportation system, including the subway, and the presence of numerous jobs in areas like the science research complex, which contributes to an increased number of reachable jobs per grid.

In the Gwangju-Jeonnam region, Gwangju Metropolitan City exhibits the best public transportation job accessibility, with the highest number of grids offering access to over 1,100 jobs. Additionally, Mokpo, Yeosu, Suncheon, and Gwangyang also show a high number of reachable jobs. Mokpo's strong performance is attributed to its KTX station and extensive accessibility via maritime transport, while Yeosu, Suncheon, and Gwangyang benefit from being major centers of heavy chemical industries, hosting numerous jobs.

Within the Jeonbuk region, Jeonju has the most grids with accessibility to over 1,000 jobs. Iksan, a KTX stop, and Gunsan, with its Saemangeum development and industrial complexes hosting automotive manufacturing plants, also show high job accessibility.

The Daegu-Gyeongbuk region finds Daegu Metropolitan City with the best accessibility. It boasts the most grids that allow access to over 1,300 jobs, with some grids offering access to a maximum of approximately 3,600 jobs. This high accessibility appears to be influenced by Daegu's subway system and Dongdaegu Station. Furthermore, Gumi City, home to production plants of large corporations, and Pohang, a hub for heavy chemical industries, also have numerous grids providing access to over 1,300 jobs. Most other areas in this region recorded similarly low accessibility levels.

In the Busan-Ulsan-Gyeongnam region, Busan has the highest number of grids with access to over 2,400 jobs, with some grids reaching up to approximately 8,600 jobs. Jinju and Changwon, both with concentrated KTX stations and industrial complexes, have many grids with access to over 1,500 jobs. Ulsan, a prominent industrial city, also has numerous grids offering access to over 1,500 jobs via public transportation.

Finally, in the Jeju region, grids providing access to over 1,100 jobs are predominantly concentrated in Jeju City, forming around the airport.

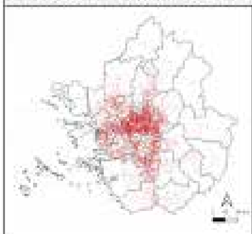
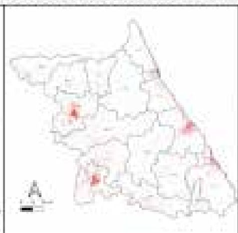
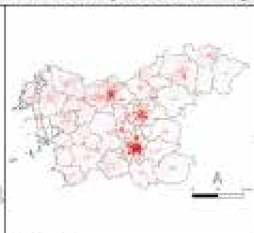
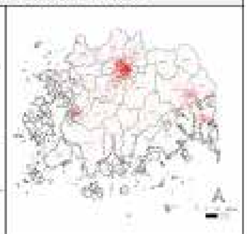
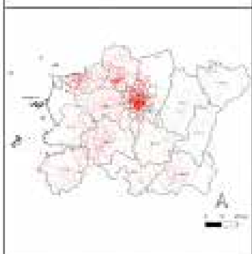
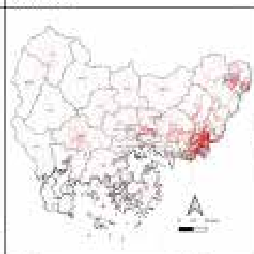
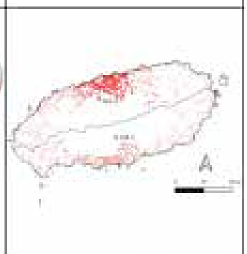
Integrated Results

The Seoul Metropolitan Area and the Busan-Ulsan-Gyeongnam Area (BUK Area) showed the highest numbers of reachable jobs per grid, relative to their populated grids. In the Seoul Metropolitan Area, this is due to the concentration of businesses and talent from metropolitan centralization, and the establishment of a public transportation system capable of accommodating a large population. Furthermore, the presence of KTX stations and the metropolitan subway system enhances job accessibility for citizens. In the BUK Area, the presence of KTX stations and industrial complexes, including Ulsan, provides a large number of jobs that are well-connected by public transportation.

