Cities 28 (2011) 70–82

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea

Hyungun Sung *, Ju-Taek Oh [1]

The Korea Transport Institute, 2311 Daewha-dong, Ilsanseo-gu, Goyang-si, Gyeonggi-do 411-701, Republic of Korea

ARTICLE INFO

Article history:
Received 27 February 2010
Received in revised form 8 July 2010
Accepted 10 September 2010
Available online 6 October 2010

Keywords:
Transit-oriented development
Rail station area
Density
Diversity
Design
Accessibility

ABSTRACT

This study determines whether transit-oriented development (TOD) planning factors identified from western case studies can be applied to the city of Seoul, Korea, which is characteristic of dense development. The authors illustrate the distributional patterns and characteristics of planning factors such as transit supply service, land use, street network and urban design at each rail station area. To identify effects of TOD planning factors upon the transit ridership at the targeted 214 rail station areas in Seoul, the study develops multiple regression models for transit ridership, which are differentiated at the levels of time of day, day of the week, and transit mode at the respective rail station areas. The analysis results suggest that TOD planning factors can have a significant positive impact in forming a transit-oriented city. They also indicate that some TOD planning factors, compared to low-density cities in Western countries, need to be carefully applied towards Seoul in order to achieve the objective of regenerating a transit-oriented city. In summary, rather than focusing mainly on increasing development density, it is necessary to concentrate more on such strategies as strengthening the transit service network, increasing the land-use mix index, and restructuring the street networks and urban design to be more pedestrian friendly around rail stations.

Introduction

Sprawling urban settlement patterns have resulted in increasing social costs such as traffic congestion and environmental degradation, as well as impedance of social and spatial integration. In the early 1990s, a movement towards a return to traditional land-use patterns began to get recognition as a way to address these urban problems. These land-use patterns mainly include high-density development, mixed use, and pedestrian-friendly urban design, especially near transit centers such as rail stations.

Among planning methods, transit-oriented development (TOD), first proposed by an American architect and planner by the name of Calthrope (1993), has recently gained attention. The TOD-based planning movement is commonly identified with the US and European nations. Many American cities such as San Francisco and Atlanta have incorporated TOD concepts, and such planning and policy concepts as both the Urban Village of England and the ABC Policy of the Netherlands are also well-known TOD policy cases. Recently, some Asian governments like Hong Kong, Taiwan and China have also begun to examine the possibility of implementing these concepts in order to tackle their urban problems, especially traffic congestion resulting from the disconnect between urban development and transportation (Cervero & Day, 2008; Cervero & Murakami, 2010; Lin & Shin, 2008).

Likewise, TOD has been recognized as one of the key planning methods in Korea to resolve traffic problems by inducing high-density development in both the inner city and the suburban areas. But Korea has yet to have a boost in TOD-based development primarily due to the lack of realistic analysis of the effects of TOD planning factors at the city and regional level. TOD could become a convincing planning model to the general public and policy makers when thorough examination and analysis is conducted on how and to what extent TOD would alter travel patterns.

The study thus analyzes whether TOD planning factors identified from foreign case studies can be applied to Seoul, Korea. Many Korean planning experts and policy makers are skeptical towards applying this planning concept to Korean cities since most cities in Korea are already compact. Despite the existing compact land-use pattern in Korean cities, TOD planning methods can still be useful in Korea due to diverse concepts inherently included in TOD development, such as mixed land-use and pedestrian-friendly road networks and urban designs. Therefore, the authors have tried to identify what factors are more significantly effective in promoting transit ridership in the city of Seoul. To that end, this study first analyzes distributional patterns and characteristics of planning factors identified from preliminary studies and also those of

* Corresponding author. Tel.: +82 31 910 3210; fax: +82 31 910 3233.
E-mail addresses: hgsung@koti.re.kr (H. Sung), jutaek@koti.re.kr (J.-T. Oh).
[1] Tel.: +82 31 910 3174; fax: +82 31 910 3537.

0264-2751/$ - see front matter Crown Copyright © 2010 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.cities.2010.09.004

planning factors representing existing Korean urban form characteristics such as transit service levels, land-use patterns, street networks, and urban design patterns at each rail station area. After that, multiple regression analysis models are developed to analyze the relationship of derived planning factors to transit ridership at each rail station area. This process thereby verifies the strong associations of each TOD planning factor, and also determines the applicability of TOD—according to the respective planning factors—in Korea.

Research design

Research background

The city of Seoul, the capital city of South Korea, is located at the center of the Korean Peninsula. As of 2007, Seoul accommodated 10.4 million residents within an area of 603.3 km^2. Its population density reaches a level of 17,127 person/km^2, making Seoul the most densely populated city in the world as shown in Fig. 1. The concept of TOD planning was originally derived from North America where most large cities, excepting New York, have experienced low-density sprawl, resulting in worsening traffic congestion and degraded environmental quality.

A major focus in American cities regarding TOD planning has been centered on increasing development density (density) as well as mixing land uses (diversity) and creating pedestrian-friendly urban design (design) near transit centers (Cervero & Kockelman, 1997). After investigating the literature on empirical studies of TOD planning factors in American cities, Ewing and Cervero (2001) identified that the application of the 3-D planning factors (density, diversity and design) tend to reduce total trips and total vehicle miles traveled by 3–5%. Also, conducting a comparative analysis between an automobile-oriented city and a transit-oriented city, Cervero (1996) demonstrated that the latter has about 30% fewer total trips and vehicle miles traveled than the former. As an increasingly advocated concept supported by much empirical evidence in American cities, TOD has become one of key planning methods to manage urban growth smartly in the 21st century. In addition to the 3-D planning factors, two more factors—destination accessibility and distance to transit—need to be added to the TOD planning concept to tackle excessive dependence on automobile travel in the United States (Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; Hamin & Gurran, 2009).

In Asian, especially Chinese, cities, TOD planning concepts have been applied in places experiencing suburbanization and traffic congestion. In a case study of Hong Kong, Cervero and Murakami (2010) conclude that TOD application is much more effective in increasing transit ridership and housing prices than just transit-adjacent development. In addition, examining the relationship of the TOD planning concept and transit ridership in Taipei, Lin and Shin (2008) find that the latter is significantly greater in a built environment consistent with TOD. However, it is said that its application effects, especially diversity ones, may be different between American and Chinese cities due to cultural differences (Lin & Shin, 2008). Additionally, Zhang (2004) demonstrates that the development of mixed land-use near a transit center is not statistically significant in attracting transit mode choice. In this regard, it is thus necessary to identify impacts of TOD planning concepts on mode choice and transit ridership in the real world.

In Korea, the TOD planning concept may not be new since Kang (1980) proposed a rail-oriented development model 30 years ago to accommodate a projected population of 10 million in the year 2000. Calling it the Rosario's Concept, shown in Fig. 2, Kang asserted that such urban problems as traffic congestion and inordinate consumption of developable land could be resolved if new housing supply, while managing rapid urban growth, were to be concentrated into a 1 km radius of rail stations in Seoul along the four railway lines under construction and four additional planned railway lines. His suggestion was reflected in the 2010 and 2016 City Comprehensive Plans (1990 and 1996, respectively) to induce a high-density development plan associated with traffic calming techniques within rail station areas (Sung et al., 2006). However, such efforts were set aside as the central government announced a project constructing two million housing units at the five new-towns around the suburbs of Seoul in the late 1980s.

Kang's concept was, in Korea, revived along with American planning movements such as New Urbanism, traditional neighborhood development and transit-oriented development. While temporarily resolving skyrocketing housing prices and housing-supply shortages, the new-town development project resulted in an increase in travel distance and automobile use (Lee & Ahn, 2005; Sung & Kim, 2007). Since the early 21st century, American TOD planning concepts have begun to be practically introduced

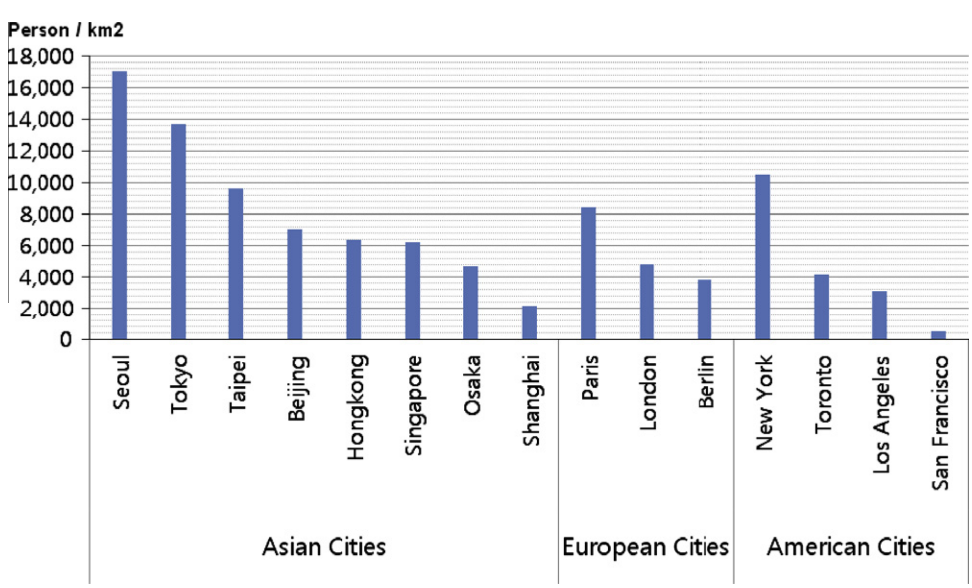


Fig. 1. Population densities of world cities. *Source*: Byun and Kim (2008).

