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A Study on Categorizing Subway Station Areas in Seoul

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Abstract

Metro of a metropolitan city is a traffic node and have big impact on the use of city land, urban development is concentrated upon the city railway stations. Previous studies on categorizing subway station have been conducted based on land use patterns, urban spatial structure and the number of people who use subway station, so studies on categorizing subway station by energy consumption are not enough. The purpose of subway system is easing traffic congestion, so many people use subway system. Especially, subway stations are located in crowed area. In corwed area, people cause a lot of energy, so measurement of energy consumption is useful to categorize subway stations. Therefore, for categorizing subway stations, this study clarify characteristics of each of stations and implement factor analysis and cluster analysis. In addition, the study analyzes categorizing subway stations.

Keywords - energy consumption;subway stations;factor analysis;cluster analysis;categorizing subway stations

1. Introduction

1.1 Study Background & Purpose

The urban railway has become the center of city traffic flow, gathering new commercial districts and residential areas around. In this aspect the urban railway plays a very positive role in regional development and urban concentration decentralization.[1]

Literature on the characteristics and typology has mainly studied passengers getting on and off the railways, service use behaviors, urban spatial structure, etc., leaving energy consumption less researched. It can be expected that energy consumption would be concentrated in more crowded places with railway service users. Based on this assumption, it is deemed significant to set the energy consumption amount as a factor to classify areas under railway station influence.

In this study, for the typology of railway station adjacent areas in Seoul Special City of South Korea, literature review was conducted and each station adjacent area was investigated for their characteristics. Then the factor analysis and cluster analysis were implemented along with variance analysis of clusters according to each factor. Based on the research findings, this study seeks to classify and interpret station adjacent areas depending upon their types.

1.2 Study Method & Scope

This study examined 229 subway stations of metropolitan line numbers 1 through 8 located within the administrative district of Seoul Special City, ROK. From each station, the areas within 500m radius were defined as those under station influence.

Previous studies have set station adjacent areas diversely from 180m (Seong-Chan Jeon, 1996) up to 1,400m radius (Washington D.C.). In this present study, however, the scope of station influence area was not defined independently but borrowed from the specific guidelines of Urban Planning Act to be 500m as generally recognized for station adjacent area radius. The subway stations in Seoul have 1.1km distance in between themselves on average, including multiple stations having shorter than 1km distance between themselves. Their station adjacent areas are overlapped. In this case, such overlapping areas were included in each corresponding station adjacent area.

For the typology of station adjacent areas, the variables were used herein based on the data of the number of passengers getting on and off in 229 subway stations as of 2013 (Seoul Metro, Seoul Metropolitan Rapid Transit Corporation). Also, based on the GIS (Geographic information System) program, the floor areas were estimated, which corresponded to each purpose (public use, business, leisure time activity, dwelling, and daily shopping) within 250m and 500m radius from each station. Then, by using this, the ratio of total energy consumption to commercial-purposed floor areas was calculated. The online map service of a Korean portal site, Daum, was used to identify the number of bus stops in subway influence areas. The subway line map of Seoul Metro traffic center was employed herein to gain the number of transit routes. Based on such factors, this study implemented the factor analysis and cluster analysis of the statistical analysis program, SPSS/PC+as well as variance analysis to classify station adjacent areas and interpret the characteristics thereof according to types

2. Definition & factors affecting energy consumption ase of Use

2.1 Definition of subway adjacent area

In general, station adjacent areas mean the geographical area under the influence of stations. And the areas are deemed to include people using them for diverse purposes such as daily commuting for work, school, etc. According to Article 2-1 of Rail-Oriented Development and Use Law, station adjacent areas refer to the railroad stations constructed and operated under the Railroad Construction Act, Framework Act on Railroad Industry Development, and Urban Railroad Act along with their adjacent areas. Article 24 of the Enforcement Decree of Korea Rail Network Authority Act regulated the station adjacent area and railroad adjacent area as the adjacent areas to railroad lines and stations confirmed by the enforcement plans approved by Minster for Land, Infrastructure and Transport.

In previous studies, station adjacent areas were defined as 500m as generally presented by relevant laws and regulations with slight differences according to research purposes, methods and approaches.

