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EVALUATION OF THE INTEGRATION OF BIKE ROUTES TO THE RAIL TRANSPORT SYSTEM IN ZEYTİNBURNU DISTRICT

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INTRODUCTION

The rapid transformation of socioeconomic mobility in urban areas, population growth, and the growing physical environment poses many problems for citizens. The main problem is related to traffic; therefore, public transportation is the key issue in highly populated urban areas. Increasing individual use of automobiles leads to environmental issues in urban areas, such as traffic congestion, noise pollution, and air pollution, thus affecting urban accessibility negatively.

The harmony and integration of all transportation modes, such as pedestrian, bicycle, motor vehicle, bus, and rail systems, are important for healthy and safe mobility (Yıldırım et al., 2021). In addition, integrated bicycle and public transportation reveal energy-efficient, environmentally friendly cities, promoting alternative transportation (Saplıoğlu and Aydın, 2018). Strategic sustainable urban transport planning is one of the main goals to improve cycling and reduce automobile use in developing and developed countries (Iacono et al., 2010; Litman et al., 2000). In this regard, bicycles can replace individual vehicles for short and middle-distance journeys when used as a part of the integrated transfer along with public transportation. Moreover, the bicycle stations and bike rental services are offered by municipalities worldwide, which support bicycles as a sustainable alternative in relation to public transportation and promote their integration (Frumkin et al., 2004).

The use of bicycles is the basis of the concept of bikeability, which can be defined as an individual's desire to use a bicycle as a means of transport or physical activity (Neilsen and Skov-Petersen, 2018). Bikeability is measured based on the suitability of infrastructure elements for the use of bicycles, such as the effectiveness of bicycle routes (bikeways, shared roads, road lines, signs and markers, and lighting), parking lots, interaction with motor vehicle traffic, topography, relationship with green areas, and an individual's capacity and aim to ride a bicycle (Lowry et al., 2012).

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The present study aims to analyze the relational structure of the city to integrate bicycle roads into rail transport systems and envisage solutions for bikeability (**Figure 1**). Zeytinburnu, which one the largest districts in İstanbul, was selected as pilot study area to increase the use of bicycles as a means of physical activity and recreation and as an integrated part of rail transportation back in 2002. Two projects were launched in Zeytinburnu; the first was in 2002, namely Istanbul Bicycle-Route Planning by IBB. The second was in 2009 (BAKSI, 2021), namely Integrated Smart bicycle-sharing System (İsbike). İsbike stations and bicycle routes (shared and segregated bicycle routes) are not only located in the coastal line and green areas now in 2022; in fact, the Zeytinburnu district has bicycle routes of 44 km. and 37 bicycle stations, which are closely related to the public transportation networks in the district. Therefore, the Zeytinburnu district in Istanbul was selected as a case study area in this research. The present study method consists of three phases, (P1) The physical structure of the distirict is analyzed with space syntax methods, (P2) New bicycle routes are generated depending on the bicycle and rail transport data, and (P3) Bicyclists experienced these routes and evaluated the routes related to physical, environmental and visual factors with a survey.

LITERATURE REVIEW ON BIKEABILITY AND ITS INTEGRATION INTO THE CITY

Bikeability

Cycling is a green and active form of travel that assists physical activities, consumes minimal energy, and produces pollution (Lin and Wei, 2018). For this reason, local and national governments increase their efforts to design bicycle-friendly cities to promote bicycle use in integration with public transport stations in short and medium distances for mobility planning (Vietinghoff, 2021; Yang et al., 2019). A comprehensive strategy needs to be developed, infrastructure planning, design criteria, and integration with other modes of transport to support cycling in cities and ensure the bikeability of urban space (Meireles and Ribeiro, 2020). In the current literature, it becomes interesting first to review the built environment attributes to establish the nature of cycling. The built environment includes the physical elements of the urban space, its spatial configuration, public transportation systems, and the environmental psychology of the people living in the city (Handy et al., 2002). Studies examine the relationship between bicycle use and the built environment through criteria such as bicycle infrastructure and services, traffic safety, land use mix, integration with the public transport system, comfort, and attractiveness (Piatkowski and Marshall, 2015; Osama et al., 2017). Thus, the design of urban spaces that are suitable for bicycle use is essential for the sustainable development

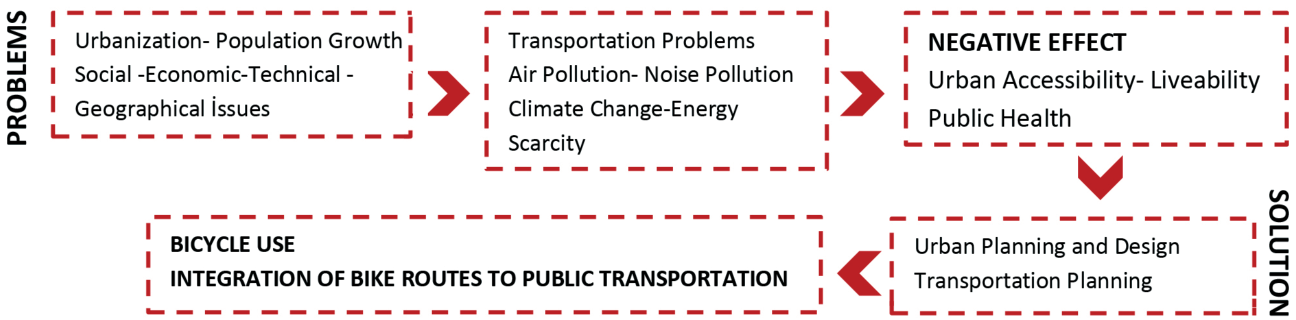


Figure 1. Problem and suggested solution of the study

of cities. Regarding this, the concept of bikeability and its evaluation criteria include variables related to urban form.

Bikeability is the desire and ability of a person to ride a bicycle and the suitability to the urban space. It is used as a basic concept of the possibility of the citizen choosing the bicycle as a mode of transportation or entertainment. There are a lot of important research on bikeability, some of which are bicycle route conditions and levels of service (Lowry et al., 2012), bicycle friendliness (Krenn et al., 2015), bicycle accessibility (Saghapour et al., 2017), and the concepts of cycling quality (Grigore et al., 2019), which provides a clear definition of bikeability in the context of urban mobility.

For the concept of bikeability, which is a combination of objective and subjective factors, the factors affecting cycling have been investigated (Dill and Voros, 2007; Fraser and Lock, 2011). Moreover, street networks, including streets, roads, bridges, and bikeways, are researched for their role in shaping the travel behavior of travel modes (Boeing, 2019; Emmanouilidis, 2013). The spatial configuration of the city is one of the most critical factors affecting bikeability (Alattar et al.,2021). The theory of natural movement, which Hillier et al. (1993) put forward, indicates that the urban space configuration and street layout are formatted for the individual, and many studies support this (Hillier et al., 1993; Hillier and Iida, 2005; Manum and Nordstrom, 2013; Alattar et al., 2021). For this reason, cyclist behavior and urban space order are closely related. Efforts are being carried out to promote sustainable urban transportation planning, evaluating and integrating bicycle infrastructure with the sustainability of individual prosperity and urban environments for regular use of bicycles in urban areas (Castañon and Ribeiro, 2021). Despite these studies, there is a lack of research into bicyclists' route selection and the role of the spatial configuration on cycling activity (Law et al., 2014, Manum et al.,2017). Therefore, in this study, the Space Syntax method is used to evaluate bikeability and the relationship of the spatial configuration of the urban built environment.

