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Research Article

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Investigation of the road network structure around rail transit stations

Oruc Altintasi[a,*], Alper Kundakci[b]

[a]*Department of Civil Engineering, Faculty of Engineering and Architecture, Izmir Katip Celebi University, Izmir, Turkey*
[b]*Department of Civil Engineering, Faculty of Engineering and Architecture, Izmir Katip Celebi University, Izmir, Turkey*

Highlights

- Road network connectivity around rail transit stations were examined
- Road network connectivity scores were evaluated for different buffer zone sizes
- Stations near the high-density areas revealed a higher connectivity score

Abstract

This study examined the connectivity of road networks around rail transit stations in İzmir, Türkiye, using intersection density and connected node ratio metrics. The analysis was conducted within 800 m, 600 m, and 400 m catchment areas around these stations, which were considered reasonable walking distances. Rail transit stations and road networks were digitized using ArcGIS Pro software. The research identified variations in connectivity scores among different stations and buffer zones. Stations in high-density areas like Konak and those near the ferry port showed higher connectivity scores, indicating well-integrated street networks that support multimodal transportation. In contrast, stations such as Ataşehir and Mavişehir, where intersection densities were lower, demonstrated significant connectivity challenges, underscoring the necessity for targeted urban planning interventions.

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1. Introduction

Enhancing rail transit station connectivity is regarded as a key strategy for i) reducing the high intensity of traffic flow due to the private vehicles [1], ii) promoting sustainable urban mobility, and iii) creating more liveable cities [2,3]. To decrease the private car use, cities have aimed to expand their rail transit networks, strategically positioning stations to facilitate connections with other environmentally friendly transportation modes and enhance multimodal connectivity [1,4-5]. Friedrich et al. [6] stated that rail transit systems are regarded as the core of public transportation system in China, improving the road network connectivity of the cities. According to the Song et al. [7], establishing a new rail transit network resulted in an increase of 25% of urban road network connectivity. Yang and Liang [1] stated that 57.5% of rail transit stations in Wuxi, China had low connectivity. The connectivity of the stations was assessed in terms of average transfer time, interchange demand, comfort and interchange information services. In addition to these, evaluating the rail transit station connectivity has been evaluated for the different purposes such as the integration of non-motorized modes such as bicycles for first/last mile travels. For example, Guo et al. [8] investigated the impact of the several independent variables for the frequencies of bicycle-metro system integration. The intersection density, is a way of measuring the connectivity score, was found significant variable affecting the number of bicycle-metro integration. In contrast, Wu et al. [9] investigated the impact of the connectivity level of road network near the stations for bike-metro integration in Shenzhen, China. Different buffer zone size was trained but it was not found significant variable.

In addition to the aforementioned studies, it is crucial to outline the connectivity level of the road network around rail transit stations in terms of various buffer zones and metrics. This aspect has not been comprehensively discussed in the literature, highlighting the need for further exploration which is the focus of this research. The Light Rail Transit (LRT) network in İzmir serves as a vital component of the city's public transportation system, linking various neighbourhoods and facilitating the movement of people across the urban landscape. Despite the evident importance of these networks, there is a need for comprehensive studies that assess their effectiveness

[*]*Corresponding author: oruc.altintasi@ikcu.edu.tr (O. Altintasi), +90 232 270 5511*

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in enhancing connectivity and accessibility within the city. This study focuses on the evaluation of the road network connectivity around the two rail transit stations serving in İzmir, Türkiye. Two connectivity measures were selected from the literature and the results concluded about the current stations connectivity level. The results will inform urban planners and policymakers about the areas where connectivity can be enhanced, ultimately contributing to a more efficient and accessible urban transportation system.

2. Methodology

The methodology section is composed of two main subsections. Firstly, the study area is introduced, followed by the evaluation process of road network connectivity around rail transit stations.

