IJEGEO
International Journal of Environment and Geoinformatics 10(2): 033-039 (2023)

Research Article

A Case Study of Tramline Analysis with Transit-Oriented Development Approach: Bursa T2 Tramline

Betül Şengüler[1,*], Zaide Duran[2]*

[1] Graduate School, Informatics Institute, Geographical Information Technologies, Istanbul Technical University, Istanbul, TURKIYE
[2] Geomatics Engineering, Civil Engineering, Istanbul Technical University, Istanbul, TURKIYE

* Corresponding author: Z. Duran
E-mail: duranza@itu.edu.tr

Received 28.02.2022
Accepted 06.04.2023

How to cite: Şengüler and Duran (2023). Tramline Analysis with Transit Oriented Development Approach: Bursa T2 Tramline Case Study. *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(2): 033-039, doi. 10.30897/ijegeo.1256911

Abstract

The article highlights the importance of transportation systems in urbanization processes, especially in densely populated cities where the need for transportation and infrastructure systems arises as cities spread toward their peripheries. Public transportation systems' priority transportation policies are developed by local governments to meet accessibility at the optimum level, minimize harmful environmental effects, and save time and cost. Transit-oriented development (TOD) is a planning approach adopted in many cities to reduce private vehicle use by developing public transit stations around high-density mixed land use and walkable environments. This study assesses the potential for TOD development at eleven stations of the T2 tram line on the Bursa-Istanbul road, using the 6Ds of built environment variables as indicators and GIS methods and applications to measure all spatial indicators. TOD indexes were examined for each station to identify potential improvement strategies, and each station was classified as having a high, medium, or low TOD index. By understanding the specific strategies for different TOD indices, this article aims to support development areas to improve local urban development towards higher TOD levels.

Keywords: Transportation Systems, Sustainability, GIS, TOD

Introduction

The concept of sustainability, which is the subject of much research today, and various strategies and tools have been developed to integrate it into cities, especially in the context of urban planning, is taken as a basis for the development of cities. One of the important factors of sustainability-oriented urban development is transportation planning. With transportation planning strategies, objectives such as smart urban growth and revitalizing secondary centers come to the fore. Transit-driven development (TOD) has emerged as a practical tool to foster smart growth, revitalize declining urban environments, and expand lifestyle options. Researchers such as Owens (1992), Calthorpe (1993), Cervero and Kockelman (1997) defined the TOD approach, in which the connection of sustainable urban development and transportation systems is established as the main purpose, as an urban development model in which sustainable transportation strategies are produced together with its conceptual framework. Based on the public transport-oriented development approach; In high-density mixed land-use areas, around the spaces where walking distance is created at optimum levels, there is to reduce in the use of private vehicles and the negative environmental conditions by developing public transportation stations. According to the logic of this model, it is important to develop the design and orientation of cities in a way that facilitates the use of public transportation. TOD, "...reducing the use of automobiles and the use of public transport and human-powered modes of transport; It defines it as a planning technique aimed at promoting high-density, mixed-use, environmentally friendly development in areas within walking distance of public transport hubs. (Sung and Oh, 2011) Likewise, TODs "...higher-density mixed-use housing located within walking distance of key transit points such as train or bus stations, or around activity centers such as large shopping malls/offices. and commercial developments. (Bhishna et al., 2005)