Moreover, bicyclists' route selection behaviors and preferences are multidimensional and complex. Empirical studies on the use of bicycles and route selection have demonstrated that bicycle users took several criteria, such as distance, the number of crossroads, bicycle stations, and safety, into account (Broach et al., 2011; Dill and Carr, 2008; Winters et al., 2011). It is of utmost importance to analyze physical and behavioral factors which influence route selection in detailed transportation models and create new approaches to reshape new routes in light of these factors.

Studies on modeling the route selections of bicyclists have various limitations, including lack of detailed biking data, quantification of spatial analysis, and use of non-spatial models (Liu et al., 2016; McCahill and Garrick, 2008; Orellana and Guerrero, 2019; Raford et al., 2007). Studies with traditional data sources argue that spatial details are insufficient in route planning. New emerging technologies and data sources are used to collect remote detection images, mass resource utilization, and GPS data from mobile devices (Winters et al., 2016; Alattar et al., 2021). These data collecting methods are useful to evaluate bikeability in large-scale comparisons. However, they evaluate very limited aspects of cycling, keeping subjective indicators out of evaluation. In this study, the bikeability concept is evaluated in a comprehensive manner using subjective and objective methods to fill this gap, and numerical findings on the performance of these routes are obtained.

Bikeability in Turkey

The use of bicycles in Turkey is relatively low due to the various infrastructure problems, insufficient bicycle roads and parking lots, and social unawareness. Nevertheless, in recent years, interest in bicycles has increased in some cities of Turkey, paving the way for new projects related to the improvement of biking infrastructure and focusing on more transportation projects (IBB, 2020). Bikeways have been constructed in some major cities such as Bursa , Ankara , Konya, Samsun, Denizli, Eskişehir , Antalya, Sakarya, Kayseri, İzmir, and İstanbul. However, since these roads are not yet integrated into the existing public transportation systems and there are insufficient bicycle routes in these cities, bicycles have still not been as widespread as they should be. Therefore, it is always necessary to plan bikeways and routes within the scope of transportation networks, determine design criteria, analyze the physical and social conditions of the urban space, and understand bicyclists' specific needs.

When legal and administrative initiatives are analyzed, it can be observed that *Bisiklet Yolları Yönetmeliği* (Regulation on Bicycle Roads) was published by the Ministry of Environment and Urbanization in 2019, underlines the importance of planning bikeways as an integrated part of public transportation networks and other vehicles. This guide aimed to pioneer various implementations that would increase the economic, environmental, and social benefits of the bicycle as a means of transport and offer various social, technical, and economic information about the pre-and post-construction period of bicycle roads through examples from major projects (Ministry of Environment and Urbanization, 2019). The guide also emphasizes that bicycle roads should not only be planned for physical and recreational activities but also as integrated systems to rail transport. In this respect, it envisaged a detailed route-planning process and model to offer solutions to different transportation goals. The factors that need to be analyzed in the route-planning model were divided into three main topics as physical, environmental, and visual factors.

This study focuses on Istanbul, as the largest city of the country with a population of over 15 million people with a population of over 15 million people, in the framework of various urban planning projects. For this purpose, firstly, the regulation prepared by the Directorate of Transportation and Coordination of IBB has been reviewed. The publication of *Istanbul Bike Route Planning*, launched in 2002, was followed by the IBB Transportation Planning Directorate in 2006 by the publication *Analysis, Planning Istanbul Bike and Pedestrian roads*. Finally, the IBB Transportation and Coordination Directorate prepared the Istanbul Bicycle Master Plan in 2019. Introduced as the first bicycle road planning project, it envisages and proposes a total bicycle road of 630 kilometers for the whole city. The project specified specific objectives and main strategies by considering social, spatial, environmental, and economic benefits. In this paper, current conditions, legislation, and standards were analyzed, and the existing bicycle transportation infrastructure was evaluated based on the physical environment data of the city. İsbike's bicycle stations are also analyzed, which are used as means of transport and recreation, helping to increase the popularity of bicycles. In addition, these data offer valuable information regarding the diversity of bicyclist profiles in Zeytinburnu. Finally, new bicycle routes were planned in the existing Istanbul rail transportation network (**Figure 2**) and recreational purposes of providing

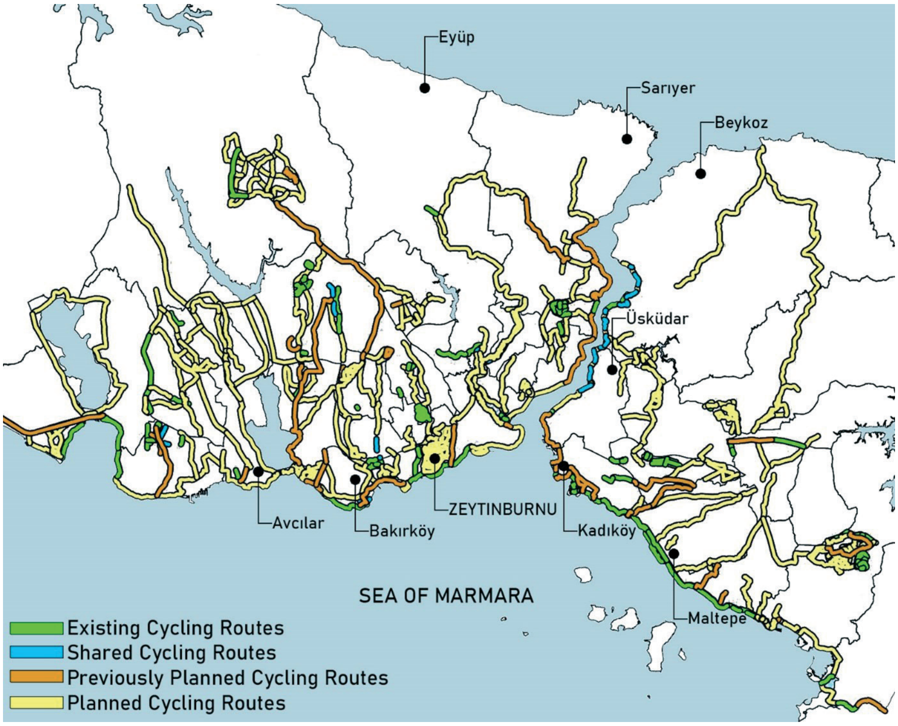


Figure 2. Suggested bicycle routes for Istanbul Metropolitan Area (IBB Directorate of Transportation and Coordination, 2020).

insight into Istanbul's potential bicycle road construction projects (IBB, 2020).

Bicycle and Rail Transport Integration and Bike-Sharing Systems

The bicycle is a healthy, reliable, economical, and sustainable alternative to mobility for integration into the public transport system over short and medium distances (Pucher and Buehler, 2008). The integration of the bike roads with public transport systems has been planned in many ways in history. The process started in 1940 with bicycle use in ferries, buses (1970), and railways in 1980 (Schneider, 2005). These studies aim to increase the use of public transportation and cycling to improve sustainable urban mobility. However, there is still not enough research on the spatial configuration analysis of the city in terms of bikeability (Saplıoğlu and Aydın,2018).

