TOD Factors Influencing Urban Railway Ridership in Bangkok

Varameth Vichiensan
Department of Civil Engineering
Kasetsart University
Bangkok, Thailand
fengvmv@ku.ac.th

Nattapon Suk-kaew
Mass Rapid Transit Authority of Thailand
Bangkok, Thailand
natthapon62@hotmail.com

Masanobu Kii
Faculty of Engineering and Design
Kagawa University
Takamatsu, Japan
kii@eng.kagawa-u.ac.jp

Yoshitsugu Hayashi
Center for Sustainable Development and Global Smart City
Chubu University, Aichi, Japan
y-hayashi@isc.chubu.ac.jp

***Abstract*— Currently, three urban railway system are running in Bangkok Metropolitan Region - Bangkok Transit System (BTS) Bangkok Mass Rapid Transit (MRT) and Airport Rail Link (ARL). However, the development pattern in the area around train stations are different. This paper presents a cluster analysis of urban railway stations in Bangkok that has influence railway ridership. The cluster analysis shows that transit station classification can be classified into three clusters – high-density commercial areas, high-density residential areas (most are in dense residential areas and close to economic areas) and medium-density commercial and residential areas (most are in moderate and low residential areas). Next, the multiple linear regression analyses determined the TOD factors that affect the number of transit passengers at each station of the three clusters. It is found that land use diversity factors, design factors, station proximity factors, and transport accessibility factors all contribute to the urban rail transit usage, but at different effects among the three clusters. At the end, it is recommended for Cluster I stations to encourage mixed-use development of workplace, commercial, and residential buildings. For Cluster II station, convenience of travel including walking, station access, and inter-modal transfer must be emphasized, while for Cluster III, diversity of residence and service is equally important to the easy access to station in longer distance by bus.**

Keywords—Station Clusters, Transit Oriented Development, Urban Railway

I. INTRODUCTION

The rapid population increase, suburbanization, rapid economic growth, motorization, and increase in car dependency are the common urban problems found in the growing cities around the world. However the situation is becoming more severe and difficult to solve in the developing countries where there are several factors that are not controllable, such as disordered development, unstable political climates, etc. Bangkok, the capital of Thailand, is presently facing suburbanization, traffic congestion, and air pollution, which are originated by the poor urban configuration. Since 1960 Bangkok Metropolitan Region of Thailand has undergone rapid urbanization. Population in Bangkok takes 16.8% of the country and produces 44.2% of GDP. Presently the city is extremely busy with almost all kinds of activities. Physically, resident and employment locations are largely concentrated in the inner core. Such urban structure unavoidably generates huge amount of travel demand, which are mostly made by long distance trips by private vehicles.

A. *Urban Development*

The city of Bangkok was established on the right bank of the Chao Phraya River in 1782 with a territory of 3.5 km2 and population of about 50,000. The city has built canals for communication and security functions. Since then people have been attracted to reside along the waterway network. Population has been continuously increasing with migrants from countryside and foreign countries. The city has continuously expanded to the west side of Chao Phraya river, so-called Thonburi side. The city has expanded to the north, the east, and the south, making population of 650,000 and built-up area of 43 km2 in 1940. After the World War II, a decentralized policy was devised throughout the country. Roads and highways were developed to provide better transport and communication, having Bangkok as a center. The first National Economic and Social Development plan was initiated in 1961, focusing on nationwide economic growth and promoting industrial investment. Moreover, the road network expanded to serve the inaccessible areas. Uncontrolled urban development resulted in longer commuting trips in daily life. In 1960, having 2 million population, Thai government started to develop the first comprehensive Bangkok urban plan, resulting in a so-called the Greater Plan 1990 or Litchfield Plan, named after a consulting firm Litchfield Whiting Bowne & Associates from United States. The plan is based on road transportation network being like typical American cities. It was later revised in 1971 by the Department of Town and Country Planning but still promote road transportation to tackle with traffic congestion but it conversely induced more traffic and rapidly accelerated urban sprawl during 1980s.