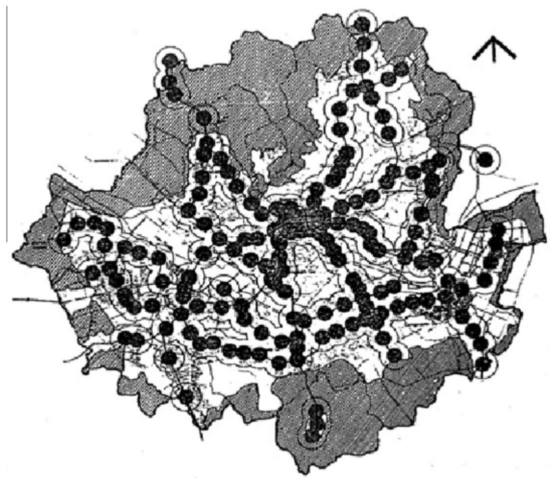


Fig. 2. Rosario concept (1980). *Source*: Kang (1993).

to urban and transportation planners in Korea with an effort to tackle worsening traffic congestion (Kwon & Oh, 2004).

Ever since then, several studies related to TOD planning techniques have begun to be referred to in Korean journals and institutional reports. Sung and Kim (2005) demonstrated that diverse types of rail station areas such as residential-oriented, employment-oriented, and mixed-use rail station areas exist in the city of Seoul, after analyzing rail ridership by time of day and day of the week. Both Lim (2006) and Sung and Kwon (2006) also identified that land-use patterns are closely coordinated with urban railway ridership and modal split at the level of rail station areas. Their empirical studies implied that land-use patterns among the TOD planning factors such as density and diversity could be applied to Seoul. Despite those empirical studies, many policy makers and planning experts have been skeptical towards the application of those principles to Korean cities due to an already existing high density in most cities. Such doubts may arise due to the fact that TOD ostensibly appears to focus more on density itself than diversity, design, destination accessibility or distance to transit. In this regard, the other planning factors of TOD need to be examined further to demonstrate TOD applicability to the cities in Korea. This study thus intends to identify the relationship between TOD planning factors and transit ridership at each rail station area in the city of Seoul, which has a higher development density than not only other Korean cities, but also other major cities in the world.

Research boundaries, data and methodology

To examine the relationship between TOD planning factors and transit ridership, the study focuses on the urbanized rail station areas within a 500 m-radius of a rail station in the city of Seoul. With 287 km of total urban railways and 80,711 buses under operation as of 2006, the city of Seoul has one of the most advanced and extensive transit systems in the world. Most citizens take public transit, which covers 66.3% of total trips: among the total trips, 38.5% is via urban railway, excluding national railways, and 27.8% by bus. Despite the high modal share of public transit, the average daily traffic speed on major arterial roads in Seoul is lower than 20 km/h, a speed almost equaling that of New York City. Seoul's first urban heavy rail line opened in 1973; as of May 2010, the city of Seoul has 10 operating urban railway lines. Fig. 2 shows Seoul's major railway lines and stations. A total of 214 subway stations in Seoul were selected for the study out of a total of more than 250, many of which are new and therefore lack adjacent land use data. However, the results of the analysis are not expected to be statistically deviant because changes in land-use patterns resulting from the new railways' opening are not expected to occur within a short time period. Fig. 3 shows urban railway networks and the 500 m radius circles around rail stations analyzed in the study.

The data employed to identify the relationship between TOD planning factors and transit ridership at Seoul's rail station areas was acquired from diverse sources managed by public authorities such as local transit agencies and local and central governments. For the analysis, the study manipulates the database to obtain transit ridership at each rail station area and TOD planning factors such as the quantity and quality of transit service, the density and diversity of land use and the features of the road network and urban design around the rail station.

Data on transit ridership, differentiated by time of day, day of the week and transit mode, was extracted using Smart Card[2] data matched with the location identification numbers of bus stops and rail stations. To date, the Smart Card has been used by over 10 million people per day, covering more than 95% of all transit users in Seoul. It was developed to manage both real-time transit traffic flows and the transparent fare revenue system in 2004. For the purposes of this study, it provides useful information on where each transit user gets on and off, what transit mode is used at what time, and whether a trip involves transferring to another transit mode or a different bus route.

Data on the quantity and quality of transit service potentially influencing transit ridership were also adopted in the study. Rail service data representing the location and features of railways and stations, such as the distance between the two nearest rail stations and the number of station exits, were obtained from the 2007 Urban Railway Plan issued by railway authorities. Matching the bus route management program with bus stop identification numbers used by the city of Seoul, the data provide the location information of bus stops on a GIS map and the bus service information such as bus allocation for each bus route. In that way, the dataset makes it possible to provide the information on bus service being operated within each rail station area, such as how many times a bus route is operated per day and how many bus stops are located within the area.

The data on both land use and urban design factors representing TOD planning factors such as density, diversity and design of each rail station area were gained from diverse databases such as the national transport database managed by the Ministry of Land, Transport and Maritime Affairs and the land registration and building taxation profile maintained by the Ministry of Administration. Fig. 4 shows an example of road network, land use and building design patterns within the 500 m-radius of rail station areas in Seoul.

Developing multiple regression models

Analysis methodology and process

To investigate the relationship between TOD planning factors and transit ridership at the targeted 214 rail station areas in Seoul,

[2] The Smart Card, or Integrated Circuit Card (ICC), is an embedded integrated circuit on a personal credit card (Park, Kim, & Lim, 2008). It records information for each transit user at a time to distribute fare revenues collected every day to transit authorities and private bus companies under an integrated fare system, which is a distance-based system. It records the personal card number, on- and off-boarding time, boarding mode, transfer times, bus route ID and number, etc. Such information is recorded by a terminal on either the bus or station whenever each user gets on and off. The study uses 2-day data on April 19 (Thursday) for weekday and 15 (Sunday) for weekend, officially obtained by the Seoul Metropolitan Government. Based on boarding data, total transit users are 11.4 million people for weekday and 10.7 million for weekend.

