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A Study on the Improvement of Density and Diversity Indicators Reflecting Network Distance in Interpretation of Urban Spatial Structure*

도시공간구조의 해석에 있어 네트워크 거리를 반영한 밀도 및 다양성 지표의 개선에 관한 연구

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Abstract

This study deals with the ambiguity of the design index among the 3Ds indices (Density, Design, and Diversity) of transit-oriented development (TOD). Unlike density and diversity, design is difficult to quantify arithmetically. We have thus developed a methodology in our study to replace existing 3Ds indices with “2Ds with D (Density with Design, Diversity with Design).” “2Ds with D” is a method that considers the accessibility of walkways at each point in calculating the density and diversity indices. We applied this analytical methodology to 287 station areas of the Seoul Metropolitan Railway. Furthermore, we compared and analyzed which index is better in reflecting the station user among “3Ds” and “2Ds with D” indices. The analysis found that in CBD, the analysis method presented in this study showed higher explanatory power than the existing method, but the difference was not large, and the explanatory power was rather low in other regions. This paper is the first to present the concept of 2Ds with D index to academia and confirm its applicability. It will have a great influence on the study of TOD in the future.

Keywords: TOD, Station Catchment Area, Density, Diversity, Design

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Ⅰ. Introduction

1. Background and Purpose

Many urbanists have been studying the built environment to find ways of reducing air pollution, carbon, and transport energy because the built environment is thought to influence travel demand.

Research into urban planning has focused on increasing the number of urban rail users. Transit-oriented development (TOD) in particular has become an important paradigm since the early 2000s. TOD is the concept of increasing the number of station users by increasing the density and diversity of land use around the catchment area of urban rail stations and designing roads with easy access to the stations (Cervero, Ferrell and Murphy 2002). Several empirical studies have been conducted to determine the impact of land-use density and diversity on the number of station users (Cervero 1996; Cervero and Kockelman 1997; Ewing and Cervero 2001; Cervero and Murakami 2009; Lin and Shin 2008; Sung, Choi, Lee and Cheon 2014; Yoo 2013).

TOD consists of high land-use density, diversity, and a pedestrian-friendly design. Empirical studies on the effects of TOD have focused on how it shapes public transportation usage rates and non-motorized travel. Calthorpe introduced the concept of TOD in the late 1980s and developed its guidelines (Calthorpe 1993). Cervero and Kockelman (1997) labeled the components of TOD the "3Ds": density, diversity, and design. On analyzing land use and the effect of these indicators on travel patterns, they found that higher density and more diverse land use decreased car traffic. Additionally, public transportation increased when the city's design elements were more pedestrian-friendly. Ewing and Cervero (2001) summarized several TOD studies and found that the socioeconomic characteristics of passengers, as well as density, diversity, design, and local access, influenced travel demand. They added "destination accessibility" as the fourth element of TOD, creating the "4Ds." Ewing, Bartholomew, Winkelman and Walters et al. et al. (2007) extended the concept from 4Ds to "5Ds," adding "distance to transit" (Ewing, Bartholomew, Winkelman and Walters et al. 2007). Many studies (Li 2012; Dirgahayani and Choerunnisa 2018) have analyzed and evaluated TOD based on the 5Ds. As an increasingly advocated concept supported by substantial empirical evidence from American cities, TOD has become one of the key planning methods for managing urban growth intelligently in the twenty-first century (Ewing, Bartholomew, Winkelman and Walters et al. 2007; Hamin and Gurran 2009).

TOD studies have been conducted in Asian cities since the early 2000s. TOD planning concepts have been applied in Asian cities experiencing suburbanization and traffic congestion, particularly in China. In a Hong Kong case study, Cervero and Murakami (2009) concluded that TOD is more effective in increasing transit ridership than transit-adjacent development. Taipei, (Lin and Shin 2008) found that TOD planning increases ridership when the built environment is consistent with TOD principles. However, the impact of TOD, particularly the effect of diversity, may differ between

American and Chinese cities because of cultural differences (Lin and Shin 2008). One such example is provided by Zhang (2004), in a study that demonstrated that mixed land-use development near a transit center does not significantly impact transit mode choices in Hong Kong. This analysis is not limited to Hong Kong. Sung, Choi, Lee and Cheon (2014) and Yoo (2013) discovered that mixed land use was a factor in lowering the demand for public transportation in Korea, contrary to its role in major US cities. Thus, it is necessary to identify the impacts of TOD planning concepts on transit mode choices and transit ridership in specific national contexts.

On the basis of the preceding studies, it can be seen that the meaningful indicators for the demand for public transportation differ depending on the region. Also, we see that that 3Ds are used as an important index in most studies.

Furthermore, it can be seen that many studies have demonstrated the impact of public transport demand on the density, diversity, and design of various cities around the world. Density refers to the number of opportunities there are to use the urban rail station. In general, the number of buildings or the total floor space in the public transit catchment area is used to quantify density. Diversity refers to the number of opportunities for various activities there are. To quantify diversity, various methods such as Shannon's diversity index are applied. Design is an important factor and it refers to the how easy accessibility of the train station. However, unlike density and diversity, there is no formalized methodology to quantify design. Its ambiguity about ease of access makes it difficult to quantify. Some studies (Singh, Lukman, Flacke and Zuidgeest et al. 2017; Sung and Oh 2011) have used the total length of roads as the design index, but this assumes that the longer the road is, the better the design of the area; there is also a limit to connecting it to the travel demand.