2.1. Study area

In this study, the Konak and Karşıyaka trams in İzmir province were examined. The Konak tram is located in the Konak district, one of the central and busiest areas of İzmir. The tram line is 12.8 kilometers long and comprises 19 stations (Figure 1). It runs from Fahrettin Altay Station, a major transportation hub, to Halkapınar Station. Along its route, the tram passes through significant locations such as Konak Square and the historic Kemeraltı Bazaar. The Karşıyaka Tram serves the Karşıyaka district, which is located on the northern shore of Izmir Bay. The total length of Karşıyaka tram is 8.8 km and it has 14 stations and passes through various residential areas, commercial districts, and transportation hubs. It serves between Ataşehir and Alaybey stations (Figure 1).

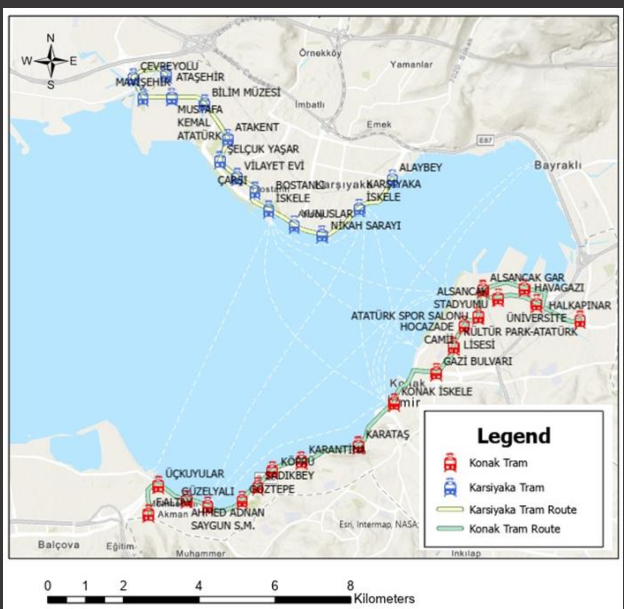

Figure 1. LRT routes in İzmir, Türkiye

2.2. Evaluation process of the road network around rail transit stations

ArcGIS Pro software was utilized to digitize the rail transit stations and road network data. Three different catchment areas (buffer zones) were defined, considering reasonable walking distances of 400 m, 600 m, and 800 m. These values were selected based on studies in the literature. For example, Li et al. [10] conducted a study to investigate the best catchment area using the metro ridership data of the six cities in USA, concluding that the catchment area of rail transit stations was in between 600 m -1200 m. El-Geneidy et al. [11] stated that the typical walking distance to rail transit stations is generally around 800 m. However, this value was found to range from 400 m to 900 m for North American cities [12]. Kim et al. [13] preferred to take 400 m, while 600 m catchment area was taken in studies [14-16].

An example buffer zone of each station for the 600 m is illustrated in Figure 2. Sea regions have been removed from the area of the buffers. The road network topology was examined. Intersection and dangle nodes, as well as the number of links within each buffer calculated automatically in ArcGIS Pro software (Figure 2). Two metrics from the literature were chosen for connectivity analysis: intersection density [17-21] and Connected Node Ratio (CNR) [17,22]. Intersection density measures the number of intersections per unit area, with higher densities generally indicating greater connectivity [17]. The CNR is calculated by dividing the number of street intersections by the total number of nodes (intersections plus cul-de-sacs). In other words, the number of real nodes divided by the total nodes (real + dangle). A higher CNR indicates that more nodes are interconnected, signifying a more connected network [17]. These metrics were derived separately for each station within the selected buffer zones.