Station-based bike-sharing systems are being developed to improve sustainable urban mobility and increase physical activity (Zhang and Mi, 2018; Mrkajić and Anguelovski, 2016). These systems are being enhanced in cities to expand sustainable urban mobility and physical activity. They are implemented to complete the scope of public transportation networks easy to reach in urban areas (Shaheen et al., 2013). Bicyclists can rent, ride and return to stations at any time. Many services, such as station security, availability ratio, and the intensity of use, need to be provided and managed (Shui and Szeto, 2020). In means of coordinated use of cycling and public transport, there are several studies in the literature to measure the performance of integration between bike-sharing and public transport systems (Shaheen et al., 2013). In addition, the relationship between the behavior of bicyclists, route preferences, and their determinants is of great importance (Saplıoğlu and Aydın, 2018). These studies highlight the importance of user preferences for cycling and public transport integration. However, there is not enough research on public transportation and bike-sharing system integration and evaluation as holistic and qualitative research. This study will be a novel one to examine bike and rail transport integration, bike-sharing systems, urban space interaction, and user experiences.

Space Syntax Based Research on Bikeability

Space syntax methodology was introduced in the 1970s to analyze a living space in terms of its architecture, urban planning, and user interactions from a social perspective. Focusing on *probabilities* and *realities*, the space syntax method aims to conclude the factual data obtained from functional, spatial, and formal interactions between a city and its citizens (Hiller and Hanson, 1984; Raford et al., 2007). Space syntax adopts a multidisciplinary approach; it can be used to evaluate the sociophysical development of a city and adopt relevant strategies to offer solutions to urban problems (Özbek and Özer, 2014).

Many studies dealing with space syntax to model bicycle users' route-selection behaviors can be found in the existing literature. Paul (2011) demonstrated that origin-destination data could be used for a detailed analysis and the improvement of transportation problems, such as traffic congestion, safety, and infrastructure, and the development of strategies for these problems. Raford et al. (2007) employed space syntax in a study to predict bicycle users' route selection behaviors in central London through an analysis of urban transportation networks. They concluded that bicyclists usually benefited from routes with less angular changes, revealing a strong correlation between them. McCahill and Garrick (2008) evaluated and tested various space syntax values through data obtained from Cambridge, MA, to model the distribution of bicycle volume in the urban transportation network and created a linear regression model including population density and distribution of workers as well as a space syntax measurement that estimates the number of total bicyclists accurately. Manum and Nordstrom (2013) surveyed to map bicyclists' route selections and compared them with the results of space syntax analysis.

It can be observed in these studies that space syntax analysis is a popular method of modeling bicycle users' route-selection behaviors. However, it must be noted that several factors limit space syntax analysis. Thus these studies were strengthened by other research methods, such as surveys, observation, and bicyclists' experiences of route selection.

MATERIAL AND METHOD

The method used in this study consists of three phases: In Phase 1, a space syntax analysis has been done to conduct depth and integrity measures of Zeytinburnu district. The road data is obtained from the OpenStreetMap web application, roads that are not suitable for bicycles are detected (Data Set 1). The aim was to analyze physical patterns, the network of topological relationships, and mobility potentials in Zeytinburnu. To this aim, DepthMapX software is used for connectivity, integration, and metric choice analysis (**Figure 4**).

In Phase 2, this data is used to generate suitable bicycle routes to detect the start and end İsbike stations. Related public transportation data were obtained from IBB Transportation/ Coordination Department, the 2019 user number data (yearly) of Zeytinburnu Metro Station, Topkapı Tramway Station, Zeytinburnu Marmaray Station, and Kazlıçeşme

Marmaray Stations are obtained (Data Set 2). Also, İsbike's 2019 year-round bicycle rent count is obtained depending on each station. With the use of these data, among 35 İsbike stations in Zeytinburnu, it is aimed to generate four different routes between each start and end station pair. Each route is decided to have four İsbike stations on it (starting station, first station, second station, end station). Finally, 24 possible bicycle routes are generated with DepthMapX software.

Finally, in phase 3, these 24 routes were experienced by independent bicyclists. Their experiences were recorded. This data was used to understand the users' views on and perceptions of the bicycle routes in the district. Eight bicyclists volunteered from a local bicycling club, and their experiences were recorded through the Strava application (Data set 3) (**Table 1**). After the rides, the bicyclists are asked to answer a survey. The survey asked them to answer the questions and rate the criteria related to physical, environmental, and visual factors. The integration scores are calculated depending on the bicyclists' answers and ratings. The formula of the integration value is generated by the authors, focusing on the importance of each criterion. Finally, the integration score of each bicycle route was calculated and evaluated and shown in **Table 3**. These three stages were analyzed together to reveal the potential of each bicycle route.

CASE STUDY

Zeytinburnu is one of the major problem areas in Istanbul in terms of traffic congestion and transportation problems due to its central position in the city. It has a flat topographic structure and an active intersection of transportation systems with Marmaray and M1-A metro lines, T1-T4 tram lines, and Metrobus stations. To overcome these traffic problems, Zeytinburnu Municipality launched a bicycle mobility project, "ZEYBİS", to offer transportation solutions and raise public awareness on environmental and health issues. A similar project organized by EMBARQ (2014), states that when the safety level of the bicycle pathways within the district become acceptable, cyclists, including cyclist communities and independent women, men, and children, use bicycle for transportation. The same situation happened in Zeytinburnu; at the same time, various activities and contests have been organized to increase the use of bicycles and raise awareness about this issue, and İsbike data shows that the bicycle rent count is gradually increasing (IBB, 2020).

Phase1- Space Syntax Analysis	
Data Set 1	**Analysis Method**
• District maps are derived from Open Street Map web application, • The roads which are not suitable for bicycle are detected,	• Space Syntax analysis (depth and integrity) is done with DepthMapX software
Phase2- Route Generation with the data from IBB Transportation/ Coordination Department and Isbike	
Data Set 2	**Analysis Method**
• Density of users for 2019 year round: Zeytinburnu Metro, Topkapı Tramvay, Zeytinburnu Marmaray and Kazlıçeşme Marmaray Stations. • Density of usage for 2019 year round: İsbike Stations. • Route 141-143 bicycle route data from "İstanbul Bicycle Main Plan" of IBB Transportation/Coordination Department	• Route Generation for bicycles,
Phase3- Bicyclists experience through the routes	
Data Set 3	**Analysis Method**
• Bicyclists rode 24 Routes, and the data is collected through the Strava application, • A survey is replied by bicyclists.	• Survey analysis, determining integration and correlation values on physical, visual and environmental factors.