The Jeonbuk Area and Gwangju-Jeonnam Area, which had similar proportions of reachable grids via public transportation relative to populated grids, also showed similar numbers of reachable jobs. In the case of the Daejeon-Chungcheong Area, despite having a similar proportion of public transport-reachable grids relative to populated grids as the Jeonbuk and Gwangju-Jeonnam Areas, its higher number of reachable jobs suggests that the public transportation service infrastructure might be relatively weaker compared to the abundance of jobs. Conversely, the Daegu-Gyeongbuk Area, which had a lower proportion of public transport-reachable grids relative to its populated grids, showed a higher number of reachable jobs than the Jeonbuk and Gwangju-Jeonnam Areas, demonstrating the significant impact of industrial complexes. Such industrial complexes contain a large number of jobs, and improving their accessibility through public transportation could lead to a more efficient transportation service establishment.

Lastly, the Gangwon Area recorded the lowest proportion of public transport-reachable grids relative to its populated grids, and also showed the lowest number of reachable jobs. This suggests that while public transportation services may be insufficient, the supply is proportionate to the smaller population.

Table 7: Number of Reachable Jobs within 1 Hour per Grid - by Urban Area

			
Seoul Metropolitan Area	Gangwon Area	Daejeon Chungchung Area	Gwangju Jeonnam Area
			
Jeonbuk Area	Daegu Gyeongbuk Area	Busan Ulsan Gyeongnam Area	Jeju Area

4. Discussion

This study aimed to overcome the limitations of existing public transportation accessibility and mobility analyses. It did so by using nationwide empirical data to measure public transportation service levels at a precise spatial unit (500m x 500m grid). The research distinguishes itself from previous studies by integrating various transportation modes beyond single modes or administrative district analyses. It also quantified mobility and accessibility by constructing a direct section network based on actual usage data.

Public transportation mobility was defined as the "number of grids reachable within the same time," and accessibility was defined as the "number of jobs reachable within the same time." Based on these definitions, the study empirically analyzed inter-regional disparities in transportation services across urban areas. The results showed that the Seoul Metropolitan Area and the Busan-Ulsan-Gyeongnam Area exhibited the highest levels in both the number of grids and the number of jobs reachable within one hour via public transportation. This signifies that these regions possess well-established infrastructure and transfer systems. In contrast, the Gangwon region recorded the lowest figures for both public transportation accessibility and the number of reachable jobs, confirming the existence of a service gap between regions.

Specifically, it was confirmed that regions with economic hubs, such as industrial complexes, have more job opportunities when public transportation accessibility is high. This suggests that for regional areas, simply attracting businesses is not enough; the quality of transportation services that enable access to these jobs is crucial for enhancing regional competitiveness. To counter the concentration in the Seoul Metropolitan Area, it is essential to build competitive public transportation networks within each urban area. This can serve as an important strategic criterion for establishing regional balanced development policies.

5. Conclusion

This study moved past traditional administrative district-focused approaches by doing a grid-based, precise analysis. This let us assess actual service levels based on where people truly live. This method can provide helpful foundational data for creating public transportation policies that are practical for daily life and ensure fairness across regions.

However, this study has a few limitations. First, we didn't categorize reachable jobs by industry type, so we couldn't analyze which industries are more closely tied to public transportation accessibility. Second, even though different public transportation modes affect how people move in various ways, we didn't consider factors like transport capacity or service density. This might lead to a difference between the perceived and actual service levels. Third, we didn't re-integrate the grid-based analysis results back into administrative district units, which would have made them more applicable for policy.

This research is important because it used real-world, nationwide transportation network data to quantify and visualize the actual travel ranges and reachable opportunities for citizens. This clearly highlighted the imbalance in public transportation across different regions. In the future, we can expand this into more detailed policy-based research by adding analyses like job accessibility by industry, comparing the influence of different modes, and re-integrating data at the administrative district level. This will help us develop customized mobility policies.

References

Aleta, A., Meloni, S. and Moreno, Y. (2017) 'A multilayer perspective for the analysis of urban transportation systems', Scientific Reports, 7(1), 44359.

Alessandretti, L., Aslak, U. and Lehmann, S. (2020) 'The scales of human mobility', Nature, 587(7834), pp. 402-407. doi: https://doi.org/10.1038/s41586-020-2909-1.

