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Article

A method proposal for determining bicycle paths in cities: The case of Denizli (Türkiye)

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ABSTRACT

Despite technological advancements, bicycle transportation has a historical role that has endured and shaped human transportation history. For effective transportation with non-motorized vehicles, it is essential to identify infrastructure opportunities and understand the impacts of the current situation on transportation behaviors. The study area includes the Merkezefendi and Pamukkale districts of Denizli city center. Four different interrelated methods were used in the research: Landscape Analysis, Delphi Technique, Questionnaire Application, and AHP (Multi-Criteria Factor and Weighting). The research consists of four main parts: data collection, evaluation, analysis, and results. Thus, a method proposal allowing for a comprehensive evaluation for establishing a bicycle lane network in the city center of Denizli was aimed. To achieve this, the natural, cultural, and socio-economic characteristics of the selected districts of Merkezefendi and Pamukkale, chosen as the research area, were highlighted. Opinions of employees in various institutions, individuals volunteering in relevant non-governmental organizations (to use the Delphi Technique with 15 experts), and the public (by questionnaire with 863 people) were gathered to develop a bicycle lane network proposal using a holistic planning approach. As a result, a comprehensive set of criteria was evaluated, and inclusiveness was applied extensively. In contrast to other studies, the factors influencing bicycle use in Denizli city center were not limited to literature reviews only but involved a Delphi technique with expert opinions, a survey with the views of bicycle users in the city center, and the researcher's experience and observations. The results obtained through versatile decision-making processes forming the basis of landscape planning studies were evaluated together. Consequently, a method proposal that can be used in planning studies in our country's cities in this regard was developed.

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INTRODUCTION

Despite technological advancements, bicycle transportation has a historical role that has endured and shaped human transportation history. In urban and rural centers where daily travel is short (less than 5 km), bicycles are a suitable means of reducing traffic congestion. Additionally, bicycles offer advantages such as safety, efficiency, low cost, health benefits, and environmental friendliness. Due to these advantages, bicycles can