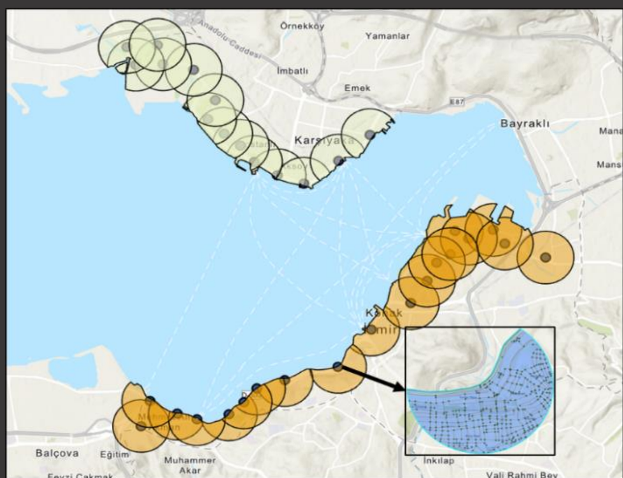

Figure 2. Illustrations of 600 m buffer zones of rail transit stations

3. Results and Discussions

The intersection density results for various buffer zone sizes around each station are summarized in Table 1. For Karşıyaka tram, the highest intersection density is observed at Bostanlı İskele, a value of 365.7 at 400 m. This indicates a very dense and well-connected street network at close proximity, further supported by high values of 267.2 at 600 m and 222.1 at 800 m, reflecting excellent connectivity across different distances.

Table 1. Intersection density values for different sizes of buffer zones

No	Name	400m	600m	800m
	Karşıyaka Tram			
1	Yunuslar	169.43	158.61	170.08
2	Nikah Sarayı	77.39	76.24	109.54
3	Karşıyaka İskele	122.93	143.44	157.15
4	Bostanlı İskele	365.67	267.15	222.05
5	Alaybey	235.66	193.21	201.94
6	Çarşı	195.18	192.97	188.49
7	Vilayet Evi	163.48	169.27	177.26
8	Selçuk Yaşar	332.47	306.57	264.07
9	Atakent	300.41	292.67	279.90
10	Bilim Müzesi	101.46	90.19	117.87
11	Mustafa Kemal Atatürk	69.63	66.31	85.55
12	Mavişehir	89.41	70.60	79.92
13	Çevreyolu	58.49	68.46	69.14
14	Ataşehir	59.68	91.96	53.22
	Konak Tram			
1	Alsancak Gar	165.12	142.23	134.89
2	Halkapınar	155.18	142.36	130.81
3	Havagazı	148.05	100.91	77.94
4	Alsancak Stadyumu	79.58	109.64	109.50
5	Konak İskele	391.69	317.02	295.50
6	Gazi Bulvarı	212.87	212.21	202.84
7	Karataş	248.93	237.40	259.86
8	F.Altay	137.27	117.60	125.83
9	Karantina	178.45	208.27	189.40
10	Ahmed Adnan Saygun	107.69	106.63	128.87
11	Göztepe	110.82	181.12	168.70
12	Güzelyalı	169.28	173.10	170.73
13	Köprü	106.03	149.21	148.96
14	Sadıkbey	69.22	75.02	115.48
15	Üçkuyular	148.51	78.43	64.34
16	Kültür Park-Atatürk Lisesi	121.36	109.64	117.25
17	Hocazade Camii	149.21	162.69	158.47
18	Üniversite	109.42	104.34	96.57
19	Atatürk Spor Salonu	127.32	129.98	146.72

Conversely, Ataşehir records the lowest intersection densities across all distances, with values of 59.7 at 400 m, 92.0 at 600 m, and 53.2 at 800 m, suggesting significant connectivity challenges and a less integrated street network that may impede accessibility. Atakent station shows consistently high average intersection densities, with values of 300.4 at 400 m, 292.7 at 600 m, and 279.9 at 800 m, indicating a robust and well-integrated urban network that facilitates better mobility and accessibility. In contrast, Mavişehir has the lowest average intersection densities, with values of 89.4 at 400 m, 70.6 at 600 m, and 79.9 at 800 m, pointing to a less dense street network and highlighting potential areas for connectivity improvement. Regarding the Konak tram stations, Konak İskele, Gazi Bulvarı, and Karataş stations show higher intersection density values. These stations are located in areas predominantly characterized by commercial and residential zones. Konak İskele exhibits the highest intersection densities across all buffer zones with 295.5 at 800 m, 317.0 at 600 m, and 391.7 at 400 m. This makes it the most connected area, suggesting excellent connectivity and potential for pedestrian movement. Karataş, with consistently high intersection densities of 259.9 at 800 m, 237.4 at 600 m, and 248.9 at 400 m, indicates robust connectivity and strong urban integration. Alsancak Gar station, with intersection densities of 134.9 at 800 m, 142.2 at 600 m, and 165.1 at 400 m, shows moderate connectivity, supporting good accessibility without being overly dense. Halkapınar station, exhibiting intersection densities of 130.8 at 800 m, 142.4 at 600 m, and 155.2 at 400 m, indicates a balanced level of connectivity. Sadıkbey station, with lower intersection densities of 115.5 at 800 m, 75.0 at 600 m, and 69.2 at 400 m, suggests poorer street network connectivity and potentially lower accessibility. Üçkuyular station, displaying the lowest intersection densities with values of 64.3 at 800 m, 78.4 at 600 m, and 148.5 at 400 m, indicates significant challenges in connectivity. Additionally, Intersection density values were visualized using color-coded maps (Figure 3) where green indicated high intersection density and red indicated low intersection density. These maps were created for each buffer zones around the stations. The maps helped in visually interpreting the spatial distribution of intersection density and identifying areas with varying levels of connectivity.