Bangkok Metropolitan Region (BMR) area comprises the central area called Bangkok Metropolitan Area (BMA) and its five adjacent provinces. BMR covers 7,758 sq km. The total population of BMR in 2005 is 10,661,047 or 16.8% of the total population of Thailand. The central area of BMR is centered to almost all urban activities: business district, high to medium density residential areas, as well as industrial area. In 2005, BMR produced a GDP of about 3,139,084 Million Baht, which accounts for about 44.2% of the country's GDP. Since 1960 BMR has been undergoing rapid urbanization and industrialization. The increase in population is due to the development of infrastructures such as road networks as well as real estates. From 1987 to 2000, the number of populations has been decreasing in the inner area, but increasing in the middle area. That is, the population density in the inner area decreased from 15.27 to 11.09 thousand/sq km (that is 3.25 to 2.36 million). The outer area has increase in the population density from 0.77 to 1.28 thousand/sq km (which is 0.67 to 1.12 million).

B. Transportation

Since 1960, Bangkok has rapidly grown from being a small compact city located on the eastern area of the Chaopraya River to a large sprawling urban area due to the emphasized plans of transportation infrastructure development such as road, bridge and expressway network. This development has unavoidably become one of the important factors in accelerating the growth of suburbanization. Physically, locations of employment are largely concentrated in the inner core. Such urban structure unavoidably generates huge amount of travel demand, but the present 458 bus routes operating 13,942 buses (as of May 2018) are still not enough to accommodate the travel demand especially from/to suburban areas. Thus, traveling on private car is far superior for people who can afford. This claimed to be caused of a car dependent city that made Bangkok has faced critical traffic congestion (Rujopakarn, 2003). Major of travels in Bangkok are made by means of road transport. Meanwhile, the public transport service is inadequate. It does not comprehensively cover the whole urban area. People living in sub-urban areas then prefer traveling by private car than using bus. This produces large amount of traffic volume on road and causes traffic congestion. In 2000, there were 4,076 kilometers of road length, which accounts to 58.45 square kilometers. As of March 2019, the expressway network length in BMR is 235.5 kilometers.

Rail transit system has been introduced to alleviate the traffic issues and mainly serves people between suburban to the central part of Bangkok. As of March 2019, there are 5 lines of urban railway services in BMR, namely BTS Sukhumvit line (31 stations in 37.02 km), BTS Silom line (13 stations in 14.67 km, MRT Blue Line (19 stations in 21.2 km) MRT purple line (16 stations in 23.6 km), and Airport Rail Link (8 stations in 28.6 km). In addition, a few more railway lines are under-construction and will open for service in the near future. These include Sukhumvit line extension (additional 16 stations in 19 km), Blue line extension (additional 20 stations in 26.7 km), Pink line (30 stations in 34.5 km), Yellow line (23 stations in 30 km), Orange line (29 stations in 34.1 km), (Gold line (3 stations in 1.8 km), Red line suburban trains (41 stations in 96.5 km), Purple line extension (17 stations in 23.6 km), etc. The impact of urban railway on urban development has become more obvious. For example, after the BTS Skytrain in Bangkok has opened, many buildings (e.g. office buildings, hotels, condominium, etc.) have been renovated and constructed by developers and land price along the corridor has remarkably increased [1]

C. Objective

The objective of this study is to classify the urban railway stations in Bangkok by the factors that contribute to the transit-oriented development (TOD). The study area covers the area within a 500-meter radius around 55 urban railway stations of three urban railway lines. These are 30 stations of the BTS Green lines, 18 stations of MRT Blue line, and 7 stations of Airport Rail Link line, as shown in Figure 1

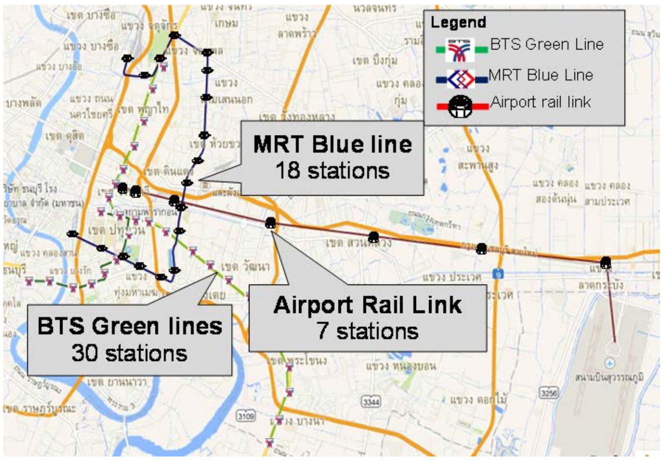

Figure 1 Study Area around the Railway Stations

II. Transit-Oriented Development Factors

The Transit-Oriented Development (TOD) model has in recent years taken a central role in transport policy and become one of the key planning paradigms aimed at reversing auto oriented developments. Its origins can be traced back to 1993 and find expression in a book by American Architect Peter Calthorpe. Although several definitions for TOD have emerged over the years, they all however capture the same essence. [2] define TOD as "...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 centres". Planning and implementing TOD has become widely cast in the context of the "5Ds": Density, Diversity, Design, Distance to Transit, and Destination Accessibility. These variables are considered very crucial in achieving the objectives TODs, as illustrated in Figure 2.

