# The Study on Association between Urban Factors and Walkability of Transit Oriented Development (TOD)

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ABSTRACT

The study of the relationship among the factors determined the characteristics of the station and the scores of each station were conducted based on the 5Ds component. The five factors consisted of 27 sub-factors which are the density (D1-D6), diversity (Di1-Di5), design (Ds1-Ds6), distance to transportation (Dt1-Dt5), and destination accessibility (Da1-Da5). Through analyzing the relationships among influencing variables by using multi-linear regression analysis with the Stepwise method, it was found that there were five models with the acceptable $R^2$ values, indicating the significance and suitability of the equations. The classification of 4 different groups of transit stations could be created based on the characteristics of all four groups, which are Sub CBD, Urban, CBD, and Special district along the blue line of the BTS Skytrain line and the dark green line (Mor Chit - On Nut station) among 35 stations. Therefore, it can be concluded that the factors used in the analysis are appropriate for the classification of stations which equip urban planners and policymakers for designing more targeted strategies. Finally, the comparative context of the area development around transit station corresponding to the needs of the commuters can be demonstrated for enhancing land-use efficiency and walkability.

## 1. INTRODUCTION

Bangkok is the capital of prosperity of Thailand and represents a megacity with rapid economic development. There are job centers concentrated with various supportive businesses, resulting in a fast rate of urban expansion, particularly the suburban area. Thus, travelling between the residential zones and the workplace causes traffic congestion in the city and air pollution [1]. This urbanizing situation can be considered the main problem of urban areas in Thailand due to the transportation network that places too much emphasis on road construction for automobiles. The effects on the way of life in the city are inevitable from the increasing number of cars in a short time affecting urban people's lifestyles. When the road plays a vital role in shaping the way of life in the city, it has become more and more a part that creates problems for society. The above problems caused many agencies to turn their attention to alleviate traffic problems in Bangkok. One of the solutions to these problems is to encourage Bangkok people to shift to public transportation and execute a significant construction of the rail transport system development plan that covers the entire city of Bangkok and the surrounding provinces. An extension of new routes and networks was aimed to follow the idea of transporting people from residential areas to the employment center, along with the center of government offices, workplaces, tourist attractions, and department stores. There are 28 projects currently under construction and development planning to be completed in 2029, there will be a rail transport network that can facilitate connections throughout the regional mobility of Bangkok and its suburbs with a total of 13 lines of railway network [2]. The occurrence of a multimodal point for a rail system will induce a positive effect on the area around the station. The property value around the station will be higher since the catchment area nearby the stations tends to attract many passengers of derived future demand from the current rail transport station area. It is demonstrated that at the transfer point, there will be more users than other stations. The intersection of the traffic will create a diversity of land use, space usage and increase employment and density, which will create revenue from passenger demand and real estate in the influenced area. The transition location of the transportation node will be transformed into a potential area suitable for development [2].

However, notable spatial variations lead to the classification of a grouping of transit stations which several studies consider the *5Ds* factors to make the characterization consisting of density, diversity, design, distance to transportation, and destination accessibility [2]. All practical factors can be applied to identify the relationship among factors and to capture both

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the relative strength and the feedback of transport and land use. This key information can help to illustrate different TOD characteristics and to analyze the station features that lead to the most suitable pattern of TOD around the station for maximum efficiency and usability. This study aims to characterize the current station clustering regarding policy variables of *5Ds* together with the weight determination of variables. Regression analysis and test the validity of existing concepts are adapted to create an effective urban development plan [3], [4]. This application of the TOD concept will lead the way to a compact settlement with a supportive walking environment, with a high population density in the vicinity of transportation which can also promote the ridership of public transport [5], [6].

## 2. LITERATURE REVIEW

### *Transit Oriented Development Indicators*

According to the TOD principles and to achieve sustainable development, the station area should develop into a unique TOD area along the transit alignment. With planning and design of TOD area, this may reduce the amount of travelling by private car to the destination and encourage the utilization of the mass transportation system [2]. On the other hand, people in non-TOD districts may travel to the TOD area by private cars rather than public transportation. However, according to the TOD principles, it is aimed at creating an environment for the TOD area to be successful. Therefore, this study adopted the main factors of TOD planning in 5 dimensions which are [7];

- *Density*: There must be many residences, a working population, and enough tourists in the area. This density should be facilitated within walking distance from a residence, workplace, and tourist attraction to the train station [8].
- *Diversity*: Land use in areas designated as TOD should have a mixture of land-use types with a variety type of housing, buildings with different architectural styles. The stations must be connected with various nodes around the stations [9].
- *Design*: The physical environment design around the station area and its residents must be supported by the facilities in the area that help promote walking and bicycle [10].
- *Distance to Transit*: The distance between the transit station and the destinations of residences and workplaces must be compacted in response to the behavior of the people. Most of commuters need to travel and access various activities conveniently and quickly which means a reduction in commuting time and travel expenses by public transport [11].
- *Destination Accessibility*: The system must connect to several significant areas of activity in the surrounding area of transit stations, e.g., shops, business center and residential area that attracts the number of people to easily connect [12].

Creating an environment in the TOD area according to the five dimensions is for helping to promote the development of the proximity area of transit station successfully. TOD will benefit from creating social interaction among district level to the larger scale of a living atmosphere. Commuters as a target user in the area are more likely to frequent meet each other in the TOD area compared to others.

### *Factors Influencing the Development of TOD*

The successful development of TOD depends on many factors; in particular, the selection of a suitable area for TOD development must be a coherent area, urban development policy, and direction of development. The main factors under the TOD principle to be considered include [13] & [14]:

1) The physical availability of the area is conducive to further development and space utilization according to TOD principles. TOD is an area that can be easily connected to essential places with high quality and standard of public transportation systems.
2) The land and buildings are mixed-used for employment, offices, residential area, shops, restaurants, various lifestyle facilities in a neighborhood within walking distance of one another.
3) The liveliness of neighborhoods/neighborhoods around TOD must be maintained.
4) The sufficiently vacant land or undeveloped land for TOD development must be evaluated for future development.
5) The physical environment of the TOD area affects the number of passengers using public transport, reducing their dependence on private cars. Improving the road conditions with the inclusivity concept can help to increase the use of bicycles or other active mobility.
6) The smaller block sizes contribute to a more encouraging walking environment.

