Exploring Agglomeration Pattern According Transfer of Urban Rail System in Seoul, Korea

Heesoo KIM [a], Junghwa KIM [b], Soyoung YOO [c], Nobuhiro UNO [d]

[a,d] *Department of Urban Management, Kyoto University, Kyoto, Japan*
[a] *E-mail: kim.heesoo.24z@st.kyoto-u.ac.jp*
[d] *E-mail: uno.nobuhiro.2v@kyoto-u.ac.jp*
[b] *Department of Urban & Transportation Engineering, College of Creative Engineering, Kyonggi University, Gyeonggi 16227, Korea; E-mail: junghwa.kim@kyonggi.ac.kr*
[b] *Innovative Transport Policy Division, Korea Railroad Research Institute, Gyeonggi 16150, Korea; E-mail: syyou@krri.re.kr*

Abstract: In Seoul City, which has 298 subway and railway stations, these stations and their surrounding areas are continuously changing and developing as new train services are introduced. This study focuses on Seoul as a city with a densely built urban railway system and classifies the railway system into different types based on the ability to transfer between stations, such as the number of available transfer routes. The study compares the distribution of population activities and commercial districts among these types. Additionally, differences in population activities are analyzed based on mobile phone data. ANOVA analysis and the Bonferroni post hoc test were used for comparison and verification. The results indicate that transfer stations between subway lines show higher active population and a greater presence of commercial districts compared to transfer stations between railways and subways. Moreover, statistically significant differences were found in both commercial districts and population activities among different transfer types.

Keywords: Transfer station, Commercial districts, Population, Agglomeration

1. Introduction

Seoul accepted Western and Japanese civilizations in the 20th century, started operating a tram service, and led urban development at the same time. The subway in Seoul, which started with Line 1, has steadily increased, and the subway stations and railway stations in Seoul are 298 in total (excluding overlapping stations). Seoul has grown into the city with the third most railway stations in the world after New York (468) and Paris (301). At the same time, new lines and private lines have opened, and the number of subway stations in Seoul is steadily increasing. The number of transfer stations has also steadily increased, and as of 2020, the number of urban railway transfer stations in Seoul has reached 78. In addition, Shinbundang Line is scheduled to be additionally extended (from Sinsa to Yongsan), and with the announcement and opening of the GTX line, the number of transfer stations is expected to increase steadily in the future. Along with this, interest in transit stations has increased in within the country. A plan to expand a general transit center or a complex transit center has already been established. However, there is insufficient research on the impact of general transit centers or complex transit centers on the station influence area, and there is also insufficient research on the impact of the facilities such as general transit centers, complex transit centers, or the transit itself on the surrounding commercial districts and population. A traffic impact assessment plan is needed for facilities where transportation facilities and commercial facilities coexist, such as a complex transit center, and for this purpose, it is necessary to analyze the impact on land use, commercial areas, and population inducement in the station influence area.

Therefore, through this research, this study analyzed the impact of railway transfers on the commercial districts or population density of the station influence area and suggest the purpose of this research as follows. First, I will compare the accumulation of the active population by transfer level and analyze the impact of transfer level on population movement. Secondly, I'll compare commercial districts around the stations by transfer level and analyze the influence between transfer level and commercial districts.

At this time, targeting the city of Seoul, the alley, development, and traditional market commercial districts are compared, focusing on areas within 500m from the station, and the active population is compared. The definition of each variable is explained in Data. In this study, population data is defined as active population. Active population is defined as the number of people with their mobile phone powered on populations in a specific space unit on a specific day at a specific time.

2. Literature reviews

This study focused on previous studies on changes in land use/development, land price, and changes in passengers near stations or subway transfer stations. Prior research has mainly focused on changes in land use/development, land prices, and employment near stations due to the opening of the High-Speed Rail (HSR), and the research on the transfer level of subways is insufficient.

Therefore, the literature review on the change in station influence by high-speed rail station and the change in station influence by subway and complex transit center are reviewed in two parts, and the difference from this study is presented. The following is a literature review on the impact of high-speed rail on the station area.

Chigusa et al. (2022) analyzed the effect of the opening and expansion of the high-speed railway Shinkansen in Kyushu, Japan, on land prices reflecting changes in the distribution of economic activities. The Hedonic Pricing Method methodology was used for comparison between the comparative group and the control group. As a result, it was analyzed that the large metropolitan area benefited from the increase in land prices, while the small metropolitan area located between the stations suffered losses due to the decrease in land prices, indicating that the positive effect was limited to the area around the Shinkansen station. Kim et al. (2018) analyzed the agglomeration effect around the high-speed railway station through the analysis of hot spots in the service industry near the high-speed railway (HSR). It analyzed the areas where high-speed railway stations in Japan and Korea were located and confirmed the accumulation of service industries within a 1-kilometer radius of some stations. Fang et al. (2022) analyzed the impact of High-Speed Rail (HSR) on urban economic development and population growth in China. A spatial pattern was dynamically analyzed by establishing an accessibility model by year. While HSR promotes the economy of the metropolis, it results in population decline and economic downturn in small and medium-sized cities, suggesting that policies should be implemented by referring to this for more integrated development in future HSR planning and new railway construction.

As a result of the literature review on the changes in the station area by the high-speed rail, the relationship between the land price analysis and economic promotion in the vicinity mainly caused by the high-speed rail was analyzed. In common, high-speed rail showed a positive effect on the land price and economy near the high-speed rail, but it was found that small towns away from the station brought about economic recession. Existing studies focused on high-speed rail stations, but this study is different in that it tried to analyze the effect of the rail system on the station area through comparison between high-speed rail stations and subway stations.

The following is a literature review on the effect of subway stations or multimodal transfer centers on station influence areas.