With the TOD approach, "3D (Density, Diversity, Design)" development strategies emerged (Cerveroand Kockelman, 1997). All features of the built environment, regardless of scale, include some elements and combinations of density, diversity, and design. These elements were determined as the main headings of the analysis studies carried out in urban areas planned to be developed within the scope of TOD (Cervero and Kockelman, 1997). In transportation-oriented urban development scenarios, density, diversity, and design principles constituted diversifiable planning resources. However, to produce more general to specific solutions in transportation strategies, it is aimed to increase the accessibility of public transportation systems used by the majority of the population, between residential areas and equipment areas. In this direction, the concepts of public transportation distance and accessibility to the destination have been included in the TOD concepts, and the planned functioning between the transportation systems and the city has been strengthened. (Cervero and Murakami, 2008). The 3D and 5D (Density, Diversity, Design, Destination accessibility, Distance to transit) the model includes the main components identified in the development of TOD strategies. All of these components have emerged as concepts focused on urban and transportation systems. However, together with these components, the demands of the population have the potential to directly affect the development of the city. In this context; with the concept of "demand management", the connection between supply-demand balance and transportation-oriented urban development was established, and a 6D (Density, Diversity, Design, Destination accessibility, Distance to transit, Demand Management) model was created in line with the demands of the population, which constitutes the dynamic structure of the city. (Ogra and Ndebele, 2014).

This scope of work; by examining the stops of the T2 tram line on the Istanbul road, which is one of the main transportation arteries of Bursa, with the TOD model, is aimed to develop planning strategies that will revive the areas behind in urban development. The calculation of the TOD index for 11 stations on the T2 line route was carried out by evaluating the parameters determined under the main headings of the TOD components by the Analytical Hierarchy Process (AHS) method. All parameters were calculated separately for each station, and TOD index values were produced on a station basis. The calculation of TOD index values with the AHP method was carried out in 4 steps. In the first step, the weights of the parameters were determined and the weight matrix was created. In the second step, the true value of each parameter was standardized and normalized so that its true value was in the range of 0-1. In the third step, the standardized values were calculated based on categories, and the TOD index value was calculated as a result of the sum of 4 different category values. In the fourth step, the calculated TOD index values were evaluated on a station basis and development strategies were suggested.