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play a significant role in sustainable land use planning, transportation, recreation, and economic development initiatives. For effective transportation with non-motorized vehicles, it is essential to identify infrastructure opportunities and understand the impacts of the current situation on transportation behaviors. The suitability of bicycle infrastructure systems (bicycle lanes, corridors, boulevards, and traffic-free streets) has a significant impact on promoting bicycle usage (Moudon et al., 2005; Krizek & Johnson, 2006; Dill, 2009; Schepers et al., 2017). The expansion of bicycle and pedestrian paths plays an active role in encouraging non-motorized travel, contributing not only to attracting new users but also fostering a perception of high safety and secure riding (Kellstedt et al., 2021; Larsen & El-Geneidy, 2011; TEAC, 2011). Studies on this subject have observed an increase in bicycle users in areas where physically separated bicycle paths were created (Li et al., 2012; Frondel & Vance, 2017), or bicycle infrastructure was developed (Iacono et al., 2010; Emond & Handy, 2012; Konstantinidou & Spyropoulou, 2017; Le et al., 2019). The idea of assessing the suitability of an area for bicycle use is a product of studies aiming to explain mobility models based on structural features (Cervero & Kockelman, 1997; Ewing & Cervero, 2010). To develop and evaluate future scenarios of bicycle transportation, compiling data on current bicycle trends in different regions worldwide, analyzing the current state of bicycle transportation, and presenting the existing picture of urban bicycle use is crucial. Therefore, in the literature, specific routes for bicycle paths (or bicycle usage) have been assessed in studies encountered (Altunkasa et al., 2006; Milakis & Athanasopoulos, 2014; Sönmez, 2019; Alkılınç et al., 2021). This is a significant issue in urban bicycle transportation because cyclists do not travel on just one route. Users have requirements for selecting routes at different levels. Therefore, there is a need to determine the suitability of used paths in a few studies (Hsu & Lin, 2011; Alkılınç et al., 2021) rather than conducting studies for appropriate route determination for a single route, as pointed out by Sener et al. (2009). The researcher should initially evaluate all alternative routes between the starting and destination points for cyclists. Criteria used for determining bicycle routes vary depending on the natural, economic, social, and cultural structure. Therefore, planning and designing bicycle paths require specific evaluation criteria tailored to the study area. Many studies have focused on limited evaluations, considering only criteria such as road width (Altunkasa et al., 2006; Küçükpehlivan, 2015; Cengiz & Kahvecioğlu, 2016; Sönmez, 2019), road usage status (Altunkasa et al., 2006; Sener et al., 2009; Hsu & Lin, 2011; Milakis & Athanasopoulos, 2014; Yılmaz, 2014; Cengiz & Kahvecioğlu, 2016; Saplıoğlu & Aydın, 2018; Sönmez, 2019; Mansuroğlu & Dağ, 2020), traffic (flow) speed (Sener et al., 2009; Hsu & Lin, 2011; Milakis & Athanasopoulos, 2014; Yılmaz, 2014), relationship with parks and green areas (Altunkasa et al., 2006; Milakis & Athanasopoulos, 2014; Küçükpehlivan, 2015; Cengiz & Kahvecioğlu, 2016; Sönmez, 2019; Özkan et al., 2020; Alkılınç et al., 2021), relationship with public transport (bus) stops (Cui et al., 2014; Milakis & Athanasopoulos, 2014; Yılmaz, 2014; Küçükpehlivan, 2015; Saplıoğlu & Aydın, 2018; Alkılınç et al., 2021), which allows limited evaluations. In addition to these criteria, some studies have used criteria such as parking conditions on roads (Sener et al., 2009; Yılmaz, 2014; Saplıoğlu & Aydın, 2018), presence of signalization on roads (Sener et al., 2009; Yılmaz, 2014; Saplıoğlu & Aydın, 2018), road/sidewalk landscaping (Mansuroğlu et al., 2019; Sönmez, 2019), relationship with existing bicycle paths (Sener et al., 2009; Yılmaz, 2014; Saplıoğlu & Aydın, 2018; Özkan et al., 2020), relationship with existing bicycle parking areas (Yılmaz, 2014; Saplıoğlu & Aydın, 2018), slope-distance relationship (Milakis & Athanasopoulos, 2014), sidewalk width (Hsu & Lin, 2011). Criteria such as the relationship with bicycle maintenance places and the relationship with existing bike share stations were evaluated for the first time within the framework of comprehensive planning methodology in this study. In this study, considering the impact of recent economic issues in our country and the shift of users towards bicycle use, especially in Denizli due to its completed urban development, the suitability levels of roads for bicycle use in urbanized areas of Denizli were determined by considering all alternative routes within the study area boundaries. Thus, a method proposal allowing for a comprehensive evaluation for establishing a bicycle lane network in the city center of Denizli was aimed. To achieve this, the natural, cultural, and socio-economic characteristics of the selected districts of Merkezefendi and Pamukkale, chosen as the research area, were highlighted. Opinions of employees in various institutions, individuals volunteering in relevant non-governmental organizations, and the public were gathered to develop a bicycle lane network proposal using a holistic planning approach. As a result, a comprehensive set of criteria was evaluated, and inclusiveness was applied extensively. In contrast to other studies, the factors influencing bicycle use in Denizli city center were not limited to literature reviews only but involved a Delphi technique with expert opinions, a survey with the views of bicycle users in the city center, and the researcher's experience and observations. The results obtained through versatile decision-making processes forming the basis of landscape planning studies were evaluated together. Consequently, a method proposal that can be used in planning studies in our country's cities in this regard was developed.

MATERIAL AND METHODS

Material

The study area includes the Merkezefendi and Pamukkale districts of Denizli city center (Figure 1). Despite being recognized primarily as an industrial city, Denizli is also a significant tourism destination. In Denizli, there are 22 ancient cities, including the Pamukkale-Hierapolis World Heritage Site and the Laodikea Archaeological Site, both listed on the World Heritage Tentative List. The increasing use of transportation, mainly by road, in the developing industrial and tourism sectors exacerbates transportation issues in the city. The transportation issues in the Merkezefendi and Pamukkale districts, which form the city center of Denizli, and the associated problems such as environmental pollution, noise pollution, and various health issues have been decisive factors in selecting these two districts as the study area (Figure 1). The boundary of the study area was selected to include the area within 4 km of the centers (Çamlık Park and Pamukkale University), determined by considering the average cycling distances of the public (3-5 km) and literature reviews.

To determine the suitability of the city for bicycle use, various numerical, vector, qualitative, and quantitative research materials were utilized. This includes data from ASTER GDEM (ASTER Global Digital Elevation Map) for creating slope and aspect maps (United States Geological Survey, 2021), Open Street Map data (Open Street Map, 2020) for digitizing transportation infrastructure systems, Denizli Meteorology Provincial Directorate (2019) data for evaluating the city's bioclimatic comfort, Turkish Statistical Institute (2023) data for assessing the population and other socio-economic characteristics, KGM (General Directorate of Highways, 2023) statistics for analyzing and evaluating the city's transportation system, and various reports (Denizli Provincial Directorate of Culture and Tourism, 2023; General Directorate of Forestry, 2023;) for evaluating natural and cultural features. Additionally, efforts toward promoting bicycle transportation in Denizli were examined. Furthermore, ArcGIS 10.0 and IBM Statistics SPSS Version 20.0 programs were used in the evaluation and interpretation of data obtained from the components of bicycle transportation systems, regulations, standards, and literature reviews for the planning of bicycle transportation systems.