This study concentrates on the influence of these three dimensions (density, design, and diversity) on the demand for public transportation. However, from our point of view, although the three indicators have proved to be influential on travel demand, we raise the question of whether it is appropriate to separate them and use them as independent variables in the analysis of public transport demand. Density and diversity can be said to be mutually independent, because regardless of density, diversity can be increased or reduced in an area. However, density and design and diversity and design have some connection with each other. Although there be such interrelationships, the three indicators have conventionally been used independently of each other in previous studies.

This hypothesis is based on the loss of information that occurs in the process of simplifying the real world. In other words, in order to understand the complex real world and reveal causal relationships within it, people simplify various phenomena and produce them in the form of data. And in the process of simplifying reality, information is lost. In order to overcome these limitations, research is underway to construct and analyze data in a way that reduces possible information loss (Wang, Hall and Subaryono 1990; Woo, Shin and Yoo 1997; Oh and Jung 1999).

We judged that the previous studies (Calthorpe 1993; Cervero and Kockelman 1997; Ewing and Cervero 2001; Ewing, Bartholomew, Winkelman and Walters et al. 2007) calculated and analyzed the land use characteristics of the Station Influence Area by density, diversity, and design indicators, respectively, are a simplified case of the real world, and that information was lost during this process. The reason for this judgment is that when people who use the railroad want to use a building within the station area, they judge the density(use) and distance of the building at the same time without separating them. (The relationship between density and design and diversity and design is presented in more detail in '2. Conceptual Framework'.)

This study examines whether density and design, and diversity and design can exist independently of each other, and proposes new indicators. In other words, to analyze the effect of design on public transportation demand, previous studies have calculated an independent index of design and analyzed the influence relationship. However, categorizing the design separately from the density and diversity indicators of the building is somewhat out of touch with reality. Therefore, we intend to derive more realistic research results by combining design elements with the density and diversity indicators of buildings.

Therefore, the purpose of this study is to present more relevant or better indicators than the previously used 3Ds indicators to identify the impact of the surrounding built environment on travel demand. This study proves that the method of this study is better than the quantification method used in the previous studies comparing with the explanation power in terms of the total users using the public transit station. The study area is Seoul which is the capital city of South Korea and the base year is 2015. Seoul has the largest number of subway stations in Korea (283 subway stations.)

2. Conceptual Framework

Among the 3Ds indicators, density is calculated based on the number of buildings or total floor space in the transit catchment area. Generally, a transit catchment area is defined as the area within half a mile (approximately 500 m), calculated as Euclidean distance, from the subway station. However, this definition assumes that all buildings within 500 m of a subway station have the same opportunity to use the station. This is a binominal though of whether or not it was included within 500 meters from the station. However, as we know well, even buildings within 500 m can have different opportunities for using the station because there is a decrease in opportunities in proportion to distance (Tobler 1970; Lee 1998). For example, two buildings: one (A) was built right in front of a station and the other (B) was built near the 500 m radius. However, they do not have the same opportunity to use the station (T) (see left one of <Figure 1>). Therefore we need to apply opportunity decay based on the distance between the station (T) and the buildings (A and B).

For this reason, some researchers have studied the relationship between the density of building development in the station area and the pedestrian network (An, Jang and Lee 2016; An, Jang and Lee 2012; Sung and Choi 2014).

Related studies have revealed that the network distance between urban railway stations and buildings has a significant effect on the development density of buildings.

These studies have revealed that the network distance between each building in the station area and the station is an important factor, but there is a limit to which the influence relationship between public transportation demand; this needs further investigation.

Apart from the aforementioned studies, a study was also conducted that classified the planning elements of TOD by distance and analyzed the effect on the demand for public transportation. Kim, Shin and Sung (2013) classified the TOD planning elements based on the linear distance and analyzed the effect of the planning elements according to each distance on the demand for public transportation. As a result of the analysis, it was confirmed that the density and diversity of development had a significant influence on the demand for public transportation depending on the distance from the station. However, the study had a limitation in that the distance between the station and each building was calculated using several buffers based on the linear distance. In other words, it did not reflect the network distance that users at the station experienced.

Figure 1 _ Density and Distance (Left), Density and Design (Right)