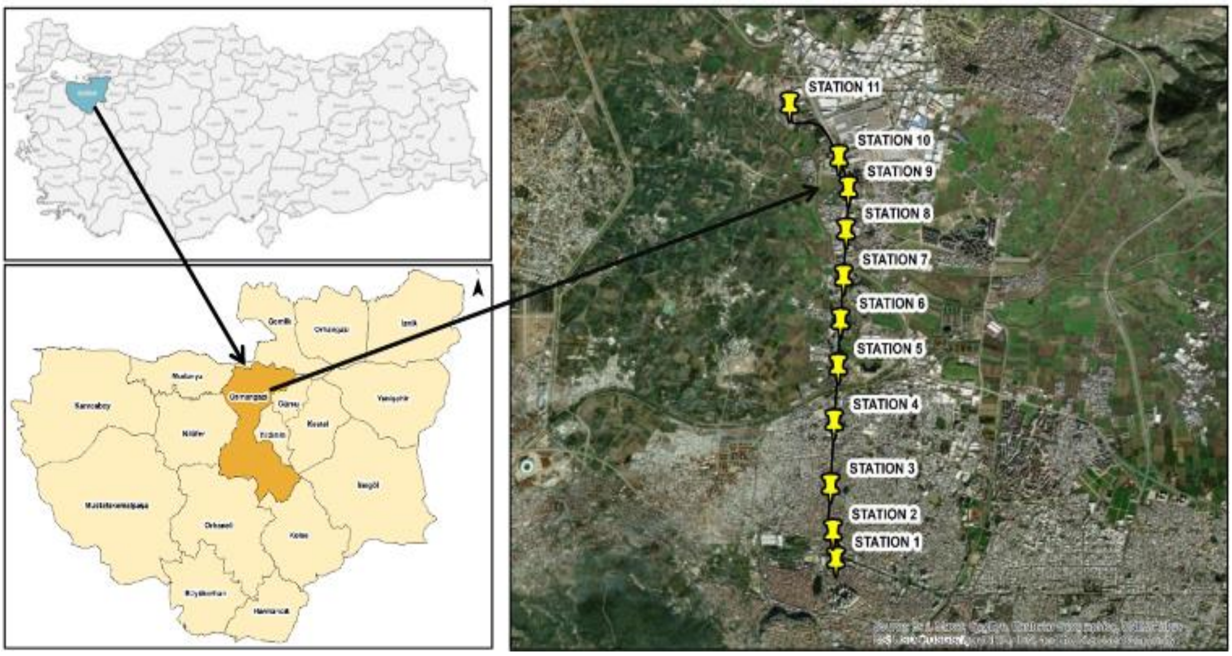

Fig. 1. Study Area

Study Area

Bursa province; is located in the northwest of Turkey and southeast of the Sea of Marmara. It is surrounded by Bilecik in the east, Istanbul and the Marmara Sea in the north, Eskişehir and Kütahya in the south, and Balıkesir in the west. It is Turkey's 27th largest city in terms of area. Bursa city center; It is among the provincial centers that can be reached by land, air, and sea. Within the borders of Bursa province, there is a highway and four main highway axes connecting the country's highway to the transportation network.

Osmangazi is one of the central districts of Bursa. Since it is one of the first settlements of the city, it is located as a central point in terms of transportation and infrastructure. In Bursa's main transportation connections, road and rail systems work in an integrated manner. There is also the T2 tram line, which is the subject of research, on the D575 highway, which provides the connection between Bursa and Istanbul.

Materials and Methods

Within the scope of the study, analyses were made using ArcGIS software at the stations of the T2 line. At all stations, the center point was taken and areas with a radius of 500 meters were created. Land use, transportation infrastructure, and socio-economic situation analyses were made on this radius.

Two parameters were calculated within the scope of the density and demand management category. With the determined parameters, density calculations of the population and urban study area data in each of the station areas of the line were made within the area with a radius of 500 meters.

Table 1. Category and Parameters

Category	Parameter Name	Code
Density and Demand Management	1. Population Density	A_1
	2. Urban Work Area Density	A_2
Diversity	3. Land Use Diversity	B_1
Design and Destination Accessibility	4. Pedestrian Catchment Area	C_1
	5. Pedestrian Road Density	C_2
	6. Mixed-Use Level	C_3
	7. Green Area Density	C_4
Distance to Transit	8. Bus Stop Density	D_1
	9. Bus Line Density	D_2

Table 2. TOD Index Value

Stations	Density and Demand Management Index	Diversity Index	Design and Destination Accessibility Index	Distance to Transit Index	TOD Index
Station 1	0,23	0	0,12	0,25	0,61
Station 2	0,20	0,06	0,10	0,25	0,60
Station 3	0,21	0,04	0,06	0,22	0,52
Station 4	0,10	0,06	0,11	0,13	0,41
Station 5	0,16	0,01	0,12	0,06	0,35
Station 6	0,17	0,03	0,06	0,06	0,31
Station 7	0,13	0,09	0,10	0,05	0,38
Station 8	0,11	0,10	0,08	0,09	0,38
Station 9	0,08	0,20	0,07	0,03	0,39
Station 10	0,02	0,16	0,08	0,06	0,32
Station 11	0,03	0,19	0,03	0,11	0,36