Method

Four different interrelated methods (Landscape Analysis, Delphi Technique, Questionnaire Application, and AHP; Multi-Criteria Factor and Weighting) were used in the research. The research consists of four main parts: data collection, evaluation, analysis, and results (Figure 2). All methods used in the research and their stages are interconnected. Therefore, using multiple methods in different sections is believed to validate and increase the reliability of the obtained data.

The first phase of the study covers all kinds of data collection. At this stage, information on national and international standards and national legislation related to the creation of bicycle lanes (construction techniques, routes, and networking) and the dissemination of cycling (training activities and other activities, user characteristics) were presented. In this context, the

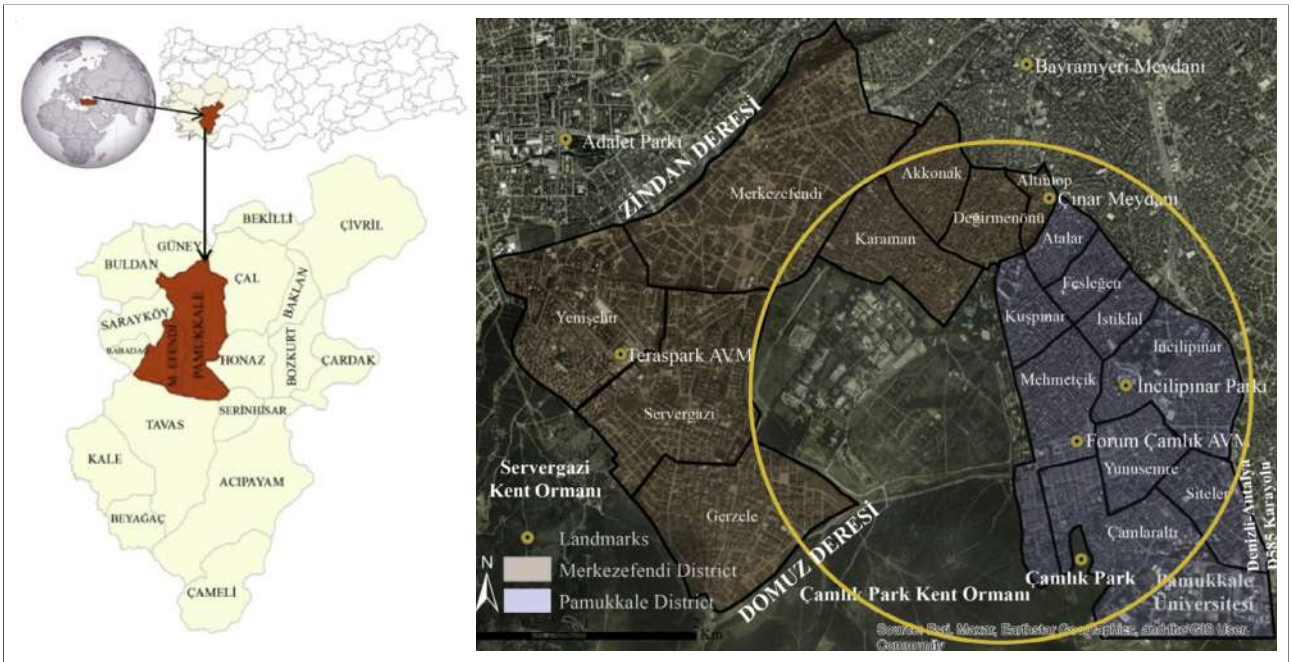

Figure 1. Study area location and some important areas.