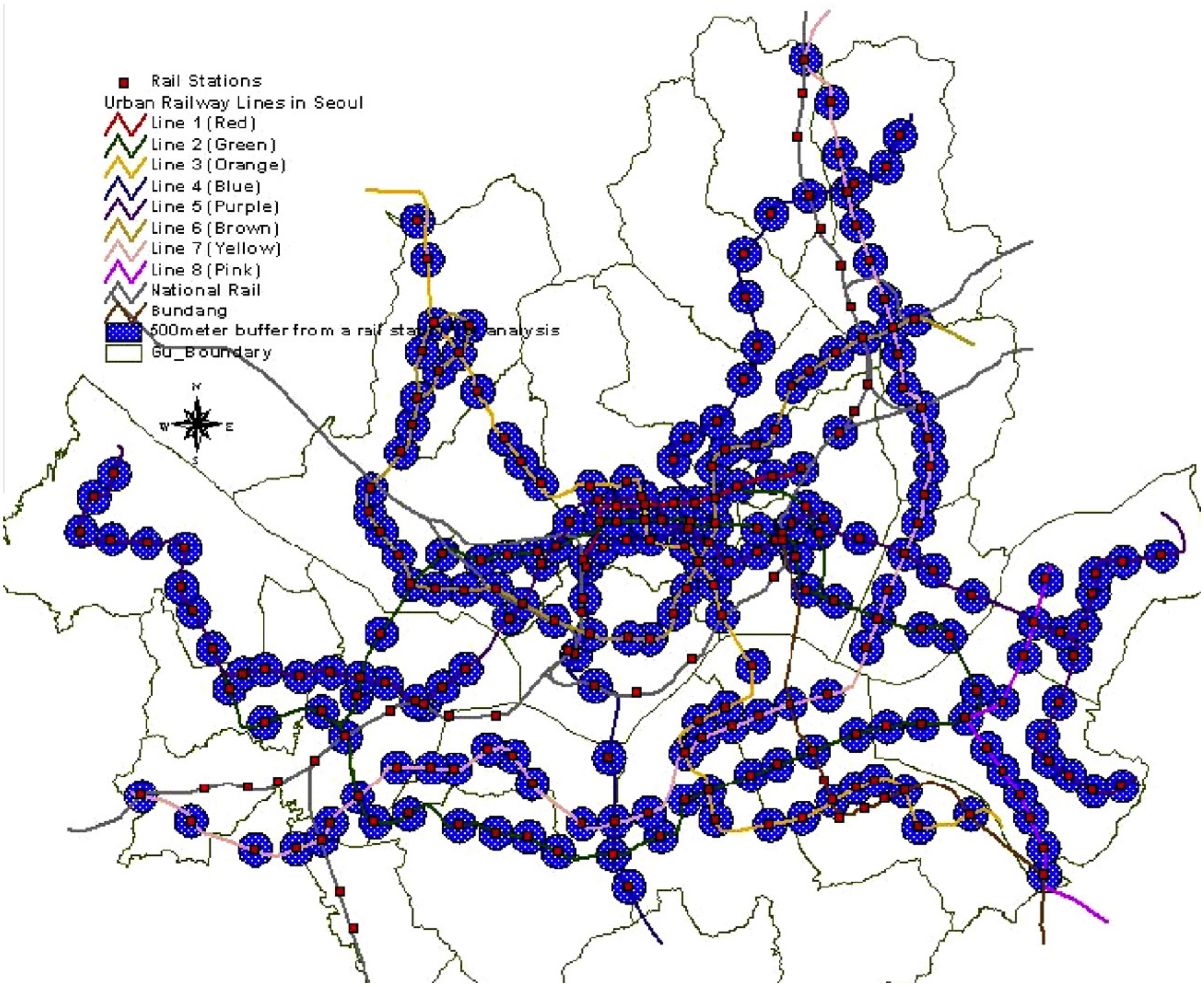
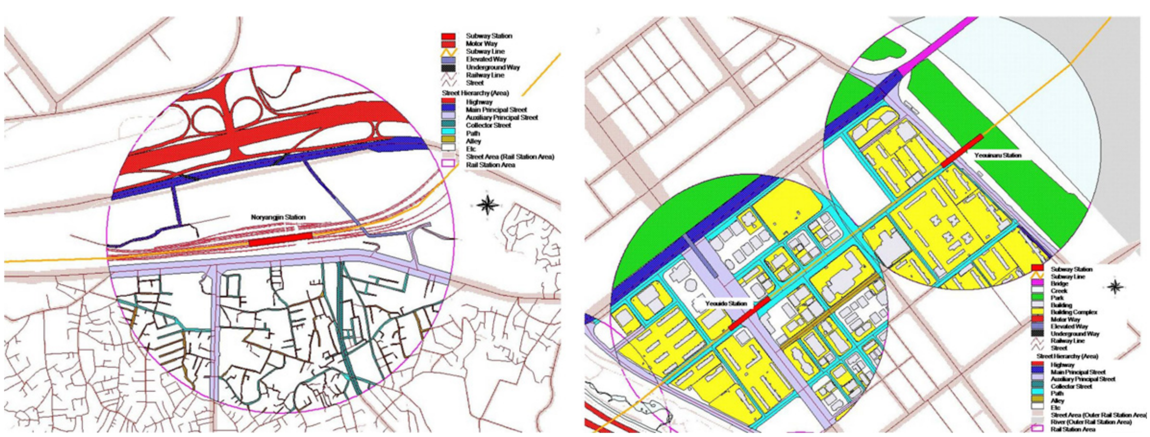


Fig. 3. Railway network and rail station areas in Seoul.



(a) Road Network of Noraynjin Station

(b) Land Use and Design of Yuido and Yuinaru Stations

Fig. 4. Examples of road network, land use and design within the rail station areas.

the study employed multiple linear regression models on dependent variables of transit ridership by time of day, day of the week and transit mode with the same explanatory variables such as transit service, density, diversity and urban design factors for which details are given below. Transit ridership at the Seoul rail station areas is classified into weekday and weekend, bus and rail, peak hour and non-peak hour, and alighting and boarding because they are varied by travel purpose and urban spatial structure. For instance, while travel ridership on weekends tends to be higher for leisure trips than for commuting trips, it tends to be concentrated at the rail station areas with urban functions for commercial, leisure, and recreational facilities. With the same logic, alighting

Table 1
Average daily users at rail station areas in Seoul depending on user ridership characteristics.

			Alighting/boarding	On-average transit users	Log transfer value
Day of the week	Weekday		Alighting	30,439.6	9.99
	Weekend		Alighting	16,801.9	9.37
Mode	Weekday	Bus	Alighting	12,328.0	8.97
		Subway	Alighting	18,111.6	9.45
		Transfer	Alighting	8371.4	8.34
Time of the day	Weekday	Morning peak	Alighting	5523.4	8.34
		Morning peak	Boarding	6214.6	8.27
		Morning non-peak	Boarding	4668.6	7.98

ridership at either a rail station or a bus stop is much higher than boarding in the morning peak time at the employment-oriented rail station areas. Thus, it is important to identify the relationship between temporal patterns and TOD planning factors.

Before analyzing the envisaged multiple regression models developed here, the study inspects the correlation and causality among independent variables with very close caution. Thus, the study not only conducts a correlation analysis between explanatory variables to develop multiple regression analysis models, but also utilizes the variation inflation factor (VIF) to identify multicollinearity between the selected variables. Generally, with a greater VIF, a particular explanatory variable is more likely to be expressed in terms of a linear function model by other explanatory variables, and multicollinearity could exist. There is no formal standard to determine the bottom line for its tolerance. Generally speaking, an explanatory variable with a VIF value greater than 10 has a multicollinearity problem in the model. With the explanatory variables selected after examining such problems, multiple regression analyses are conducted.

Dependent variables and transformation

As discussed above, transit ridership has a varying ridership pattern depending on weekday or weekend, bus or rail, single-travel or transfer-travel, and time of day at each rail station area. Thus, it is necessary to identify the relationship between such discrete use patterns and TOD planning factors by utilizing daily, modal, and temporal ridership as dependent variables within the envisaged multiple regression analysis model.

For the purpose of analysis, the daily transit ridership will be determined by the boarding volume of the day; the modal transit ridership will be categorized into on-board ridership for bus, rail, and transfer trips; and the temporal ridership will be classified into boarding and alighting ridership during the morning peak time (7 AM–9 AM) and morning non-peak ridership (9 AM–12 PM). On-board ridership was set as a basis in determining weekday and weekend use patterns. And, in regards to the modal ridership, ridership for bus, ridership for rail, and transfers among bus-to-bus, bus-to-rail and vice versa have been selected as dependent variables because of the necessity to examine their respective relationship with TOD planning factors.

With regards to temporal ridership, the morning peak-time boarding volume is used to identify the association between the ridership for rail station areas dominated by residential land use and TOD planning factors; alighting ridership in the morning peak hour is used to identify the relationship between the ridership for employment-oriented rail station areas and TOD planning factors; and alighting ridership also is used to identify the relationship between the ridership for shopping-oriented rail station areas and TOD planning factors. Table 1 shows the average number of users by day of the week, mode, and time of day.

The dependent variables selected here have positive numeric characteristics with a far-left non-linear distribution. Thus, they need to be transformed into a logarithmic form in order to get a normal distribution and also avoid a negative expectation in the model. Fig. 5 shows distribution patterns of on-board weekday transit ridership for both (a) original data and (b) transformed data and it proves that the logarithmic transformation is closer to a normal distribution. Table 1 also illustrates statistical outlines of transit ridership by time of day, day of week and transit mode employed for the regression model with logarithmic transformation values.