Kim et al. (2018) analyzed the impact of the development of the Dongdaegu Complex Transit Center on neighborhood apartment prices. The analysis result showed that the closer to the Dongdaegu complex transit center, the higher the market price was formed, and the development of the Dongdaegu Complex Transit Center positively affected the local housing market. At the same time, it reaffirms meaningful implications by presenting the marginal effect according to the distance from the complex transit center. In addition, it reaffirmed the general trend of the real estate market that if subway stations exist within a 750m radius of the apartment complex, apartment prices are formed high by the utility of subway station accessibility or convenience. Lim et al. (2013) analyzed the current status of the transfer station influence area by making descriptive statistics using the number of users, land use, and traffic characteristic variables of the station influence area of 52 metropolitan transfer stations (Line 1-9 and Bundang line) in Seoul to propose a rational development direction for the Seoul Metropolitan Transit Station area. It was found that the number of passengers getting on and off at the transfer station is related to the land use development density (total associative area), besides, the degree of mixed use by kinds of land use is nonsignificant. On the other hand, it was found that the centrality index and the number of transfer users are higher in transfer stations located in the city center. Therefore, the development of the transfer stations in Seoul must consider not only the number of users getting on and off, but also the number of the transit passengers. It was concluded that it is necessary to set the development direction in consideration of the centrality of the urban railway network. The Seoul Institute (2012) analyzed the impact of the opening of the Shinbundan Line. It was analyzed through a demand estimation model to examine the internal changes of Seoul and major roads and railways connecting Seongnam/Yongin and Gangnam caused by the opening of the Sinbundang Line. A division of means was implemented by using the utility before the opening of the Shinbundang line calculated, and the utility that changed after the opening of the Shinbundang line, and the gradual incremental logit model. The share ratio was calculated by applying an additive logit only to zones where changes occurred in the network due to the construction of new subways. The result of analysis showed that the total annual benefits generated by the opening of the Shinbundang line will reach about 275 billion won. The demand for use is about 37 to 42% of the demand for the implementation agreement, which has not reached the initial forecast demand, various alternatives had been suggested. However, the impact of the opening of the Shinbundang line on the population, land use, and concentration of facilities in the station influence area was not analyzed, which is different from this study. Zhen et al. (2014) analyzed the density level of business offices in the urban railway transfer stations using GIS spatial analysis technique, and the analysis results are as follows. The density of the business offices varied depending on the radius of the subway transfer station, and the highest density of business offices was found within 500m of the transfer station. Furthermore, it was analyzed that the radius of 800 to 1500m in the station influence area was the area with the most active business activities. In addition, it was concluded that that the new business offices are mainly located close to the stations. However, this research differs from the above research in that it compares and analyzes the density of the office spaces and the active populations before and after the transfer station and considers the presence or absence of other means of transfer.

As a result of the literature review on changes in the station area due to the subway and multimodal transfer center, the gross floor area and land use status near the transfer station or multimodal transfer center, and the effect on apartment prices were analyzed. In addition, previous studies analyzed the office density according to the radius of transfer stations, but this study is different in that it compares and analyzes the status of commercial districts and the density of active population in the station area and considers other transfer means.

3. Data

Ahead of analyzing the effect of the station on the commercial district and the active population of the station area, location data of the station, transfer information data, location data of the commercial district, and building information data of Seoul were collected. Table 1. is the list of data collected for analysis and the information included in the data.

Table 1. Number of stations by transfer type

Data	Information	Size
Station_sub	Transfer status, Location, Name etc.	298 stations
Station_exp	Location, Name etc.	10 stations
Commercial alley area	Location, Name, Width etc.	1,090 areas
Developmental commercial area	Location, Name, Width etc.	249 areas
Traditional market area	Location, Name, Width etc.	326 areas
Active population	Census output area, Population by time(24hour) etc.	19,153(area)×24(h)
Building	Construction date, Total floor area, Location, Usage etc.	668,529 buildings

The commercial districts used public data (2020) provided by the Seoul Open Data Square in Seoul, and there are 1,665 commercial districts in Seoul. It is a concept that divides commercial districts in Seoul into developmental commercial districts, commercial alley areas, and traditional market areas. Each definition is as follows.

The commercial alley area is a commercial district with a high density of alley stores, and alley stores are stores that include businesses that are close to life, stores that are outside of the developed commercial area, and stores that have hinterland in the highly residential areas. They usually are formed in densely populated residential areas that mainly operate restaurants, retail, and service industries. Also, the stores that include extensive distribution facilities in the commercial district are excluded, and it refers to the commercial alley area, including more than 30 stores, and a total of 1,090 commercial districts are formed. Fig. 1 below depicts the distribution of commercial alley areas within Seoul city.

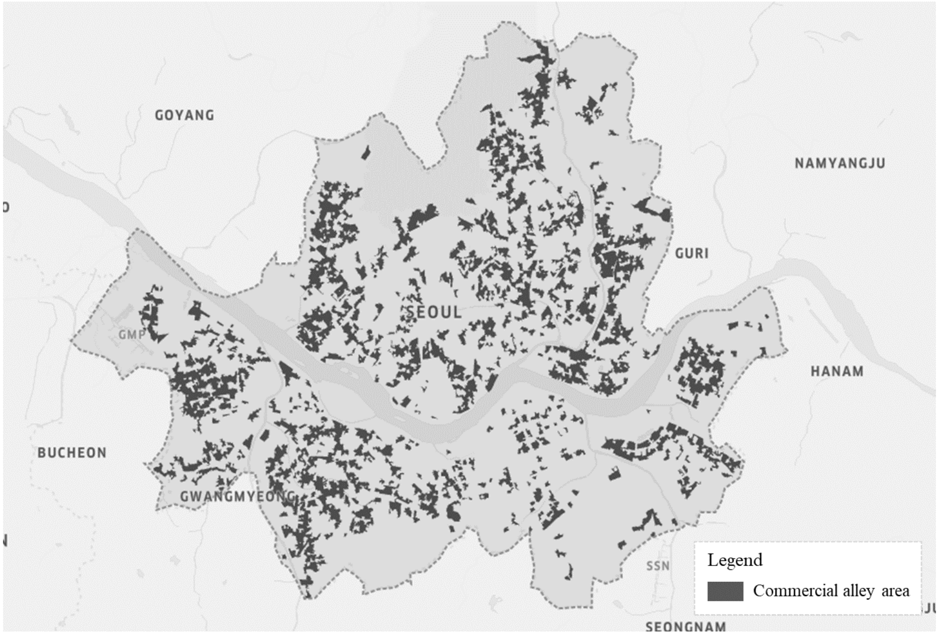

Figure 1. Distribution of Commercial alley area

Developmental commercial areas are defined as developmental commercial areas where less than 50 stores within 2,000 square meters are distributed and within the range of walking without considering the hinterland in accordance with Article 5 of the Liquidity Industry Development Act. Therefore, it is defined as a district where eight major business categories such as wholesale, retail, food, accommodation, life services, finance, real estate, academics, education, medical welfare, culture/art/religion, and tourism/leisure/entertainment, Etc. are concentrated, and a total of 249 commercial districts are formed. Fig. 2 below depicts the distribution of commercial alley areas within Seoul city.