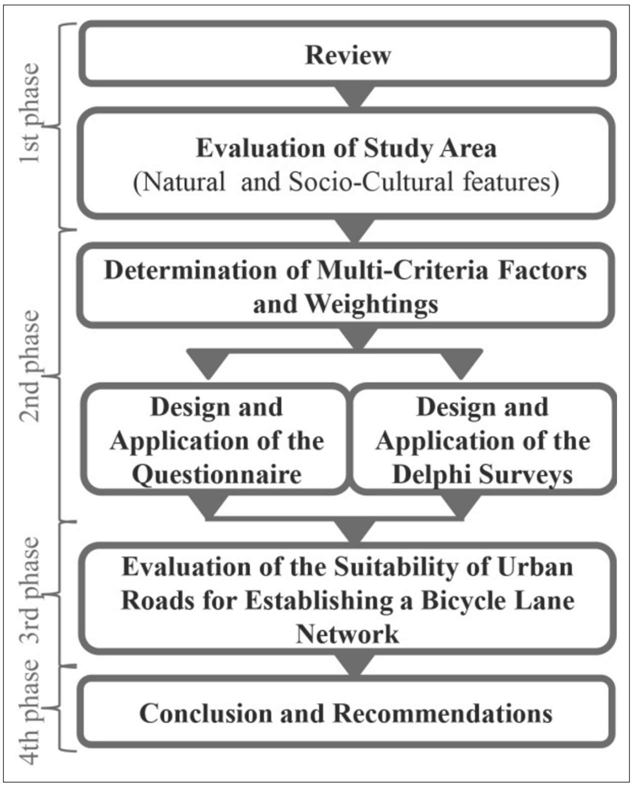

Figure 2. Method flow chart.

"Regulation on Bikeways" (Official Gazette, 2019) and the relevant standards were also examined in detail. At this stage, natural (climate, topographical features, vegetation cover) and socio-cultural structure characteristics (population, transportation facilities, and data on bicycle transportation, current land use status, protected areas) of Merkezefendi and Pamukkale districts were revealed. These data were obtained through interviews with the institutions and organizations described in the material section, plans, projects, and reports made by these institutions, as well as field observations and surveys.

In the second phase of the study, qualitative and quantitative studies were conducted to analyze the opinions of the participant groups. At this phase, the Delphi technique was utilized, and expert opinions and the opinions of the public (to use questionnaires) and bicycle users living in Denizli were consulted. Thus, the consistency, accuracy, and reliability of the data obtained (by using qualitative and quantitative data together) were tested.

In the third phase of the research, criteria influencing bicycle usage in Denizli were determined by evaluating data obtained from expert forms through the Delphi technique and survey applications. Within the framework of these criteria, field studies were carried out, and the suitability of the roads for bicycle use was evaluated using the weighting method. Evaluations were made in terms of suitability for bicycle use in the transportation network providing access to 2 centers (Pamukkale University and Çamlık Park) in Denizli city, where people want to reach by bicycles. In the final phase of the research, utilizing all this data, the suitability of roads in Denizli for bicycle usage was determined and mapped. The methods and techniques used in these study phases are described below:

Delphi Technique

The Delphi technique is a valuable tool for collecting data when researchers need insights from relevant individuals in the problem-solving phase. This technique, conducted in three stages with multidisciplinary participation, involved experts from both technical (2 architects, 3 landscape architects, 1 map technician, 3 urban planners, or 4 civil engineers) and sociological (3 NGOs, 1 public health specialist, 1 sociologist) disciplines. The Delphi technique survey consisted of three rounds, with responses analyzed from 18 experts in the first round, 17 experts in the second round, and 15 experts in the third round. Previous studies by Karacaoğlu (2009), Gencturk & Akbas (2013), Meijering et al. (2015), Kalaycı (2017), Adu-McVie et al. (2021), and Lei et al. (2023) faced similar situations, concluding their research when the number of expert feedbacks was acceptably more than the minimum required (7 experts). Following this approach, the data collection phase of the research using the Delphi technique was concluded by evaluating the opinions of 15 experts.

In the first part of the Delphi questionnaire, there were statements (11) related to the determination of the demographic structure of the participants. In the second part, opinions about the evaluation criteria were included. In this section, experts were asked to express their opinions on the main evaluation criteria that are thought to have an impact on cycling comfort in urban transportation. After the completion of the first-round Delphi technique survey, the responses of all experts were compiled and evaluated. Based on this evaluation, criteria that could be considered in creating a bicycle path were categorized, and second-round survey forms were prepared. The second-round survey form, prepared using standard forms, was sent to experts with adjustments based on a 5-point Likert scale. The results obtained from the second-round survey were re-evaluated. Following the second-round evaluation, a third-round survey form was created. At the end of the research, criteria with a consensus among experts were determined through statistical analyses. These agreed-upon criteria were then utilized in the assessment of the suitability of roads for bicycle use.