2.2 Urban spatial structure & factors affecting energy consumption

To categorize the urban subway stations according to their energy consumption amounts, factors affecting energy consumption needs to be established. There are diverse factors with direct or indirect effect on energy consumption. However, it is practically impossible to use all of the relevant factor information. In this study, the following four aspects were set as the factors.

First, the number of annual users of each station is a factor with most direct influence on energy consumption. Places crowed with users become used for specific purposes such as business, residence or commercial activity. The concentration of visitors causes heavier load upon cooling/heating system and ventilation facility, etc. For these reasons, such places are expected to use relatively more energy than less crowded sites.

Second, the number of bus stops and number of transit lines in each subway station in the station adjacent areas defined above are recognized as factors herein. In Seoul, people can use a transportation card to pay for the transit from subway line to another subway line or from subway to bus. The numbers of bus stops and transit lines have a direct relationship with the number of users of corresponding facilities. Thus, they are viewed valid factors of energy consumption.

Third, the total energy consumptions according to distances from station, including 250m and 500m, are set as effective factors herein. The total energy consumption is actually impossible to identify so the GIS (Geographic Information System) program was employed herein. First, the floor areas corresponding to each purpose (public use, business, leisure time activity, residence, and daily shopping) were estimated within the 250m and 500m radiuses from every station. Then by multiplying the purpose-specific basic unit, the total energy consumption amounts were calculated.

Forth, the commercial building proportions according to distance – 250m and 500m – were set as effective factors. Since commercial structures are operated for commercial purposes, this study used the ratio of floor areas used for business, leisure time activity and daily shopping out of the total floor areas. Commercial structures are viewed to have a higher basic energy unit than building used for other purposes due to diverse facilities and equipment. And the proportion of commercial areas is deemed to have a significant relationship with the total energy consumption. For these reasons, they were set as effective factors.

3. Typology of station adjacent areas based on investigation & factor analysis

3.1 Analyzing outline and characteristics of researching area

The Seoul Special City has 9 subway lines in total. Of them The Seoul Metro manages line numbers 1 through 4; and Seoul Metropolitan Rapid Transit Corp., lines 5 through 8. As of 2014, Lines 1~4 run the total distance of 137.9km with 120 stations and Lines 5~8 run 162.2km with 157 stations.

This study investigated 229 stations with available data among the total of 277 stations of Lines 1~8 by Seoul Metro (Lines 1~4) and Seoul Metropolitan Rapid Transit Corp. (Lines 5~8) in the administrative districts of Seoul. The line number 9 is managed by Seoul Metro.

It was partially constructed based on the BTO (Build-Transfer-Operate) structure using private fund for profit generation.

For this reason, information availability of Line 9 is limited and left out of this research.

Table.1 line1~line4 summary - http://www.seoulmetro.co.kr

division	sum	Line 1	Line 2	Line 3	Line 4
section	Line1,2, 3,4	Seoul ↔ Cheongnyangni	Seongsu ↔ Seongsu	Jichuk ↔ Ogeum	Danggogae ↔ Namtaeryeong
number of station	120	10	50	34	26

Table.2 line5~line8 summary - http://www.seoulmetro.co.kr

division	sum	Line 5	Line 6	Line 7	Line 8
section	Line5,6, 7,8	Banghwa↔ Macheon	Eungam↔ Bonghwasan	Jangam↔ Bupyeong -gu Office	Amsa ↔ Moran
number of station	157	51	38	51	17

This study investigated 229 stations with available data among the total of 277 stations of Lines 1~8 by Seoul Metro (Lines 1~4) and Seoul Metropolitan Rapid Transit Corp. (Lines 5~8) in the administrative districts of Seoul. The line number 9 is managed by Seoul Metro. It was partially constructed based on the BTO (Build-Transfer-Operate) structure using private fund for profit generation. For this reason, information availability of Line 9 is limited and left out of this research.

3.2 Establishment of variable DB for factor analysis

3.2.1 Traffic connection facility

In intra-city population movement by public transportation, the existence of transfer facility has a huge effect on the convenience of move. And population movement is closely related to urban spatial structure. Moreover, since the Seoul urban subway allows people to transfer to buses without an extra charge by using a transportation card. In this situation, it seems valid to use traffic connection data to identify the types of station adjacent areas.