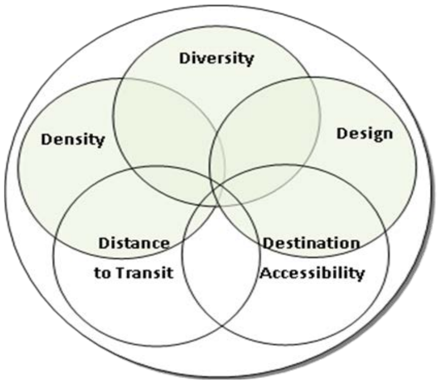

Figure 2 TOD Built Environment Factors

A. Density

Density of population and employment within a 500m-radius area around the station are calculated. For example, the population density in Figure 3 shows that the population is somehow concentrated in the 500-meter buffer area around the railway stations.

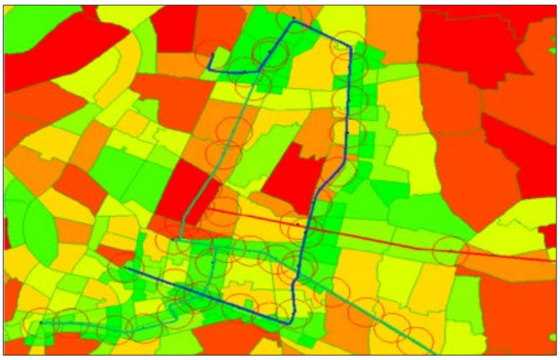

Figure 3 Population Density along the Railway Lines

B. Diversity

The diversity of use of land is quantified by the land use diversity index such as in [3]. The formula is:

$$\text{Land use diversity} = 1 - \sum \left(\frac{a}{A}\right)^2$$

where a is the area of specific land use type, A is the total land area.

1) Building Floorspace

Floorspace of each building is obtained from BMA building database in GIS, as shown in Figure 4. Building categories are office building, shopping mall, shop house, education, government institution, and others: hospital, stadium, museum, theatre, and religious). The density of buildings by category in the influence area is then computed.

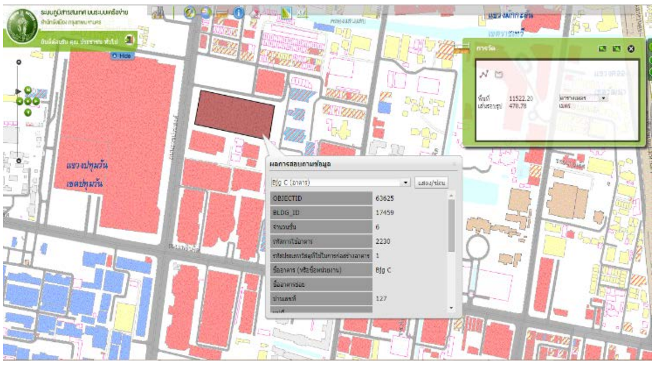

Figure 4 Spatial Database of Building Floorspace

2) Land Use Regulation

The land use regulation in Bangkok, so-called Bangkok Land Use Comprehensive Plan, has been enacted since 1996. Land use Regulations have important role on building control and development. The city plan is a guideline of city growing directions, and it encourages infrastructure networks which related to land use and economic activities. It controls urban developments in the areas which lack of infrastructure and public welfares. The plan has regulated of some activities which are strictly prohibited, allowed, and allowed with condition. The density is controlled by the maximum floor area ratio (FAR) and the minimum open-space ratio (OSR). It also specifies the set back open space along main canals and main roads, and take control of building height and size, regulates some industry list, and provides incentive to investment by giving bonus for some types of buildings.

3) Service

The availability of public and private service such as bank, convenience store, and medical clinic within an area 500-meter around each station are also determined by GIS database.