Table 1. Material and method of the study

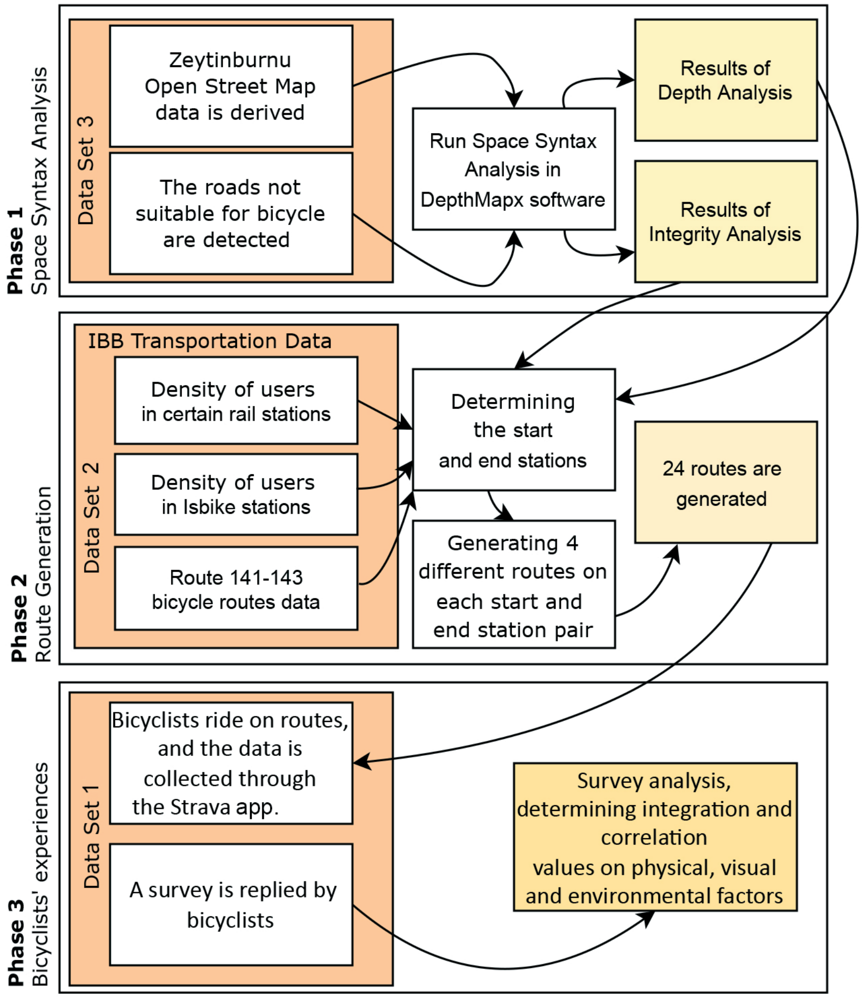


Figure 3. Flow chart of the method

Out of 102 İsbike stations in the European side of Istanbul, 37 active İsbike stations are currently located in Zeytinburnu, which aim to popularize bicycles and encourage citizens to use rental bicycles as a means of public transport transportation. Beyond functioning as a recreational activity for bicycle users, these stations are located in different parts of the district to better integrate into the existing public transportation systems and thus allow citizens to travel easily. This site was also selected as a pilot area by İsbike back in 2009, and the use of bicycles was supported by both IBB and Zeytinburnu Municipality through various slogans drawing attention to a healthy life and an environmentally friendly transportation system.

A study by IBB in 2020 demonstrated that Zeytinburnu has a characterized historical urban structure but developed without a proper urban planning project, making it unsuitable to support bicycle roads. In addition, since the physical conditions of the road networks were not feasible for a separate bicycle road, a shared bicycle road that would contribute to the bicycle transportation network was proposed and constructed in Zeytinburnu (**Figure 3**).

Phase 1: Zeytinburnu Space Syntax Analysis

The Space Syntax method is a model where spatial configurations are graphically analyzed based on dynamic and static measurements (Hillier et al., 1993). Space Syntax Analysis is also done in the Zeytinburnu district to analyze the connectivity, integration, and choice parameters. Connectivity value is the number of neighbors directly connected to any place. The integration value is the normalized value of the distance of any field from all other fields. The metric selection is calculated by calculating the number of times each segment falls on the shortest path between all pairs of segments within a selected distance measured in metrics (Hillier et al., 1993).

In **Figure 4**, the graphic represents the shortest and longest lines describing all urban space gaps. The axial map is created with these lines. Each axis line at the intersection points is divided by other lines, producing a segment map based on the axial map. A segment map calculates integration and selection measurements of a specific urban street network, and connectivity is measured (**Figure 4a**). After the axial and segment maps are converted into graphs and topological (metric choice) analytics (Figure 4-c), a linear link-based integration analysis is presented (**Figure 4b**), and accessibility is expressed spatially, not in metric terms. Integration among various syntax measures is the most important criterion when applied to the segment and axial maps of the space syntax. The value of an integration line in a segment or axial map is defined for the shortest paths between the line and all other lines on the network. It also analyzes how each axis is associated with others in terms of integration analysis and routing. In space syntax analysis, geographical information and urban data for the study area were obtained from the OpenStreetMap database (Minghini and Frassinelli, 2019), a free, online geographic information service and database of street-level features. This study considered only bicycle-friendly roads' data for spatial analysis due to the Bicycle Roads Regulation (IBB, 2020).

This space syntax analysis is based on the interpretation of connectivity, integration, and metric choice parameters to analyze the movement potential of the cyclists in the field. First, the axial map of the district is created. Then angular integration and selection values were calculated on the axis map created using the DepthmapX software to represent the potential for movement. The analysis is limited to 1000 m. radius to determine bike motion. These analyses are also used for generating routes (**Figure 4d**) in Section 4.2.

Figure 4. Space Syntax analysis of Zeytinburnu District from DepthMapX (a) Connectivity, (b) Integration, (c) Metric Choice Analysis and (d) Generated routes

Figure 4 shows the segment angular integration of Zeytinburnu, highlighting the axes with high integration. Unexpectedly on this map, 10. Yıl Caddesi is not the city's most integrated road, probably because its connections between these streets and other streets aren't enough. However, the start and end of this street are the stops and İsbike stations of the public transportation system. In addition, Zübeyde Hanım Caddesi has the highest level of integration, Prof. Turan Güneş Caddesi and İnönü Bulvarı have also a high integration value. Integrated streets are the regions in the district with commercial and cultural centers and university campuses.

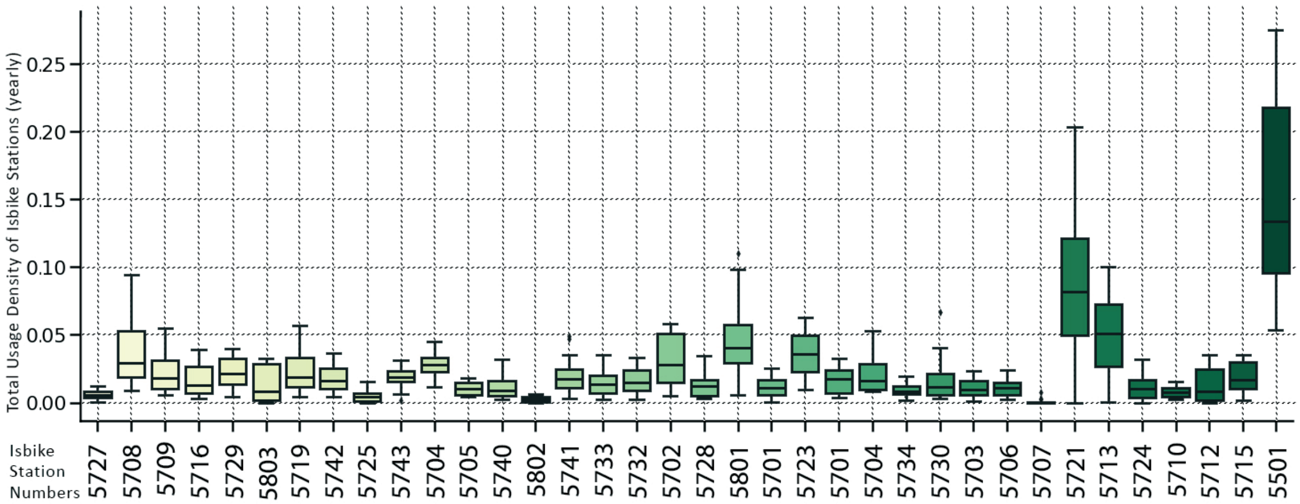
Phase2: Route Generation with transportation data

The Zeytinburnu have different types of bicycle lanes, only one of them is segregated (Route 3), but most of them are shared roads. Zeytinburnu Municipality built the bicycle roads. Whereas, İsbike stations are built in certain locations, can be seen in **Figure 6**. The main problem is, it has never been evaluated as if the İsbike stations are built in the proper spots to integrate the rail transport system with the bicycle roads. Within this perspective, possible bicycle routes are defined by authors between the main rail transport stations and İsbike stations.