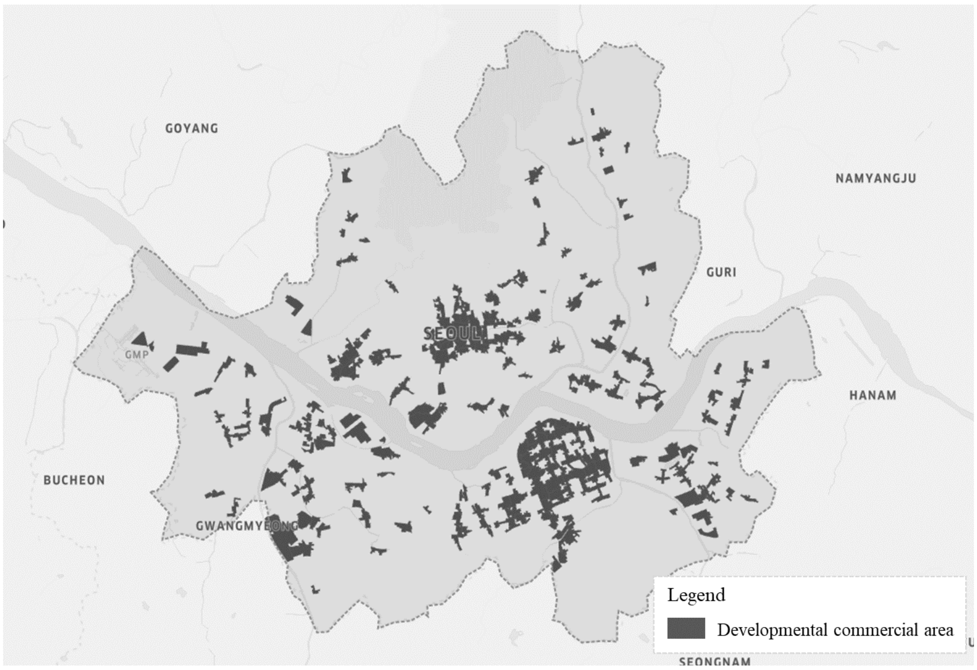

Figure 2. Distribution of Development commercial area

The traditional market areas are permanent or regular markets that have been naturally formed in particular regions over a long period of time, and 326 appropriate traditional market areas have been designated from the traditional market list designated by the government and the city of Seoul through the commercial district's information of the Small and Medium Venture Business Ministry (Small Business Market Promotion Corporation)/Seoul Metropolitan City (spatial information officer)/Korea Land Information Corporation using the commercial establishment database which is an essential database for commercial district analysis services in our village stores. Fig. 3 below depicts the distribution of Traditional market area within Seoul city.

Figure 3. Distribution of Traditional market area

The active population data is sourced from the city of Seoul and is publicly available. It is estimated using KT mobile phone signals captured at 6,000 base stations throughout Seoul. This data provides an estimation of the population present in specific spatial units at a particular day and time, including individuals working during the daytime and those actively moving around the city. It encompasses both the resident population and the active population. For this study, the 24-hour active population data from December 6, 2022 (Tuesday) was utilized. This data is valuable as it enables us to understand where and how many people gather at different times of the day, considering the dynamic nature of urban dwellers. However, the active population data provided by Seoul is aggregated and classified into 19,153 administrative districts, which may lead to lower accuracy. Therefore, in this study, it is necessary to reassign the active population to smaller units than the aggregate district level in order to identify local concentrations of the active population within a 500-meter radius of the stations. To achieve this, the active population is primarily reassigned based on the total area of the buildings, and secondarily reassigned using a 50m x 50m grid for further analysis. The provided visualization depicts the active population data from Seoul, which has been processed using Kepler.gl. Regarding the building data, the study utilizes the national GIS building integrated standard information data (2022) provided by the Ministry of National Transportation. This dataset contains a total of 668,529 building information entries, which are employed to reallocate the active population data according to the total floor area of each building.

4. Methodology

4.1 Station type classification

Subway and HSR (High Speed Rail) stations utilized the subway station information data (2022) obtained from the Forest Big Data Exchange. The study focused on a total of 298 subway and railway stations in Seoul. The transfer hierarchy of these stations was categorized into four types. To analyze the variations in station influence based on factors such as the presence of subway transfers, the number of transfer routes, and the inclusion of railway transfers, stations were divided into four groups: single subway stations without transfer lines, single railway stations without transfer lines, transfer stations between subways, and transfer stations between subways and railways. Fig. 4 visually illustrates the classification of station transfer types. Within type 3, further subdivisions were made, namely type 3-2, type 3-3, and type 3-4, based on the number of subway lines available for transfer at each station. The second digit of type 3-* represents the number of routes sharing a focused station.

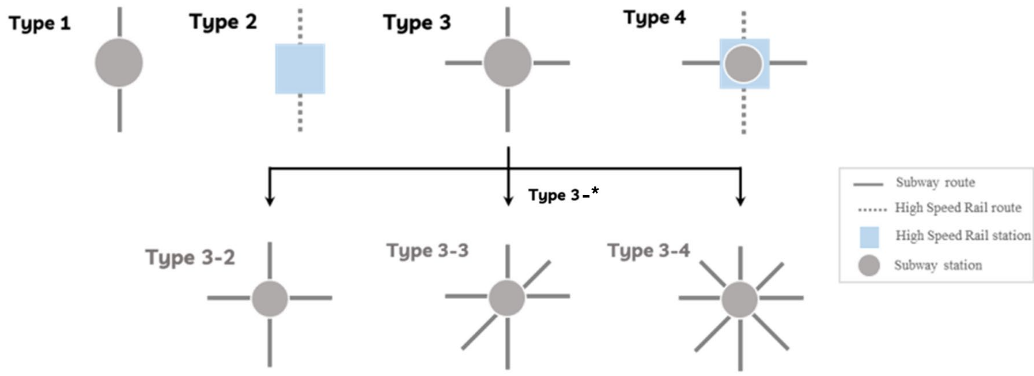

Figure 4. Transfer type

The transfer types were further classified based on whether the station is a subway station, a railway station, or a transfer station. The number of stations for each type is presented in Table 2. In this case, there are zero stations in Seoul that are exclusively used for railways (type 2), so this study focuses on type 1, type 3 (type 3-2, type 3-3, type 3-4), and type 4.

Table 2. Number of stations by transfer type

Transfer type		**The number of stations**
Type 1: A subway station without a transfer line		219
Type 2: A railway station without a transfer line		0
Type 3: A subway-subway transfer station	- Sharing 2 line	60
	- Sharing 3 line	7
	- Sharing 4 line	2
Type 4: A railway-subway transfer station		10
Total		298

Table 3 presents the average distance between stations in the Seoul subway system. The data reveals that the average distance between stations is less than 1km, with certain stations even being less than 500m apart. This indicates that defining the station influence area based on general international standards may not be appropriate for the domestic context. Consequently, for this study, the station influence area was defined within a 500m radius from each station.

Table 3. Average distance between stations by Seoul subway line

Line1	Line2	Line3	Line4	Line5	Line6	Line7	Line8
871	1,170	1,144	1,243	1,037	931	1,143	1,102

4.2 Data processing

The active population data provided by Seoul City is calculated based on administrative dongs, resulting in variations in the areas of the counting districts. Moreover, the allocation of the active population does not take into account geographical characteristics such as parks or mountains, nor does it consider the presence of buildings, which can lead to lower reliability of location information. However, considering that the average distance between subway stations in Seoul is 1 km, it is more suitable for this study to analyze the active population at a more detailed level rather than using the administrative dong unit. Therefore, in this study, the active population is allocated based on the assumption that buildings with larger gross floor areas (GFA) can accommodate a larger population and stimulate demand. To achieve this, a 50m x 50m grid is created to enable a more granular analysis and reallocation of the active population according to the total area of each building. The process of reallocating the active population is illustrated in Fig. 5.