Questionnaire

Concurrently with the Delphi technique, a survey was conducted with 863 people using face-to-face interview techniques through standard forms for individuals residing in the Denizli city center. The purpose of the survey was to determine the opinions of individuals within the study area regarding bicycle usage. Data obtained from the survey forms were coded, computerized, and evaluated using IBM Statistics SPSS Version 20.0 software. Frequency analysis was conducted to determine the socio-economic characteristics of the participants, their levels of participation in the survey scales, and the frequency of respondents. To assess the suitability of comparison tests for two or more variables, normality testing was performed using the "Kolmogorov-Smirnov" and "Shapiro-Wilk Test."

AHP; Multi-Criteria Factor and Weighting

In the third phase of the study, various methods were explored to identify suitable roads for bicycle usage. Although multi-criteria methods have been widely used in the transportation context (Giuliano, 1985; Schwartz & Eichhorn, 1997; Yedla & Shrestha, 2003; Tudela et al., 2006; Macharis & Pekin, 2009; Chow et al., 2013), limited applications have been found in bicycle transportation research so far (Gold, 1980 (utilized by Altunkasa et al., 2006); Aultman-Hall et al., 1997; Altunkasa et al., 2006; Hsu & Lin, 2011; Milakis & Athanasopoulos, 2014). The criteria for the methods used in the study were developed by drawing on the mentioned studies for value assignment and calculation. A new evaluation framework (Table 1) was created to align with the research objectives and the study area. In the assignment and calculation of the values of the criteria, an evaluation system was created in accordance with the purpose of the study (Table 1). The subunits of the evaluation factors were given scores ranging from "-1 to +3" (-1 is not appropriate, +1 is slightly appropriate, +2 is appropriate, and +3 is very appropriate).

In the final phase of the research, utilizing all this data, the suitability of roads in Denizli for bicycle usage was determined and mapped. In this context, maps for each criterion affecting bicycle usage in the city center of Denizli were prepared in ArcGIS. These maps were evaluated using the Analytic Hierarchy Process (AHP), one of the multi-criteria decision-making methods, to identify roads suitable for bicycle usage. The AHP was applied in ArcGIS using the "Weighted Overlay" sub-tool under the "Overlay" function in the "Spatial Analyst Tools" of the "Arctoolbox." As a result of the analysis, the roads in the city center were classified based on their suitability for bicycle usage. Thus, the suitability of roads for bicycle usage in the city center was determined. In this context, urban roads were categorized into 4 groups based on suitability levels: not suitable, less suitable, suitable, and highly suitable. However, recognizing that this classification alone was insufficient, a systematic proposal for a bicycle network covering the entire study area of Denizli was developed, considering the connection of the roads with determined suitability levels to existing bicycle paths within the city. The aim was to create comprehensive and safe bicycle riding areas within the city.

FINDINGS

In this section, the characteristics of the area and the results of quantitative and qualitative research are presented. In line with the findings, the suitability of the roads for bicycle usage is discussed and presented using the analytical hierarchy process, one of the multi-criteria decision-making methods.

Features of the Area

The features of the research area that affect bicycle usage and routes were examined under the titles of natural and socio-cultural structure.

Natural Features

Climate features: The average temperature in Denizli is 16.2 °C, the average relative humidity is 59.3%, and the average total precipitation is 571.9 mm according to the long-term averages (1957-2019) (Table 2). Considering the studies on the effect of urban climatic comfort on the rate of bicycle use, it was necessary to evaluate the climatic data in the city. At this stage, the climate characteristics of the city were evaluated using Denizli Provincial Directorate of Meteorology (DPDM, 2019) climate stations' data. Thermal comfort/biocomfort distribution was calculated using the discomfort index (temperature-relative humidity relationship) and classes formulated by Cetin et al. (2019). The study area is located within the comfort zone in terms of thermal comfort classifications.

Topographic features: Slope is an important factor affecting comfortable and safe cycling. Slope is categorized as 0-2% (8.79%), 2-6% (25.60%), 6-12% (22.04%), 12-20% (17.22%), 20-30% (11.99%), and 30+% (14.22%). Aspect also has some influence on bicycle use. It is important in terms of providing comfort by considering the prevailing wind direction in the city center. In rural areas, it affects recreation and mountain biking route determination studies more. According to the results of the aspect analysis in Denizli city, the areas with West (15.08%), Southwest (14.11%), North (14.12%), and Northeast (13.67%) aspects have the highest rates.