Based on the number of times a bicycle is rented or left at that station, the rental rate of each bicycle station was calculated using İsbike data released by the IBB Directorate of Transportation and Coordination in 2020. Yearly usage data of İsbike stations are evaluated in the box diagram shown in **Figure 5**; total usage density shows the renting performance of that station. For instance, İsbike station 5702 was used at a similar rate in all quarters throughout the year. However, despite a higher usage rate than the station mentioned earlier, 5501 5721 displayed significant variations depending on the season. When spatial data of İsbike stations are visually represented on the map based on their usage rates, it can be observed that bicycle user density is higher in different zones, such as residential areas, major public institution buildings, university campuses, and centers of attraction, such as shopping malls. Therefore, it can be concluded that the densest İsbike stations are 5501 and 5721 (**Figure 5**).

The spatial and statistical data obtained from the different modes of rail transportation, such as Metro, Marmaray, Tramway, and İsbike bicycle

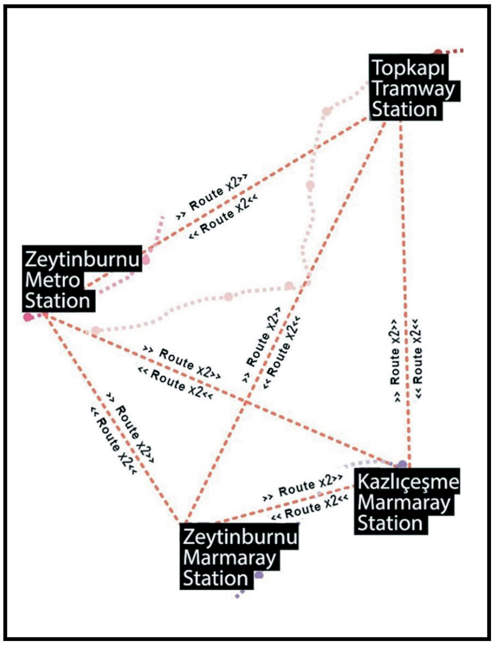
Figure 5. User density of İsbike stations (green bars show the change in the number of rentals in a year, while the black error bars show the standart deviation of a station)



stations, reveal that the region has gained more urban accessibility in recent years. In this phase of the method, bicycle routes were generated between the rail transport stations to evaluate the bikeability and reveal the integration of bicycle travel with other rail transport modes. In **Figure 6** (left image), the main rail transport stations are determined, and four different bicycle routes between each pair. **Figure 6** (right image) shows the exact path of each route, also pointing out the İsbike stations. Starting and ending points of these routes are Zeytinburnu Metro Station, Topkapı Tram Line, Zeytinburnu Marmaray Line, and Kazlıçeşme Marmaray Stations (**Figure 7**). During the route-generation phase, in line with space syntax analysis taken into consideration, 24 different bicycle routes were created that will intersect with two İsbike stations on the route. These routes have been designed as round trips, considering the use of the road and existing shared bicycle roads.

Phase 3: Experience and Evaluation of the Routes

After routes were generated in section 4.2, it is decided to get the ideas of the bicyclists on the bikeability of these routes. Therefore, eight bicyclists from a local bicycling club familiar with the area participated in the study. Three independent bicyclists tested these 24 routes (Table 2), and their experiences, speed and stop points were recorded via Strava application (mobile app). The bicyclists are coded as BR1, BR2, … BR 8, and each



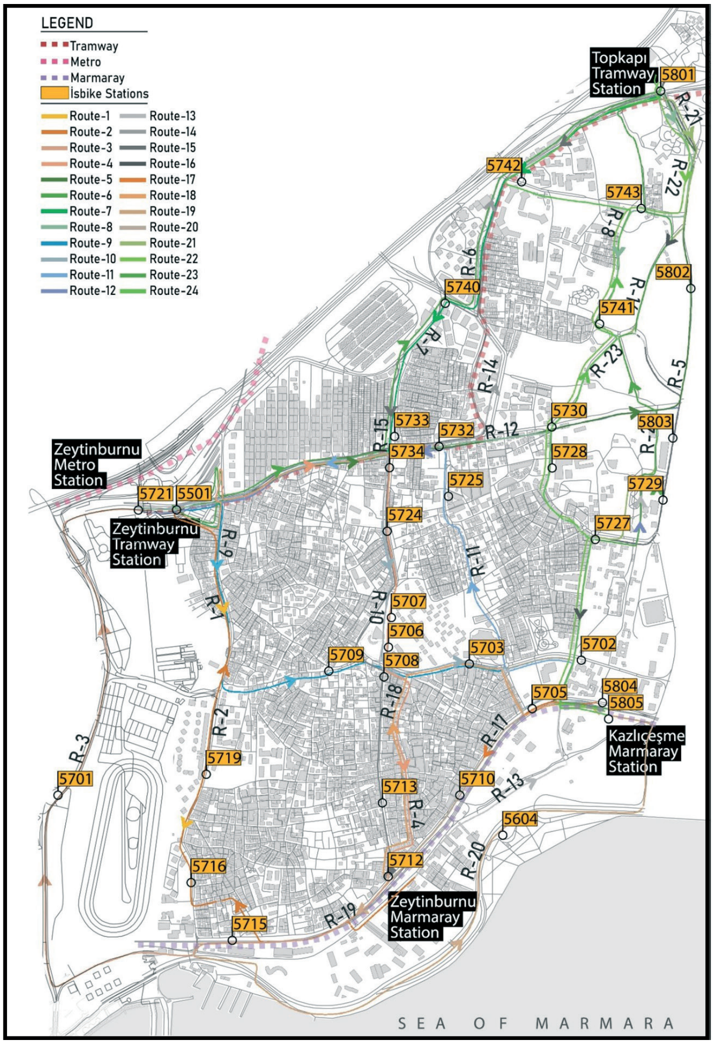


Figure 6. (left) Image shows the generation matrix of the routes between the stations , (right) Image shows the 24 generated bicycle routes, and the İsbike stations on them.