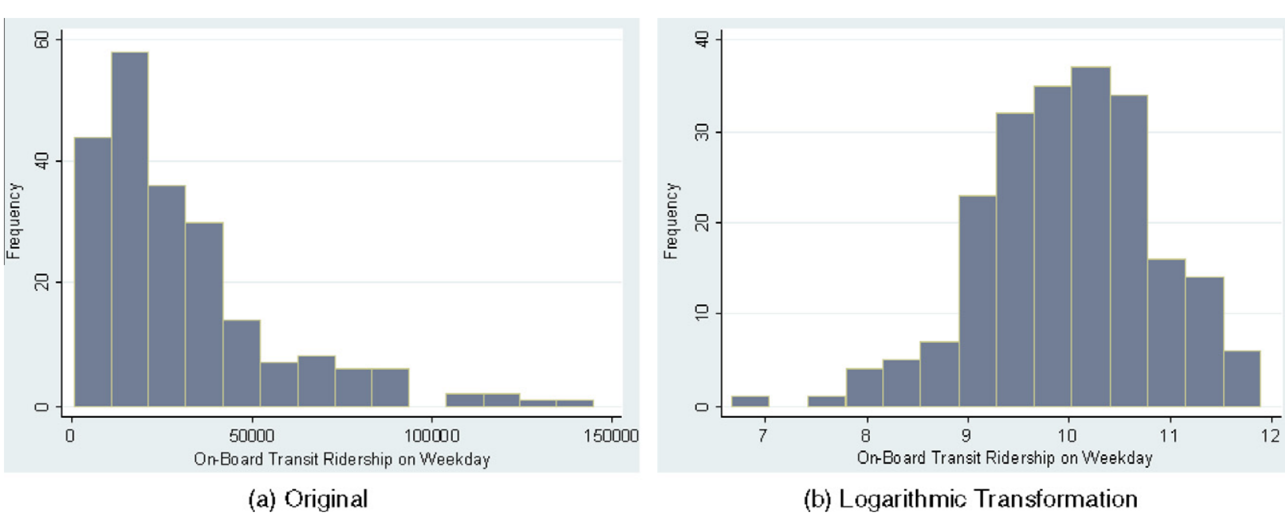


Fig. 5. Original distribution and logarithmic transformation for weekday–boarding ridership.

Table 2
Correlation analysis of TOD planning-factor variables.

Variable	Transit supply characteristics						Characteristics of land use				
	Busline	Allocate	dis_20 km	Busstop	st_dis	st_exit	Density	r_land	c_land	Office	lum_4
Allocate	−0.2480	1									
dis_20 km	0.2685		1								
Busstop	0.3604	−0.1983	0.2164	1							
st_dis					1						
st_exit	0.3594	−0.3373		0.2507	0.3494	1					
Density	0.2564	−0.1448	−0.1185	0.1331	−0.0415	0.3245	1				
r_land	−0.3244	0.2655				−0.2220	0.2364	1			
c_land	0.3880	−0.3490		0.2236	0.0653	*0.5247*	*0.6766*	−0.2498	1		
Office	0.4293	−0.2621	−0.1715			0.3442	*0.7343*	−0.3981	*0.5995*	1	
lum_4	0.3448			0.1974		0.4838	0.1749	−0.5013	*0.5811*	0.3469	1
lum_2		−0.2500	−0.1508			0.2328		−0.2188	0.2943	0.1413	*0.5392*
acc_s_t	−0.2582	0.2147	0.1282		−0.1314	−0.3271	−0.2356	0.2358	−0.3246	−0.3348	−0.4119
acc_r_t	−0.2403	0.1853	0.1529			−0.2966	−0.1944	0.2120	−0.2693	−0.3022	−0.3685
reg_acc	0.3421	−0.2735	−0.1995	0.1679	0.1905	*0.5758*	0.4708	−0.3235	*0.6599*	0.5534	0.4885
rlength	0.1625	−0.1530		0.2713	0.3821	0.4516		−0.1368	0.4002		0.3585
r_band2				−0.2213	−0.2344	−0.1248	0.1933	0.1195		0.1592	−0.1893
rl012_r	0.2284				0.2044	0.1406		−0.1930		0.2613	
ic4		−0.1407		0.2529		0.2032			0.3229		0.3192
ic0	0.1298			0.2697		0.1178			0.1209		0.1362
bg_m_g				−0.2049		−0.1160			−0.2121		−0.2980
bd_m_g				−0.2045	−0.1315	−0.1205	0.1494				−0.1993
	Accessibility				Characteristics of street network and urban design						
	lum_2	acc_s_t	acc_r_t	reg_acc	rlength	r_band	rl012_r	ic4	ic0	bg_m_g	bd_m_g
acc_s_t	−0.2626	1									
acc_r_t	−0.2430	*0.9144*	1								
reg_acc	0.2951	*−0.5900*	*−0.5272*	1							
rlength		−0.1940	−0.1565	0.4869	1						
r_band2				−0.2007	*−0.6634*	1					
rl012_r		−0.1358	−0.1463		−0.2899	*0.5749*	1				
ic4	0.1564			0.1553	*0.5272*	−0.4398	−0.4217	1			
ic0			−0.1671	0.2017	*0.6012*	*−0.6054*	−0.4117	0.4885	1		
bg_m_g				−0.1849	−0.3749	*0.5478*	0.3639	−0.3216	−0.3587	1	
bd_m_g				−0.1962	*−0.5446*	*0.7586*	0.4015	−0.3888	−0.5038	*0.7122*	1

Table only includes values whose cautionary values are lower than 1%, and italics values indicates correlation coefficient higher than 0.5.

Planning factors and multicollinearity tests

TOD is a planning technique that aims to reduce automobile use and promote the use of public transit and human-powered transportation modes through high density, mixed use, environmentally-friendly development within areas of walking distance from transit centers. As mentioned above, proxy variables for the 3-D factors, rail-transit accessibility, and transit service level of each rail station are developed from diverse data sources. First, explanatory variables for density including total, residential, commercial and office densities are estimated by calculating the development density (m^2) for the floor areas of buildings by land use. Second, diversity factors are derived from land-use mix (LUM) index[3] for two different use types: One is a variable to represent an index with two land-use types (lum_2), residential and non-residential areas, and the other one is to represent four types (lum_4), for residential, commercial, office and others. Third, three accessibility proxy variables are used to measure the travel time from one area to a given rail station area by either car or rail. The first is regional accessibility by rail, developed by Lee (2004),[4] for the Seoul Metropolitan Area. The other two accessibility measures represent the average travel time (in min) consumed to get to three central business districts (CBDs) including City Hall, Kangnam and Yeoido from a given rail station by taxi and rail, respectively.[5] Fourth, design factors are used to measure the degree of convenience for pedestrian and automobile use with varying forms of street and building patterns. Characteristics of the street network, such as the width and density of streets and four-way intersections within a given rail station area, are some of the design factors used in the study. Finally, variables on the quality and quantity of transit service at a given rail station area are introduced to investigate their association with transit ridership. They include average allocation times for a bus route, number of bus routes with under-20 km operation distance, the number of exits at a rail station, and the distance between two adjacent stations.

[3] The land-use mix (LUM) index is computed via the following formula: $Entropy = \sum_j \frac{(P_j \times \ln(P_j))}{\ln(J)}$. As the level of land-use mix increases, the index value gets closer to 1. The LUM index has been previously used by other researchers to represent the degree of land-use diversity for a given area (e.g., Cervero & Kockelman, 1997and Cerin, Leslie, Owen, & Frank, 2007). Krizek (2003) criticizes the LUM index, suggesting that it only reflects the presence of land-use types, not their mixing intensity. To address this limitation, two types of LUM indexes are used in the study.

[4] Lee (2004) developed the accessibility index (A_i), which is based on railway accessibility, considering the weight of either number of jobs or housings. In the formula, W_j is represented by jobs or residents in the destination j. Parameter β indicates that nearby destinations are given greater weight than remote ones. A generalized cost C_{ij} denotes the travel time between the origin i and the destination j. The study used the index data that Lee computed via the following formula: $A_i = \sum_j W_j \exp(-\beta c_{ij})$.

[5] Most of the Korean studies examining either accessibility or urban structure for the city of Seoul have included either distance or travel time to city hall, Kangnam, and Yeoido from a given area, since they are major economic activity centers in the city as well as the metropolitan area. For example, they are employed in the two studies (Bae, Jun, & Park, 2003; Kim & Suh, 2009) investigating the relationship between accessibility and land prices in the city of Seoul. In this regard, the study also employs them as proxy variables for the accessibility to the CBDs.