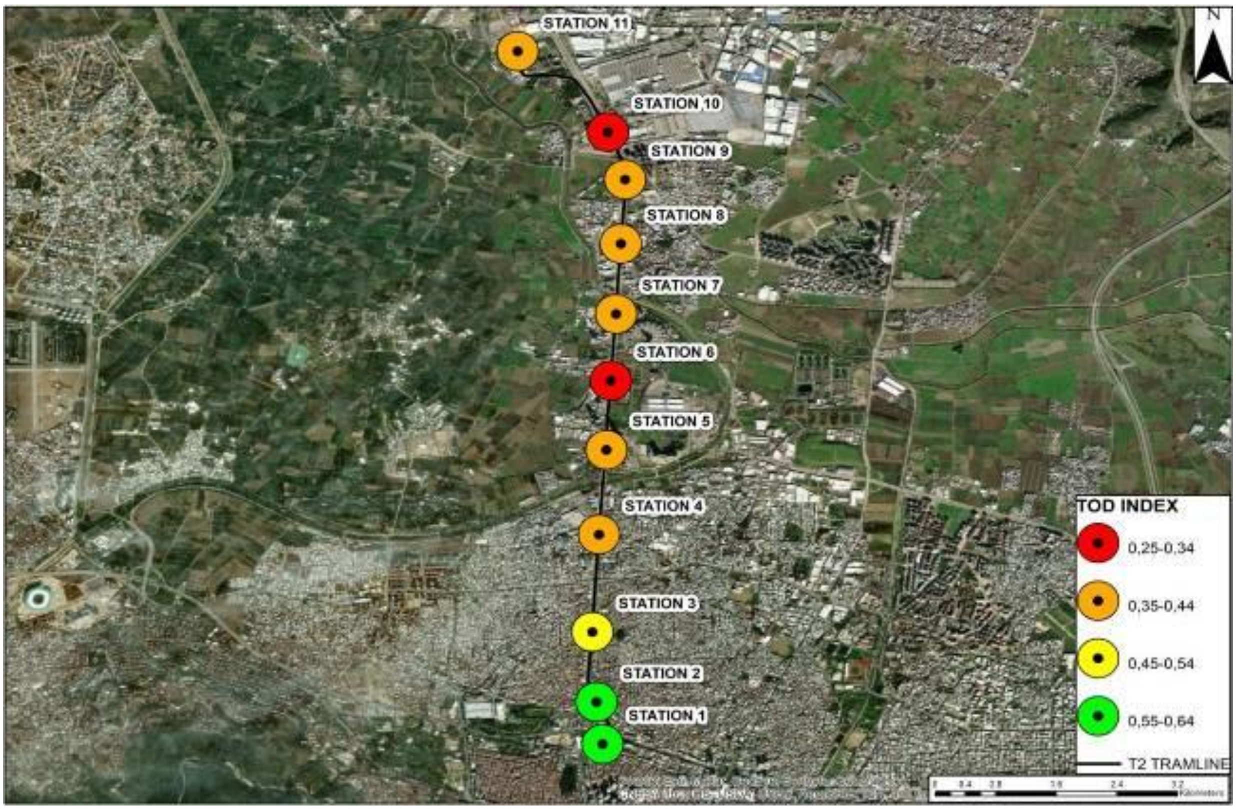

Fig. 2. Map of TOD Index Per Stations

Within the scope of the diversity category, the effects of the diversity of land use on transportation are measured. Depending on the variety of land use, the balance of demand and accessibility of transportation to urban areas emerges. To measure the land use diversity, the source data was obtained from the 1/5000 scale master development plan, and calculations were made with the TOD entropy method. For each station, the land use diversity was calculated with the following equations.

$$Q_{lui} = \frac{S_{lui}}{S_i} \quad (1)$$

$$\sum_i Q_{lui} x ln(Q_{lui}) = Q_{ai}\, x\, ln(Q_{ai}) + \ldots + Q_{hi}\, x\, ln(Q_{hi}) \quad (2)$$

$$LU_d(i) = \frac{-\sum Q_{lui}{}^{xln}(Q_{lui})}{\ln(n)} \quad (3)$$

$LU_d(i)$: Land use diversity value at the station
Q_{lui}: Certain land use share window i
$Q_{ai}.Q_{bi} \ldots Q_{ni}$: a.b…n certain land use share found for land use classes
n: Total number of land use classes within the analysis window i
S_{lui}: Total area of the specific land use within the analysis window i
S_i: Total area of the analysis window i