Bus stops within 500m radius from stations are accessible by foot for 5~10 minutes, so people can walk to transfer. The number of such bus stops were identified in this study by using the bus stop search function on a Korean web portal, Daum. From each station, a 500m-radius circle was drawn on the map and bus stops inside the circle were counted.

3.2.2 Number of transfer stations

Since the transfer from a subway line to another subway line is also exempted from double charge, its data were deemed useful traffic connection data. Based on the subway line map service of Seoul Metro transportation center (http://dmzap1.seoulmetro.co.kr), 229 stations of the 8 Lines were found and their numbers of transferable lines were counted.

3.2.3 Number of annual users

The number of annual users was found from the data of Seoul Metro and Seoul Metropolitan Rapid Transit Corp. Of the data on annual user numbers of 229 stations in Lines 1~4 and Lines 5~8, respectively, the accessible 2013 data set was obtained including the numbers of users according to year, date, time of use and station of use. The station-specific yearly user numbers were aggregated. The yearly numbers of users of 229 stations are as follows;

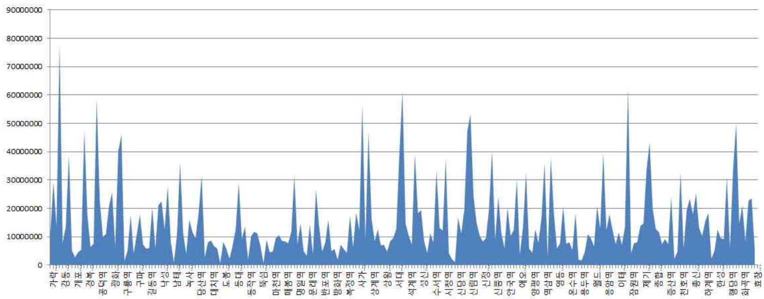


Fig.1 Annual ridership of each station(unit : person)

The average number of users of 229 stations is approximately 15.13 million people. In terms of each station, the Gangnam Station showed the higher number of 78.1 million followed by Jamsil Station with 62.41 million and Seoul Station with 63.1 million.

3.2.4 Total energy consumption according to station adjacent area distances

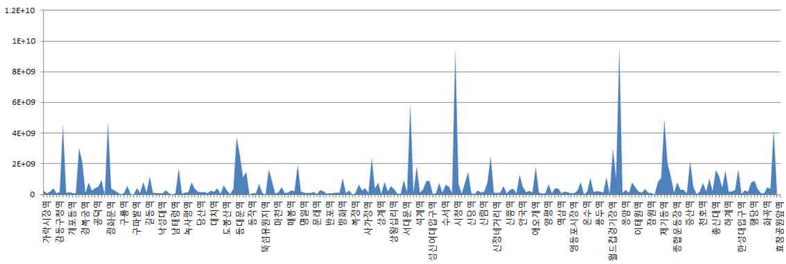
Existing studies on station adjacent areas categorized them according to passengers getting off and on, official land values, urban structural characteristics and traffic volumes. But only few examined the total energy consumption for categorization. The energy consumption amounts according to the distance from station are closely related to urban spatial structure. And they are viewed significant in urban planning, etc. and recognized as a variable for this research analysis.

The distances from station are set as 250m and 500m. The floor area data are obtained for each structural purpose of use then multiplied by the basic unit to produce total energy consumption.

$$\text{energy consumption(Mcal/yr)} = \text{unit}(\text{Mcal/m}^2 \times \text{yr}) \times \text{total area}(\text{M}^2) \quad (1)$$

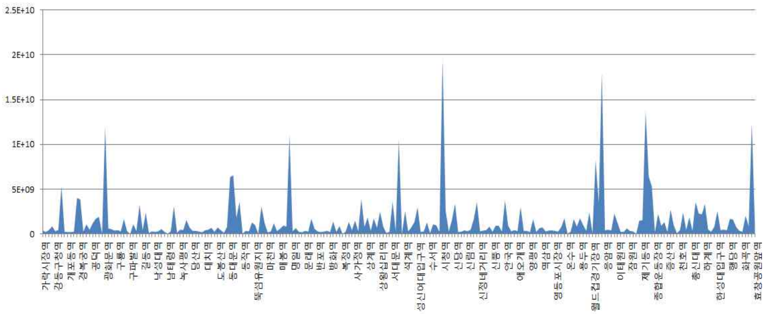
The total energy consumption amounts according to the distance from station (250m, 500m) are as follows;

Fig. 2 The total energy consumption of the 250m range (단unit : Mcal/yr)



The total energy consumption within the 250m radius from 229 stations averaged at 649,541,025 Mcal/yr. The Euljiroipgu Station recorded the highest energy consumption with 9,616,482,562 Mcal/yr followed by City Hall Station with 9,548,907,818 Mcal/yr.