The selected TOD planning factors are tested to examine the correlation between explanatory variables before conducting regression analyses. Table 2 shows the coefficient values. Among them, variables with a relatively high correlation are the number of station exits (st_exit), development density (density), commercial-use density (c_land), land-use mix index (lum_4), average travel time to three CBDs by taxi and subway (acc_s_t and acc_r_t, respectively), total road length (rlength), average road width (r_band2), and building complex area (bg_m_g). Of these variables, total development density and commercial-use density have a correlation coefficient of 0.7343; accessibility to an urban railway and street have that of 0.9144, and the building complex area, the average road width and the average building area per building have that of over 0.7, indicating that the multicollinearity of these variables needs to be examined.

To test multicollinearity, a VIF is used in this study. The VIF formula is as follows:

$$\mathrm{VIF}_k = 1/\left(1 - R_k^2\right)$$

In the formula, R_k is the deterministic coefficient of the variable k in the developed regression analysis model; generally, if R_k is 10 or above, it could likely be an explanatory variable with multicollinearity problems. After an ex ante analysis of the developed regression analysis model, total development density (density) and road accessibility (acc_r_t) variables generally showed a VIF value of 10 or above; thus, they were excluded from the analytical model. Specific VIF values will be shown with the results of the regression analysis.

An ex ante analysis of the functional relationship between the transit ridership characteristics and explanatory variables showed that the relationship between four-way intersection density (ic_4) and average building complex area (bg_m_g) is more clearly expressed in terms of a quadratic function than in a linear relationship. Fig. 6 illustrates a distribution of four-way intersections and the weekday transit boardings; and it shows that a quadratic function is more appropriate than a linear line in representing this relationship.

After excluding total development density and road accessibility variables through the correlation and multicollinearity analysis, the 20 variables shown in Table 3 are selected to be used in the final analysis. The impact of the exclusion on achieving the overall research objective is manageable by making an inference from the following relationship: total development density is closely related to the development density by land-use type and road accessibility to each rail station area is closely related to that of the railway accessibility.

Analysis result and discussions

Analysis results

Daily ridership and TOD planning factors

Table 4 outlines the results of regression analysis on potential TOD planning factors that affect the weekday and weekend boarding transit volumes in Seoul's rail station areas. The adjusted R-squared of the regression analysis model involving the selected 20 explanatory variables is found to be 75.3% for the weekday ridership and 66.6% for the weekend ridership. The fact that the adjusted R-squared for the weekday ridership is 10% higher than that of the weekend ridership means that the weekday travel patterns are better explained than those of the weekend by TOD planning factors. Additionally, since the VIF values of the selected independent variables are lower than the value 4.95, the bias resulting from multicollinearity can be considered negligible.

The weekday and weekend transit ridership reflect an everyday-purpose pattern and leisure-purpose pattern, respectively, of using the rail station areas. In other words, a difference in the influence of TOD planning factors (statistical significance, directionality, and intensity of influence) within the weekday/weekend analysis results stresses the need to introduce different major factors to each rail station area depending on their respective types.

TOD planning factors that are highly related to both weekday and weekend transit ridership are found to be, in terms of transit supply, a greater number of bus lines, a shorter headway, a greater number of bus stops, and a greater distance between neighboring stations; and these factors turned out to increase transit ridership. On the other hand, a large number of short-distance bus lines and stations have shown to have a statistically significant positive effect on the weekday ridership, but fail to have a statistically significant impact on the weekend ridership.

With regards to planning factors related to land use, a higher value in residential density results in greater weekday and weekend transit ridership. This can be explained by the fact that residential areas serve as trip origination locations for everyday-purpose and leisure-purpose trips. The weekday ridership value seems to be high a trail station areas with higher office building floor areas, while the weekend ridership value is high a trail station areas where retail and commercial buildings are densely clustered.

Rail station areas with a high land-use mix index of the four land uses—residential, commercial, business and others—seem to have significantly increased weekend ridership. However, rail station areas with commercial and business mixed use do not have statistically significant effects on weekday and weekend transit ridership. In addition, the impact of the accessibility index via subway is also not statistically significant.

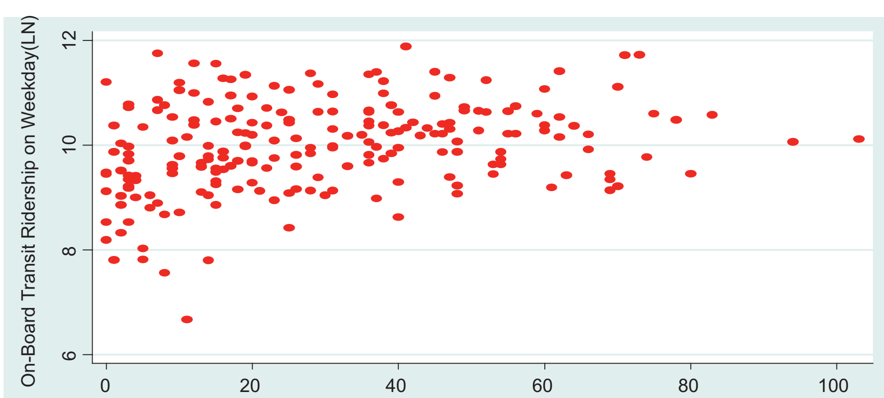


Fig. 6. Distribution of four-way intersection and transit ridership (weekday, boarding).

Table 3
Summary statistics of explanatory variables for TOD planning factors.

Explanatory variables				Avg.	St. dev.	Min.	Max.
Transit supply characteristics	Bus	Number of bus route (buslines)		12.56	9.02	1	53
		Average headways (allocate)		10.06	2.23	6.62	20
		Number of short bus route (dis_20 km)		1.35	1.67	0	9
		Number of bus stops (busstop)		15.59	8.06	2	44
	Railway	Distance between stations (st_dis)		1.34	0.63	0.35	4
		Number of station exists (st_exit)		6.01	2.87	1	15
Land use characteristics	Density	Residential density (r_land)		574231.20	318002.80	100	15,94,450
		Commercial density (c_land)		187062.60	140347.90	275	846,814
		Business density (office)		159921.90	288965.10	73	20,50,141
	Diversity	Land-use mix index for four land uses (lum_4)		0.67	0.20	0.0338	0.9917
		Commercial/business mix index (lum_2)		0.81	0.17	0.3226	1.0000
	Regional accessibility	Three downtown subway accessibility (acc_s_t)		29375.49	28031.38	68	157,136
		Regional subway accessibility (reg_acc)		0.01	0.00	1.0×10^{-9}	0.024
Design characteristics	Street network	Total road length (rlength)		22988.37	13570.30	1423.68	73007.09
		Average road width (r_band2)		9.47	5.08	3	37
		Percentage of drive way (rl012_r)		0.22	0.13	0	1
		Four-way intersection density	1st (ic4)	29.20	21.81	0	103
			2nd (ic4ic4)	1326.02	1705.41	0	10,609
		Dead end road (ic_t)		91.53	70.85	0	310
	Building design	Average building group area	1st (bg_m_g)	9383.01	24334.10	188.7	178502.5
			2nd (bg2)	6.77×10^{8}	3.97×10^{9}	35613.7	3.19×10^{10}
		Average building area of each building (bd_m_g)		175.93	170.57	36.1	1400.4

Table 4
Multiple regression analysis result summary of daily transit ridership.

Explanatory variables			Weekday		Weekend		VIF
			Beta	*t*-Value	Beta	*t*-Value	
Transit supply characteristics	Number of bus route (buslines)		0.275	5.70^{***}	0.348	6.20^{***}	2.01
	Average headways (allocate)		−0.233	-5.91^{***}	−0.224	-4.88^{***}	1.34
	Number of short bus route (dis_20 km)		0.088	2.17^{**}			1.44
	Number of bus stops (busstop)		0.201	4.88^{***}	0.209	4.36^{***}	1.46
	Distance between stations (st_dis)		0.260	5.25^{***}	0.280	4.88^{***}	2.11
	Number of existing stations (st_exit)		0.122	2.42^{**}			2.19
Land use characteristics	Residential density (r_land)		0.152	3.04^{***}	0.127	2.19^{**}	2.14
	Commercial density (c_land)				0.130	1.86^{*}	3.14
	Business density (office)		0.147	2.65^{***}			2.64
	Land-use mix index for four land uses (lum_4)		0.204	3.26^{***}	0.155	2.12^{**}	3.38
	Commercial/business mix index (lum_2)						1.59
	Seoul subway accessibility (acc_s_t)						1.80
	Regional subway accessibility (reg_acc)						3.59
Design characteristics	Total road length (rlength)		−0.179	-2.52^{**}			4.34
	Average road width (r_band2)						4.94
	Percentage of drive way (rl012_r)						2.33
	Four-way intersection density	1st (ic4)	0.328	2.17^{**}	0.373	2.12	2.02
		2nd (ic4ic4)	−0.233	-1.81^{*}	−0.280	-1.87^{*}	
	Dead end road (ic_t)				0.129	1.98^{**}	2.72
	Average building group area	1st (bg_m_g)	−0.318	-2.10^{**}			2.55
		2nd (bg2)	0.229	1.73^{*}			
	Average building area of each building (bd_m_g)		0.233	3.53^{***}	0.288	3.76^{***}	3.75
	No. obs		214		214		
	F-value		30.5		20.3		
	Prob > *F*		0.000		0.000		
	R-squared		0.779		0.700		
	Adj_*R*-squared		0.753		0.666		

VIF values of two selected variables for the quadratic function are values prior to quadratic function.
* Indicate 10% cautionary level.
** Indicate 5%.
*** Indicate 1%.