All of these factors play an essential role in the development of TOD areas. According to TOD principles, the most critical factor is the availability of the areas that are more conducive to commuting behavior. Based on the 5D concept, a comprehensive set of factors should not be overlooked for the accessibility analysis and potential development pattern in the surrounding area for promoting more local access with non-motorization groups [16]. The materials and methods will be explained in detail as shown in the next section.

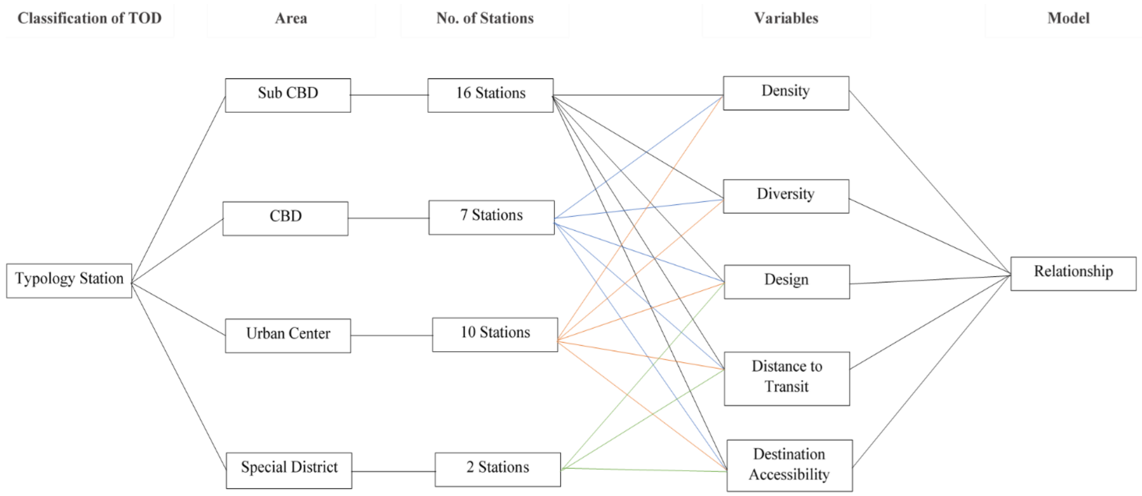



**Fig 1. The Relationship Between Typology of Transit Stations and *5Ds* Factors.**

**Table 1. The List of Transit Oriented Development Variables**

| Variables | | Description of variables |
|---|---|---|
| Density *(D)* | *D1* | Building density (number of buildings /grids) |
| | *D2* | Population density (person/ grids) |
| | *D3* | Density recreation area (grids) |
| | *D4* | Density of public utilities and facilities (grids) |
| | *D5* | Density of the commercial district (grids) |
| | *D6* | Density of residential areas (grids) |
| Diversity *(Di)* | *Di1* | Mixed-Use (grids) |
| | *Di2* | A variety of housing (number of point/ grids) |
| | *Di3* | Number of public transport lines in the area such as buses, taxi, motorcycle taxi, others (number of point/ grids) |
| | *Di4* | Number of road junctions in the area (number of point/ grids) |
| | *Di5* | Government office (number of point/ grids) |
| Design *(Ds)* | *Ds1* | Pedestrian area (meter/ grids) |
| | *Ds2* | Parking (square kilometer/ grids) |
| | *Ds3* | Bicycle parking (number of point/ grids) |
| | *Ds4* | Bicycle path (meter/ grids) |
| | *Ds5* | Green area (square kilometer/ grids) |
| | *Ds6* | Land price (bath/ grids) |
| Distance to Transit *(Dt)* | *Dt1* | The distance between the station and residence (meter/ grids) |
| | *Dt2* | The distance between the station and workplace (meter/ grids) |
| | *Dt3* | The distance between stations to commercial sources (meter/ grids) |
| | *Dt4* | The distance between the station and the infrastructure (meter/ grids) |
| | *Dt5* | The distance between the station and recreation area (meter/ grids) |
| Destination Accessibility *(Da)* | *Da1* | Accessing the work area (meter/ grids) |
| | *Da2* | Access to residential areas (meter/ grids) |
| | *Da3* | Access to commercial (meter/ grids) |
| | *Da4* | Access to recreation areas (meter/ grids) |
| | *Da5* | Access to other public transportation such as buses, taxis, motorbikes Public transport, etc. (meter/ grids) |

## 3. MATERIALS AND METHODS

This study derived factors from station characteristics obtained from the literature review. There are *5Ds* factors focused in this study which are density, diversity, design, distance to transportation, and destination accessibility. This study analyzed physical data obtained from a government agency, as shown in Table 1 and Fig 1. By studying the relationship of variables used in the analysis, the classification of 35 stations of the Blue Line (Bang Sue - Hua Lamphong) and the Green Line (Mor Chit - On-Nut) was analyzed and the result was demonstrated in Table 2 - Table 6. Multiple linear regression analysis was carried out to estimate the relationships between explanatory variables, which represented the characteristics among different stations and the typology of the stations. In this case, the stepwise method was used for model selection, where the significant level for variable selection is set to an alpha of 10 percent. From the evaluation through the area of grids (40 * 40 meters) around the station within a radius of 500 meters, there are a total of 2,572 grids in the service radius area of the proximity of the BTS station. By input five factors to classify four station groups, the classification result consists of Sub CBD, Urban Center, CBD, and Special district.