C. Design

1) Shared Walk-Bike way

The suggested bike routes in central Bangkok are shown in Figure 5. The route is pedestrian sidewalk along the street, to be shared-used with bike. The width varies from 2.5 to 4.5 meter. Some locations are in good and smooth condition such as the one at BTS Victory Monument Station shown in while some are not smooth such as at MRT Queen Sirikit National Convention Centre Station, shown in Figure 5 lower left and lower right respectively.

Figure 5 Suggested Bike Routes on Shared Walk-Bike Ways

2) Pedestrian Crosswalk

The pedestrian crosswalk at intersection include the at-grade and elevated crosswalk such as shown in Figure 6.

Figure 6 Elevated Pedestrian Crosswalk

D. Distance to Transit

The Euclidean distance from each location to station is measured as shown in Figure 7.

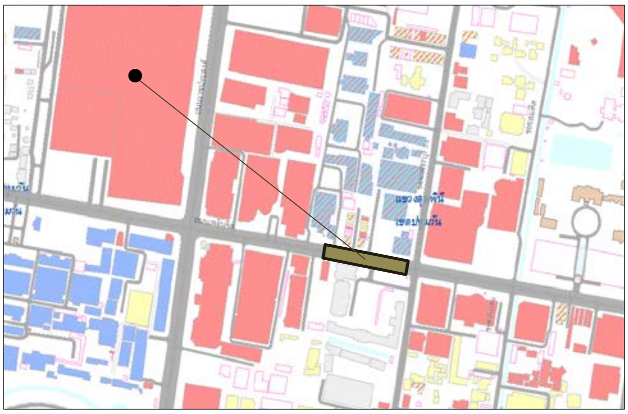

Figure 7 Distance to Transit Station

E. Destination Accessibility

Transport Fundamental Geographic Data Set (Transport FGDS)

1) Road length

Length of road in the 500-meter station buffer area are determined, as shown in Figure 8.

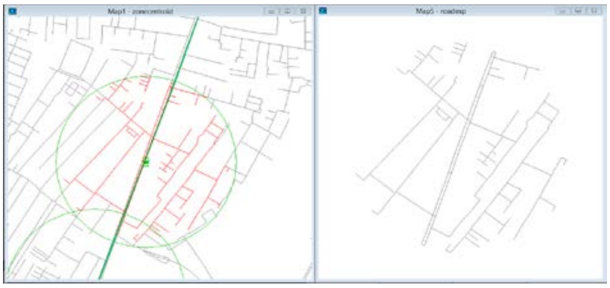

Figure 8 Road length

2) Bus service

Bus service available in the buffer area is determined by counting the number of bus routes available, as shown in Figure 9

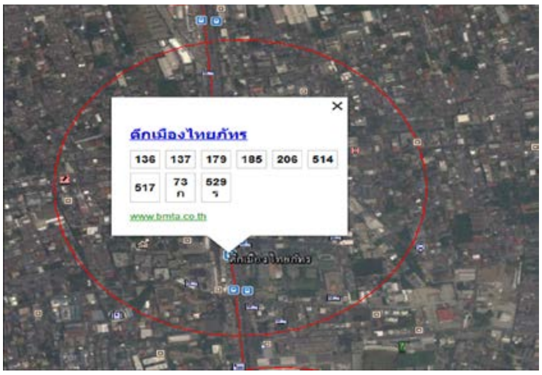

Figure 9 Bus Service Availability

The other information used in the subsequent analysis include the number of condominiums in the buffer area, the number of transfer facility such as Park & Ride, Railway Line Transfer Station, Boat-Rail transfer location, etc., and the number of motorcycle taxi service available at the stations.

III. Cluster Analysis

Classifying urban railway stations provide information for proper planning and management such as balancing node and place functions of the station [4], building strategic transport and land use plan [5], and evaluating the performance of station area transit-oriented development for different latent class of the stations [6].

A. Descriptive Statistics

The descriptive statistics of the data used in this study is shown in Table 1.