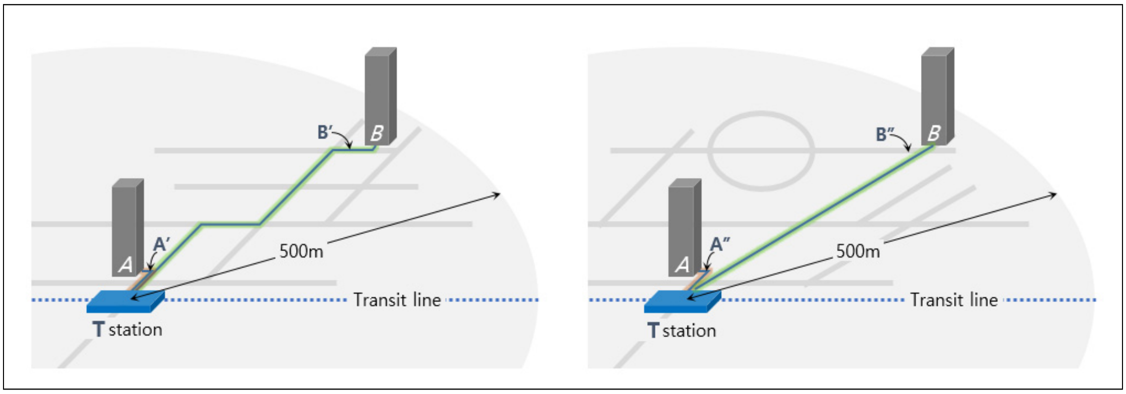


Figure 2 _ Diversity and Distance

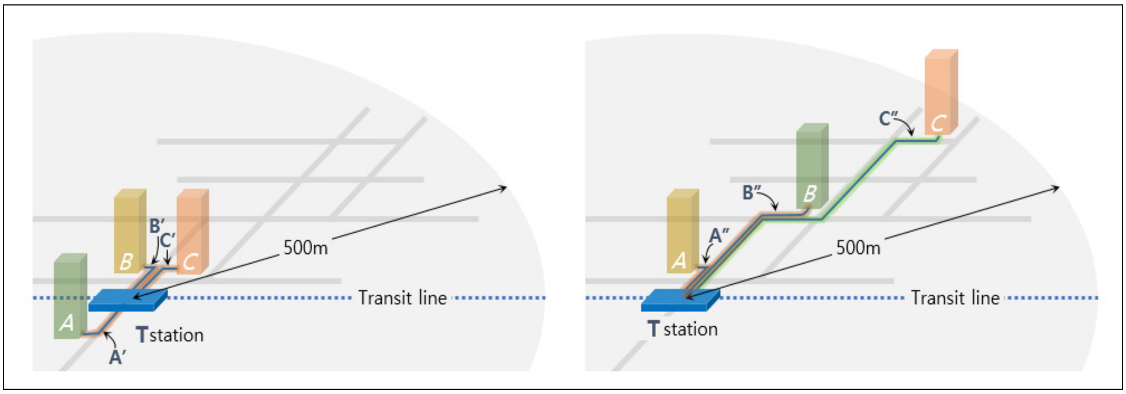
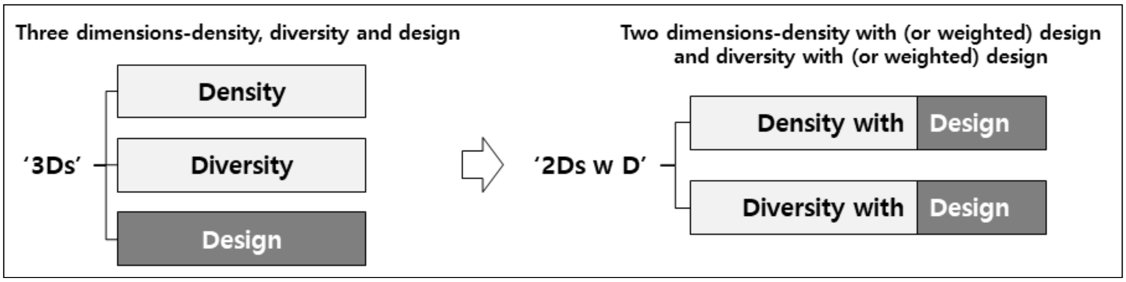


Figure 3 _ Concept Diagram for the '2Ds w D'



The distance from the station to the building should have been calculated based on a pedestrian network, not the direct distance because people travel along the walkways. The left side of Figure 1 shows that the path from Building A to Station T is A' and the path from Building B to Station T is B' based on the pedestrian network. There is a difference between the two paths (|A'-B'|). When we calculated the degree of opportunity of Building B using our proposed density-weighted approach, the degree of opportunity of Building B decreased as much as the difference between the two paths (|A'-B'|). Let us then suppose that the street design was changed to increase Building B's accessibility to the station (as shown in the right side of <Figure 1>). It shows that the difference in the path between the two buildings can be different according to the change in street design (|A'-B'|-|A"-B"|>0). In other words, the street design can affect the difference of the paths, which means that design is related to density to check the effect on travel demand at the station. This point can be applied to the diversity factor as shown in <Figure 2>.

Therefore, we suggest two dimensions, the density-weighted design and diversity-weighted design (denoted as '2Ds w D') instead of the existing three dimensions (i.e., density, diversity, and design (3Ds) (see <Figure 3>). Using this concept, we attempted to prove that these two factors offer a better assessment than the original 3Ds factors in calculating the number of passengers at the transit station.

II. Transit catchment area designation and classification

1. Transit catchment area designation based on network distance

In the literature, transit catchment area is defined in various ways (Cervero and Kockelman 1997; Cervero, Ferrell and Murphy 2002; Chatman 2013). Generally, a transit catchment area is defined as the area within half a mile (approximately 500 m) from the train station (Cervero and Murakami 2009; Guerra and Cervero 2013; Renne, Tolford, Hamidi and Ewing 2016). However, this definition has been criticized for not reflecting the walking patterns of people. Indeed, this definition does not reflect the walking environment of the transit catchment area. Recently, to overcome this limitation, the network analysis of Geographic Information System (GIS) has been used to extract the actual walking area around the station to include it in the definition of the transit catchment area (Schlossberg and Brown 2004; Andersen and Landex 2009; Gutiérrez, Cardozo and Garcia-Palomares 2011; Guerra, Cervero and Tischler 2012).