## 4. RESULTS AND DISCUSSIONS

Fig. 2 and Fig. 3 represent all five models based on cluster analysis of 5 groups. All five models demonstrate the $R^2$ values higher than 0.5, which indicates the suitability of all calibrated models. The goodness of equations and the p-value of significance confirmed the value less than 0.05. The analysis result can be used to reject the main hypothesis and accept that the regression value of the best regression line with significant statistical confidence. The linear relationship is statistically significant, and the analytic equation can be created as depicted in Table 7. The selected variables in the different typology of stations were input into the developed model, as shown in Fig. 4.

*Groups 1: Sub CBD*; It was found that all 16 stations represent as district with high density. It represents a secondary business center and the potential to grow into a new economic district (New Central Business District). The main factor was influenced by the intersection of the new mass transit network in the future, e.g., the East Ratchadaphisek Road and Rama 9 Intersection, the location of MRT Rama 9 and MRT Thailand Cultural Center. It will play a vital role as an important interchange station between the MRT Blue Line and MRT Orange Line.

*Groups 2: Urban Center;* It is an area with mixed land use or multiple land use in the same area of commercial and residential areas. The allocation of recreation area, infrastructures and institution area, represents a densely populated area. There are various socio-economic activities, e.g., business areas for wholesaling consumer products and fashion products. There are multiple tourist attractions of arts and culture, government agencies, both the military and the police.

**Table 2. Summary of Density *(D)* Related Variable of Different Station Group**

| | Typology | No. of Stations | Density | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *D1* | | | *D2* | | | *D3* | | | *D4* | | | *D5* | | | Sig. |
| | | | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | |
| 1 | Sub CBD | 16 | 246.47 | 65.14 | 50.25 | 11.26 | 0.71 | 2.72 | 9.87 | 0.83 | 2.68 | 117.98 | 0.80 | 40.16 | 88.64 | 18.51 | 22.89 | .000 |
| 2 | Urban Center | 7 | 214.95 | 138.67 | 32.05 | 6.10 | 0.73 | 1.85 | 51.96 | 1.00 | 24.20 | 74.28 | 0.24 | 22.48 | 139.98 | 37.25 | 33.63 | .000 |
| 3 | CBD | 10 | 237.33 | 119.83 | 38.08 | 5.58 | 1.79 | 1.07 | 34.04 | 1.00 | 11.40 | 99.29 | 5.80 | 27.89 | 113.01 | 34.60 | 29.54 | .000 |
| 4 | Special District | 2 | 221.17 | 162.04 | 41.81 | 3.46 | 1.82 | 1.16 | 21.99 | 17.48 | 3.19 | 89.84 | 76.76 | 9.25 | 100.57 | 60.51 | 28.33 | .000 |
| | Summary | 35 | 246.47 | 65.14 | 40.22 | 11.26 | 0.71 | 2.11 | 51.96 | 0.83 | 13.87 | 117.98 | 0.24 | 32.56 | 139.98 | 18.51 | 28.95 | .000 |

**Table 3. Summary of Diversity *(Di)* Related Variable of Different Station Group**

| | Typology | No. of Stations | Diversity | | | | | | | | | | | | | | | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Di1* | | | *Di2* | | | *Di3* | | | *Di4* | | | *Di5* | | | |
| | | | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | |
| 1 | Sub CBD | 16 | 138.04 | 5.41 | 33.69 | 1.73 | 0.72 | 0.26 | 27.00 | 5.00 | 5.00 | 28.00 | 10.00 | 7.21 | 43.38 | 0.00 | 14.15 | .000 |
| 2 | Urban | 7 | 62.28 | 6.62 | 21.58 | 1.50 | 0.01 | 0.50 | 35.00 | 7.00 | 10.58 | 29.00 | 13.00 | 5.68 | 28.60 | 1.00 | 10.89 | .000 |
| 3 | CBD | 10 | 53.78 | 8.52 | 14.11 | 1.65 | 0.08 | 0.51 | 39.00 | 7.00 | 9.00 | 28.00 | 10.00 | 6.17 | 56.85 | 1.00 | 18.04 | .000 |
| 4 | Special District | 2 | 33.06 | 7.15 | 18.33 | 1.29 | 0.03 | 0.89 | 50.00 | 15.00 | 24.75 | 29.00 | 22.00 | 4.95 | 72.64 | 47.40 | 17.85 | .000 |
| | Summary | 35 | 138.04 | 5.41 | 24.46 | 1.73 | 0.01 | 0.45 | 50.00 | 5.00 | 9.58 | 29.00 | 10.00 | 6.62 | 91.79 | 0.00 | 22.28 | .000 |