Vegetation: In densely populated urban areas, the anthropogenic effects on natural and sensitive areas, as well as protected areas, tend to be more significant compared to rural areas. Additionally, aesthetic/visual concerns within the city and the misdirection by local authorities often result in the frequent use of exotic plant species (*Acer negundo, Ailanthus altissima, Albizia julibrissin, Koelreuteria paniculata, Lagerstromia indica, Liriodendron tulipifera, Magnolia grandiflora, Melia azedarach, Morus platanifolia, Morus papyrifera, Paulownia tomentosa, Prunus cerasifera 'Nigra', Robinia pseudoacacia, Sophora japonica, etc.*) in urban landscape applications. All these factors contribute to the reduction of natural vegetation within the city, and

Table 1. Evaluation criteria and suitability values

Evaluation Criterion	Sub-Criteria	Score*
Road Widths (RW)	2,75 m ≤ RW < 5,50 m	+1
	5,50 m ≤ RW < 11,00 m	+2
	11,00 m ≤ RW ≤ 20,00 m	+3
Sidewalk Width (SW)	SW < 2,90 m	-1
	2,90 m ≤ SW < 4,00 m (one-way bicycle path)	+1
	4,00 m ≤ SW < 5,40 m (two-way bicycle path)	+2
	5,40 m ≤ SW ≤ 10,00 m (two-way bicycle path and green strip)	+3
Slope-Distance Relationship	< %5,00 (distance not significant)	+3
	%5,00 ≤ Slope < %7,00 (max. 240 m)	+2
	%7,00 ≤ Slope < %8,00 (max. 120 m)	+1
	%8,00 ≤ Slope < %9,00 (max. 90 m)	
	%9,00 ≤ Slope < %10,00 (max. 60 m)	-1
	Other (roads not suitable according to the Bicycle Paths Regulation in terms of Slope-Distance relationship)	
Parking Condition	Roads Without Parking	+2
	Parked Roads	+1
Road Usage Status	Pedestrianized Street	+2
	One-way Vehicle Road	
	Two-way Vehicle Road	+1
Traffic (flow) Speed (TS)	TS ≤ 30 km/h	+3
	30 km/sa < TS < 50 km/h	+2
	50 km/sa ≤ TS < 70 km/h	+1
	≥ 70 km/h	-1
Existing Bike Path Relationship	≤ 250,0 m.	+2
	> 250,0 m.	+1
Existing Bike Park Areas Relationship	≤ 250,0 m.	+2
	> 250,0 m.	+1
Existing Bike Share Stations Relationship	≤ 250,0 m.	+2
	> 250,0 m.	+1
Bike Maintenance Areas Relationship	≤ 250,0 m.	+2
	> 250,0 m.	+1
Relationship with Parks and Green Areas	Roads connected to parks and green areas	+2
	Roads not connected to parks and green areas	+1
Relationship with Public Transport (bus) Stops on Roads	Roads with stops	+2
	Roads without stops	+1
Existence of Traffic Signalizations on Roads	Roads with signalization	+2
	Roads without signalization	+1
Road/sidewalk Landscaping	Roads with suitable landscaping for bicycle use	+3
	Roads/sidewalks without landscaping (not hindering bicycle use)	+2
	Roads/sidewalks with faulty landscaping hindering bicycle use	+1

*-1 is not appropriate, +1 is slightly appropriate, +2 is appropriate, and +3 is very appropriate.

Table 2. Climatic data at Denizli climate station (using DPDM, 2019)

Climatic Data	Value
Average High Temperature (°C)	22.5
Average Low Temperature (°C)	10.7
Average Temperature (°C)	16.2
Average Relative Humidity (%)	59.3
Average High Relative Humidity (%)	93.1
Average Low Relative Humidity (%)	23.4
Average Total Precipitation (mm)	571.9
Average Number of Rainy Days	91.1
Average Wind Speed (m/sn)	1.3
Average Number of Stormy Days	5.7

research indicates that these areas may have a lower level of aesthetic/visual appreciation.

Studies conducted by Gürcan (2014) and Acar (2016) in the city center of Denizli reveal the presence of various plant cover types, including maquis, rock, forest, hygrophilic, and cultural vegetation types. The natural plant cover in Denizli city center encompasses 103 families, 379 genera, 568 species, and 576 taxa (Gürcan, 2014). Some common natural plant species observed in the city include *Arabis alpina* subsp. *brevifolia, Arbutus unedo, Asparagus acutifolius, Carlina biebersteinii* subsp. *brevibracteata, Cedrus libani, Cistus creticus, C. salviifolius, Dianthus elegans* var. *elegans, Juncus acutus* subsp. *acutus, Laurus nobilis, Lathyrus saxatilis, Platanus orientalis, Myrtus communis, Phillyrea latifolia, Pinus brutia, P. nigra, Pistacia terebinthus, Populus alba* subsp. *alba, Quercus coccifera, Q. petrea, Q. robur, Salix babylonica,* and *Vitex agnus-cactus*.