Table 1 Descriptive Statistics

	Min	Max	Avg	s.d.
Density variables				
1. Population density (person/km2)	1,443	40,758	12,913	8,237
2. Employment density (person/km2)	499	93,027	23,125	22,363
3. Household density (household/km2)	434	11,103	3,662	2,226
4. Floorspace of school/college (m2)	0	322,520	41,004	63,704
5. Floorspace of office (m2)	101	1,548,389	252,688	321,430
6. Floorspace of shopping store (m/2)	0	1,214,810	149,242	305,294
7. Floorspace of commercial building(m2)	4,308	1,418,358	316,455	346,300
8. Other floorspace (m2)	0	226,121	27,645	86,948
Diversity variables				
9. Land use diversity index	0.32	0.81	0.62	0.14
10. Total land of office building (m2)	101	80,497	22,950	16,496
11. Total land of shopping mall (m2)	0	157,026	13,032	27,040
12. Total land of housing (m2)	23,029	241,195	118,041	55,738
13. Number of medical clinics	0	9	3	2
14. Number of retail building	0	35	10	9
15. Dummy of high-density residential area	0	1	0.31	0.47
16. Dummy of high-density commercial area	0	1	0.58	0.50
17. Floor area ratio	0.50	10	7.84	2.02
18. Open space ratio	3	100	5.90	13
Design variables				
19. Road length (lane-km)	4	39	23	7
20. Number of pedestrian crosswalks	0	20	7	4
21. Presence of shared walk-bike ways (dummy)	0	1	0.35	0.48
22. Dummy of elevated crosswalk	0	1	0.20	0.40
23. Dummy of transfer facility	0	1	0.47	0.50
Accessibility variables				
24. Motorcycle taxi service (No. of vehicle)	12	269	172	60
25. Small shuttle van vehicle (No. of vehicle)	34	1475	365	257

B. Station Clusters

The two-step cluster analysis of the 55 urban railway stations in Bangkok is conducted. The result is shown in Table 2. It is clearly shown that the 55 stations could be classified into three different clusters. Cluster I stations are found to be in the high-density commercial areas that have high employment density, large amount of area for education institutions, shopping centers, commercial or office buildings. It has the highest degree of land use mix, as indicated by the highest land use diversity index. The floor-area ratio is the highest while the open space ratio is the lowest. The road network is the most intensive. The crosswalks are most present while the elevated crosswalk is dominant. The intermodal transportation transfer facilities are also the most available. Cluster II stations are found to be in the high-density residential areas that have high population and household density, and the most land developed for housing. Cluster III stations are consequently found to be in lower or medium-density mixed commercial and residential areas. It is clear that the open-space ratio is the highest among the three clusters where walk and bikeways are present.

Table 2 Attributes of Three Station Clusters

Cluster	I	II	III	F-test
Class member (No. of stations)	18	22	15	
Density factors				
1. Population density (person/km2)	13,511	16,253	7,297	3.787
2. Employment density (person/km2)	38,909	17,358	12,642	8.219
3. Household density (household/km2)	3,845	4,565	2,117	4.040
4. Floorspace of school/college (m2)	77,581	41,362	11,037	7.984
5. Floorspace of office (m2)	502,789	179,041	75,030	11.067
6. Floorspace of shopping store (m/2)	337,929	54,719	4,861	13.250
7. Floorspace of commercial building(m2)	631,691	231,558	77,137	22.608
8. Other floorspace (m2)	131,131	44,603	19,885	16.763
Diversity factors				
9. Lad use diversity index	0.72	0.63	0.55	9.015
10. Total land of office building (m2)	33,479	18,977	17,044	5.415
11. Total land of shopping mall (m2)	26,418	8,007	4,340	4.240
12. Total land of housing (m2)	107,402	151,017	82,442	16.739
13. Number of medical clinics	5	3	1	9.453
14. Number of retail building	17	8	4	16.475
15. Dummy of high-density residential area	0.06	0.55	0.27	7.664
16. Dummy of high-density commercial area	0.94	0.41	0.40	10.651
17. Floor area ratio	9.72	7.23	6.47	16.976
18. Open space ratio	3.14	4.41	11.40	3.282
Design factors				
19. Length of road (lane-km)	28	21	16	7.699
20. Number of pedestrian crosswalks	9	7	4	10.230
21. Presence of shared walk-bike ways (dummy)	0.22	0.27	0.60	13.362
22. Dummy of elevated crosswalk	0.44	0.14	0.00	7.040
23. Dummy of transfer facility	0.72	0.18	0.60	20.488
Accessibility factors				
24. Motorcycle taxi service (No. of vehicle)	194	160	140	4.264
25. Small shuttle van vehicle (No. of vehicle)	73	31	22	6.927