**Table 4. Summary of Design *(Ds)* Related Variable of Different Station Group**

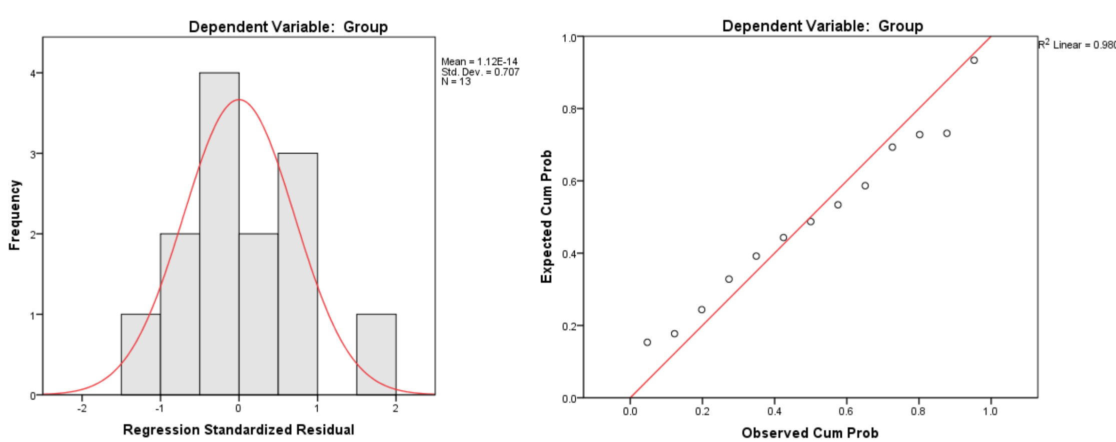
| Typology | | No. of Stations | Design | | | | | | | | | | | | | | | | | | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Ds1* | | | *Ds2* | | | *Ds3* | | | *Ds4* | | | *Ds5* | | | *Ds6* | | | |
| | | | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | |
| 1 | Sub CBD | 16 | 33.58 | 6.04 | 8.50 | 500.00 | 10.00 | 139.19 | 16.00 | 8.00 | 1.93 | 40.18 | 0.00 | 11.91 | 83.82 | 4.70 | 22.18 | 5.50 | 0.80 | 1.31 | .000 |
| 2 | Urban Center | 7 | 30.28 | 9.47 | 7.96 | 2281.00 | 600.00 | 726.31 | 24.00 | 10.00 | 6.82 | 1160.86 | 279.28 | 353.48 | 60.54 | 9.92 | 22.54 | 3.00 | 1.90 | 0.48 | .000 |
| 3 | CBD | 10 | 18.67 | 6.03 | 4.27 | 700.00 | 100.00 | 215.06 | 40.00 | 8.00 | 9.97 | 1841.48 | 426.95 | 387.44 | 67.28 | 4.40 | 19.55 | 3.00 | 1.70 | 0.62 | .000 |
| 4 | Special District | 2 | 27.25 | 11.63 | 11.05 | 1230.00 | 850.00 | 268.70 | 24.00 | 18.00 | 4.24 | 1.00 | 0.00 | 0.71 | 101.71 | 58.52 | 30.54 | 4.80 | 1.80 | 2.12 | .000 |
| Summary | | 35 | 33.58 | 6.03 | 7.19 | 2281.00 | 4.00 | 692.01 | 40.00 | 8.00 | 7.57 | 1841.48 | 0.00 | 537.36 | 101.71 | 4.40 | 23.08 | 5.50 | 0.80 | 0.97 | .000 |

**Table 5. Summary of Distance to Transit (Dt) Related Variable of Different Station Group**

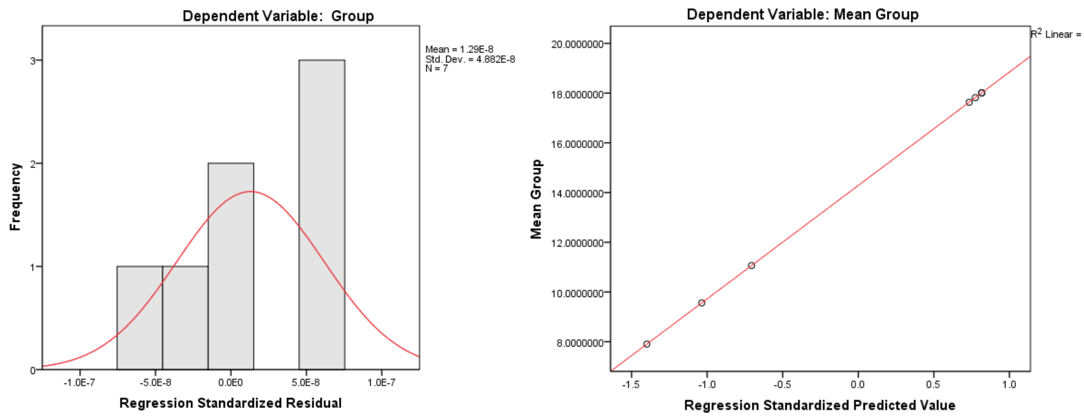
| Typology | | No. of Stations | Distance to Transit | | | | | | | | | | | | | | | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Dt1* | | | *Dt2* | | | *Dt3* | | | *Dt4* | | | *Dt5* | | | |
| | | | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | |
| 1 | Sub CBD | 16 | 115.00 | 41.00 | 24.51 | 121.00 | 57.00 | 23.26 | 104.00 | 68.00 | 11.79 | 119.00 | 72.00 | 14.76 | 128.00 | 68.00 | 15.45 | .000 |
| 2 | Urban Center | 7 | 96.00 | 50.00 | 14.93 | 112.00 | 72.00 | 13.83 | 108.00 | 58.00 | 23.55 | 116.00 | 52.00 | 25.51 | 132.00 | 65.00 | 29.15 | .000 |
| 3 | CBD | 10 | 112.00 | 47.00 | 21.02 | 128.00 | 63.00 | 21.02 | 110.00 | 45.00 | 20.98 | 125.00 | 60.00 | 20.91 | 113.00 | 48.00 | 19.36 | .000 |
| 4 | Special District | 2 | 67.00 | 57.00 | 7.07 | 83.00 | 73.00 | 7.07 | 78.00 | 71.00 | 4.95 | 86.00 | 65.00 | 14.85 | 102.00 | 79.00 | 16.26 | .000 |
| Summary | | 35 | 115.00 | 41.00 | 20.50 | 128.00 | 57.00 | 19.78 | 110.00 | 45.00 | 17.50 | 125.00 | 52.00 | 18.48 | 132.00 | 48.00 | 19.19 | .000 |