CNR values for Karşıyaka Tram stations varies from 0.67 to 1.00, with the latter indicating well-structured road networks (Table 2). While the Nikah Sarayı station has a lower CNR value, Mavişehir and Mustafa Kemal Atatürk stations each has a value of 1. It is important to note that, despite the lower intersection density values around these stations, the CNR results were very high. Therefore, relying on a single metric to evaluate connectivity is not robust. On the other hand, Nikah Sarayı stations has both lower intersection density and CNR; hence further improvements are necessary to enhance the connectivity to this rail transit station. For the Konak Tram station (Table 2), it can be concluded that CNR scores of the station are very close to the 1.00, indicating the perfect structured road network. Alsancak Stadyum station has a lower CNR score, whereas Köprü and Üniversite stations have the highest scores. However, for the Alsancak Stadyum station, increasing the buffer zone size results in a higher CNR for this station.

4. Conclusions

This study provides a thorough evaluation of the connectivity of the road network structure around the Light Rail Transit Stations serving in İzmir, Türkiye. Two different metrics were selected, intersection density and connected road ratio (CNR) for this purpose. By assessing intersection densities and CNR within 800 m, 600 m, and 400 m buffer zones around each tramway station, the research highlights significant variability in urban connectivity. This approach provides insights into connectivity levels and identifies areas for potential improvements. Stations such as Bostanlı İskele, Selçuk Yaşar, and Atakent exhibit higher intersection densities, indicating well-connected road networks. In contrast, stations like Mavişehir, Çevre Yolu, and Ataşehir have lower intersection densities, suggesting areas where connectivity improvements are needed. For areas with low intersection densities, urban planning efforts should focus on improving the street network to enhance connectivity and accessibility. This could include adding more intersections to create a more integrated street network.

Table 2. CNR values for different sizes of buffer zones

No	Name	400m	600m	800m
	Karşıyaka Tram			
1	Yunuslar	0.91	0.93	0.91
2	Nikah Sarayı	0.67	0.74	0.85
3	Karşıyaka İskele	0.87	0.94	0.93
4	Bostanlı İskele	0.91	0.93	0.94
5	Alaybey	0.92	0.93	0.92
6	Çarşı	0.94	0.96	0.95
7	Vilayet Evi	0.96	0.95	0.96
8	Selçuk Yaşar	0.98	0.98	0.97
9	Atakent	0.97	0.95	0.96
10	Bilim Müzesi	0.86	0.88	0.89
11	Mustafa Kemal Atatürk	1.00	0.99	0.97
12	Mavişehir	1.00	0.95	0.92
13	Çevreyolu	0.94	0.91	0.92
14	Ataşehir	0.88	0.94	0.92
	Konak Tram			
1	Alsancak Gar	0.90	0.90	0.91
2	Halkapınar	0.90	0.90	0.91
3	Havagazı	0.96	0.94	0.87
4	Alsancak Stadyumu	0.73	0.83	0.88
5	Konak İskele	0.93	0.92	0.92
6	Gazi Bulvarı	0.97	0.94	0.93
7	Karataş	0.96	0.96	0.96
8	F.Altay	0.95	0.96	0.98
9	Karantina	0.92	0.96	0.96
10	Ahmed Adnan Saygun	0.91	0.93	0.93
11	Göztepe	0.94	0.96	0.94
12	Güzelyalı	0.92	0.90	0.93
13	Köprü	1.00	0.99	0.99
14	Sadıkbey	0.95	0.94	0.96
15	Üçkuyular	0.98	0.98	0.95
16	Kültür Park-Atatürk Lisesi	0.97	0.98	0.98
17	Hocazade Camii	0.99	0.99	0.97
18	Üniversite	1.00	0.98	0.94
19	Atatürk Spor Salonu	0.94	0.96	0.96