	public transport start point (also an İsbike station)	first stop (FS1)	second stop (SS1)	third stop (TS1)	final stop (FS2)	total distance (km)	
Route 1	Metro (Zeytinburnu)	5501 Zeytinburnu Metro 1	5719 Bozkurt Camii	5716 80. Yıl Cumhuriyet Parkı	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	3,73	Between Zeytinburnu Metro - Zeytinburnu Marmaray
Route 2	Metro (Zeytinburnu)	5721 Zeytinburnu Metro 2	5719 Bozkurt Camii	5715 Zübeyde Hanım Caddesi 3	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	3,68	
Route 3	Marmaray Zeytinburnu	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5715 Zübeyde Hanım Caddesi 3	5701 Veliefendi Hipodrom	5721 Zeytinburnu Metro 2	5,60	
Route 4	Marmaray Zeytinburnu	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5713- Zeytinburnu Noterliği	5706- Zeytinburnu Kaymakamlık	5501 Zeytinburnu Metro 1	3,35	
Route 5	Metro (Zeytinburnu)	5501 Zeytinburnu Metro 1	5730- Zeytinburnu İmam Hatip Lisesi	5802 Kozlu Otobüs Durağı	5801 Topkapı Tramway Durağı	4,32	Between Zeytinburnu Metro- Topkapı Tramline
Route 6	Metro (Zeytinburnu)	5721 Zeytinburnu Metro 2	5734 Zeytinburnu Belediyesi Aşevi	5740 Kiptaş Merkezefendi Meydanı	5801 Topkapı Tramway Durağı	4,97	
Route 7	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5740 Kiptaş Merkezefendi Meydanı	5733 Mevlana Caddesi	5501 Zeytinburnu Metro 1	4,84	
Route 8	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5743 FSM Üniversitesi	5732 Öğretmenler Parkı	5721 Zeytinburnu Metro 2	4,89	
Route 9	Metro (Zeytinburnu)	5501 Zeytinburnu Metro 1	5709 74. Sokak	5703 Zeytinbunu Akdem	5804 Kazlıçeşme Marmaray 1	3,39	Between Zeytinburnu Metro- Kazlıçeşme Marmaray
Route 10	Metro (Zeytinburnu)	5721 Zeytinburnu Metro 2	5733 Mevlana Caddesi	5707 Zeytinburnu Kültür Merkezi	5805 Kazlıçeşme Marmaray 2	3,54	
Route 11	Marmaray Kazlıçeşme	5804 Kazlıçeşme Marmaray 1	5725 Dr. Sadık Ahmet Sokak	5732 Öğretmenler Parkı	5501 Zeytinburnu Metro 1	3,69	
Route 12	Marmaray Kazlıçeşme	5805 Kazlıçeşme Marmaray 2	5727 100. yıl Meslek Lisesi	5803 Biruni Üniversitesi	5721 Zeytinburnu Metro 2	3,57	
Route 13	Zeytinburnu Marmaray	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5729 Belgradkapı Sosyal Tesisleri	5802 Kozlu Otobüs Durağı	5801 Topkapı Tramway Durağı	5,27	Between Zeytinburnu Marmaray- Topkapı Tramline
Route 14	Zeytinburnu Marmaray	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5724 Zeytinpark	5742 Cevizlibağ Atatürk Öğrenci Yurdu	5801 Topkapı Tramway Durağı	5,60	
Route 15	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5740 Kiptaş Merkezefendi Meydanı	5708 58. Bulvar	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	3,38	
Route 16	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5803 Biruni Üniversitesi	5710 Zübeyde Hanım Cad. 1	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5,69	
Route 17	Marmaray Kazlıçeşme	5804 Kazlıçeşme Marmaray 1	5705 Zeytinbunu İtfaiye	5710 Zübeyde Hanım Cad. 1	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	1,37	Between Zeytinburnu Marmaray- Kazlıçeşme Marmaray
Route 18	Zeytinburnu Marmaray	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5713 Zeytinburnu Noterliği	5703 Zeytinbunu Akdem	5805 Kazlıçeşme Marmaray 2	2,09	
Route 19	Zeytinburnu Marmaray	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	5715 Zübeyde Hanım Cad. 3	5604 Kazlıçeşme Sahil park	5804 Kazlıçeşme Marmaray 1	2,67	
Route 20	Marmaray Kazlıçeşme	5805 Kazlıçeşme Marmaray 2	5702 Süleymaniye Kadın Doğum Hast.	5705 Zeytinbunu İtfaiye	5712 Zübeyde Hanım Cad. (Marmaray Zeytinburnu)	1,81	
Route 21	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5802 Kozlu Otobüs Durağı	5729 Belgradkapı Sosyal Tesisleri	5804 Kazlıçeşme Marmaray 1	3,66	Between Topkapı Tramline- Kazlıçeşme Marmaray
Route 22	Topkapı Tramline T1	5801 Topkapı Tramway Durağı	5741 Merkez efendi Parkı	5728 Textil Port	5805 Kazlıçeşme Marmaray 2	4,03	
Route 23	Marmaray Kazlıçeşme	5804 Kazlıçeşme Marmaray 1	5727 100. yıl Meslek Lisesi	5803 Biruni Üniversitesi	5801 Topkapı Tramway Durağı	3,87	
Route 24	Marmaray Kazlıçeşme	5805 Kazlıçeşme Marmaray 2	5730 Zeytinburnu İmam Hatip Lisesi	5743 FSM Üniversitesi	5801 Topkapı Tramway Durağı	3,87	

Figure 7. Generated routes and the İsbike stations on them

bicyclist rode 10 routes. The routes are given to bicyclists in a random order. They experience these routes in mid-November 2019, during weekend morning hours. In the table, the start and stop İsbike stations are also noted with their number codes.

After the bicycle riding experience, a survey is given to bicyclists to evaluate the routes they drove. In the survey, the evaluation criteria are; (i) The physical factors; route ergonomy, wayfinding, start-end stations, and stops in route; (ii) the environmental factors; vehicle and human traffic, desired speed, and integration to the rail transport system; and (iii) visual factors; landmarks in the route and greenery (**Table 3**). In order to evaluate these criteria, a survey is given to bicyclists and asked them to evaluate each route on a Likert scale (1-not relevant, 5-highly relevant). After all replies are taken on an online survey platform (Survey Monkey), the authors generate a formula with these criteria to find an overall integration value. However the weights of the criteria depends on the past experiences and observations during site trip. Since this work has been developed through a graduate course in YTU, the discussions are made through graduate students (architects), and come up with a consensus on which criteria affect the other in a positive or negative way. We have proposed that criteria A (Route Ergonomy), B (Wayfinding), E (desired speed), F (integration to railway), G (landmarks in the route) and H (greenery) affect the integration positively, whereas D1 (vehicle traffic), D2(human traffic), C1 (stops in route) and C2 (start and end stops in the route) affect negatively. The formula is:

$$[(AxBxExFxGxH)/(((D1+D2)/2)x2/((1/C1)+(1/C2)))]^{1/4}$$

Table 2. Route Experience Matrix by Bicyclists

	(start) İsbike station code	(end) İsbike station code	1st Tour	2nd Tour	3rd Tour	4th Tour	5th Tour
Route 03	5712	5721	BR1	BR3		BR5	
Route 01	5501	5712	BR1	BR3		BR5	
Route 04	5712	5501	BR2	BR4		BR6	
Route 02	5721	5712	BR2	BR4		BR6	
Route 13	5712	5801	BR3	BR1		BR7	
Route 15	5801	5712	BR3	BR1		BR7	
Route 14	5712	5801	BR4	BR2		BR8	
Route 16	5801	5712	BR4	BR2		BR8	
Route 19	5712	5804			BR3	BR4	BR1
Route 20	5805	5712			BR5	BR6	BR2
Route 11	5804	5501	BR5	BR7		BR1	
Route 09	5501	5804	BR5	BR7		BR1	
Route 12	5805	5721	BR6	BR8		BR2	
Route 10	5721	5805	BR6	BR8		BR2	
Route 23	5804	5801	BR7	BR5		BR3	
Route 21	5801	5804	BR7	BR5		BR3	
Route 24	5805	5801	BR8	BR6		BR4	
Route 22	5801	5805	BR8	BR6		BR4	
Route 17	5804	5712			BR7	BR8	BR3
Route 18	5712	5805			BR1	BR2	BR4
Route 05	5501	5801		BR3	BR2		BR1
Route 07	5801	5501		BR3	BR2		BR1
Route 06	5721	5801		BR8	BR4		BR5
Route 08	5801	5721		BR8	BR4		BR5

* BR1, BR2, BR3, BR4, BR5, BR6, BR7, BR8 are independent bicyclists who voluntered to be part of this study. The scheme shows which cyclist ride which route.