Within the scope of accessibility and design category, pedestrian catchment area, pedestrian road density, green area density, and mixed-use level parameters were calculated. Density calculations were made within the 500-meter radius of the study area data in the pedestrian road and green area density parameters. In the pedestrian catchment area parameter, the area that the pedestrian can reach within 10 minutes has been determined. In this context, the pedestrian speed used in traffic pedestrian crossings is taken as a basis for determining the pedestrian speed. In the mixed-use level parameter, based on the land use data to measure the accessibility level within the scope of the TOD index; Calculations were made with the following mixed-use level formula between residential areas and non-residential urban areas. (Zhang and Guindon, 2006)

$$MI(_i) = \frac{\sum_{ni} S_c}{\sum_{ni} (S_c + S_r)} \quad (4)$$

MI : Mixed-use level for the workstation
Sc : Total non-residential land use for the station
Sr : Total residential area for the station

Within the scope of the public transportation distance parameter, density calculations were made so that the stop and line density of the public transportation lines outside the T2 line in Bursa would be within the area with a radius of 500 meters. Since analytical and spatial values in different categories are used when calculating parameter values, the values are standardized with the maximum-minimum method. With this method, values are linearly standardized between 0 and 1. Analytical values in population density calculations; In land use items, this method was used to produce results with the same method since it is used with a real value. With the formula below, all parameters belonging to the categories are standardized with values between 0 and 1.

$$ri: \frac{xi - minxi}{maxxi - minxi} \quad (5)$$

r_i: Standard value
$minx_i$: Minimum parameter value
$maxx_i$: Maximum parameter value

The TOD index values for 11 stations were calculated with the following formula by processing the standardized parameter values with the weight values of 4 categories and the weight values of 9 codes.

$$R_i : \Sigma((\Sigma W_k.r_{ik}) * W_{ka}) \quad (6)$$

W_k : Code weight value
r_{ik}: k standart value
W_{ka}: Category weight value
R_i : TOD index value

Results and Discussion

Among the TOD model studies from the literature, Jakarta metropolitan area and Arnhem-Nijmegen city area studies were examined. TOD index values of 54 stations were evaluated by using the 3D model as a method in the Jakarta metropolitan area. The range of TOD index values of 54 stations varies between 0.26 and 0.58. The surroundings of stations with high TOD index values tend to be in urban areas. In this context, it was concluded that stations with low TOD index values are located in suburban areas. For this reason, the stations that need to increase the TOD index value are determined as station, located in suburban areas. The criteria with particularly low values at the designated stations will be improved and the integration of public transport lines will be ensured. In this way, problems such as traffic congestion, air pollution, and traffic safety in the region will be reduced (Taki et al., 2017). In the Arnhmen-Nijmegen city area, the TOD index values of 21 stations were determined by using the criteria created for the study, the 5D model. TOD indexes were created by calculating 18 indicators within the scope of eight criteria obtained in this direction. The highest value of the TOD index resulted as 0.76, and points such as the highest TOD values for the train stations of Arnhem and Nijmegen on a regional scale, and that the degree of urbanization decreases with distance as the distance from these cities increases. At the regional level, development strategies to improve TOD levels at stations adjacent to Arnhem and Nijmegen, where scores dropped abruptly at first, were identified as having the potential to be identified as a priority. (Lukman, 2014)

In this study, the index values of 4 different categories for which the parameters were created for the station were calculated and the TOD index was formed from the sum of the calculated index values. The results of TOD index values are shown in Table 2 below. According to the calculated TOD index values, Station 6 has the lowest value of 0.31, while Station 1 has the highest value of 0.61. When the average level of 0.50 is taken as the limit from the TOD index values, 3 stations are above this limit and 8 stations are below the limit. The resulting map is shown in Figure 2 below.