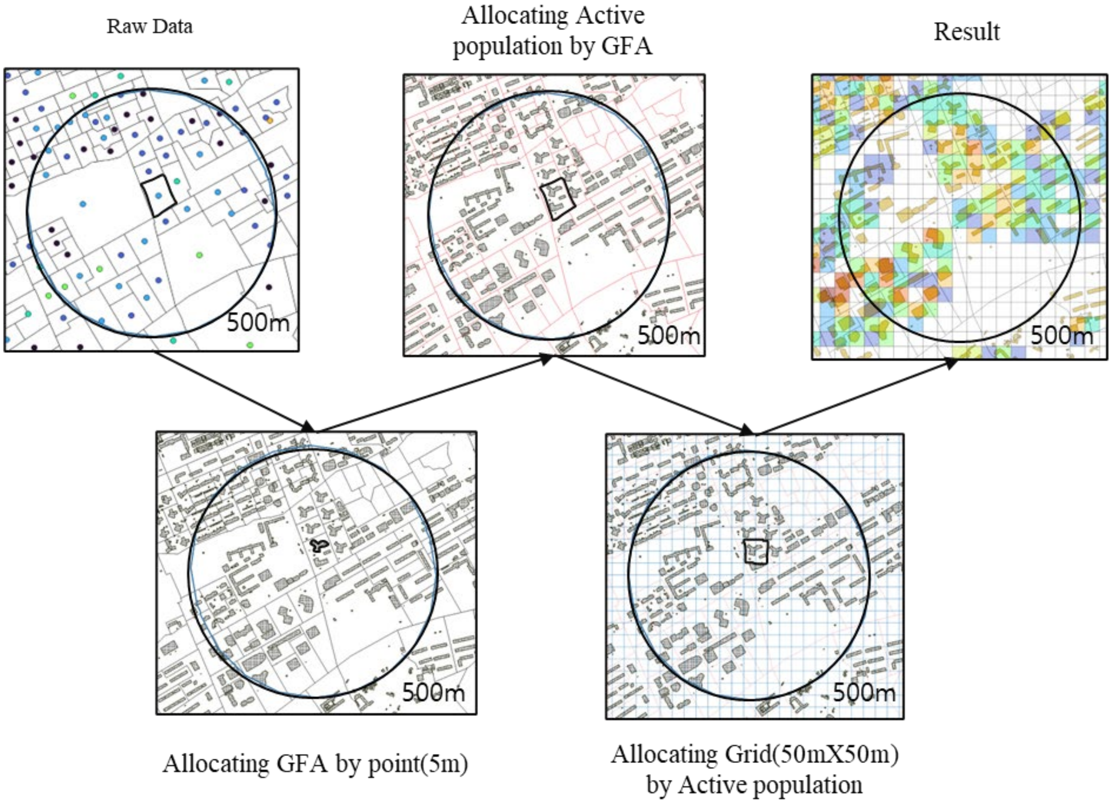

Figure 5. Procedure for reallocation of active population

First, the building data of Seoul were plotted at 5m intervals, and the total floor area was proportionally assigned based on the number of points contained within each building. Subsequently, the active population within each output area, defined by administrative dongs, was allocated according to the total floor area of the respective points. This allocation was made based on the assumption that buildings with larger gross floor areas can accommodate a greater population and stimulate demand. Next, a 50m x 50m grid file was generated for Seoul, and the active population for each grid was recalculated by aggregating the active population assigned to the points located within the boundaries of each grid. Fig. 6 illustrates the active population reallocated through this process.

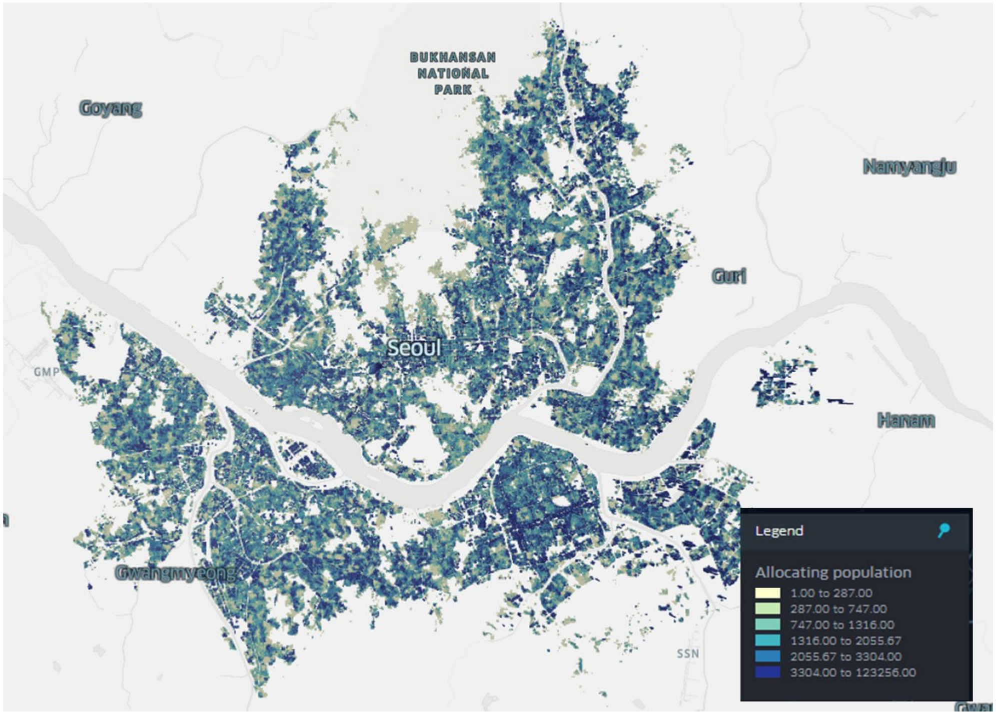

Figure 6. Reallocated active population.

The impact of transfer levels and the influence between commercial districts is analyzed in this study by examining how the transfer level affects the movement of the population. The aggregation of the active population based on the transfer level of the transfer station is compared. Specifically, the average number of active individuals within the 50m x 50m grid in the station influence area is compared with the number of individuals in the developed commercial areas, commercial alley areas, and traditional market areas.

5. Impact of commercial are on agglomeration

5.1 Result of the analysis of commercial power

A total of 219 subway stations in Seoul were analyzed, and among them, type 1 stations refer to simple subway stations without any transfer subway lines. The study focused on the developed commercial areas, commercial alley areas, and traditional market areas located within a 500m radius of the station influence area. The results are as follows: on average, the station influence area of type 1 subway stations included 1.22 developed commercial areas, 3.86 commercial alley areas, and 0.99 traditional market areas. The distribution of commercial facilities within the station influence area of type 1 stations is illustrated in Fig. 7.