Fig. 3 The total energy consumption of the 500m range (단 unit : Mcal/yr)

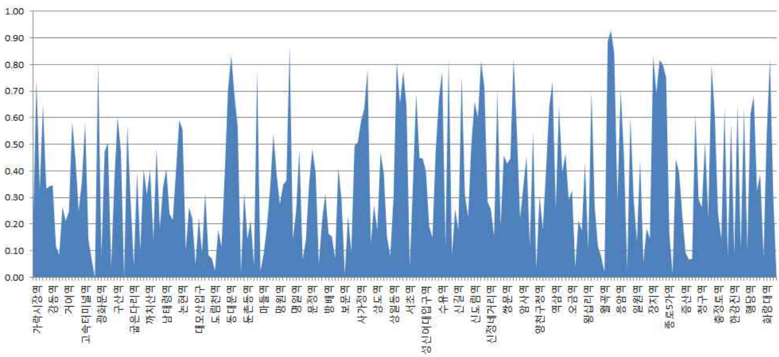


In the 500m-radius areas, the 229 stations' average energy consumption was 1,450,232,082 Mcal/yr. The City Hall Station was found to use energy the most at 19,505,235,752 Mcal/yr followed by Euljiroipgu Station at 17,992,238,620 Mcal/yr. Whereas the station used the smallest amount of energy was Gupabal Station recording 83,827 Mcal/yr. These results are similar to those in the previous 250m-radius case. And the graph generally showed similar trend.

3.2.5 Ratio of commercial floor areas according to the distance of station adjacent area

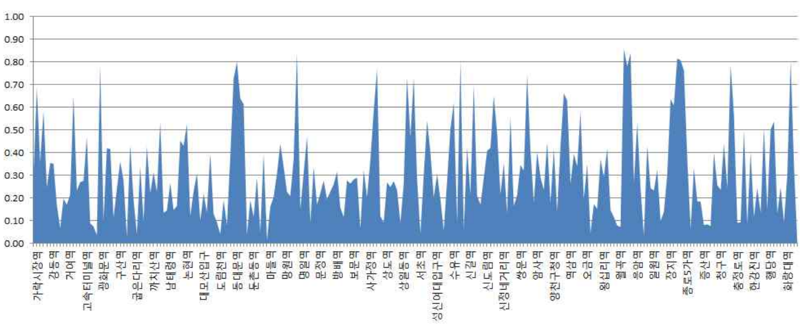
Commercial-purpose structures are expected to have more ventilation and electricity facilities, etc. than structures for other purposes. And such diverse facilities will cause huge energy consumption. The ratio of commercial floor area is gained by producing the ratio of business/leisure activity/daily shopping floor areas out of the total floor areas for all of the 5 purposes (public use, business, leisure time activity, residence and daily shopping).

Fig. 4 Commercial area ratio is also reminiscent of the 250m range (unit : %)



The ratio of commercial floor area within the 250m radius from each station was measured at 36.2% on average. The commercial floor area ratio was found highest in the Euljiro-4-ga Station recording 93% followed by Euljiro-3-ga Station with 89%. It seems because both stations have general commercial districts and central commercial districts in the nearby areas to result in a very higher ratio of commercial floor area.

Fig. 5 Commercial area ratio is also reminiscent of the 250m range (unit : %)



In the 500m radius range, the average ratio of commercial floor areas was 31.4%. The Euljiro-3-ga Station showed the highest commercial floor area ratio at 86% followed by the Euljiroipgu Station at 84%. This finding is consistent with that in the 250m radius case. And the reason is deemed because the stations have nearby central and general commercial districts.