Socio-Cultural Features

Population: The population of Merkezefendi and Pamukkale districts has been steadily increasing. The population of Merkezefendi district was 336,818 in 2022, while Pamukkale district had a population of 347,926 (Turkish Statistical Institute, 2023). The presence of a university in Pamukkale district contributes to a higher number of young, dynamic individuals who are potentially inclined towards bicycle usage.

Transportation facilities and studies on bicycle transportation: Denizli, being a crucial intersection connecting the Aegean and Central Anatolia regions and recognized for its significance in agriculture, industry, and cultural tourism, has heavy motor vehicle traffic. According to the obtained data, as of the current situation, there are 14.85 km of bicycle lanes in the city center, and plans for proposed bicycle lanes have been made. However, it is noteworthy that as of 2022, the proportion of bicycle lanes within the transportation system in Denizli is only 0.63%. In addition, considering the city's population of 684,744 people in 2022 and the number of registered automobiles (215,984) and motorcycles (77,472), the motor vehicle ownership rate in the city is quite high, reaching 28.29%. This situation indicates the dominance of motor vehicles in the transportation preferences of the city's residents. The lack of connectivity among existing bicycle lanes contributes to the inadequacy of the bicycle transportation network. Consequently, due to insufficient bicycle infrastructure, the public perceives bicycle usage for transportation as unsafe.

Land cover: The land use status of Denizli city was evaluated according to the CORINE Level 3 land cover class. It is observed that coniferous forests have the largest share in the city, accounting for 24.67%. Continuous urban structure represents 2.71%, indicating that the city is continuously developing and there is a need for new settlements.

Protected areas: In terms of protected areas, the largest conservation area within Pamukkale district boundaries is the Pamukkale Special Environmental Protection Area (Pamukkale ÖÇKB-6,656 ha), with 97 registered conservation areas in the district. The protected areas within the district include various types such as ancient city (2), tumulus (5), archaeological site (13), necropolis area (10), marble quarry (1), rock tomb (8), cultural structure (7), religious structure (12), cemetery (6), civilian architecture example (36), agricultural industry structure (2), and military structures (Dağ & Mansuroğlu, 2023).

In the Merkezefendi district, the most well-known conservation area is the ancient city of Laodikeia, which is included in the Temporary Cultural Heritage List with reference number 5823 in UNESCO's meeting on April 15, 2013. In the district, there are 1 ancient city, 4 tumulus, 6 archaeological sites, 5 necropolis areas, 7 rock tombs, 12 cultural structures, 17 religious structures, 3 industrial structures, 3 cemeteries, and 58 examples of civilian architecture, totaling 112 registered conservation areas (Dağ & Mansuroğlu, 2023).

Delphi Technique and Questionnaire Application

Of the 18 experts who participated in the Delphi study, 16.7% were female, and 83.3% were male. Of these, 72.3% were married, 11.1% were single, and 5.6% were divorced. The youngest expert participating in the study was 30 years old (1 person) and the oldest was 55 years old (2 people), with the average age of the group being 41. Details about the participants' age, occupation, and education level are presented in Table 3.

Of the survey participants, 49.9% were female and 50.1% were male. The youngest respondent was 18 years old (48 people), and the oldest respondent was 78 years old (1 person), with an average age of 31.46 years. Participants in the 18-24 age group constituted the highest proportion

Table 3. Socio-economic characteristics of the expert group

Age	Percent (%)	Occupation	Percent (%)	Education Level	Percent (%)
30-34	33.3	Academician	44.4	High School/College	11.1
35-44	33.3	Civil Servant	33.3	University	33.3
45-54	22.2	Worker	5.6	Master's Degree	11.1
≥ 55	11.1	Private Sector	16.7	Doctorate	44.4

(45.3%), followed by the 25-34 age group (21.9%), the 35-44 age group (16.9%), the 45-54 age group (10.0%), the 55-64 age group (4.2%), and the 65 and over age group (1.7%). Some individuals beyond a certain age expressed a lack of interest in participating in the survey, possibly due to the common perception that bicycles are predominantly used by younger individuals. The rate of high school (46.3%) and university (34.1%) graduates is notable. Regarding occupations, 30.0% of participants are students, 16.3% are civil servants, and 13.6% work in the private sector (Table 4).