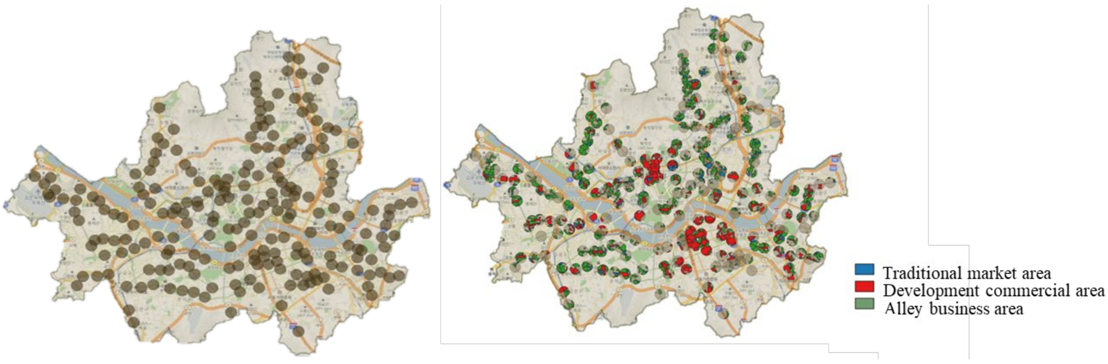

Figure 7. Station influence of type 1

Type 3 stations refer to subway-to-subway transfer stations, and the analysis focused on 69 stations in Seoul, categorized based on the number of transfer lines. Among them, 60 stations share two routes, and the analysis considered the developed commercial areas, commercial alley areas, and traditional market areas within their station influence areas. The results indicate that, on average, the station influence area of subway-to-subway transfer stations with two shared routes includes 2.25 developed commercial areas, 4.38 commercial alley areas, and 2.03 traditional market areas. Additionally, there are 7 stations that share three routes, and the analysis was conducted on the developed commercial areas, commercial alley areas, and traditional market areas within their station influence areas. The findings reveal that, on average, the station influence area of subway-to-subway transfer stations with three shared routes encompasses 4.29 developed commercial areas, 6.14 commercial alley areas, and 4.86 traditional market areas.

Moreover, two stations share four routes, and the analysis was performed on the developed commercial areas, commercial alley areas, and traditional market areas within their station influence areas. The results indicate that, on average, the station influence area of subway-to-subway transfer stations with four shared routes includes 2.00 developed commercial areas, 6.00 commercial alley areas, and 2.00 traditional market areas.

Overall, it was observed that the developed commercial areas, commercial alley areas, and traditional market areas within the station influence area of subway-to-subway transfer stations increase as the number of transfer routes increases, except for the stations that share four routes. However, the stations sharing four routes have a limited sample size, resulting in lower reliability of the analysis results. The distribution of commercial facilities within the station influence area of type 3 stations is depicted in Fig. 8.

Figure 8. Station influence of type 3

Type 4 stations refer to transfer stations between railways and subways. The analysis focused on 10 stations in Seoul, considering the developed commercial area, commercial alley area, and traditional market area within their station influence areas. The results indicate that, on average, the station influence area of railway-subway transfer stations includes 1.40 developed commercial areas, 6.00 commercial alley areas, and 2.70 traditional market areas. Fig. 9 illustrates the distribution of commercial facilities within the station influence area of type 4 stations.

Figure 9. Station influence of type 4

The analysis of commercial influence based on transfer levels revealed that there is a positive correlation between the number of transfer options and the presence of developed commercial areas, commercial alley areas, and traditional markets within the station influence areas. However, in the case of railway-subway transfers, despite the increase in the number of transfer options, there was no significant increase observed in the developed commercial areas and traditional market trade areas within the station influence area. Table 4 presents the average number of developed commercial areas, commercial alley areas, and traditional market areas according to the transfer levels.

Table 4. Average number of commercial districts by transfer type

Area	**Type 1**	**Type 3-2**	**Type 3-3**	**Type 3-4**	**Type 4**
Commercial alley area	1.29	2.25	4.29	2.00	1.40
Developed commercial area	3.87	4.38	6.14	6.00	6.00
Traditional market area	0.99	2.03	4.86	2.00	2.70

The comparison between the commercial districts in the entire city of Seoul and the commercial districts within the station influence areas is as follows. Since the station influence areas encompass the entire commercial districts of Seoul, the comparison focused on the distribution rather than the absolute number of commercial districts.

According to Fig. 10, in the entire business area of Seoul city, the commercial alley area, the developed commercial area, and the traditional market area accounted for 65.5%, 15.0%, and 19.6% respectively. Conversely, within the commercial districts of the station influence areas, the commercial alley area, the developed commercial area, and the traditional market area accounted for 58.9%, 21.7%, and 19.4% respectively. The analysis reveals that the distribution of developed commercial areas in the station influence areas is relatively higher compared to the entire commercial districts of Seoul city, while the distribution of commercial alley areas in the station influence areas is relatively lower. In terms of the traditional market area, no significant difference was observed between the distribution in the station influence areas and the distribution in Seoul city. These findings indicate that the station influence areas have experienced more growth in developed commercial districts compared to other regions.

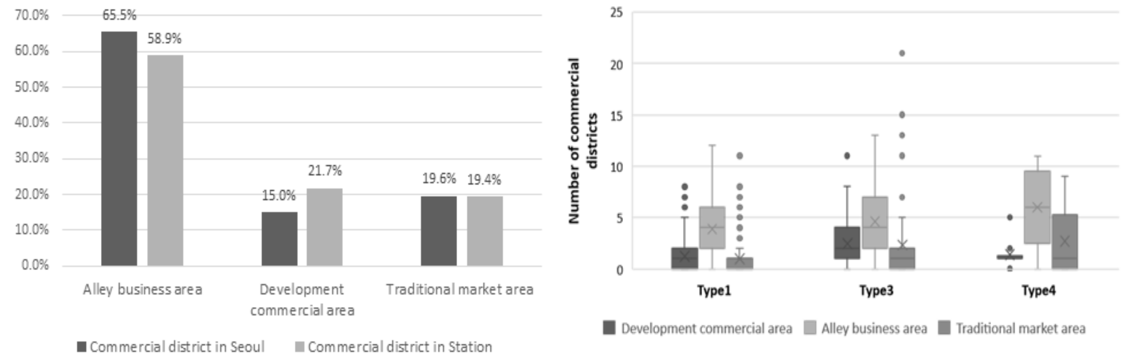

Figure 10. Comparison of commercial area ratios according to the presence or absence of station

The analysis of commercial districts within the station influence areas based on transfer types is presented below. Fig. 10 displays statistical data on commercial districts in the station influence areas, represented as a box plot graph, categorized by transfer type. The findings indicate that as the number of transfer levels increases, the number of commercial alley areas and traditional market areas also increases.

Comparing subway-to-subway transfer stations (type 3) to single stations without any means of transfer (type 1), all three categories—developed commercial areas, commercial alley areas, and traditional market areas—show an increase. However, in the case of subway-to-railway transfer stations (type 4), commercial alley areas and traditional market areas increase while developed commercial areas decrease. Hence, subway-railway transfer stations (type 4) have a higher presence of commercial alley areas and traditional market areas compared to subway-to-subway transfer stations (type 3), whereas type 3 exhibits a greater number of developed commercial areas.