In this study, we have used the network analysis method, which is a method that can calculate the walking area of people more reasonably and precisely, to define the transit catchment area. Specifically, we used pedestrian network data of Seoul within 500 m from its 283 stations (see <Figure 4a>). Therefore, the transport catchment area of Seoul, in this study, is based on the network distance that exists within the transport catchment area based on the Euclidean distance. However, it excludes areas where the walkway is not connected and areas that can be reached through many turns within the transport catchment area based on the Euclidean distance.

Figure 4 _ Designated and Classified Transit Catchment Area

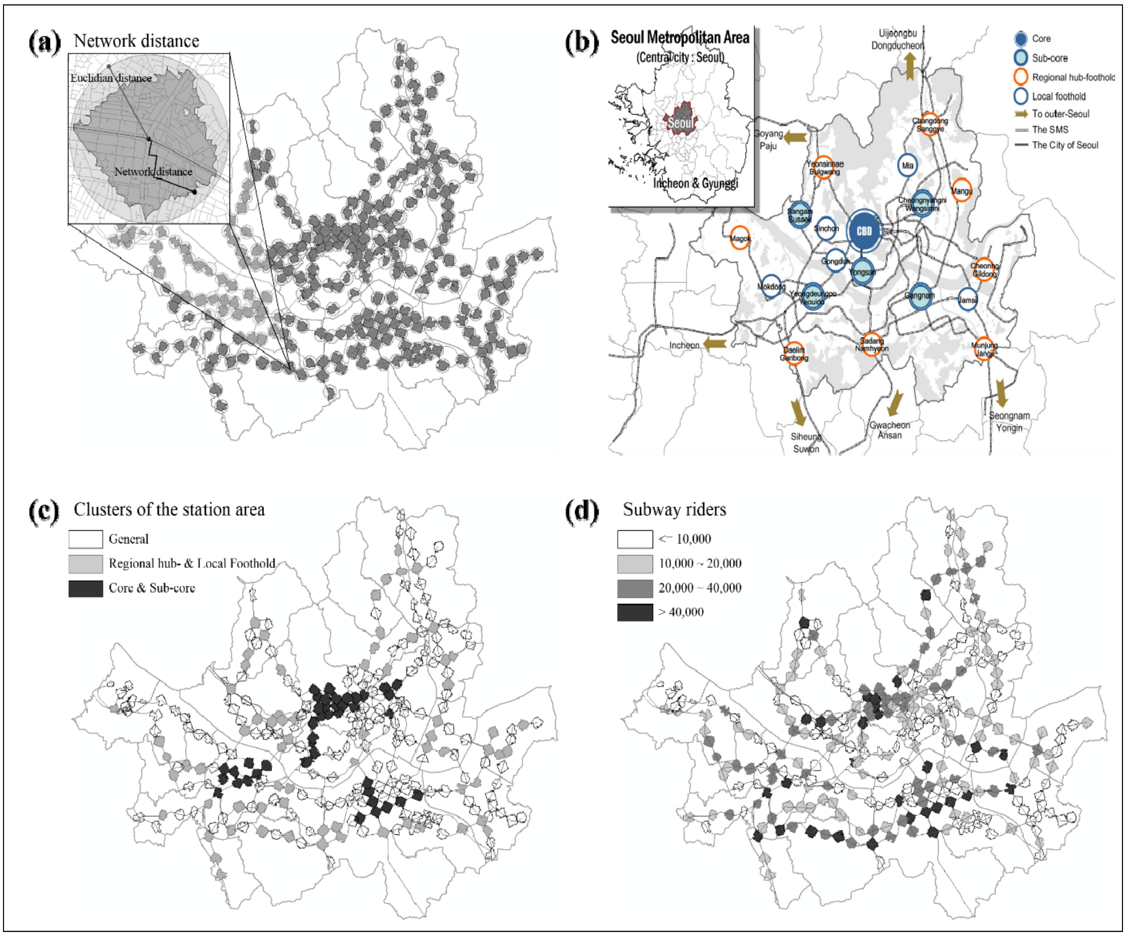


Table 1 _ Number of Stations and Average Number of Passengers per Type

Variable	General	Regional Hub- & Local Foothold	Core & Sub-Core
n	167	70	46
mean of rider ship	11,964	25,274	30,864

2. Cluster and rider ship of the station

The City of Seoul, which had a population of approximately 9.74 million people as of 2017 covers an area of around 606 km^2. It is surrounded by the Province of Gyeonggi and the City of Incheon, which have populations of approximately 12.85 million and 2.93 million people, respectively, and jointly cover an area of 11,164 km^2 (see <Figure 4b>). The City of Seoul, the Province of Gyeonggi, and the City of Incheon together constitute the Seoul Metropolitan Area (SMA). In terms of socioeconomic dependency, the Province of Gyeonggi and the City of Incheon are firmly associated with the City of Seoul as its hinterlands. The City of Seoul, which has a complex urban structure, includes one core, five sub-cores, eight regional hub-footholds, and five local footholds. The City of Seoul has a master plan for urban development with 2020 as the target year (Lee, Yi and Hong 2013). This study was divided into three types based on a preceding study (Park 2015), which classified the transit catchment area based on Seoul's master plan for urban development (see <Figure 4c>).