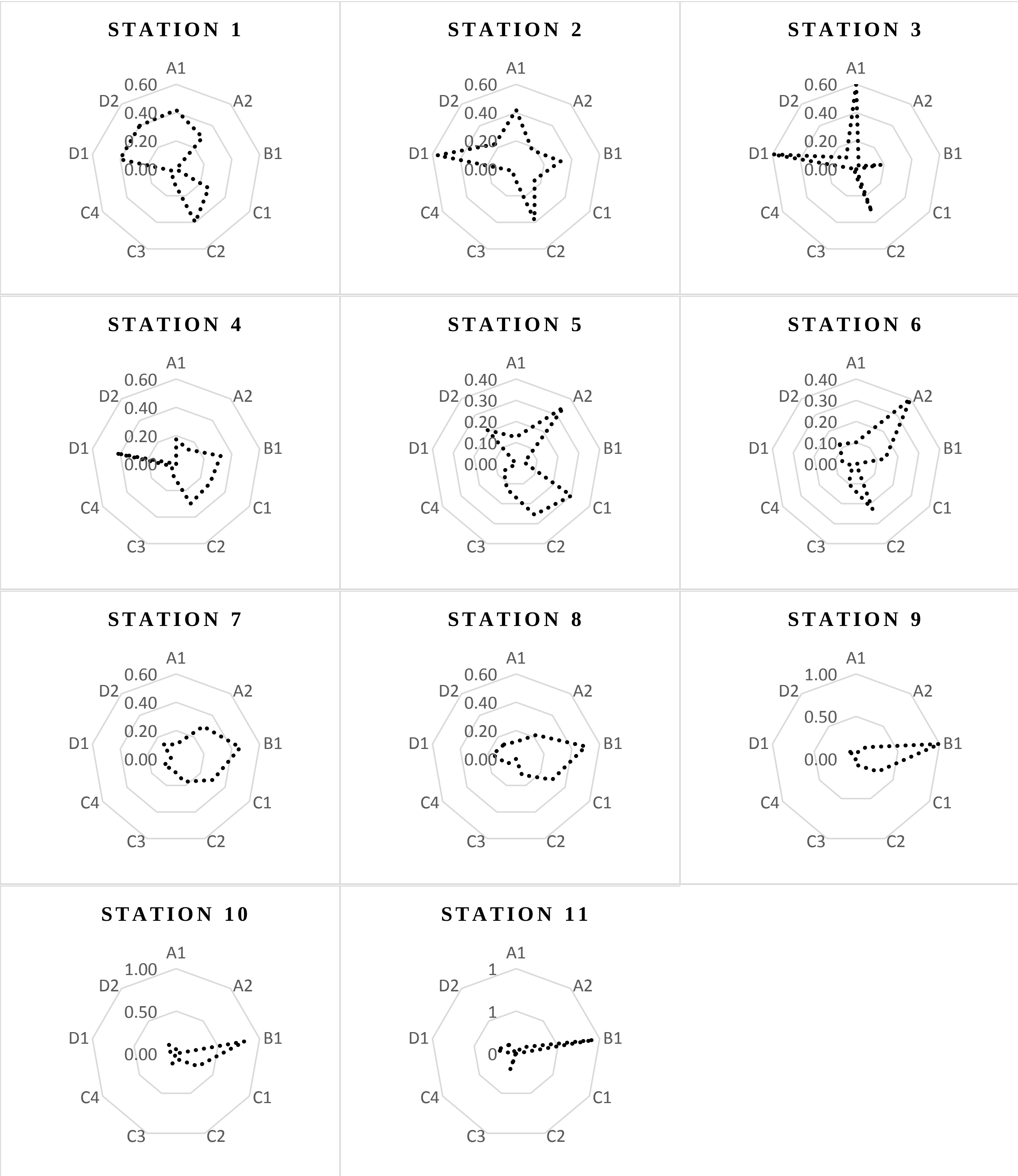

Fig. 3. Radar Charts of Stations by TOD Index

Radar display was used to evaluate the TOD index values produced with the completion of the category and parameter values. Station 1, which has the highest TOD index value, has high values, especially in A1, C1, C2, D1, and D2 parameters. The reason why it is higher than the other stops in the A1 population density parameter can be seen as being in a region located in the center of the city. There are the first settlements and neighborhoods of Bursa province around the station. The fact that this parameter is high is one of the possible effects of the neighborhood lifestyle. High values of C1 pedestrian walking distance and C2 pedestrian path density parameters indicate that its central location, transportation connections, and accessibility in the area are strong. The high parameters of D1 bus station density and D2 bus line density are because the station is the intersection point of both road and rail systems, public transportation systems, public transportation circulation is high and it is also a public transportation transfer point.