**Table 6. Summary of Destination Accessibility *(Da)* Related Variable of Different Station Group**

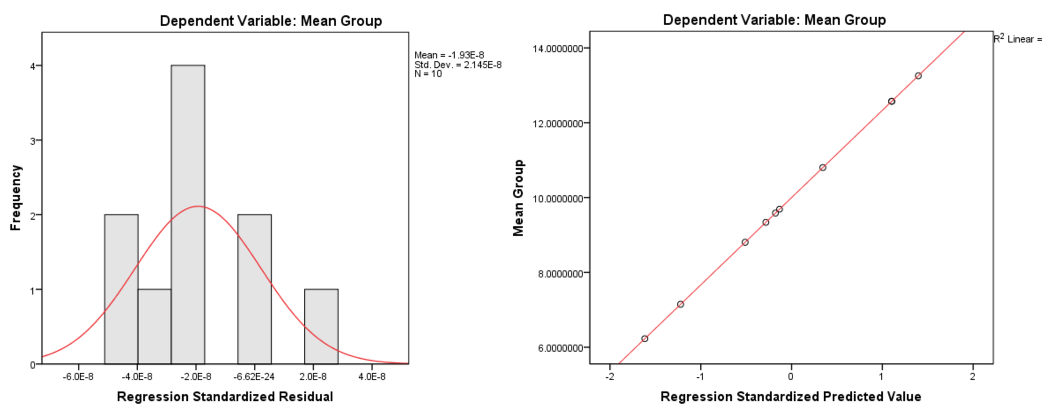
| Typology | | No. of Stations | Destination Accessibility | | | | | | | | | | | | | | | Sig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Da1* | | | *Da2* | | | *Da3* | | | *Da4* | | | *Da5* | | | |
| | | | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | Max | Min | S.D. | |
| 1 | Sub CBD | 16 | 0.80 | 0.15 | 0.21 | 0.74 | 0.65 | 0.03 | 0.83 | 0.58 | 0.07 | 1.51 | 0.62 | 0.31 | 0.97 | 0.63 | 0.09 | .000 |
| 2 | Urban Center | 7 | 0.90 | 0.25 | 0.23 | 0.73 | 0.70 | 0.01 | 0.79 | 0.70 | 0.04 | 1.34 | 0.59 | 0.27 | 0.92 | 0.72 | 0.07 | .000 |
| 3 | CBD | 10 | 0.80 | 0.28 | 0.16 | 0.74 | 0.64 | 0.03 | 0.84 | 0.59 | 0.09 | 1.53 | 0.65 | 0.34 | 0.97 | 0.64 | 0.11 | .000 |
| 4 | Special District | 2 | 0.68 | 0.33 | 0.25 | 0.73 | 0.71 | 0.01 | 0.81 | 0.75 | 0.04 | 1.42 | 1.15 | 0.19 | 0.94 | 0.87 | 0.05 | .000 |
| Summary | | 35 | 0.90 | 0.15 | 0.19 | 0.74 | 0.64 | 0.02 | 0.84 | 0.58 | 0.07 | 1.53 | 0.59 | 0.29 | 0.97 | 0.63 | 0.09 | .000 |



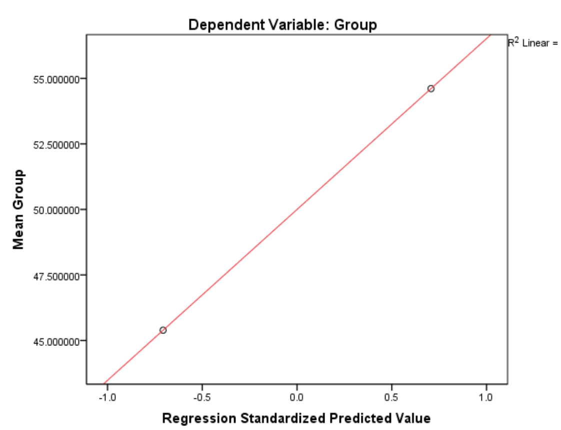

a) Cluster of "Groups 1: Sub CBD" and Its Model




b) Cluster of "Groups 2: Urban Center" and Its Model




c) Cluster of "Groups 3: CBD" and Its Model




d) Cluster of "Groups 4: Special District" and Its Model

**Fig 2. Histogram and Models for All Typology of Stations.**

This area provides transportation choices for BTS, MRT, and expressways connecting to the central business district (CBD), government areas, hospitals, and government offices in the area.

*Groups 3: CBD;* It is the area with the most social and economic activities in Bangkok because it is the allocation of large office buildings as a center for export products, top department stores, five-star hotels, and accommodations. As well as, it represents the district with the complete transportation system in Thailand for rail transportation systems, BTS, MRT, BRT, expressways, and freight ports.

*Groups 4: Special District;* It is a district that promotes the unique character of buildings and structures of medium density. Most of them have unique buildings and specific activities to the district. However, an open space in a pocket park promotes recreation and creative areas and a moderate comprehensive road network located in the inner Bangkok area within the Ratchadaphisek Ring Road. However, blog sizes are large and are not developed to the full potential of each area.

The result of the analysis in Table 7 represents the relationship of explanatory variables among different transit stations. By input all variables of different stations into the model, the calibrated result is shown in eq.1.

*Typology station = 2.330 + (0.001*bicycle path) + (0.017*government office) - (0.015*The distance between stations to commercial sources)* (1)

From the equation (1), it was found that all important factors in the classification are: bicycle path, government office, and distance between stations to commercial sources. The model's constant is 2.330, and the coefficient value of bicycle path factor is 0.001 with a sig. less than 0.05. Thus, the affecting factor can explain our equation all the most.

*Group 1 = 1.171 + (0.016*The distance between the station and recreation area) + (0.006*Parking) + (0.022* Building density) - (0.012*Mixed Use) - ( 0.720*Access to recreation areas) + (0.004*Access to other public transportation)* (2)

From equation (2), it was found that the important factor in the classification of *Group 1* is the distance between the station and recreation area, parking, building density, mixed-use, access to recreation areas, and access to other public transportation. Since it has a sig. of 0.000, which demonstrated the affecting factors are fit to the equation the most.

*Group 2 = 15.412 - (0.094*building density) - (0.340* government office) - (0.450*pedestrian area) + (0.086*the distance between the station and work place) + (24.652*access to other public transportation)* (3)

From equation (3), it was found that the important factor in the classification of *Group 2* is consisted of building density, government office, pedestrian area, the distance between the station and workplace, and access to other public transportation. The sig. of 0.000 represents the affecting factor that can explain the equation the most.