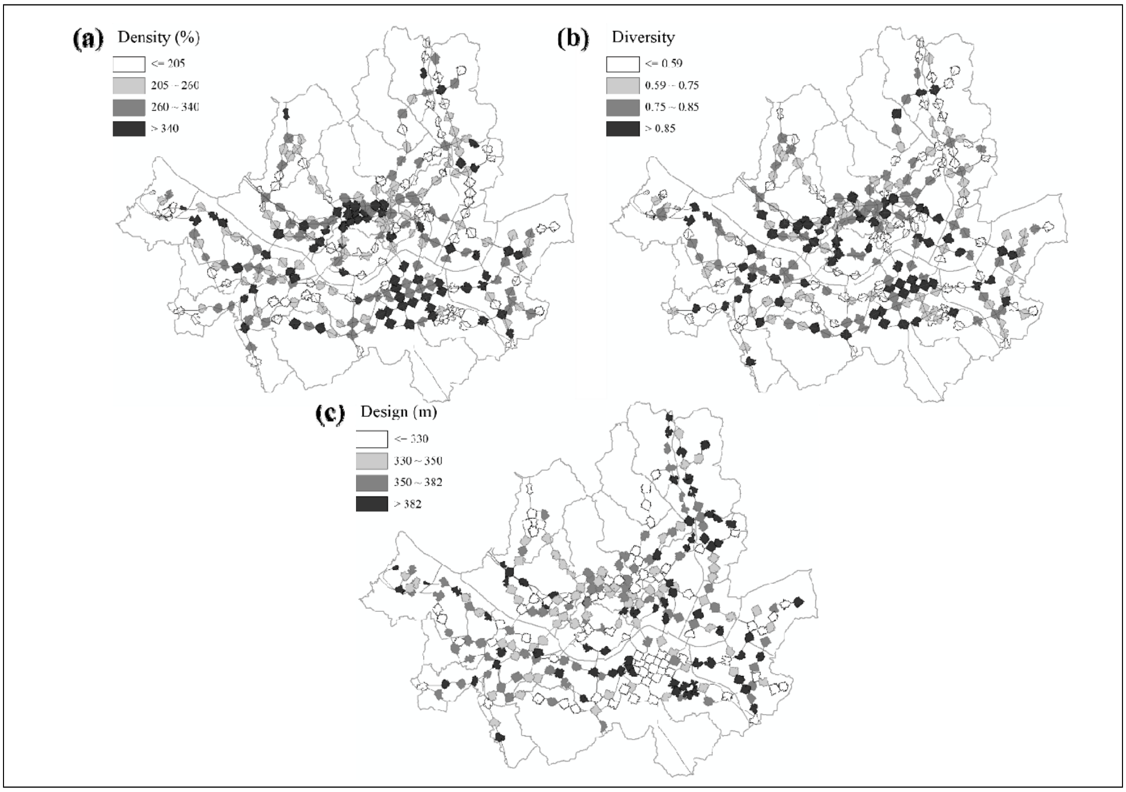
The Seoul Metropolitan Government provides daily average data on passengers at each subway station (Seoul open data plaza). We calculated the number of users of each station based on the number of subway subscribers as of December 2015 in Seoul. We found that the majority of the passengers are centered around the Central Business District(CBD) and the Gangnam sub-core area (see <Figure 4d>). The number of stations and the number of passengers were compared for each type (see <Table 1>). The average number of passengers is large in Core and Sub-core stations and small in General stations.

III. Calculation of land use indicators for transit catchment area

1. Calculation of Traditional 3Ds indices

To examine the usefulness of the 2Ds weighted design (2Ds w D) indicators of the "transit catchment area" proposed in this study, the 3Ds analysis method used in previous studies was applied first and the index was calculated. Following previous studies, the density of the transit catchment area has been applied with floor area ratio by use (Lin and Gau 2004; Cervero and Murakami 2009; Sung and Oh 2011; Taki, Maatouk and Qurnfulah 2017). The density of the transit catchment area was found to be high in the CBD and Gangnam sub-cores (see <Figure 5a>).

Figure 5 _ 3Ds Index of Transit Catchment Area in Seoul



$$density_{ij} = \frac{\Sigma_k GFA_{kj}}{FA_k} \tag{1}$$

Where $density_{ij}$ is density index of land use type j of i station's transit catchment area; FA_k is floor space of building k; GFA_{kj} is gross floor area land use type j of building k; j is land use type (residence, commerce, business, others); k is building located in i station's transit catchment area.

The diversity of the transit catchment area is based on the calculation formula used in previous studies (Cervero and Kockelman 1997; Cerin, Leslie, du Toit and Owen et al. 2007; Sung and Oh 2011) As a result of calculating the diversity of the transit catchment area, a high value was derived from the surrounding areas (Yongsan Sub-core and Upper region of Gangnam sub-core) of CBD and Gangnam sub-core. (See <Figure 5b>).

$$diversity_i = -\frac{\Sigma_j (P_j \ln P_j)}{\ln J} = -\frac{\Sigma_j \left(\left(\frac{\Sigma_k GFA_{kj}}{\sum_j \sum_k GFA_{kj}} \right) \times \ln \left(\frac{\Sigma_k GFA_{kj}}{\sum_j \sum_k GFA_{kj}} \right) \right)}{\ln J} \tag{2}$$

Table 2_ Mean Value of 3Ds Index for Each Type of Transit Catchment Area in Seoul