Among TOD planning factors, street network patterns and urban design patterns can be considered to have an influence similar to that of the transit supply characteristics. Notably, four-way intersection density and average building area are considered crucial TOD factors that can increase both the weekday and weekend transit ridership. On the contrary, road length and average building complex area exercise a great influence on the weekday ridership, while not significantly influencing the weekend ridership. A dead end road (cul-de-sac) with a higher density increases the weekend ridership, but the relationship is not statistically significant for weekday ridership. Until the density of a four-way intersection increases to a certain level, the overall transit ridership increases; however, the results show that an extremely high density of four-way intersections creates the opposite association.

Ridership by mode and TOD planning factor

An analysis of TOD planning factors regarding modal transit ridership can be utilized in affecting transit ridership by formulating strategies at railway-centered rail station areas, bus-centered rail station areas, and transfer-centered rail station areas. The adjusted *R*-squared for the regression analysis model with regards to the modal transit ridership shows a 60–70% and the analysis model for bus transit ridership was found to be even higher (Table 5).

Among TOD planning factors that affect modal transit ridership, factors having statistical significance on both modes and transfer characteristics are transit supply factors such as the number of bus lines, headways, the number of bus stops, and the distance between stations; land-use patterns such as residential density and the four-land-use mix index; and characteristics of street networks and urban design such as the average building area.

Variables with statistical significance that influence only the rail-transit ridership include the number of station exits, accessibility to the regional subway, and the percentage of driveways on streets. Notably, a greater accessibility to a regional subway increases the use of the subway; however, the accessibility to the three downtown areas in Seoul via railway does not have a statistical significance on subway use. This could be explained by the fact that the ridership for subways spreads throughout the entire Seoul Metropolitan Region rather than having a concentrated effect on the three downtown areas.

A higher drive way percentage tends to reduce the use of rail transit. This means that as a rail station area has a higher value of driveways, it promotes the use of automobiles, resulting in a decrease in rail-transit ridership.

Based on the analysis results, the degree of correlation between modal planning factors can be summarized as followed. First, in terms of transit supply characteristics, bus-related variables show a greater influence on bus- and transfer-ridership, and characteristics of subway supply tend to promote the use of subways. With regards to the characteristics of land use, in rail station areas with a high residential density and land-use mix index, the use of transit is promoted via subway and transfers. Additionally, a greater development density leads to a greater use of rail transit when compared with the use of buses or transfers. Also, with regards to the characteristics of street networks and urban design, a rail station area with a greater road length, a greater driveway percentage, and a higher average building complex area tends to lower the use of rail transit while not significantly influencing the ridership for buses and transfers.

Temporal ridership and TOD planning factors

With regards to residential-, employment- and shopping-oriented rail station areas, a multiple regression analysis of transit ridership depending on time of day was conducted to identify the relevancy between TOD planning factors and transit ridership. In residential-oriented rail station areas, the morning peak time (7 AM–9 AM) vehicle boarding distribution ratio is high; in employment-centered rail station areas, the morning peak time vehicle alighting distribution ratio is high; and, in shopping-centered rail station areas, the morning non-peak time

Table 5
Multiple regression analysis result summary of modal transit ridership.

Explanatory variables			Railway		Bus		Transfer	
			Beta	*t*-Value	Beta	*t*-Value	Beta	*t*-Value
Public transportation supply characteristics	Number of bus route (buslines)		0.105	1.85*	0.449	8.90***	0.366	6.08***
	Average headways (allocate)		−0.238	−5.16***	−0.167	−4.06***	−0.233	−4.73***
	Number of short bus route (dis_20 km)				0.082	1.92*	0.128	2.52**
	Number of bus stops (busstop)		0.145	3.01***	0.296	6.90***	0.196	3.83***
	Distance between stations (st_dis)		0.315	5.43***	0.136	2.63***	0.286	4.64***
	Number of existing stations (st_exit)		0.179	3.03***			0.121	1.93*
Land use characteristics	Residential density (r_land)		0.168	2.88***	0.106	2.05**	0.175	2.81***
	Commercial density (c_land)							
	Business density (office)		0.176	2.72***	0.108	1.87*		
	Land-use mix index for four land uses (lum_4)		0.223	3.03***	0.116	1.77*	0.197	2.52**
	Commercial/business mix index (lum_2)							
	Seoul subway accessibility (acc_s_t)							
	Regional subway accessibility (reg_acc)		0.145	1.92*				
Design characteristics	Total road length (rlength)		−0.233	−2.80***			−0.190	−2.14**
	Average road width (r_band2)							
	Percentage of drive way (rl012_r)		−0.114	−1.87*				
	Four-way intersection density	1st (ic4)			0.333	2.11**		
		2nd (ic4ic4)			−0.222	−1.66*		
	Dead end road (ic_t)				0.152	2.59**	0.129	1.84*
	Average building group area	1st (bg_m_g)	−0.357	−2.01**			−0.375	−1.99**
		2nd (bg2)					0.324	1.96*
	Average building area of each building (bd_m_g)		0.222	2.88***	0.215	3.12***	0.156	1.90*
	No. obs	214		214		214		
	F-value	19.87		27.29		16.52		
	Prob > *F*	0.000		0.000		0.000		
	R-squared	0.6959		0.7586		0.7555		
	Adj_*R*-squared	0.6609		0.7308		0.6158		

* Indicate 10% cautionary level.
** Indicate 5%.
*** Indicate 1%.

(9 AM–12 PM) vehicle alighting ratio is high. Results of regression analysis considering these patterns are shown in Table 6. The overall explanatory power of the regression analysis model for employment- and shopping-oriented transit ridership is greater than that of the analysis model of daily or modal transit ridership; however, the explanatory power for residential-centered ridership is relatively low. Most variables of transit supply characteristics are found to be statistically significant. Effects of planning factors are generally similar to the results of regression analysis on daily or modal transit ridership.

With regards to urban development density, the statistical significance differs depending on the relevancy between temporal transit ridership and the development density. In other words, the residential-oriented transit ridership increases with greater residential density; the employment-oriented transit ridership rises with greater employment density; and the shopping-oriented transit ridership climbs with greater development density of commercial or business facilities.

The land-use mix index has a varying degree of influence on each land use, but it generally increases transit ridership. On the other hand, in the cases when subway accessibility towards the three CBDs in Seoul is low, the morning peak-time alighting numbers decrease. Additionally, rail station areas with good regional subway accessibility have lower morning peak-time boardings. In other words, the rail station areas within or adjacent to employment-centered areas tend to have a smaller number of morning peak-time alightings. On the contrary, non-peak-time boarding numbers tend to have a statistically significant influence at the station-influence areas with high employment accessibility.

With regards to the street network and urban design, the four-way intersection density exercises a significant influence, regardless of the time of day, and the average building group floor area value has a statistically significant influence only on the number of morning peak boardings. Also, average building floor area is proven to exert a positive influence on promoting transit ridership at rail station areas, regardless of temporal variation.

Applicability of TOD planning factors

Transit supply- and operation-characteristics

TOD planning factors' expected directions on the transit ridership at Seoul's rail station areas and actual analysis results are illustrated in Table 7. These results can be outlined as the following according to use characteristics: the rail station areas with a higher frequency of transit operation and service provision show a higher transit ridership. In general, it is difficult to improve the level of service purposefully because ridership-dependent supply services such as the number of bus routes or the headways are conversely determined by transit ridership.

However, the results show that ridership-fixed supply characteristics such as the number of bus stops, the distance between stations, the number of existing stations, and so on can be effectively

Table 6
Multiple regression analysis result summary of temporal transit ridership.