RESULTS

The results show that Routes 2, 19, 21, and 22 have high integration within physical, environmental, and visual factors. It has been revealed that cyclists have a better driving experience on these routes, the integration with rail transport stations is high, and the rate of preferring these routes is also high. Although Routes 5, 6, 7, 11, and 12 are located on the route where İsbike stations have high usage rates, as seen in Table 3, the integration values are very low (**Table 3**).

When the statistical data collected by İsbike are analyzed, it can be observed that the usage rates of stations 5501 and 5721 located near "Zeytinburnu Metro Station" were significantly higher compared to other stations (**Figure 5**). In this respect, it can be stated since the density of bicycle rent is high, the integration values are also high in Routes 1, 2, 9 and 10.

It can be derived from Table 3 that bicycle routes passing through 10. Yıl Caddesi (Route 5, 21, 22) are preferred by bicyclists over other routes. It must also be noted that these routes house some of the highly populated centers of attraction, such as the İsbike stations 5803 and 5729. However, it is found that they cannot achieve their potential because of the dense traffic flow and roads occupied by other vehicles, therefore do not offer a comfortable bicycle ride. No significant differences were observed between Routes 10 and 15 and Routes 11 and 14, downslope bicycle routes, although the former had a higher integration score than the latter. Route 19, designed for recreational purposes, had an integration score of 4.96/5, thus being the route with the highest integration score and fulfilling its recreational functions successfully. Station 5740, a part of Routes 6 and 7, is useful

	PHYSICAL FACTORS				ENVIRONMENTAL FACTORS				VISUAL FACTORS		
	Physical Condition	Cycling Route Type	Distance		Density of Traffic		Cycling Speed	Integration to railway	Building Pattern	Relationship with the greenery	
	A	B	C1	C2	D1	D2	E	F	G	H	
	Route Ergonomy	Wayfinding	Stops in route	Start and end stops in the route	Vehicle Traffic	Human Traffic	Desired Speed	Integration to railway system	Landmarks in the route	Greenery	**INTEGRATION VALUE**
Route 1	3,67	3,83	4,50	5,00	3,33	2,33	3,50	4,50	3,17	2,83	**3,49**
Route 2	5,00	4,00	5,00	5,00	3,00	3,00	4,00	5,00	5,00	3,00	**4,47**
Route 3	3,33	3,50	3,00	3,00	3,67	2,00	3,50	4,00	3,17	3,00	**3,68**
Route 4	3,00	3,50	3,50	2,50	2,50	2,00	3,00	4,00	3,50	3,00	**3,77**
Route 5	3,50	2,75	4,50	3,50	5,00	3,75	1,75	1,50	4,00	4,00	**2,20**
Route 6	1,50	3,00	4,00	3,25	4,50	2,75	1,75	4,00	2,25	2,00	**1,82**
Route 7	1,00	1,50	3,25	1,25	5,00	3,25	1,25	1,00	3,50	1,75	**1,11**
Route 8	1,75	2,75	3,75	2,00	4,75	2,50	2,25	3,25	2,75	3,25	**2,40**
Route 9	3,00	3,20	4,40	4,00	2,60	3,00	3,40	5,00	4,00	2,40	**3,40**
Route 10	5,00	5,00	5,00	4,00	5,00	2,00	4,00	5,00	5,00	1,00	**3,56**
Route 11	1,80	3,00	4,00	3,00	2,40	3,60	2,60	4,20	2,60	2,40	**2,45**
Route 12	3,00	1,00	1,00	1,00	5,00	2,00	3,00	1,00	1,00	2,00	**1,51**
Route 13	3,25	2,75	2,75	3,50	3,75	2,50	2,50	3,75	3,00	3,00	**2,98**
Route 14	3,00	2,50	3,00	3,00	4,25	1,75	2,50	3,00	3,50	3,00	**2,85**
Route 15	2,75	3,00	3,50	4,00	4,00	3,00	3,25	4,25	4,00	3,75	**3,38**
Route 16	3,50	3,50	3,75	3,25	4,25	3,00	3,75	4,25	3,75	3,50	**3,77**
Route 17	3,33	3,67	4,00	2,33	3,00	2,33	3,67	4,67	3,33	2,67	**3,92**
Route 18	3,00	4,50	2,00	4,00	4,50	3,50	2,50	2,00	3,50	2,00	**2,58**
Route 19	4,00	4,33	4,67	2,33	3,00	2,00	5,00	2,33	4,67	5,00	**4,96**
Route 20	4,00	3,00	5,00	5,00	3,00	2,00	4,00	4,00	4,00	3,00	**3,68**
Route 21	3,40	3,60	4,40	4,00	2,20	1,80	4,20	4,40	3,60	3,40	**4,26**
Route 22	4,00	3,00	3,00	1,00	2,00	1,00	4,00	1,00	4,00	5,00	**4,54**
Route 23	2,80	2,60	4,60	3,40	2,60	2,60	3,60	4,60	3,20	3,20	**3,32**
Route 24	1,00	1,00	4,00	2,00	3,00	3,00	2,00	1,00	1,00	5,00	**1,06**

Table 3. Route experience survey results evaluating physical, environmental, visual aspects and their final integration values

for bicycle users who work here since industrial areas and cargo centers surround the region. However, it was found that this station had one of the lowest integration scores in the analysis, the reason is dense traffic and lack of greenery again. On the other hand, Route 8, which does not fully overlap the industrial area and intersect the station 5740, had a higher integration score despite its lower usage rate. Therefore, some improvements in the industrial area are quite likely to increase these bicycle users' comforts and usage rates.

Table 3 describes the integration values of the routes in several aspects. Firstly, as in physical factors, one of the most important aspects is Route Ergonomy (A). Unfortunately, the physical form of roads are bad, there are a lot of bumps and holes on the road. The bicyclists also underline that a steep slope negatively affects bikeability. Also, since there are cars parked on the side of the streets, bicyclists are interrupted by their parking. Wayfinding (B) is another physical aspect that positively affects integration value. When landmarks are on the road, it is easier to direct your route and find your way to your destination. A final physical factor is Distance, Number of stops (C1) and Start/End stops (C2) in the route. Depending on the daily routine of the bicyclist, the in-between İsbike stations will help to stop, do your business, and rent another bike along the route, which will affect bikeability as well.

Secondly, focusing on the environmental *factors*, the most crucial issue that decreases a route's integration value is Vehicle (D1) and Human traffic (D2). Bicyclists complain about the dense vehicle traffic in most routes, even on weekends. When there is traffic, Desired Speed (E) is also low, so riding a bicycle is ineffective and safe. There should be segregated bike lanes to develop a better integration to prevent this issue. A final aspect on environmental matters is Integration to Railways (F) which directly affects bikeability. Due to the densest public transport stations, it seems to be relatively high in Routes 2, 19, 21 and 22.

Finally, focusing on visual factors, Landmarks in the route (G) and Greenery (H) are two criteria that positively affect bikeability. Bicyclists underline that greenery on the sides of the bicycle roads is very convenient during long drive hours.