Station 6, which has the lowest TOD index value, has low values, especially in A1, B1, C3, C4, and D1 parameters. The reason for having low values in the A1 population density parameter is that the settlement area around the station is limited and the station area is located in an urban study area dense area. Accordingly, it is normal for B1 land use diversity, C3 complexity ratio, C4 green area density, and D1 bus station density parameters to be low. Because there are only spatial settlements that employ the area. Since it is in a position that appeals to a more working population, it remained at low levels in other parameters.

Conclusion

In this study, criteria indicators were applied to measure the TOD index based on the public transport-oriented development approach, where the concept of sustainability is the focus. A comprehensive literature review of criteria and parameters has shown how important each indicator is for reaching TOD index values. It is an important criterion that TOD is put into practice with 3D indicators at the beginning and then evaluated with 6D indicators to increase its applicability in today's modern cities.

In general, indicators are categorized as spatial and non-spatial indicators. In this study, there are 9 indicators used to calculate the TOD index. The calculation of spatial density indicators, mixed-use level, and land use diversity is based on real data. The GIS platform has been useful in the process of digitizing spatial indicators. Adapting the indicator calculation to the GIS model can speed up the process, especially when similar processing needs to be done repeatedly. GIS is also a powerful tool for combining the spatial analysis process and mathematical formula calculation. Calculation of the entropy formula representing both processes has been successfully performed in a GIS environment. In addition, the TOD index creation processes were completed with the use of AHP. Finally, the indicators and criteria used in the study were standardized with the maximum-minimum method.

Considering the TOD index values, the station values could not reach above the average 0.50 value. Considering the 3 stations with the highest TOD index value, good results could not be obtained in all parameters, although they have higher values compared to other stations. The common feature of the 3 stations is that they are close to the city center. The vitality of the city center has an increasing effect on the development of public transportation systems. The TOD level of these stations can be improved by improving the quality of the built environment surrounding the stations, focusing on economic development, and developing more optimal transportation strategies. The common feature of the stations with a low TOD index can be interpreted as the inability to implement spatial development strategies in peripheral areas other than the main transportation axis. In these areas, it can be recommended to strengthen the connections of the resident population with the working population and to change only the employment-oriented service approach. Improvement can be achieved by investing more in promoting social activities alongside economic activities and improving the quality of the transit system. In this direction, the TOD index will be useful for the development of Bursa northern axis development strategies by supporting the TOD planning process.

Calculated TOD index values are a tool for determining TOD planning goals and strategies. The methodology adopted to calculate TOD indices, with its high degree of relevance between different geographies, has been the source of transportation-oriented city development plans. Once TOD plans have been prepared and implemented, the same index can be used in specific TOD planning proposals at regional and local scales to later measure TOD conditions and thus the success of TOD initiatives. In this context; Applying the TOD index to different contexts will further enhance this tool, help optimize TOD planning, and create ready-to-implement assessment guides.

References

A.Ş., B. P. (2018). *Bursa Ulaşım Ana Planı.* Bursa: Bursa Ulaşım ve Toplu Taşım İşletmeciliği Turizm Sanayi ve Ticaret A.Ş. ve Bursa Büyükşehir Belediyesi.

BURULAŞ. (2022). *BURULAŞ Hat, Güzergah ve Durak Bilgileri.* Bursa, Osmangazi.

Çavuş, Z. B. (2013). Sürdürülebilir Kentsel Gelişme Bağlamında "*Toplu Taşıma Odaklı Kentsel Gelişme Yaklaşımı": İstanbul'a İlişkin Değerlendirme Marmaray Projesi.* İstanbul.

Çubukçu, I. (2015). *Kent Meydanı-Terminal Arası T2 Tramvay Hattı 1/1.000 Ölçekli Uygulama İmar Planı Değişikliği Açıklama Raporu.* Bursa: Bursa Büyükşehir Belediyesi.