Alessandretti, L., Karsai, M. and Gauvin, L. (2016) 'User-based representation of time-resolved multimodal public transportation networks', Royal Society Open Science, 3(160156). doi: http://doi.org/10.1098/rsos.160156.

Alessandretti, L., Natera Orozco, L.G., Saberi, M., Szell, M. and Battiston, F. (2022) 'Multimodal urban mobility and multilayer transport networks', Environment and Planning B: Urban Analytics and City Science, 50(8), pp. 2038-2070. doi: https://doi.org/10.1177/23998083221108190.

Alessandretti, L., Sapiezynski, P., Lehmann, S. and Baronchelli, A. (2017) 'Multi-scale spatio-temporal analysis of human mobility', PLoS One, 12(2), e0171686.

American Public Transportation Association (APTA) (2020) Economic Impact of Public Transportation Investment 2020 Update. Washington, D.C.: American Public Transportation Association (APTA).

Arentze, T. and Timmermans, H. (2004) 'Multistate supernetwork approach to modelling multi-activity, multimodal trip chains', International Journal of Geographical Information Science, 18(7), pp. 631–651. doi: https://doi.org/10.1080/13658810410001701978.

Baggag, A., Abbar, S., Zanouda, T. and Srivastava, J. (2018) 'Resilience analytics: coverage and robustness in multi-modal transportation networks', EPJ Data Science, 7, pp. 1-21.

Barthélemy, M. and Flammini, A. (2008) 'Modeling urban street patterns', Physical Review Letters, 100(13), 138702.

Bastiaanssen, J., Johnson, D. and Lucas, K. (2022) 'Does better job accessibility help people gain employment? The role of public transport in Great Britain', Urban Studies, 59(2), pp. 301–322.

Candelieri, A., Galuzzi, B.G., Giordani, I. and Archetti, F. (2019) 'Vulnerability of public transportation networks against directed attacks and cascading failures', Public Transport, 11(1), pp. 27-49. doi: https://doi.org/10.1007/s12469-018-00193-7.

Cervero, R., Sandoval, O. and Landis, J. (2002) 'Transportation as a stimulus of welfare-to-work private versus public mobility', Journal of Planning Education and Research, 22, pp. 50–63.

Committee for Balanced National Development (2023) 1st Comprehensive Plan for the Era of Localism (2023-2027). Sejong: Committee for Balanced National Development.

Ding, R., Ujang, N., Hamid, H.B., et al. (2019) 'Application of Complex Networks Theory in Urban Traffic Network Researches', Networks and Spatial Economics, 19, pp. 1281–1317. doi: https://doi.org/10.1007/s11067-019-09466-5.
Elgeziry, M. (2022) Disenfranchised Residents' Perceptions of the Public Transportation Accessibility-Job Opportunity Mismatch in San Bernardino, California. Doctoral dissertation, Walden University.

Fransen, K., Boussauw, K., Deruyter, G. and De Maeyer, P. (2019) 'The relationship between transport disadvantage and employability: Predicting long-term unemployment based on job seekers' access to suitable job openings in Flanders, Belgium', Transportation Research Part A: Policy and Practice, 125, pp. 268–279. doi: 10.1016/j.tra.2018.01.023.

Háznagy, A., Fi, I., London, A. and Nemeth, T. (2015) 'Complex network analysis of public transportation networks: A comprehensive study', in 2015 International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS). Budapest, Hungary, 2015, pp. 371-378. doi: 10.1109/MTITS.2015.7223282.

Han, C., Liu, X., Shen, X., Zhang, L. and Feng, N. (2019) 'Evaluating the Spatial Deprivation of Public Transportation Resources in Areas of Rapid Urbanization: Accessibility and Social Equity', Discrete Dynamics in Nature and Society, 2019, Article ID 6890362. doi: https://doi.org/10.1155/2019/6890362.

Hong, D. (2014) A Study on Improving Urban Mobility Through Transportation Network Performance Evaluation. Sejong: Korea Transport Institute (KOTI).