The stations in the three clusters are illustrated in Figure 10. It is obvious that Cluster I stations are in the central core of Bangkok where the land use regulation is designated as high-density commercial. Namely, these are stations on *BTS Sukhumvit line*: Siam station, Phaya Thai station, , Chit Lom station, Phloen Chit station, Nana station, Asok station; on *BTS Silom line*: National Stadium station, Ratchdamri station, Sala Daeng station, Chong Nonsi station, Surasak station, Saphan Taksin station; on *MRT Blue line*: Samyan station, Silom station, Sukhumvit station; and ARL: Phaya Thai station, Ratchaparob station. Next, Cluster II stations are mostly in the high-density residential area locating in the medium core of Bangkok. These are namely, *BTS Sukhumvit line*: Saphan Kwai station, Ari station, Ratchathewi station, Phrom Phong station, Thonglor station, Ekkamai station, On-nut station, Bearing station,; on *BTS Silom line*: Khrung Thonburi station, Wongwien Yai station;on *MRT Blue line*: Hua Lamphong station, Lumphini station, Khlong Toei station, Queen Sirikit National Convention Centre station, Phra Ram 9 station, Thailand Cultural Centre station, Huai Khwang station, Sutthisa station, Ratchadaphisek station, Lat Phrao station, Phahon Yothin station. Finally, Cluster III stations are in the outer low-density area, namely BTS Sukhumvit line: Mo Chit station, Sanam Pao station, Bang chak station, Punnawithi station, Bang Na station, Phra Khanong station; MRT Blue line: Bang Sue station, Kamphaeng Phet station, Chatuchak Park station, Petchaburi station; ARL: Makkasan station, Ramkhamhaeng station, Ban Thapchang station, and Ladkrabang station.

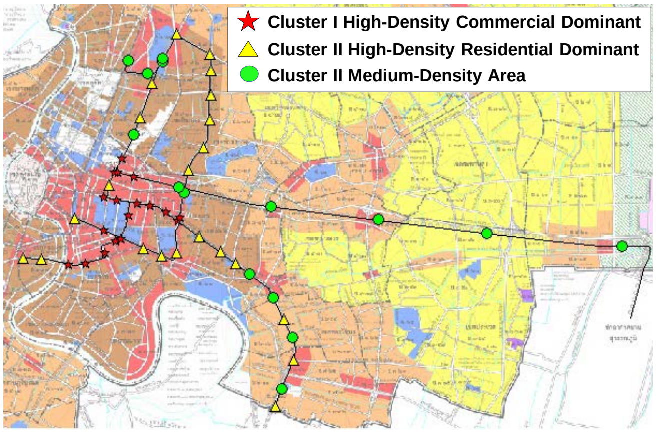

Figure 10 The Three Station Clusters

IV. Effect of TOD Factors on Railway Ridership

The built environment is found to influence travel demand along three principal dimensions: density, diversity, and design [7]. Several studies found that passenger demand highly correlated to TOD factors at urban railway station [2], [8], [9], [10], [11], etc. This section presents a regression analysis of daily passenger ridership at stations classified into three clusters mentioned in the previous section. This section presents a multiple linear regression of TOD factors on Railway transit ridership. The dependent variable is the average daily passenger at each station. The independent variables are the TOD related variables in 5 dimensions as discussed in the proceeding sections. The results of the three multiple linear regression model for the corresponding station clusters are summarized in Table 3. It is found that the coefficients are statistically significant and intuitive. The overall goodness of fit is satisfactory.