Çubukçu, I. (2015). Kent Meydanı-Terminal Arası T2 Tramvay Hattı *1/5.000 Ölçekli Nazım İmar Planı Değişikliği Açıklama Raporu.* Bursa: Bursa Büyükşehir Belediyesi.

Fard, P. (2013). *Measuring Transit Oriented Development. Enschede.*

Guindon, Y. Z. (2006). Using satellite remote sensing to survey transport-related urban sustainability: Part 1: Methodologies for indicator quantification. *Applied Earth Observation and Geoinformation*, 149-164.

Gülay Bozkurt, F. F. (2013). *1/100.000 Ölçekli Bursa İl Çevre Düzeni Planı/Ulaşım Lojistik ve Teknik Altyapı Sektörü Analiz Raporu.* Bursa: Duman Tanıtım Ltd. Şti.

Hancock, M. M. (2014). *Transit Oriented Development Strategic Plan. Denver the Male High City.*

Jean-Paul Rodrigue, C. C. (2006). *The Geography of Transport Systems.* London & New York: Rouledge.

Khan, B. B. (2006). Sustainability Framework for Transit Oriented Development in South East Queensland. I. C. Hudson içinde, *Geographic Perspectives of Queensland* (s. 31-54). Brisbane: Royal Geographic Society of Queensland.

Knowles, R. D. (2012). Transit Oriented Development in Copenhag, Denmark: from the Finger Plan to Orestad. *Journal of Transport Geography,* 251-261.

Kockelman, R. C. (1997). *Travel Demand and The 3Ds: Density, Diversity and Design. Pergamon,* 199-219.

Lai, C.-N. L.-Y. (2005*). Sustainable Development and Transit-Oriented Development Cities in Taiwan. Japan.*

Lukman, A. (2014). *Development and Implementation Of A Transit Oriented Development (TOD) Index Around the Current Transit Nodes. Enschede.*

Murakami, R. C. (2008). *Rail + Property Development: A model of sustainable transit finance and urbanism. California: UC Berkeley;* UC Berkeley Center for Future Urban Transport.

Ndebele, A. O. (2014). The Role of 6Ds: Density, Diversity, Design, Destination, Distance, and Demand Management in Transit Oriented Development (TOD). (s. 539-546). *India: Neo-International Conference on Habitable Environments (NICHE 2014).*

Oh, H. S.-T. (2011). *Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea. Cities* (s. 70-82). içinde Elsevier.

Pilatin, K. (2020). Toplu Taşıma Odaklı Gelişme Yaklaşımının Marmaray Hattı Örneği Kapsamında Değerlendirilmesi. *Tasarım Kuram,* 150-159.

Şişman, V. (2015). *Toplu Taşımacılıkta Verimlilik Yönetimi: İETT Hatlarının Diğer Toplu Taşıma Türleriyle Entegrasyonu Üzerine Araştırma.* İstanbul.

Tuğba Kütük, Ö. Y. (2019). Ankara-Batıkent ve Koru Metro İstasyonlarının Toplu Taşım Odaklı Gelişim (TOD) ve Sürdürülebilir Kentsel Tasarım İlkeleri Çerçevesinde Değerlendirilmesi. *Mimarlık Bilimleri ve Uygulamaları ,* 140-154

W. Budiati, A. G. (2018). Determining the potential for Transit Oriented Development along the MRT Jakarta corridor. *IOP Conference Series: Earth and Environmental Science* (s. 1-15). IOP Publishing.

Yalçın Yıldırım, D. J. (2020). How does transit-oriented developments (TODs) deviate noise pollution of building? A comparative study of TODs and non-TODs. *Environmental Science and Pollution Research,* 25390-25403.

Yılmaz, O. (2012). *Toplu Taşımanın ve Kullanımının Yaygınlaşması için Bir Çalışma:* İstanbul Örneği. İstanbul.