Variable	General	Regional Hub- & Local Foothold	Core & Sub-Core
Density(resident)	152.0	126.9	69.0
Density(commerce)	55.8	92.5	154.9
Density(business)	20.5	38.8	169.0
Density(others)	33.8	40.2	41.4
Diversity	0.66	0.76	0.80
Design(resident)	394.5	382.9	379.2
Design(commerce)	329.8	317.2	327.9
Design(business)	291.3	290.4	340.2
Design(others)	357.6	352.5	360.4

Where is $diversity_i$ index of i station's transit catchment area; P_j is floor area proportion of the land use type j within a i station's transit catchment area; J is number of land use types

Whereas prior studies defined the two preceding indicators relatively clearly and produces indicators, definitions of design indicators somewhat differ among scholars. This study defined the design index as a value indicating how accessible the walkway is from the station to the surrounding building. To calculate this arithmetically, previous studies applied the average distance from the station to the destination (Olaru and Curtis 2015; Sung, Lee and Cheon 2015; Lyu, Bertolini and Pfeffer 2016). As a result of design index calculation, the index of the Gangnam sub-core was relatively low when compared with other regions (see <Figure 5c>). This means that the distance between the station and the surrounding buildings is close (see <Table 2>).

$$design_{ij} = \frac{\Sigma_k (GFA_{kj} \times Dis_k)}{\Sigma_k GFA_{kj}} \tag{3}$$

Where $design_{ij}$ is design index of land use type j of i station's transit catchment area; Dis_k is network distance from the i station to k building.

2. Calculation of Traditional 2D weight Design indices

We surmised that the design elements of TOD were difficult to calculate independently, and sought a new methodology for calculating the design elements of the transit catchment area. In other words, to determine how easy it was to access buildings around the station, we estimated that it was reasonable to comprehensively calculate the density and diversity of land use combined with the walking network.

Existing studies have replaced this with the average distance between station and destination. However, this method has the disadvantage that it is difficult to analyze the relationship between each building and station because the method sums up and averages the distances between existing buildings and stations in the transit catchment area. To overcome the limitations of the existing design index calculation method and to calculate the index that meets the original purpose of the design index, we designed the "2D with D" equation which combines the density and diversity calculation method with the walking network.

The previously calculated "density index" can be used to determine if the area of the building in the transit catchment area is large or small. However, this index does not take into account whether the building is close to or far from the station. These limitations can be supplemented by including a design element in the formula that captures pedestrian accessibility between the station and the building. We constructed an equation that can reflect the walking distance (Design) to the existing density index as follows and obtained the index of each transit catchment area (see <Figure 6a>).

$$density\ with\ design_{ij} = \frac{\Sigma_k \left(\frac{GFA_{kj}}{Dis_k} \right)}{FA_k} \tag{4}$$

The existing Diversity Indicator can be used to determine whether there is only one land-use type building in the transit catchment area, or whether there is a building with various uses. However, this indicator alone does not indicate whether the use of buildings in the transit catchment area is separate from the proximate and far away parts of the station, or whether they are evenly mixed regardless of the station distance. These limitations can also be compensated by reflecting the distance between the building and the station in the diversity index formula. In this study, the index formulas that can reflect the design to the existing diversity index are constructed as below and the index of each transit catchment area is calculated (see <Figure 6b> and <Table 3>).

Figure 6 _ 2Ds w D Index of Transit Catchment Area in Seoul

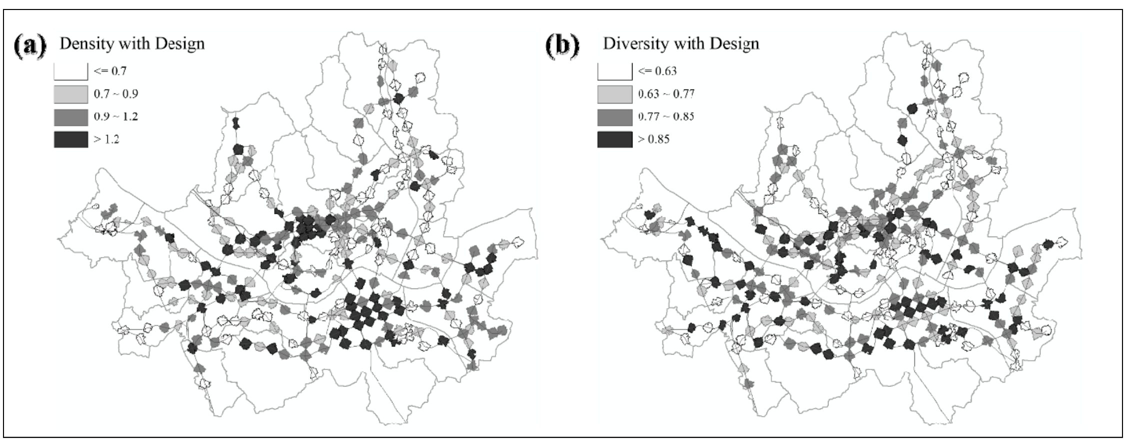


Table 3 _ Mean Value of 2Ds w D Index for Each Type of Transit Catchment Area in Seoul