Explanatory variables			Morning peak (7 AM–9 AM)				Morning non-peak	
			Boarding		Alighting		Alighting	
			Beta	t-Value	Beta	t-Value	Beta	t-Value
Public transportation supply characteristics	Number of bus route (buslines)		0.310	5.01***	0.193	4.36***	0.208	4.49***
	Average headways (allocate)		−0.250	−4.94***	−0.197	−5.46***	−0.192	−5.09***
	Number of short bus route (dis_20 km)		0.100	1.91*	0.093	2.48**		
	Number of bus stops (busstop)		0.240	4.55***	0.150	3.96***	0.164	4.16***
	Distance between stations (st_dis)		0.278	4.39***	0.231	5.09***	0.251	5.28***
	Number of existing stations (st_exit)		0.134	2.07	0.136	2.94***		
			0.089	1.85*				
Land use characteristics	Residential density (r_land)		0.304	4.76***				
	Commercial density (c_land)						0.147	2.54**
	Business density (office)				0.275	5.42***	0.128	2.40**
	Land-use mix index for four land uses (lum_4)		0.136	1.69*	0.285	4.96***	0.290	4.82***
	Commercial/business mix index (lum_2)							
	Seoul subway accessibility (acc_s_t)				−0.095	−2.27**		
	Regional subway accessibility (reg_acc)		−0.187	−2.25**			0.128	2.07**
Design characteristics	Total road length (rlength)				−0.207	−3.19***	−0.229	−3.37***
	Average road width (r_band2)							
	Percentage of drive way (rl012_r)		−0.173	−2.60**				
	Four-way intersection density	1st (ic4)	0.493	2.55**	0.328	2.37**	0.243	1.68*
		2nd (ic4ic4)	−0.290	−1.76*	−0.209	−1.77*		
	Dead end road (ic_t)							
	Average building group area	1st (bg_m_g)	−0.446	−2.30**				
		2nd (bg2)	0.341	2.00**				
	Average building area of each building (bd_m_g)		0.182	2.16**	0.182	3.02***	0.163	2.58**
	No. obs		214	214		214		
	F-value		15.15	37.94		33.85		
	Prob > F		0.000	0.000		0.000		
	R-squared		0.6356	0.8138		0.7959		
	Adj_R-squared		0.5937	0.7928		0.7724		

* Indicate 10% cautionary level.
** Indicate 5%.
*** Indicate 1%.

Table 7
Result summary of proven effects of TOD planning factors and characteristics of transit ridership.

Explanatory variables			Expected effects	Proven effects							
				Day of the week		Mode			Time of the day		
				Weekday	Weekend	Railway	Bus	Transfer	Morning peak boarding	Morning peak alighting	Morning non-peak alighting
Public transportation supply characteristics	Bus	Number of bus route	+	++	++	+	++	++	++	+	+
		Average headways	–	––	––	––	–	––	––	–	–
		Number of short bus route	+	+			+	+		+	
		Number of bus stops	+	+	+	+	++	+	+	+	+
	Railway	Distance between stations	+/–	++	++	++	+	++	++	++	++
		Number of existing stations	+	+		+		+	+	+	+
Land use characteristics	Density	Residential density	+	+	+	+	+	+	++		
		Commercial density	+		+						+
		Business density	+	+	+	+	+			++	++
	Diversity	Land-use mix index for four land uses	+	+		++	++		+	++	
		Commercial/ business mix index	+								
	Accessibility	Seoul subway accessibility	–							–	
		Regional subway accessibility	+			+			–		+
Design characteristics	Street network	Total road length	+/–	–		––		–		–	––
		Average road width	–								
		Percentage of drive way	–			–			–		
		Four-way intersection density		++	++		++		++	++	
			+	⇒ ––	⇒ ––		⇒ ––		⇒ ––	⇒ ––	++
		Dead end road	+				+	+			
	Building design	Average building group area	–	––		––		––	––	––	
				⇒ ++				⇒ ++	⇒ ++	⇒ ++	
		Average building area of each building	+/–	++	++	++	++	+	+	+	+

Note: Degree of influence of proven effect (––, –, +, ++) is estimated based on the average absolute value of the standardized coefficient (0.21295) regarding statistically significant explanatory variables.

utilized in policy formulation. For instance, the finding that a greater distance between stations increases the ridership for bus and railway is a planning factor that can be incorporated in developing a construction plan for light rail transit oran expansion in the urban railway network in the future. Also, the finding that a greater number of bus stops, regardless of the number of total bus routes, affect the ridership for buses and subways indicates that the number and location of bus stops can be a critical planning factor in devising an intermodal transit system. Finally, the result proves that the number of existing stations can be a planning factor that can promote transit ridership in general through the improvement of pedestrian accessibility and transfer convenience.

Land use characteristics

With regards to the variables relating to the characteristics of land use, the rail station areas with a higher development density tend to show a higher transit ridership. Notably, the development densities of residential and business facilities have a higher ripple effect than that of business facility development.

The rail station areas with a high land-use mix index tend to show a higher bus and rail-transit ridership, proving that mixed land-use, a TOD planning factor, is a crucial planning factor in promoting transit ridership. However, considering the findings that commercial and business mix-indexes do not have a statistically significant relationship, non-residential mixed-used development cannot be considered as an effective development policy promoting transit ridership. The increase in accessibility throughout downtowns and regions focused on rail transit mainly promotes weekday rail-transit ridership, but at the same time insignificantly influences bus or weekend ridership.

Street network and urban design characteristics

With regard to street network and urban design variables that influence transit ridership, results show that four-way intersection density and building design factors have a crucial influence. Notably, it is meaningful that a high four-way intersection density, which involves a pedestrian friendly, narrow, grid-type street network system, has a statistically significant influence.

However, the fact that four-way intersection density and transit ridership do not constitute a linear function relationship but rather a block-type quadratic relationship reflects a peculiar urban condition of Korean cities, especially in Seoul. Seoul has utilized a grid-type broad road network for new housing developments within its boundaries since the 1970s, having experienced rapid population growth and insufficient housing stock. On the other hand, areas with atypical, non-grid pattern, narrow road networks have unintentionally evolved into lower-income areas with relatively better job accessibility. It is characteristic of Seoul to have two such road network patterns simultaneously. In other words, designing an appropriate number of intersections to form a grid-type street network would promote transit ridership; but excessive use of the grid pattern—small-block-oriented street networks—can rather discourage transit use.

Also, results show that transit ridership increases when a group of buildings such as apartments or schools are constructed as a single usage at the site whose area is very large or very small. It implies that a pedestrian travel-path tends to penetrate through the building complex when the building complex area is very large; and a pedestrian travel-path tends to not be hampered by the building complex area when the building complex area is very small. Thus, this finding implies that there is a need to orient the building complex design in a way that does not block pedestrian travel paths.

A high driveway percentage at rail station areas is found to reduce ridership for rail transit and also ridership for residential-centered rail station areas. It means that when rail station area development plans or intermodal transportation system development plans have a policy objective of promoting rail-transit ridership or residential-centered rail station use, street network design policy should be carefully drafted in a way that reduces the percentage of driveways.

Conclusion and policy implications

Overall, this study identified that TOD planning also can be applied to the city of Seoul, even though its development density is already higher than the cities in Western nations. It suggests that TOD planning factors can play a significant role in inducing a transit-centered city when applied in a rail station area redevelopment plan or in a transit-oriented new-town development plan. In other words, TOD planning factors could be successfully applied to the development of rail station areas in Korea just as foreign case studies have shown. Considering that Seoul is already a high-density city, TOD planning and policies in high-density Asian cities need to differ some what from those of Western cities. Application strategies of TOD planning need to emphasize not density itself but the other TOD factors. From the analysis results, three main application strategies can be drawn: enhancing a transit center function, diversifying land use and guiding pedestrian-friendly road networks and urban designs, while providing the density bonus to attract such planning factors in the rail station area.

First, the quality and quantity for intermodality between bus and rail transit services within rail station areas should be focused upon in order to create a more transit-oriented city.

The United States and other Western countries, where the TOD concept was first developed and applied, tend to generally emphasize the 3-D (density, diversity, and design) planning factors around a transit center. However, in Seoul or Tokyo, where the transit network has already been well developed, the quality and quantity of transit service, in addition to the 3-D planning factors, can be expected to contribute to achieving TOD objectives such as relieving traffic congestion and consuming fewerland resources. The study results demonstrated that not only do transit supply- or operation-characteristics correspond with transit ridership, but also that ridership-fixed variables, not necessarily corresponding with it, are closely related with transit ridership. For example, easy access to bus and rail transit service, represented as the numbers of bus stops and rail station exits, not only affects increases in transit ridership within a rail station area but also has a positive association with transit ridership through transfers between rail and bus transit service. In this regard, better connectivity between both modes around a transit center could have synergistic effects on attracting more transit riders. It implies that designing an easy transfer between bus and rail service around a rail station could be more effective in increasing transit ridership in urbanized areas with high development densities.