Fig. 11 illustrates the distribution of commercial districts within the station influence areas. The commercial alley area comprises the highest percentage, while the developed commercial area and traditional market area have the highest proportions across all types. type 2 shows a higher percentage of the developed commercial area within the station influence area compared to type 1. Additionally, type 3 exhibits a lower percentage of developed commercial areas but a higher percentage of the traditional market area within the station influence area.

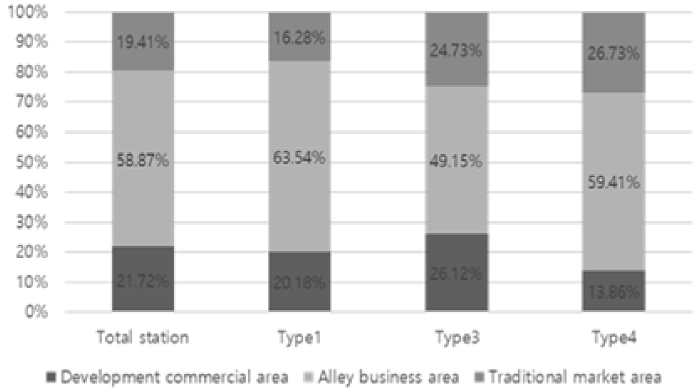

Figure 11. Comparison of commercial district distribution by transfer type

5.2 Statistical significance test of analysis of commercial power

In this study, types are classified based on the transfer lines of the stations, and the distribution of population activities and commercial facilities is compared among different types. The study proposes three or more types, and ANOVA analysis is conducted. As shown in Figure 12, type 3 is further divided into type 3-2, type 3-3, and type 3-4. To determine whether there are statistically significant differences among these subtypes, ANOVA analysis is performed for each commercial facility category, specifically for type 3-2, type 3-3, and type 3-4. If statistically significant differences are observed, type 3-2, type 3-3, and type 3-4 cannot be classified as the same group, and it would be appropriate to conduct ANOVA analysis for type 1, type 3-2, type 3-3, type 3-4, and type 4. If no statistically significant differences are found, type 3-2, type 3-3, and type 3-4 can be considered as a single group (type 3) for analysis.

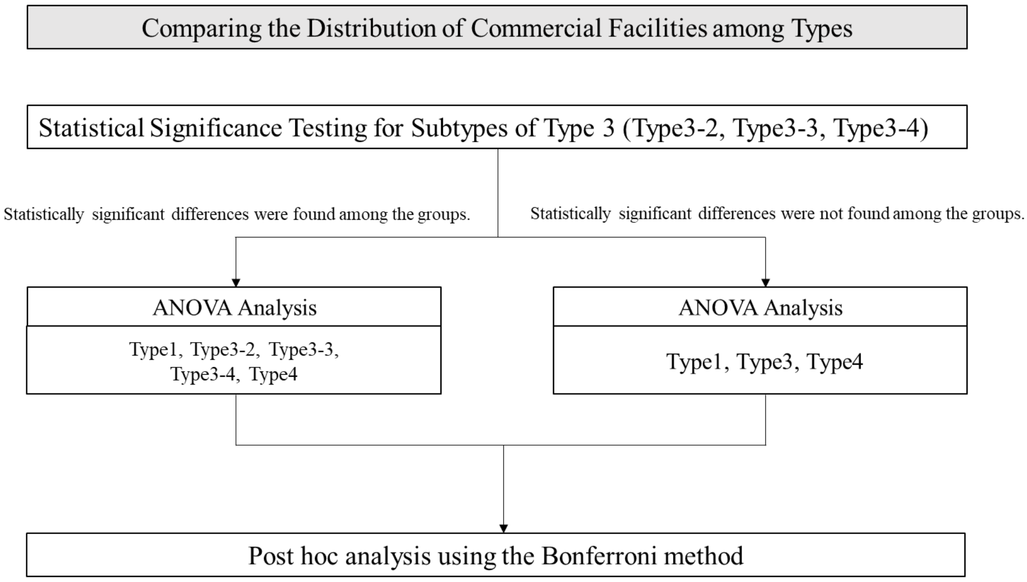

Figure 12. Process for Comparing the Distribution of Commercial Facilities among Types

Although ANOVA analysis can determine if there are differences among the groups, it is necessary to perform post hoc analysis to identify specific group(s) that exhibit significant mean differences. There are various methods available for post hoc tests, and the choice of the post hoc test should consider factors such as the sample sizes of the groups and other conditions. In this study, the sample sizes of the stations varied for each type, and the comparisons were made among multiple groups rather than comparing a control group to several experimental groups. In this situation, the Bonferroni post hoc test is widely used due to its broad applicability and reputation as the most common and practical method. Additionally, it can be applied to ANOVA, multiple t-tests, and nonparametric tests. Therefore, the Bonferroni method was employed as the post hoc test in this study.

To assess the statistical significance of the differences between transfer types, both a t-test and one-way analysis of variance (ANOVA) were conducted. Initially, the analysis focused on determining whether there were disparities in the development of commercial districts based on the number of subway transfers within each district. Specifically, a t-test was performed to compare type 3 stations sharing two lines (type3-2) with those sharing three lines (type3-3). Due to the limited sample size of only two cases, type 3 stations sharing four lines (type3-4) were excluded from the analysis.

The t-test was employed to examine the differences between type3-2 and type3-3 stations in terms of the developed commercial area. The analysis yielded a p-value of 0.024, leading to the rejection of the null hypothesis. Consequently, it was concluded that there was a significant difference between the two groups (refer to Table 5).

Table 5. T-test analysis result between type3-2 and type3-3 in the developed commercial area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	25.98	1	25.98	5.37	***0.02***
Error	314.48	65	4.841		
Sum	340.66	66			

An analysis of variance (ANOVA) was conducted on four types: type 1, type 3-2, type 3-3, and type 4. Table 6 presents the results of the ANOVA analysis, specifically focusing on the developed commercial area. The obtained p-value was found to be statistically significant, indicating a difference among two or more groups and leading to the rejection of the null hypothesis. Subsequently, post hoc analysis was performed to compare the differences between each group, employing the Bonferroni method to account for the varying sample sizes across groups.

The post hoc analysis revealed significant differences between type 1 and type 3-2, type 1 and type 3-3, type 3-2 and type 3-3, and type 3-3 and type 4. Evaluating the impact of the developed commercial area formation across the four types, it was observed that type 3-3 had a relatively higher influence on the formation of the developed commercial area compared to the other types. This suggests that stations sharing multiple subway lines play a significant role in the development of commercial districts.