Variable	General	Regional Hub- & Local Foothold	Core & Sub-Core
Density with Design (resident)	0.0052	0.0039	0.0021
Density with Design (commerce)	0.0025	0.0038	0.0071
Density with Design (business)	0.0010	0.0016	0.0061
Density with Design (others)	0.0014	0.0015	0.0019
Diversity with Design	0.6876	0.7732	0.7652

$$diversity\ with\ design_i = \frac{\Sigma_j \left[\left\{ \frac{\Sigma_k \left(\frac{GFA_{kj}}{Dis_k} \right)}{\sum_j \sum_k \left(\frac{GFA_{kj}}{Dis_k} \right)} \right\} \times \ln \left\{ \left(\frac{\Sigma_k \left(\frac{GFA_{kj}}{Dis_k} \right)}{\sum_j \sum_k \left(\frac{GFA_{kj}}{Dis_k} \right)} \right) \right\} \right]}{\ln = J} \quad (5)$$

IV. Analysis

1. Analysis Model Setting

We have confirmed by regression analysis how much the TOD index proposed in this study contributes to explaining the ridership of subways compared to the existing TOD analysis index. In this study, regression analysis was performed by classifying the subway stations into three types. The existing TOD land use index calculation method (3Ds) and the indicator calculation method presented in this study (2Ds w D) were applied to the model and the explanatory power is calculated and compared. The multiple regression model applied in this study is as follows:

$$3Ds\ : Rider_i = \alpha + \Sigma_j \beta \cdot density_{ij} + \beta \cdot diversity_i + \Sigma_j \beta \cdot design_{ij} \quad (6)$$

$$2Ds\ w\ D\ :\ Rider_i = \alpha + \Sigma_j \beta \cdot Density\ with\ Design\ _{ij} + \beta \cdot Diversity\ with\ Design_i \quad (7)$$

Where $Rider_i$ is number of passengers in station i; α is constants; β is parameters

2. Analysis Result

We analyzed the explanatory power of each model based on the existing 3Ds method and the 2Ds w D method presented in this study based on the Adj. index. In the case of the general station area, the existing 3Ds model explained about 21.3% of the ridership of each station, and the 2Ds w D model had only about 7% explanatory power. In other words, comparing the two models analyzed for the transit catchment area of the general station

Table 4 _ Multiple Regression Model Analysis Results

Variable			General				Regional Hub- & Local Foothold				Core & Sub-Core			
			β	Std.	t	VIF	β	Std.	t	VIF	β	Std.	t	VIF
3Ds	Constant		7,210	-	1.135	-	63,671	-	2.873	-	15,063	-	0.374	-
	Density	Resident	-274	-0.040	-0.462	1.573	-2,607	-0.085	-0.651	1.904	3,348	0.079	0.461	2.255
		Commerce	8,224 ***	0.414	5.086	1.400	8,885 ***	0.396	3.935	1.136	9,969 ***	0.419	3.054	1.450
		Business	2,157	0.077	0.880	1.596	6,601	0.167	1.384	1.626	5,460 **	0.443	2.487	2.449
		Others	473	0.024	0.303	1.324	5,398	0.168	1.304	1.865	12,883	0.145	0.916	1.931
	Diversity		-813	-0.017	-0.157	2.349	18,565	0.162	0.961	3.165	-14,363	-0.073	-0.352	3.287
	Design	Resident	8.34	0.066	0.816	1.362	-73.15 **	-0.278	-2.652	1.230	60.17	0.140	1.112	1.217
		Commerce	3.55	0.050	0.655	1.231	20.72	0.081	0.592	2.118	-8.89	-0.028	-0.186	1.777
		Business	-34.83 ***	-0.225	-2.818	1.341	-107.38 **	-0.257	-2.272	1.431	-95.04	-0.226	-1.406	1.998
		Others	21.45 **	0.172	2.337	1.143	-21.42	-0.078	-0.703	1.396	16.58	0.052	0.353	1.665
	Adj. R^2		0.213				0.383				0.417			
2Ds w D	Constant		4,045	-	1.437	-	-6,983	-	-0.578	-	-22,144	-	-0.976	-
	Density with Design	Resident	-53,231	-0.056	-0.578	1.697	715,605	0.082	0.807	1.149	-979,989	-0.075	-0.542	1.723
		Commerce	634,882 ***	0.234	2.741	1.305	3,116,466 ***	0.486	5.002	1.050	2,185,642 ***	0.750	3.682	3.708
		Business	-37,073	-0.009	-0.112	1.185	2,162,471 **	0.245	2.280	1.282	2,544,821 ***	0.714	5.650	1.426
		Others	-142,255	-0.043	-0.494	1.330	1,595,139 **	0.244	2.224	1.342	-2,854,543 **	-0.484	-2.555	3.207
	Diversity with Design		9,927 **	0.205	2.456	1.238	13,308	0.108	0.935	1.495	38,299	0.250	1.381	2.939
	Adj. R^2		0.070				0.379				0.496			

revealed that the existing model has higher explanatory power. Analysis of the 3Ds model showed that the number of passengers was higher when the density of commercial facilities was high in the transit catchment area and the business facilities were close to the station. At the same time, the 2Ds w D model shows that the number of passengers is high in the transit catchment area where the density of commercial facilities reflecting the distance is high and the mixture of land use is high (see <Table 4>).