*Group 3 = -7.046 - (0.361*population density) - (0.014*density of public utilities and facilities) + (0.098* bicycle parking) + (0.006*bicycle path) - (0.030*green area) +(0.070*the distance between the station and recreation area) - (0.635*access to the work area) + (6.128*access to other public transportation)* (4)

From equation (4), it was found that the important factor in the classification of Group 3 consists of population density, the density of public utilities and facilities, bicycle parking, green area, the distance between the station and recreation area, access to the work area, and access to other public transportation. Since all four factors have a sig. of 0.000 which represent the factor affecting the equation the most.

*Group 4 = -62.563 + (124.085*access to other public transportation)* (5)

From equation (5), it was found that the important factor in the classification of Group 4 consists of access to other public transportation. The explanatory factor represents sig. of 0.000 and demonstrates the affecting factors fit the equation the most.

From **Table 7**, the variables that were focused the most in the table represented by the *Sig.* value and the *B* value to demonstrate at the most influential variables. The correlation values of *B* values present both positive values and negative values for identify the tendency of policy variables. Non-significant variable presents the least influential variables for analysis. In the overall model, it was found that the important factors in this classification of the station groups are bicycle path, government office, and the distance between stations to commercial zones. All three variables have a significance level lower than 0.05, which indicates the reliability of the factors used in these station groupings. It is vital to assess the suitability for the actual data (suitability of the model) which was shown by the value of $R^2$ represented 96.3 percent of the variance. This model can be adopted for prediction because the difference between the model and the observed data is expected to be small value.

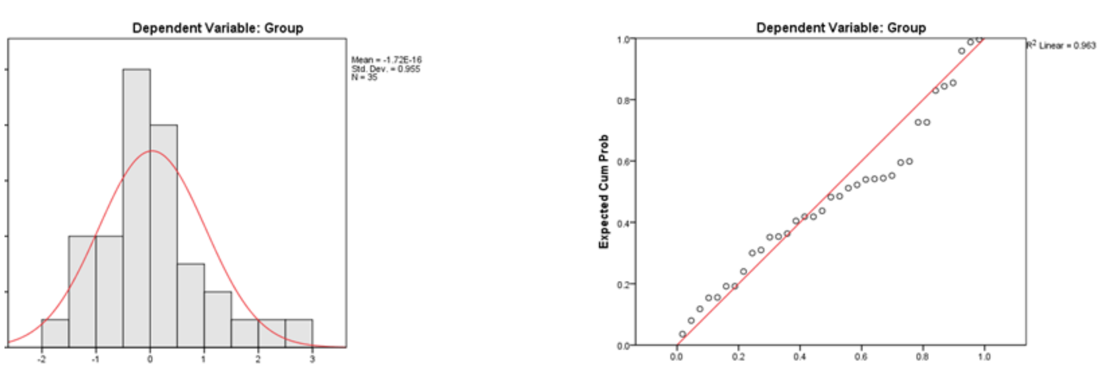



**Fig 3. Histogram and Models of "5 Groups"**

**Table 7. Result of Model Calibrations**

| Model | | | Unstandardized Coefficients | | Standardized Coefficients | *t* | Sig. |
|---|---|---|---|---|---|---|---|
| | | | B | Std. Error | Beta | | |
| All | | (Constant) | 2.330 | .621 | | 3.754 | .001 |
| | *Ds4* | Bicycle path | .001 | .000 | .661 | 5.300 | .000 |
| | *Di5* | Government office | .017 | .006 | .374 | 2.979 | .004 |
| | *Dt3* | The distance between stations to commercial sources | -.015 | .007 | -.254 | -2.061 | .003 |
| Group 1 | | (Constant) | 1.171 | .175 | | 6.704 | .001 |
| | *Dt5* | The distance between the station and recreation area | .016 | .002 | .242 | 6.491 | .001 |
| | *Ds2* | Parking | .006 | .000 | .833 | 24.766 | .000 |
| | *D1* | Building density | .022 | .001 | 1.136 | 17.906 | .000 |
| | *Di1* | Mixed-Use | -.012 | .001 | -.404 | -9.919 | .000 |
| | *Da4* | Access to recreation areas | -.720 | .155 | -.222 | -4.647 | .004 |
| | *Da5* | Access to other public transportation | .004 | .001 | .087 | 3.036 | .003 |
| Group 2 | | (Constant) | 15.412 | .000 | | 27.869 | .000 |
| | *D1* | Building density | -.094 | .000 | -.662 | -6.796 | .000 |
| | *Di5* | Government office | -.340 | .000 | -.812 | -6.088 | .000 |
| | *Ds1* | Pedestrian area | -.450 | .000 | -.785 | -1.369 | .000 |
| | *Dt2* | The distance between the station and workplace | .086 | .000 | .260 | 0.108 | .000 |
| | *Da5* | Access to other public transportation | 24.652 | .000 | .398 | 0.523 | .000 |
| Group 3 | | (Constant) | -7.046 | .000 | | -2.846 | .000 |
| | *D2* | Population density | -.361 | .000 | -.165 | -1.333 | .000 |
| | *D4* | Density of public utilities and facilities | -.014 | .000 | -.162 | -1.324 | .000 |
| | *Ds3* | Bicycle parking | .098 | .000 | .420 | 2.725 | .000 |
| | *Ds4* | Bicycle path | .006 | .000 | .974 | 7.802 | .000 |
| | *Ds5* | Green area | -.030 | .000 | -.251 | -1.562 | .000 |
| | *Dt5* | The distance between the station and recreation area | .070 | .000 | .583 | 3.847 | .000 |
| | *Da1* | Accessing the work area | -.635 | .000 | -.044 | -2.097 | .000 |
| | *Da5* | Access to other public transportation | 6.128 | .000 | .295 | 2.989 | .000 |
| Group 4 | | (Constant) | -62.563 | .000 | | .008 | . 000 |
| | *Da5* | Access to other public transportation | 124.085 | .000 | 1.000 | .083 | .000 |