Table 6. ANOVA analysis result between types in the developed commercial area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	104.28	3	34.76	12.234	***.000***
Error	829.66	292	2.84		
Sum	933.95	295			

A t-test was performed to compare the differences between subway stations sharing two lines (type 3-2) and subway stations sharing three lines (type 3-3) in terms of the commercial alley area. The t-test analysis resulted in a p-value of 0.2, leading to the acceptance of the null hypothesis. Consequently, it was concluded that there was no significant difference between the two groups (Table 7). The average number of commercial alley areas was found to be similar, indicating that the number of transfer routes did not have an effect on the presence of commercial alley areas. Therefore, for further analysis, types 3-2 and 3-3 were combined and classified as type 3.

Table 7. T-test analysis result between type3-2 and type3-3 in the commercial alley area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	19.41	1	19.41	1.693	***0.20***
Error	745.04	65	11.46		
Sum	764.45	66			

ANOVA analysis was conducted on type 1, type 3, and type 4 to examine the differences in the commercial alley area. Table 8 presents the results of the ANOVA analysis between the types. The obtained p-value was statistically significant, indicating that there were differences among two or more groups, leading to the rejection of the null hypothesis. Subsequently, a post hoc analysis was performed to compare the differences between each group using the Bonferroni method, considering the different sample sizes across groups. The Bonferroni results for the commercial alley area are presented in Table 9. The analysis revealed a significant difference only between type 1 and type 4. Evaluating the formation of commercial alley areas among the three types based on the number of commercial alley areas, it was observed that both type 1 and type 4 had a greater influence on the formation of commercial alley areas compared to type 3. In other words, the presence of commercial alley areas varied depending on whether the station was a subway station or a railway station rather than a subway transfer station.

Table 8. ANOVA analysis result between types in the commercial alley area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	62.56	2	31.28	4	***0.02***
Error	2275.61	293	7.77		
Sum	2338.16	295			

Table 9. Bonferroni analysis result between types in the commercial alley area

(I)Type	**(J)Type**	**Average gap(I-J)**	**Standardization error**	**P-value**
Type1	Type3	-.69958	.38908	0.22
	Type4	-2.13242	.90118	***0.05***
Type3	Type1	.69958	.38908	0.22
	Type4	-1.43284	.94476	0.39
Type4	Type1	2.313242	.90118	***0.05***
	Type3	1.43284	.94476	0.391

A t-test was conducted to compare the differences between subway stations sharing two lines (type 3-2) and subway stations sharing three lines (type 3-3) in the traditional market area. The T-test analysis between type 3-2 and type 3-3 yielded a p-value of 0.07. Consequently, the null hypothesis was accepted, leading to the conclusion that there was no significant difference between the two groups (Table 10). Based on this, it was determined that the average number of traditional market areas did not differ significantly depending on the number of transfer routes. As a result, type 3-2 and type 3-3 were combined and classified as type 3 for further analysis.

Table 10. T-test analysis result between types in the traditional market area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	49.99	1	49.99	3.42	***0.07***
Error	948.80	65	14.60		
Sum	998.78	66			

ANOVA analysis was conducted on type 1, type 3, and type 4. Table 11 presents the results of the ANOVA analysis comparing these types in the traditional market area. The obtained p-value was less than 0.05, indicating statistical significance and rejecting the null hypothesis. This result suggests that there are differences among two or more groups. Subsequently, post hoc analysis was performed to assess the differences between each group using the Bonferroni method, considering the varying sample sizes between groups.

The Bonferroni results for the traditional market area among the different types are shown in Table 12. The analysis revealed a significant difference only between type 1 and type 3. Evaluating the impact of the three types on the formation of traditional markets based on the number of traditional market areas, it was observed that type 1 and type 3 had a more pronounced influence compared to type 4. Consequently, this implies that the presence of subways and the number of subway transfers have a greater impact on the formation of traditional markets rather than the number of railway stations.

Table 11. ANOVA analysis result between types in the traditional market area

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	110.60	2	55.30	10.35	***.000***
Error	1564.86	293	5.34		
Sum	1675.46	295			

Table 12. Bonferroni analysis result between types in the traditional market area

(I)Type	**(J)Type**	**Average gap(I-J)**	**Standardization error**	**P-value**
Type1	Type3	-1.33749	.32265	***.000***
	Type4	-1.70913	.74731	0.07
Type3	Type1	1.33749	.32265	***.000***
	Type4	-.37164	.78345	1
Type4	Type1	1.70913	.74731	0.07
	Type3	.37164	.78345	1

6. Impact of population on agglomeration

6.1 Result of the analysis of active population on agglomeration

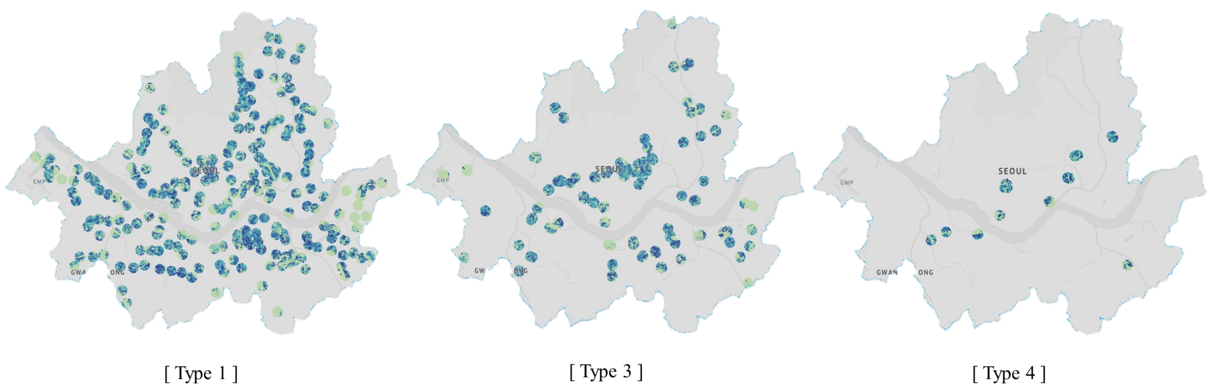

Figure 13. Comparison of commercial district distribution by transfer type

The following is a comparison of the active population in 50m grid cells based on transfer types. Fig. 13 illustrates the population distribution in the station influence area categorized by transfer type.

Type 1 stations are simple subway stations without connecting railway lines. A total of 219 stations in Seoul were analyzed. The study focused on the active population within a 500m radius of the station influence area, and the active population was evaluated over a 24-hour period. The average active population within a 50m x 50m area in the 500m station influence area of type 1 stations was found to be 1,520 people.

Type 3 stations are subway-to-subway transfer stations. The analysis covered 69 stations in Seoul, examining the active population within a 500m radius of the station influence area over a 24-hour period. The average active population within a 50m x 50m area in the 500m station influence area of type 3 stations was calculated to be 1,969 people. This represents an increase of approximately 449 people per 50m x 50m interval compared to type 1 stations.