Table 3 Regression Analysis of TOD Factors on Railway Ridership

	Cluster I Coeff. *(t-stat)*	**Cluster II** Coeff. *(t-stat)*	**Cluster III** Coeff. *(t-stat)*
Diversity factors			
1. Commercial floorspace	0.235 *(5.406)*	0.186 *(3.707)*	0.537 *(2.703)*
2. Office floorspace	0.362 *(2.839)*	0.025 *(5.353)*	
3. Land use diversity	65,292.989 *(2.417)*		39,244.506 *(3.127)*
4. Condominium unit	3.654 *(3.073)*	2.615 *(4.578)*	3.493 *(2.399)*
5. Floor-area ratio		4139.780 *(3.985)*	
Design factors			
6. intersection crosswalk		771.227 *(3.248)*	743.810 (4.877)
6. Elevated walkway	1,054.594 *(3.144)*		
7. Inter-modal transfer facility		4,773.491 *(2.097)*	
Distance to transit factors			
8. Medium-size store	-17.576 *(-3.139)*	-17.886 *(-3.076)*	-16.178 *(-2.435)*
9. Large shopping Mall	-24.686 *(-2.596)*		
9. Large office building	-39.352 *(-2.428)*		
Destination accessibility factors			
10. Bus service	616.600 *(4.129)*	161.282 *(1.788)*	371.972 *(3.414)*
11. Motorcycle taxi service		47.790 *(2.80)*	
Number of Stations	18	22	15
Adjusted R-Square	0.859	0.722	0.822

It is found that land use diversity factors, design factors, station proximity factors, and transport accessibility factors all contribute to the urban rail transit usage, but at different effects among the three clusters. For Cluster I stations locating in high-density commercial area, it is found that mixture of workplace, commercial, and residential area, seen by the diversity index, is vitally important. The easy access in short distance from station to office building, shopping stores is also statistically significant. For Cluster II stations locating in high-density residential area, the convenience of travel including walking, station access by local motorcycle taxi, and inter-modal transfer are found statistically significant, and encouraging usage of urban railway. For Cluster III stations, the diversity of residence and service is as important as the provision of good intersection crosswalk and easy access to the stations by bus.

V. Concluding Remarks

This paper has shown that the built environment factors based on the transit-oriented development (TOD) concept of 5Ds can classify the urban railway stations in Bangkok into three groups locating three different areas, namely, high-density commercial, high-density residential, and medium-density commercial and residential areas. These factors are found statistically significant to have influence on the number of railway ridership. Different degree of impact is determined for each station cluster and provide insight for future TOD policy.

Acknowledgment

This work is partly supported by JICA SATREP research project.

References

[1] Vichiensan, V., Malaitham, S., and Miyamoto, K.: 'Hedonic Analysis of Residential Property Values in Bangkok: Spatial Dependence and Nonstationarity Effects', Journal of the Eastern Asia Society for Transportation Studies, 2011, 9, pp. 886-899

[2] Sung, H., and Oh, J.T.: 'Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea', Cities, 2011, 28, (1), pp. 70-82

[3] Comer, D., and Greene, J.S.: 'The development and application of a land use diversity index for. Oklahoma City, OK', Applied Geography, 2015, 60, pp. 46-57

[4] Reusser, D.E., Loukopoulos, P., Stauffacher, M., and Scholz, R.W.: 'Classifying railway stations for sustainable transitions - balancing node and place functions', Journal of Transport Geography, 2008, 16, (3), pp. 191-202

[5] Zemp, S., Stauffacher, M., Lang, D.J., and Scholz, R.W.: 'Classifying railway stations for strategic transport and land use planning: Context matters!', Journal of Transport Geography, 2011, 19, (4), pp. 670-679

[6] Higgins, C.D., and Kanaroglou, P.S.: 'A latent class method for classifying and evaluating the performance of station area transit-oriented development in the Toronto region', Journal of Transport Geography, 2016, 52, pp. 61-72

[7] Cervero, R., and Kockelman, K.: 'Travel demand and the 3Ds: Density, diversity, and design', Transportation Research Part D: Transport and Environment, 1997, 2, (3), pp. 199-219

[8] Li, X., Liu, Y., Gao, Z., and Liu, D.: 'Linkage between passenger demand and surrounding land-use patterns at urban rail transit stations: A canonical correlation analysis method and case study in Chongqing', International Journal of Transportation Science and Technology, 2016, 5, (1), pp. 10-16

[9] Vergel-Tovar, C.E., and Rodriguez, D.A.: 'The ridership performance of the built environment for BRT systems: Evidence from Latin America', Journal of Transport Geography, 2018, 73, pp. 172-184

[10] Iseki, H., Liu, C., and Knaap, G.: 'The determinants of travel demand between rail stations: A direct transit demand model using multilevel analysis for the Washington D.C. Metrorail system', Transportation Research Part A: Policy and Practice, 2018, 116, pp. 635-649

[11] Sohn, K., and Shim, H.: 'Factors generating boardings at Metro stations in the Seoul metropolitan area', Cities, 2010, 27, (5), pp. 358-368