For the regional hub- and local foothold station, the 3Ds model explains the ridership of each station by about 38.3% and the 2Ds w D model by 37.9%. In other words, comparing two models analyzing the regional hub- and local foothold station shows similar explanatory power. The 3Ds model shows that the number of passengers increases when the density of commercial facilities in the transit catchment area is high and residential and business facilities are close to the station. The 2Ds w D model shows that the number of passengers increases as the density of commerce, business, and other facilities reflecting the distance weight is high.

V. Conclusion

In this study, we point out the limitations of the 3Ds index, which has been used in previous TOD studies and propose a methodology to overcome them. In other words, in previous studies, density, diversity, and design were separated from each other and analyzed independently. However, when considering the buildings included in the station area, density and design, and diversity and design cannot exist separately. Therefore, we calculated the density and diversity index reflecting the network distance and analyzed its effect on the demand for public transportation. The results of this study were summarized in two ways. The first results were mainly described based on the analysis results of the model proposed in this study. The second result was derived by comparing the analysis results of this research methodology with the existing research methodology.

First, the analysis results of the model proposed in this study were confirmed in detail. We divided the analysis target into three types based on the urban structure. After constructing a model for each type, analysis was performed. As a result of the analysis, the model explanatory power of the 'general' region was very low(0.070). On the other hand, the model explanatory power of 'regional hub- & local foothold' and 'core & sub-core' regions was relatively high.(0.379, 0.496) And it was confirmed that the same variable had a significant effect on the number of subway passengers in 'regional hub- & local foothold' and 'core & sub-core' regions with relatively high explanatory power. Summarizing the results of the above study, the model for estimating the number of passengers in the 'general' area through the density and diversity index considering the network distance lacks explanatory power. However, in areas other than 'general', it was confirmed that the density and diversity index considering the network distance explained about 38-50% of the number of passengers. In particular, it was proved that the density of commercial, business, and other uses reflecting the network distance between stations and buildings is a factor that significantly affects the number of passengers.

Second, the analysis results of the existing research methodology and the methodology proposed in this study were compared using explanatory power. Since the two models differ in the number of independent variables, there is a limit to objectively comparing and evaluating the models through explanatory power. There is no significant difference in the explanatory power of the models built through the two analysis methodologies. In other words, the '2Ds w D' method presented in this study did not show a remarkable increase in explanatory power compared to the '3Ds' method, which is the existing research method. When analyzed by region, the explanatory power of the model presented in this study decreased rather than the explanatory power of the existing model in the 'general' region and the 'regional hub- & local foothold' region. (0.213 → 0.070; 0.383 → 0.379) On the other hand, in the 'core & sub-core" region, the methodology presented in this study showed higher explanatory power than the existing methodologies. (0.417→0.496) In other words, in CBD, the analysis method presented in this study showed higher explanatory power than the existing method, but the difference was not large, and the explanatory power was rather low in other regions. In this way, if it is evaluated simply through explanatory power, it cannot be said that this research methodology has greatly developed the existing research model. However, this study defined the station influence area from a different perspective from previous studies and proposed a methodology for deriving indicators based on it. And it was confirmed that the model using the calculated index guarantees some explanatory power when compared with the existing research methodology. We confirmed the applicability of this research methodology through these analysis results, and were able to plan a follow-up study that supplements this research methodology more precisely.

Many studies have evaluated the 3Ds indicators as separate indicators that affect the TOD based on the case study, and have used them without further analysis. However, as presented in this study, density and diversity are very closely related to design. In other words, people comprehensively consider and judge the density(use) of buildings within the station influence area and the distance between stations without separating them from each other. In order to reflect this situation in the analysis without loss of information, we presented density and diversity indicators considering the network distance (2Ds w D).

This paper is the first to present the concept of 2Ds w D index to academia and confirm its applicability. It will have a great influence on the study of TOD in the future. We hope to supplement and develop this study by extracting various variables that were not used in this study and apply them in the analysis through subsequent research.

However, although this study is very meaningful, there are some limitations. For example, although the distance between the station and the building can be calculated through various functions, this study utilized the reciprocal of the distance. In addition, the spatial autocorrelation of users of urban railroad stations has not been reviewed. This limitation is to be addressed in our next study.

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요약

주제어: 대중교통중심개발, 역세권, 밀도, 다양성, 디자인

본 논문은 TOD의 3Ds 지표 중 디자인의 모호성을 다룬다. TOD의 디자인은 밀도와 다양성과 달리 산술적으로 계량화하는 데 어려움이 존재한다. 우리는 이 연구를 통하여 기존 3Ds 지표를 2Ds with D (Density with Design, Diversity with Design)로 대체하는 방법론을 개발하였다. '2Ds with D'는 밀도와 다양성 지수를 계산할 때 각 지점에서 보행의 편의성을 고려하는 방법이다. 이 분석 방법론을 수도권 도시철도 287개 역에 적용하였다. 그리고 기존의 3D와 '2D with D' 지표 중 도시철도 이용자의 사용자를 설명하는데 어떤 지수가 더 좋은지 비교 분석하였다. 분석 결과, CBD에서는 본 논문에서 제안한 분석 방법이 기존의 방법에 비해 설명력이 높지만, 그 차이는 크지 않고 다른 지역에서는 설명력이 다소 낮은 것으로 확인되었다. 이 연구는 학계에 2Ds with D의 개념을 제시하고 그 적용 가능성을 확인한 최초의 논문이다. 이 연구는 향후 TOD 연구에 큰 영향을 미칠 것으로 판단한다.