Type 4 stations are transfer stations between railways and subways. The analysis encompassed 10 stations in Seoul, evaluating the active population within a 500m radius of the station influence area over a 24-hour period. The average active population within a 50m x 50m area in the 500m station influence area of type 4 stations was determined to be 1,637 people. This indicates an increase of approximately 117 people compared to type 1 stations, and a decrease of approximately 332 people compared to type 3 stations for every 50m x 50m interval. Fig. 13 presents the active population in the station influence area of type 4 stations.

6.2 Statistical significance test of the analysis of active population on agglomeration

The active population assigned to the 50m x 50m grid cells within the station influence area was analyzed based on station types, and the concentration of the active population was compared among the types. To statistically examine the population differences across station transfer types, a one-way analysis of variance (ANOVA) was conducted. Furthermore, a post-hoc test using the Bonferroni method was employed to determine the significance of differences for each transfer type, considering the varying group sizes. The ANOVA analysis revealed a statistically significant difference among type 1, type 3, and type 4, with a p-value less than 0.05 (Table 13). The post-hoc test indicated significant differences in active population across all types. In other words, the type of transfer has an impact on the distribution of the active population (Table 14).

Table 13. ANOVA analysis result between types in the active population

	Sum of square	**DF**	**Mean of square**	**F-value**	**P-value**
Regression	2492398589	2	1246199295	161.037	***.000***
Error	7.730E+11	99883	7738593.561		
Sum	7.754E+11	99885			

Table 14. Bonferroni analysis result between types in the active population

(I)Type	**(J)Type**	**Average gap(I-J)**	**Standardization error**	**P-value**
Type1	Type3	-361.73	20.18	***.000***
	Type4	-130.03	44.20	***.013***
Type3	Type1	361.73	20.17	***.000***
	Type4	231.70	46.24	***.000***
Type4	Type1	130.03	44.20	***.013***
	Type3	-231.70	46.24	***.000***

7. Conclusion

In this study, the influence of transfer levels on commercial districts and the active population was investigated by categorizing transfer levels and analyzing their characteristics within the station influence area. The findings indicate that differences exist between the characteristics of the overall commercial districts in Seoul city and those within the station influence area. Specifically, greater development within the station influence area was observed for the developed commercial areas compared to the commercial districts across the entire city of Seoul.

On the other hand, the commercial alley areas and traditional market areas did not exhibit a higher level of development within the station influence area compared to the entire city of Seoul. Developed commercial areas were characterized by dense concentrations of commercial establishments, indicating the presence of large-scale commercial facilities within the station influence area.

Furthermore, variations were observed in the characteristics of commercial districts based on transfer levels. The number of commercial districts in the commercial alley area and traditional market area was found to be significant in the following order: single stations without transfers, subway-to-subway transfer stations, and subway-to-railway transfer stations. In contrast, for developed commercial areas, the number of commercial districts followed the order of subway-to-railway transfer stations, single stations without transfers, and subway-to-subway transfer stations. Additionally, differences were observed in the distribution of the station influence area across transfer levels. When comparing the distribution of commercial districts across all stations, it was observed that the development of commercial alley areas was driven by single stations without transfers, while subway-to-subway transfer stations facilitated the growth of developed commercial areas and traditional market areas. Furthermore, subway-to-railway transfer stations induced the development of traditional market areas and commercial alley areas. Therefore, the development of traditional market areas and commercial alley areas within the station influence area was promoted by the presence of railway facilities in Seoul city, as compared to subway transfers. Conversely, subway transfers stimulated the development of developed commercial areas, traditional market areas, and commercial alley areas within the station influence area. The analysis also revealed that subway-to-subway transfer stations exhibited the highest density of active population per grid (50m x 50m), whereas single subway stations had the lowest concentration of active population.

It is important to note that for subway-to-subway transfer stations, there was a decrease in the number of cases as the number of transferable lines increased (e.g., 2 transfer stations for 4 lines), which limited the possibility of conducting a detailed analysis due to the increased complexity of routes. Additionally, the active population data used in this study incorporates both the resident population and the active population. In future research, the impact on the resident population and the active population will be analyzed and presented by incorporating time data and examining the influence of increased transit routes, enabling the prediction of the development of commercial districts and the active population resulting from the construction and extensions of new transit routes.

The findings of this study provide valuable insights for policymakers and urban planners. Based on these findings, several policy recommendations can be proposed:

Enhancing Transfer Facilities, Given the positive impact of transfer stations on the development of commercial districts, it is recommended to prioritize the improvement and expansion of transfer facilities, particularly in areas with high potential for commercial growth. This can involve increasing the number of transfer lines, optimizing transfer connections, and improving station amenities to attract more passengers and stimulate commercial activities.

Transit-Oriented Development (TOD) Strategies, Adopting transit-oriented development principles can optimize land use and transportation planning around transfer stations. By promoting compact, walkable communities with a mix of land uses, including residential, commercial, and public spaces, TOD can maximize the accessibility and attractiveness of the station influence area. Policies that encourage higher-density development, pedestrian-friendly infrastructure, and public space improvements can support TOD implementation.

These policy recommendations, based on the findings of this study, can serve as a starting point for policymakers and urban planners to shape future strategies and interventions aimed at promoting vibrant and sustainable commercial districts in cities.

REFERENCES

Chigusa Okamoto, Yasuhiro Sato, (2021). “Impacts of high-speed rail construction on land prices in urban agglomerations: Evidence from Kyushu in Japan.” Journal of Asian Economic, Vol. 76, DOI: https://doi.org/10.1016/j.asieco.2021.101364

Kyungtaek Kim, Jung-Hoon Kim, (2018). "An Observation on the Socioeconomic Spatial Structure of Industry near High-Speed Rail Station-Area with Consideration for Proximity to the Station", Korean Public Administration Quarterly, Vol. 30, No. 3 pp.627-650.

Fang Wang, Zhao Liu, Pengcheng Xue, Anrong Dang, (2022). "High-speed railway development and its impact on urban economy and population: A case study of nine provinces along the Yellow River, China", Sustainable Cities and Society, Vol. 87, DOI: https://doi.org/10.1016/j.scs.2022.104172.

Changchun Kim, KeunWoo Park, Kyu-Tai Lee, (2018). "A Study on the Effect of Dongdaegu Complex Transit Center (CTC) Development on Apartment Prices in Daegu Housing Market", Journal of Daegu Gyeongbuk Studies, Vol. 24, No. 1, pp.25-41.

HyeMin Lim, JooYeon Go, Seungil Lee, (2013). “An Analysis of the Factors Influencing Users in the Transfer Station Areas of the Seoul Metropolitan Subway Based on the Characteristics of Their Land Use and Network”, Seoul Studies Vol. 14, No. 4, pp.27-41.

Zhen Maocheng, Zhang Jingqiu, Zhu Haiyong, (2014). "Overview to the Transportation Effect of Shinbundang Line and Countermeasures to Improve Operational Effectiveness”

The Seoul Institute, (2012).“Effect of metro transfer stations on office space agglomeration in Beijing”, Progress in geography, Vol. 33, No. 4, pp.499-507.