4. Typology according to energy consumption

4.1 Variable-based factor analysis

Factor analysis is a statistical method to find out the common factors aong multiple variables with deep correlations. In this study the factor analysis was implemented to reduce the quantity of variables set as explanatory variables above; summarize information accordingly; identify internal structure; and remove variables with lower significance. To implement this factor analysis, there should be at least two variables measured by interval scale or ratio scale. The ratio of each variable in the previous section against the total raw data values of station adjacent area was calculated and converted into percentage. Also, to change the factor matrix gained through factor extraction into an easily interpretable form, the Varimax method was employed herein to run the rotation, which is the most widely utilized method among the orthogonal rotation techniques. The factors extracted in these procedures were utilized for cluster analysis. The correlations among the 7 explanatory variables under this research are as follows; Producing the correlation matrix is important to assess data suitability.

Table 2. correlation number of exponent parameter

	Number of bus stop	Traffic connection facility	ridership	250m energy	500m energy	250m Commercial area ratio	500m Commercial area ratio
Number of bus stop	1.000	.077	.230	.088	.223	.111	.079
Number of transfer line	.077	1.000	.402	.203	.165	.213	.253
ridership	.230	.402	1.000	.341	.317	.500	.467

250m energy	.088	.203	.341	1.000	.946	.369	.472
500m energy	.223	.165	.317	.946	1.000	.430	.534
250m Commercial area ratio	.111	.213	.500	.369	.430	1.000	.898
500m Commercial area ratio	.079	.253	.467	.472	.534	.898	1.000

Commonness shows how much each variable is explained by the extracted factors. In other words, it indicates the explanatory power of extracted common factors. It is preferable to exclude variables with low commonness from factor analysis. In general, those with commonness not exceeding 0.4 are viewed to have a lower commonness. The initial values and extraction values of the 7 explanatory variables are analyzed as follows; As a result of this research, they are viewed to have good outcomes in general.

Table 3. commonality Analysis

	the early part	extraction
Number of bus stop	1.000	.684
Number of transfer lines	1.000	.571
ridership	1.000	.681
250m energy	1.000	.906
500m energy	1.000	.647
250m Commercial area ratio	1.000	.843
500m Commercial area ratio	1.000	.884

4.2 Total variance explained & factor matrix

Table 4. The total explained variance

ingredients	Initial eigenvalues			extraction sum of squares Loading			rotation sum of squares Loading		
	total	% dispersion	% accumulation	total	% dispersion	% accumulation	total	% dispersion	% accumulation
1	3.322	47.457	47.457	3.322	47.457	47.457	2.062	29.451	29.451
2	1.162	16.599	64.056	1.162	16.599	64.056	2.043	29.182	58.633
3	1.031	14.733	78.789	1.031	14.733	78.789	1.411	20.156	78.789
4	.855	12.216	91.005						
5	.492	7.035	98.040						
6	.090	1.283	99.323						
7	.047	.677	100.000						

The Eigen value of common factor is used to assess if an extracted common factor through the principal component analysis (PCA) is worth analyzing. Factor rotation provides convenience in interpreting factor analysis results. In this study, the Varimax rotation was employed, the most frequently utilized method. As a result, the number of factors was reduced from 7 to 3 and the outcomes are as follows;

Table 5. Factors Matrix

	component		
	1	2	3
Number of bus stop	-.333	.390	.649
Number of transfer lines	.280	-.073	.698
ridership	.479	.142	.657
250m energy	.249	.913	.097
500m energy	.285	.927	.076
250m Commercial area ratio	.867	.239	.184

500m Commercial area ratio	.865	.339	.145

To sum the results, the 7 explanatory variables were extracted into 3 factors and their explanatory power was 79%. Factor 1 is consisted of 2 variables - the ratio of commercial structures within the 250m radius and ratio of commercial structures within the 500m radius. Factor 2 includes the energy consumption of structures within 250m radius and energy consumption of structures within 500m radius. Factor 3 includes the numbers of bus stops, transfer lines and annual users. Its variables are deeply related to urban activities for the most part.

4.3 Topology of station adjacent areasbased on cluster analysis

Cluster analysis is to categorize subjects with mutually similar characteristics into multiple groups by utilizing two or more categorization variables. In this study, the Euclidean distance was used as an index to measure the inter-subject distance and the ward's method was applied to estimate distances.