CONCLUSION

The importance of the concept of bikeability, reflected in a significant number of studies in various research areas, especially mobility and transportation, has increased in recent years. Safety, comfort, and efficiency of bike infrastructures, and accessibility to destinations, environmental and visual factors are the most common characteristics associated with bikeability. The fact that there is an important agenda concerning the social distance with the Covid-19 pandemic which affects the whole world, along with environmental negativity such as the increase in individual vehicle use, traffic problems, air, and noise pollution, has made the use of bicycles even more critical. In many countries, electric scooters, vehicles, or shared mobility services are on the agenda in reducing environmental pollution and using bicycles for sustainable transportation. Turkey is also concentrating on this issue, building more bike roads day by day, and smart bike-sharing systems are also increasing rapidly.

As stated before, two critical projects on bike systems were first launched back in 2002 and 2009. The first one, namely Istanbul Bicycle-Route Planning by IBB, and the second (BAKSI, 2021), is the Integrated Smart Bicycle-Sharing System (İsbike). These are the relevant policies considered to guide this research. As in the Istanbul Bicycle-Route Planning guide, it is clearly stated that bicycle roads should be integrated with rail transport. Therefore, this research is important to show the integration degree of bicycle routes in terms of physical, environmental, and visual aspects.

The scope of this research is the evaluation of bikeability in the Zeytinburnu district with the help of space syntax analysis. Along with the integration analysis using space syntax, the district is analyzed to capture bikeability accurately. Besides, using this method, the integration values of routes are derived. As a result, the routes that start and end in main rail transport stations receive higher integration values, showing more suitable routes for cycling.

As stated before in the literature section, studies modeling the route selections of cyclists have various limitations, including lack of detailed biking data (Liu et al., 2016, McCahill and Garrick, 2008). Within this paper, it is shown that working with the local authorities for gathering data is important. Also various bicycling applications on mobile phones (like Strava), help the researchers gather more data about the experiences.

Empirical studies on the use of bicycles and route selection have demonstrated that bicycle users took several criteria, such as distance, the number of crossroads, bicycle stations, and safety, into account (Broach et al., 2011, Dill and Carr, 2008, Winters et al., 2011). Within this research, it is concluded that distance between the attraction points and bicycle stations are also major issues for the bikeability. Moreover, slope is also another issue which effects a good and convenient drive.

Promoting sustainable urban transportation planning, Castañon and Ribeiro (2021) evaluated the integration of bicycle infrastructure in urban environments. Additional to that, this research has shown that, for a sustainable city; bike routes, shared-bicycle systems and rail transport stations should be integrated in terms of physical, environmental and visual factors. One of the most important one is dense traffic and separate bicycle roads. It is observed that, in the most bicycle friendly cities such as Copenhagen, Amstermdan etc., there are separate bicycle roads alternative to vehicle roads. Cities such as Istanbul, should adopt a similar attitude constructing bicycle roads for a more sustainable future.

Finally, bikeability analysis indicates an essential tool in the bicycle network planning process and in defining strategies to encourage bicycle use, especially in urban areas. Space syntax analysis and user experiences must be integrated and evaluated to integrate bike networks into public transport. This allows the definition of a strategy for improving bike infrastructure and promoting more sustainable mobility models.

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BİSİKLET ROTALARININ RAYLI ULAŞIM SİSTEMİNE ENTEGRASYONUN ZEYTİNBURNU İLÇESİ ÖZELİNDE DEĞERLENDİRİLMESİ

Kentlerde sosyo-ekonomik hareketliliğin hızla değişip dönüşmesi, nüfusun hızla artması ve fiziksel çevrenin büyümesi birçok sorunu beraberinde getirmektedir. Bu sorunların başında, yüksek popülasyonun kent içi ulaşım talebinin artışı ile ortaya çıkan ulaşım problemleri gelmektedir. Bireysel taşıt kullanımının artışı, trafik sıkışıklığı, gürültü ve hava kirliliği gibi çevresel sorunlar beraberinde kentsel erişilebilirlik sorunlarını ortaya çıkarmaktadır. Bu nedenle, kent içerisinde erişilebilirliği arttırmak için toplu taşıma ağına, diğer temiz ulaşım araçlarının da entegre edilmesi önem taşımaktadır. Bu entegrasyonunun sağlanabilmesi için, bisikletin kısa ve orta mesafeli yolculuklarda bireysel araçlara alternatif olarak kullanılabilme potansiyeli yüksektir. Sürdürülebilir bir ulaşım aracı olarak bisiklet kullanımının teşvik edilmesi ve raylı ulaşım sistemine entegre olması için bisiklet kiralama sistemleri, bisiklet yolları ve istasyonları gibi çözümler üretilmektedir. Burada önemli olan, bisiklet rotaları ve istasyonlarının doğru planlanması ve raylı ulaşım ile optimum düzeyde entegre olmasıdır.

Bu problem alanından hareketle, İstanbul kenti Zeytinburnu ilçesi özelinde bir alan çalışması yapılmıştır. İBB (İstanbul Büyükşehir Belediyesi) bisiklet kiralama sistemi (İsbike) istasyonlarının; Marmaray, Metro ve Tramvay istasyonları ile entegrasyonu incelenmiş, uygun bisiklet rotaların belirlenebilmesi için mekânsal dizilime dayalı analizler yapılmıştır. Çalışma üç aşamadan oluşturulmuş, (P1) Open Street Map verileri ile DepthMap X yazılımında mekan dizimi analizi yapılmış, (P2) IBB'den alınan toplu ulaşım verileri ile İsbike'dan alınan verilerle uygun bisiklet rotaları oluşturulmuş, (P3) bu rotaların bisiklet sürücüleri ile deneyimlenmesi ve sonrasında fiziksel, çevresel ve görsel kriterlere göre bir anket ile değerlendirilmesi sağlanmıştır. Çalışmada, kentin fiziksel yapısını çözümleyen mekan dizimi analizleri ile kent parçası ölçeğinde bisiklet yollarının raylı ulaşım sistemine entegrasyonu değerlendirilmiş; bisiklet kullanım uygunluğuna yönelik kentsel planlama için öneriler ortaya konulmuştur.

EVALUATION OF THE INTEGRATION OF BIKE ROUTES TO THE RAIL TRANSPORT SYSTEM IN ZEYTINBURNU DISTRICT

The rapid change and transformation of socioeconomic activities in cities, the increase in the population, and the growth of the physical environment bring many problems. One of these problems is the increasing demand for transportation by the increased population. High demand for individual vehicles, traffic congestion, noise, air pollution, and environmental problems adversely affect urban accessibility, quality of life, and social health. Public transport has gained importance to provide access within the city, and other means of clean transportation should be integrated into this system. Bicycles have a high potential to be used as an alternative to individual vehicles on short and medium-distance journeys to ensure this integration into the transportation system. As a sustainable means of transportation, solutions such as bicycle rental systems, bicycle routes, and stations are planned to promote bicycle use and integrate into the rail transportation systems. The most crucial point is to plan bike routes and stations at the right spots and integrate them into the optimum level with the rail transport system.

In the scope of this paper, a field study was carried out in the district of Zeytinburnu, Istanbul. IBB (Istanbul Metropolitan Municipality) bicycle rental system (İsbike) stations have been examined for integration with Marmaray, Metro, and Tramway stations. Therefore, Space Syntax analysis has been performed to determine the relevant bicycle routes. The study was created in three stages, (P1) the Space Syntax analysis is done with Open Street Map data on DepthMapX software, (P2) Bicycle routes are generated with the IBB railway transportation and İsbike station data, and (P3) Bicyclists experienced and evaluated these routes depending on physical, environmental and visual criteria via a survey. Finally, space syntax methods are used to analyze the physical structure of the city, and the integration of bicycle paths into the rail transportation system was evaluated; suggestions for urban planning for bikeability have been put forward.

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