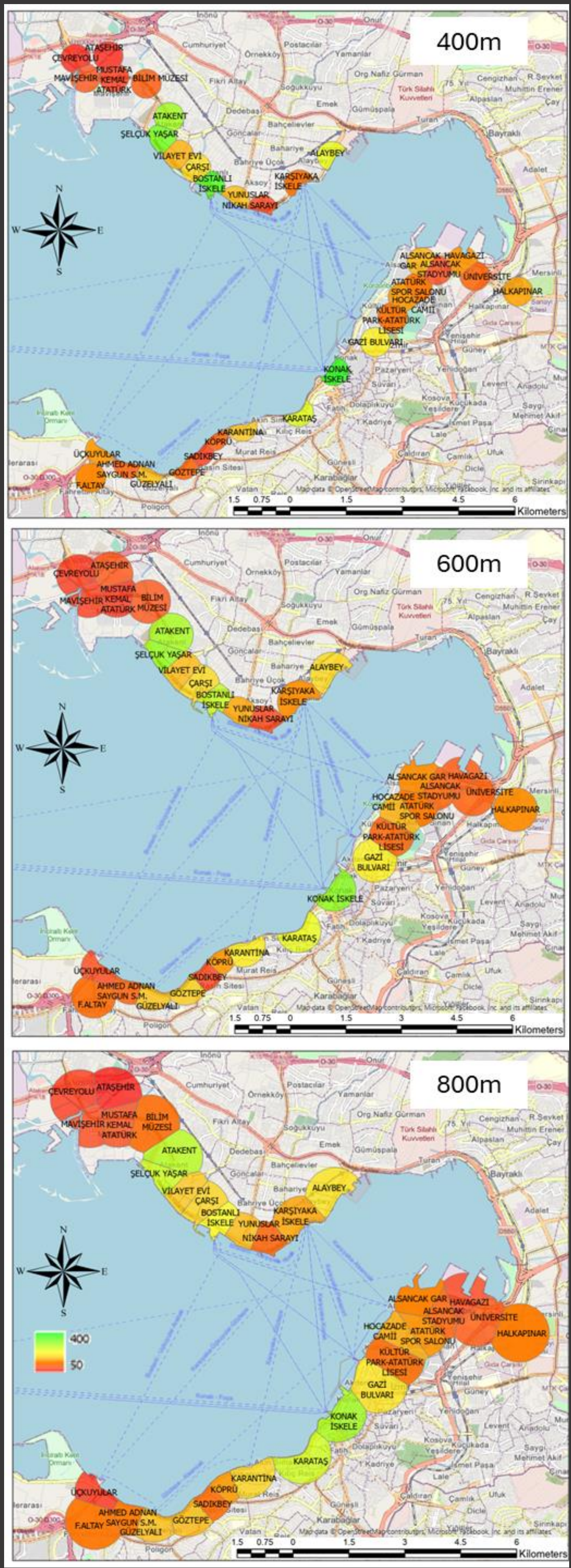

Figure 3. Coloured visuals of intersection density values for the different sizes of buffer zones

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution Statement

O. Altintasi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – Original Draft, Writing – Review & Editing; **A. Kundakci:** Data curation, Formal analysis, Investigation, Software, Visualization, Writing – Original Draft, Writing – Review & Editing.

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