(1) Cluster analysis based on Factor 1

Cluster analysis was performed based on the energy consumption within 250m and 500m radius from Factor 1 stations. As a result, categorizing into 5 groups was deemed most appropriate. After the Factor 1-based cluster analysis, to check the inter-cluster differences, the variance analysis was conducted. It found significant differences in each cluster in all of the factors excluding the number of transfer lines at the significant level of 0.05. However, the results of Factor 1-based cluster analysis are excessively concentrated on the 1st cluster. If such a weighted cluster exists, cluster characteristic analysis becomes more likely to include an error. It is because non-weighted clusters are largely affected in their average values depending upon each individual value of the components. Therefore, the Factor 1-based cluster analysis is deemed not appropriate for the typology of subway stations.

(2) Cluster analysis based on Factor 2

Cluster analysis was conducted based on the commercial area ratio within 250m and 500m radiuses from Factor 2 stations. The analysis found it appropriate to categorize into 5 clusters. After the Factor 2-based cluster analysis, to check the inter-cluster differences, the variance analysis was conducted. As a result, at the significant level of 0.05, all of the factors excluding the number of bus stops were found to have significant differences.

(3) Cluster analysis based on Factor 3

Cluster analysis was performed for the numbers of bus stops, transfer lines, and users subject to Factor 3. The analysis found it most appropriate to categorize into 5 clusters. After the Factor 3-based cluster analysis, to check the inter-cluster differences, the variance analysis was performed. As a result, at significant level of 0.05, all of the factors showed significant difference in each cluster.

(4) Cluster analysis results based on each factor

Based on the three principal factors extracted through the factor analysis, cluster analysis was performed and its results are as follows; First, Factors 1, 2 and 3 are deemed appropriate to categorize into 5 clusters. The cluster 1 of Factor 1 includes 154 subway stations; cluster 2, 47 subway stations; cluster 3, 16 subway stations; cluster 4, 6 stations; and cluster 5, 6 stations. Regarding Factor 2, cluster 1 includes 56 subway stations; cluster 2, 43; cluster 3, 72; cluster 4, 23; and cluster 5, 35 subway stations. Lastly, as for Factor 3, cluster 1 includes 55; cluster 2, 53; cluster 3, 44; cluster 4, 42; and cluster 5, 35 subway stations.

Second, to check the inter-cluster differences, the variance analysis was performed and its results are as follows; Factor 1 showed significant differences in each cluster, excluding the number of transfer lines. Factor 2 showed significant differences in each cluster, excluding the number of bus stops. Factor 3 was found to have significant differences in all of the variables.

5. Conclusion

The purpose of this study is to find the topology of urban railway stations in Seoul Special City of South Korea depending upon their energy consumption. To this end, the data were obtained on the 7 factors affecting energy consumption (number of bus stops, number of transfer lines, number of users, total energy consumption amount within 250m/500m radius from the stations, and ratio of commercial floor areas within 250m/500mradus from the stations). Then the factor analysis was conducted to extract 3 factors. For each factor, the cluster analysis and variance analysis were implemented to extract 5 clusters. And the research findings are as follows;

1. The factor analysis herein found the total energy consumption within 250m/500m radius from the stations as Factor 1; ratio of commercial floor areas within 250m/500m radius from the stations, as Factor 2; and numbers of users, bus stops and transfer lines as Factor 3.

2. The Factor 2-based cluster analysis found 5 clusters. However, they were excessively weighted upon cluster 1 and deemed inappropriate for the typology of subway stations.

3. The Factor 3-based cluster analysis found 5 clusters. Cluster 1 was residential; cluster 2, suburban; cluster 3, residential-suburban mixed; cluster 4, commercial; and cluster 5, residential-commercial mixed. Each was found to include 56, 43, 72, 23 and 35 bus stops.

4. The Factor 4-based cluster analysis identified 5 clusters. Cluster 1 was residential-suburban mixed; cluster 2, suburban; cluster 3, residential; cluster 4, residential-commercial mixed; and cluster 5, commercial. Each was found to include 55, 53, 44, 42 and 35.

5. The Factor 2-based analysis found clearer differences in each factors than the Factor 3-based method. For this reason, the Factor 2-based classification is deemed appropriate.

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