*a. Dependent Variable: Group of transit stations*

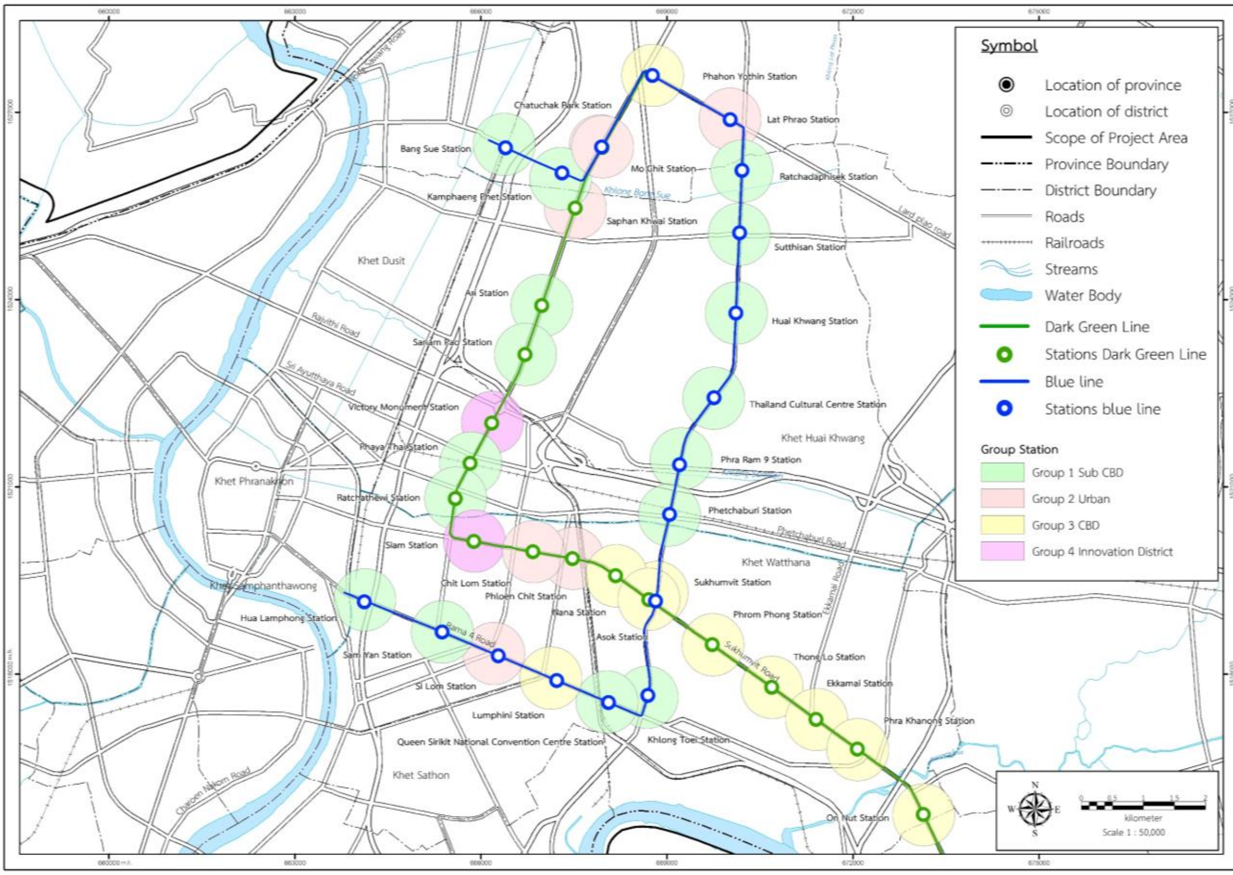



**Fig 4. Cluster Analysis of 4 Groups of Transit Stations in Bangkok Metropolitan Areas**

- *Group 1*, the variables for this classification are the distance between the station and recreation area, parking, building density, mixed-use, access to recreation areas, and access to other public transportation. The significance level is lower than 0.05. This model has $R^2$ value of 0.98 which is considered a good result of the assessment. It was demonstrated that the model is reliable and is a suitable model.
- *Group 2*, it was found that the important factors in this classification are building density, government office, pedestrian area, the distance between the station and workplace, and access to other public transportation. The significance level is lower than 0.05, with an $R^2$ value of 1.0. This group consists of 7 stations: Chit Lom Station, Ploenchit Station, Lat Phrao Station, Chatuchak Park Station, Saphan Khwai Station, Silom Station, and Mor Chit Station.
- *Group 3*, it was found that the important factors in this classification are population density, public utilities and facilities, bicycle path, green area, the distance between the station and recreation area, access to the work area, and access to other public transportation. All five factors have a significance level lower than 0.05 and $R^2$ is equal to 1.0. In Group 3, there are ten stations for this classification which consist of Thong Lor Station, Nana station Phrom Phong station, Phra Khanong station, Phahonyothin station, Lumpini station, Sukhumvit station, Asoke station, Onnut station, and Ekkamai station.
- *Group 4*, it was found that the only variable that is significant in classification is access to other public transportation. The significance level is lower than 0.05 and the $R^2$ is equal to 1.0. This group consists of 2 stations which are Victory Monument station and Siam station.

## 5. CONCLUSIONS

Therefore, it can be concluded that the characterization of the transit stations in Bangkok can be classified into four station groups (Sub CBD, Urban Center, CBD, and Special District). By adopted the *5Ds* factors for model calibration, it was found that the most important variables in all five models can be presented as shown in Fig 5. The *5Ds* factors consist of density *(D1-D6)*, diversity *(Di1-Di5)*, design *(Ds1-Ds6)*, distance to transportation *(Dt1-Dt5)*, and destination accessibility *(Da1-Da5)*. It is obviously seen that the most important variable is access to other public transportation. Furthermore, it can be noticed that the four groups of stations were related to walking with physical characteristics, typology of spaces and activities in the area.