Second, the mixed land-use strategy near a transit center as one of the TOD planning factors is still an important policy measure in attracting transit users.

The study identified that a mixed land-use pattern has almost the same relationship as high-density development with increased transit ridership. It implies that land-use diversity needs to be emphasized in achieving TOD purposes more than high-density development near a rail station. In Western cities, where low- to medium-density development dominates, a high-density development strategy can play a significant role because the maximum influence level of the tactic could be greater than in such cities as Seoul with already existing high-density development. Although even-higher-density development tactics could possibly promote transit ridership in densely developed Korean cities, there is also the likelihood that it can exacerbate the already congested traffic conditions. Thus, cautionary measures are required in the application of high-density development tactics when applying planning factors related to land use in cities like Seoul. Conversely, in regards to the mixed land-use, the mixture of residential and non-residential use—compared to the mixture between non-residential uses—is found to better promote transit ridership. Despite the fact that the mixed land-use strategy is applicable in creating a transit-oriented city, it may not automatically go together with the market economy principle when encouraging TOD-based urban development; thus, a strategic approach is necessary to offer incentives to guarantee development profits—e.g., offering a density bonus—under the condition of mixed land-use development. Such an approach to effectively induce mixed-use land development through providing a density bonus as an incentive would be more powerful in attracting more transit users if it were applied to less highly developed areas around a transit center, such as a rail station.

Third and finally, street network and urban design planning factors are important approaches in promoting transit ridership in rail station areas, but their application needs to be cautiously implemented for the city of Seoul.

Literature reviews on the impacts of TOD planning factors on Western cities, in general, gives us an idea that urban design factors such as a grid-type road network with narrow streets and a pedestrian-friendly design are positive planning factors in reducing automobile use through the reduction of automobile traffic speed and enhancing pedestrian accessibility to a transit center. As the TOD design planning factors were examined for the rail station areas in the city of Seoul, results showed that they need to be cautiously applied due to identical impacts on transit ridership by some factors. For example, the expected impacts of total road length, average road width, and percentage of driveways in Korea were identical to those in the foreign cases. Yet others have shown to have different impact patterns in terms of directionality and magnitude at statistically significant levels. The four-way intersection density or dead end road (cul-de-sac) density shows differing results when compared to the findings from literature reviews on the impact analysis of road network and urban design planning factors in Western cities. They have reported that transit ridership increase with the lower number of dead end road per unit area and with a greater number of four-way intersections. However, in this study, the density of four-way intersections—a proxy variable of a narrow grid-type street network—constitutes a quadratic function relationship with transit ridership, and also a high density of dead end roads correlated to higher transit ridership. These findings can be attributed to the difference in the urban growth pattern between American and Korean cities, especially that of Seoul. While experiencing both rapid urbanization and industrialization during the last half century, the city of Seoul had sustained a grid-type road network pattern for urban development in suburban areas to accommodate rapidly increasing population. Also, the compact residential settlement in unplanned areas with high employment accessibility where low-income people reside has naturally created a narrow and cul-de-sac road pattern. Such a peculiar network pattern in Seoul seems to differ from that of American cities. The latter have experienced an automobile-oriented urban design pattern, characterized by a non-grid, broad and cul-de-sac road network in suburban areas. The urban design factors of TOD planning need to be carefully applied to such cities as Seoul due to the discrepancy between the two, which can contribute to the differing relationships with transit ridership. The narrow grid-type road network pattern, which is characteristic of the concept of TOD planning in America, might not be as effective in Seoul.

Acknowledgements

This study was originally projected by the Korea Transport Institute to investigate TOD planning applicability and institutionalization in Korea (the project number is 2007-03). We particularly thank Eric Cempel, of the Cambridge Systematics, Inc., for his professional editing on the paper. The quality of the article was considerably improved but any error will be entirely ours if any.

References

Bae, Ch.-H., Jun, M.-J., & Park, H. (2003). The impacts of Seoul's subway line 5 on residential property values. *Transport Policy, 10*, 85–94.

Byun, Meelee, & Kim, Moonhyun (2008). *Comparison study of world major cities I and II*. Seoul Development Institute.

Calthrope, Peter (1993). *The next American metropolis: Ecology, community, and the American dream*. Princeton Architectural Press.

Cervero, R., & Day, J. (2008). Suburbanization and transit-oriented development in China. *Transport Policy, 15*, 315–323.

Cervero, R., & Murakami, J. (2010). Rail and property development in Hong Kong: Experiences and extensions. *Urban Studies, 46*, 2019–2043.

Cervero, R. (1996). Mixed land uses and commuting: Evidence from the American housing survey. *Transportation Research Part A, 30*(5), 361–377.

Cerin, E., Leslie, E., Owen, N., & Frank, D. (2007). Destinations that matters: Associations with walking for transport. *Health & Place, 13*, 713–724.

Cervero, R., & Kockelman, K. (1997). Travel ridership and the 3Ds: Density, diversity, and design. *Transportation Research D, 2*(3), 199–219.

Hamin, Elisabeth M., & Gurran, Nicole (2009). Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. *Habitat International, 33*, 238–245.

Ewing, Reid, & Cervero, R. (2001). Travel and the built environment: A synthesis. *Transportation Research Record, 1780*, 87–114 (FHWA).

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2008). *Growing cooler: The evidence on urban development and climate change*. Growing Cooler: Urban Land Institute.

Kang, B. (1980). *Development strategy for Seoul Metropolitan Area in 2000s: Focusing on subway rail station area*. Seminar on Master Plan of Seoul in 2000s. Korea Planners Association.

Kang, B. (1993). *Life culture and urban planning*. Nanam Publisher.

Kim, J., & Suh, C.-W. (2009). A study on the spatial autocorrelation in estimation of office rentals in Seoul. *Journal of Korea Planners Association, 44*(2), 95–110.

Krizek, K. (2003). Residential relocation and changes in urban travel: Does neighborhood-scale urban form matter. *Journal of the American Planning Association, 69*, 265–281.

Kwon, Y., & Oh, J. (2004). *Methods of guiding transit-oriented development and transportation system*. The Korea Transport Institute.

Lee, S. (2004). Regional accessibility measurement of Seoul metropolitan subway using GIS. *Journal of the Korea Planners Association, 39*(3), 261–277.

Lee, C., & Ahn, G. (2005). Five new towns in the Seoul Metropolitan Area and their attractions in non-working trips: Implications on self-containment of new towns. *Habitat International, 29*, 647–666.

Lim, J. (2006). Land use characteristics of rail station area affecting urban railway ridership. PhD Dissertation. Seoul National University.

Lin, J., & Shin, T. (2008). Does transit-oriented development affect metro ridership: Evidence from Taipei, Taiwan. *Journal of the Transportation Research Board, 2063*, 49–158.

Park, J.-H., Kim, D.-J., & Lim, Y. (2008). Use of smart card data to define public transit use in Seoul, South Korea. *Journal of the Transportation Research Board, 2063*, 3–9.

Sung, H., & Kim, T. (2005). A study on categorizing subway station areas in Seoul by rail use pattern. *Journal of Korean Society of Transportation, 23*(8), 19–30.

Sung, H. et al. (2006). A study on the effects of land use on travel pattern in the rail station areas of a dense city. *Journal of the Korea Planners Association, 41*(4), 59–75.

Sung, H., & Kwon, Y. (2006). Research on location of residential-use and work-travel pattern resulted from employment location change: Focusing on Gangnam rail station area. *Journal of the Korea Planners Association, 41*(4), 59–75.

Sung, H., & Kim, H. (2007). A study on sustainable urban transportation policies in the east-Asian mega-cities (the 2nd Step): Changing features and challenging issues on urban development and transportation in the Seoul Metropolitan Area, Korea Transport Institute, Policy Research Report. No. 2007-01.

The City of Seoul (1990). *The 2010 City Comprehensive Plan*. Department of Urban Planning.

The City of Seoul (1996). *The 2016 City Comprehensive Plan*. Department of Urban Planning.

Zhang, M. (2004). The role of land use in travel mode choice. *Journal of the American Planning Association, 70*, 344–360.