Hong, J., Tamakloe, R., Lee, S. and Park, D. (2019) 'Exploring the Topological Characteristics of Complex Public Transportation Networks: Focus on Variations in Both Single and Integrated Systems in the Seoul Metropolitan Area', Sustainability, 11(19), 5404. doi: https://doi.org/10.3390/su11195404.

Hwang, M. and Shim, J. (2024) 'A Study on Recent Trends in Analyzing Public Transportation Accessibility-Vulnerable Areas', Geographical Review, 70, pp. 91-108.

Ippolito, N. and Cats, O. (2024) 'Multi-modal and multi-layer robustness analysis of the European rail and air networks', Scientific Reports, 14, 26950. doi: https://doi.org/10.1038/s41598-024-76264-6.

ITF (2023) Accessibility in the Seoul Metropolitan Area: Does Transport Serve All Equally?. International Transport Forum Policy Papers No. 117. Paris: OECD Publishing. doi: https://doi.org/10.1787/4ef85abc-en.

Jang, D. (2015) A Study on Transportation Accessibility Evaluation in the Republic of Korea. Sejong: Korea Transport Institute (KOTI).

Kim, S., et al. (2020) National Railway Network Construction and Operation Strategy Based on Regional Equity. Sejong: Korea Transport Institute (KOTI).

Koo, J., Lee, G., Kim, S. and Choo, S. (2024) 'Evaluation of Public Transportation System through Social Network Analysis Approach', Sustainability, 16(16), 7212. doi: https://doi.org/10.3390/su16167212.

Korea Research Institute for Human Settlements (2023) National Territorial Policy Brief No. 929: Introduction Plan for Urban-Type DRT in Local Small and Medium-sized Cities. Sejong: Korea Research Institute for Human Settlements.

Korsu, E. and Wenglenski, S. (2010) 'Job accessibility, residential segregation and risk of long-term unemployment in the Paris region', Urban Studies, 47, pp. 2279–2324.

Kujala, R., Weckström, C., Darst, R., et al. (2018) 'A collection of public transport network data sets for 25 cities', Scientific Data, 5, 180089. doi: 10.1038/sdata.2018.89.

Lee, J. (2023) Diagnosis of Metropolitan Mobility Connectivity and National Balanced Development Response Strategy. Sejong: Korea Transport Institute (KOTI).

Lee, S., Yoo, S., Lee, J. and Kim, D. (2023) 'An Analysis of the Effects of Improving Metropolitan Public Transportation Accessibility on Tourism and Local Economic Revitalization', Smart Media Journal, 12(8), pp. 26-36.

Litman, T. (2017) Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Victoria: Victoria Transport Policy Institute.

Ma, F., Liu, F., Yuen, K.F., Lai, P., Sun, Q. and Li, X. (2019) 'Cascading Failures and Vulnerability Evolution in Bus–Metro Complex Bilayer Networks under Rainstorm Weather Conditions', International Journal of Environmental Research and Public Health, 16(3), 329. doi: https://doi.org/10.3390/ijerph16030329.

Ma, L., Ma, X. and Liu, Y. (2021) 'Research on Accessibility and Equity of Urban Transport Based on Weighted Average Accessibility and Theil Index', Journal of Advanced Transportation, 2021, Article ID 1103331

Ministry of Land, Infrastructure and Transport (2022) Transport Sector Performance Report: Domestic Passenger Transport Status by Mode. Sejong: Ministry of Land, Infrastructure and Transport.

Patacchini, E. and Zenou, Y. (2005) 'Spatial mismatch, transport mode and search decisions in England', Journal of Urban Economics, 58, pp. 62–90.

Sanchez, T., Shen, Q. and Peng, Z.-R. (2004) 'Transit mobility, jobs access and low-income labour participation in US metropolitan areas', Urban Studies, 41, pp. 1313–1331.

Yoo, D., Park, J. and Yeom, C. (2021) 'A Study on Factors Affecting the Impact of Transportation Accessibility on Population Change - Focusing on Decreasing Population Cities in Non-Metropolitan Areas', Journal of Regional Society, 29(1), pp. 49-73. doi: https://doi.org/10.31324/JRS.2021.03.29.1.49.