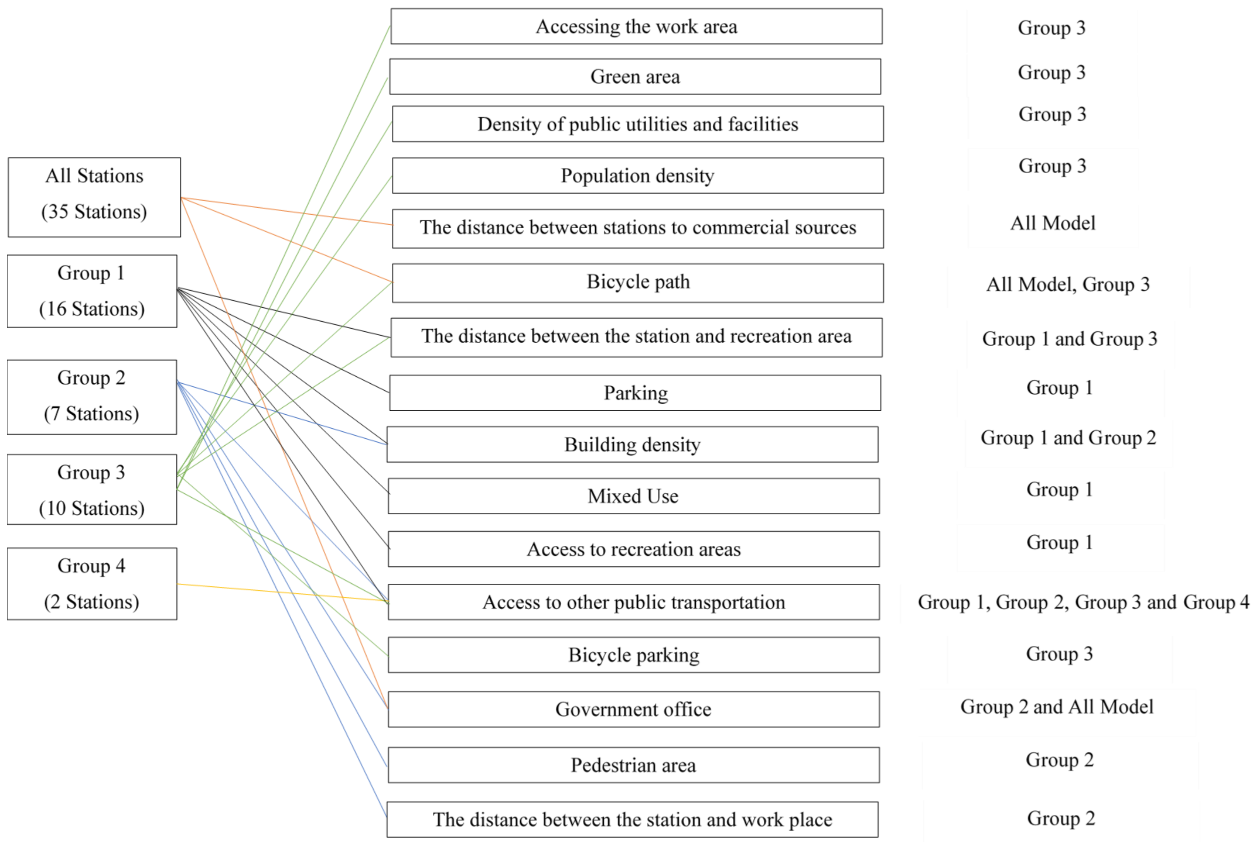



**Fig 5. Summary of Significant Variables in Different Typology of Mass Transit Stations in Bangkok Metropolitan Area**

Furthermore, it was also found that the more diverse frontiers of activity in the area, the higher of the pedestrian friendly environments (e.g., Group 1: Sub CBD and Group 3: CBD) where multiple activities were found in commercial areas, housing clusters and employment zones nearby the transit catchment area. As a result, walking must be an option to link to various travel activities around the station areas. These results reflected that *5Ds* factors could provide spatial access to pedestrian environments and walking around transit stations of Bangkok. Pedestrian environments influenced pedestrian behavior in term of physical characteristics which are density, diversity, design, destinations and distance. Public transport and road configuration must be designed to connect walkers with other built environments which few studies have identified the impact on walking volume. The measure of road configuration should combine with other walking environments by capturing the pedestrian environment's spatial accessibility and concentricity. The less important variable is the bicycle path, the distance between the station and recreation area, building density and government offices which all variables have statistical significance below 0.05 and the $R^2$ is acceptable with more than 0.5 values. This study can be used as a prototype for promoting walkability to transit stations in Bangkok.

It can be applied to other areas by considering more variables or adjusting the context and assumption to suit the contextualization of the study areas. Some of the variables used in this study can also be used as a fundamental variable for further development around other stations since it was found that the most important variable in this grouping was access to other public transport systems, which was confirmed by many studies during transit planning process among several cities, e.g., Hong Kong, New York, and Tokyo. These countries represent as one of the world's most accessible public transport systems known as comprehensive networks. With the high quality of transit service, it could facilitate commuters do not need to use their private car [16].

The study of access to other public transportation (*Da5*) is the most important factor in this study and presents similar trend with other countries. In particular, the study of walkability of TOD represents the main factor to be used in planning and development that encourages the target group of pedestrians and other commuter’s access to transit while increasing the use of public transport modes. It is necessary to consider providing more access to public transport systems since our local public transport system has been continued invest for more coverage areas in the future [2]. The understanding of different TOD typologies would be useful for urban planners and policymakers as useful tools for designing more targeted walkability strategies with recognizing of the limitations of different TOD areas. Finally, the TOD application would discourage people from using their private cars while reducing traffic and pollution problems in megacity for better coordination feedback between transport and land use for the sustainable future.

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