72.3% of the experts commute by car, 16.7% by public transportation, 5.6% on foot (1 km), and 5.6% by bicycle (6 km). Among the survey participants, 30.9% use private vehicles for transportation, 35.0% use public transportation, 19.0% walk, and 2.0% use bicycles regularly. 10.7% of private vehicle users mentioned that their transportation choice could be more economical; however, they continue to use a vehicle for the sake of shortening transportation time and comfort. Public transportation users express complaints about the overcrowding of vehicles (30.8%), lack of economic feasibility (25.4%), and untimeliness (22.4%). It was observed that bicycle users were satisfied with their transportation preferences. In Denizli, 78.8% of participants believe there is a traffic problem, and 37.1% consider infrastructure inadequacy as the most significant cause of traffic issues in the city. Additionally, participants believe that improving bicycle infrastructure will increase bicycle usage in the city (73.9%; mean: 3.97; Std. Dev.: 1.198; $p<0.001$) and partially solve transportation problems (76.1%; mean: 4.08; Std. Dev.: 1.125; $p<0.001$). Considering all these factors, the criteria to be considered for establishing a bicycle network in Denizli, based on the opinions of experts and survey participants, are presented in Table 5. After evaluations, 14 assessment criteria were identified for establishing bicycle infrastructure in Denizli, where there is a consensus between experts and bicycle users.

Determination of Multi-Criteria Factors and Weightings

In order to determine the multi-criteria factor weighting degrees, Delphi technique survey forms and data obtained from the questionnaire conducted with cyclists were used. Weight coefficients were graded according to the scores obtained. Accordingly, the difference between the highest (4.61) and the lowest (4.02) score (0.59) was calculated and proportioned to the total coefficient (3). The obtained value (0.19) was used to determine the weighting coefficient. According to Table 5, it is noteworthy that the priorities of experts and bicycle users in determining the evaluation criteria are different. For example, while experts prioritize safety-related criteria such as traffic flow speed and the presence of signalization, cyclists prioritize criteria related to road and sidewalk width, highlighting the importance of cycling comfort.

However, although cyclists indicate that the slope-distance relationship, an important criterion for cycling comfort, is of moderate importance (mean: 3.30), experts, approaching the issue technically, consider the importance level of the relevant criterion to be high (mean: 4.40) (Table 5). This situation is associated with bicycle users' awareness of the city having road features suitable for bicycle use in terms of slope distance. Additionally, differences in the opinions of experts and bicycle users are evident regarding the relationship between proposed bicycle paths and existing

Table 4. Socio-economic characteristics of the respondents

Age	Percent (%)	Occupation	Percent (%)	Education Level	Percent (%)
18-24	45.3	Civil Servant	16.3	Primary/Secondary S.	8.1
25-34	21.9	Worker	11.5	High school	46.3
35-44	16.9	Unemployed	5.9	High school (Univ.)	7.6
45-54	10.0	Student	30.0	University	34.1
55-64	4.2	Retired	5.6	Master/PhD	3.8
≥ 65	1.7	Private sector	13.6		
		Other	17.1		

Table 5. Evaluation criteria that can be used in the establishment of bicycle infrastructure according to the opinions of experts and bicycle users (public)

Evaluation Criterion	Experts' Opinions		Bicycle Users' Opinions		Average	Weight Degree
	Mean	SD	Mean	SD	Mean	
Traffic (Flow) Speed	4.80	0.41	4.12	1.09	4.46	3
Presence of Signalization	4.80	0.41	4.18	1.25	4.49	3
Road Widths	4.73	0.45	4.49	0.92	4.61	3
Sidewalk Width	4.73	0.45	4.49	0.92	4.61	3
Parking Condition	4.66	0.61	4.34	1.07	4.50	2
Relationship with Parks and Green Areas	4.60	0.50	4.26	0.97	4.43	2
Relationship with Existing Bicycle Parking Areas	4.60	0.50	4.39	0.99	4.49	2
Relationship with Existing Bicycle Paths	4.40	0.82	4.18	1.07	4.29	2
Slope-Distance Relationship	4.40	0.82	3.30	1.44	4.35	2
Relationship with Public Transport (Bus) Stops	4.53	0.51	4.41	0.99	4.47	1
Road Usage Status	4.46	0.51	3.58	1.37	4.02	1
Relationship with Bicycle Maintenance Areas	4.46	0.51	3.58	1.27	4.02	1
Relationship with Existing Bike Share Stations	4.46	0.51	3.58	1.27	4.02	1
Road/Sidewalk Landscaping	4.40	0.63	4.26	0.97	4.34	1

bicycle infrastructure. This is the consequence of the fact that existing bicycle infrastructure systems primarily serve recreational purposes. Thus, the hypothesis that more realistic and applicable planning studies can be conducted by considering expert and user opinions together is confirmed.

After obtaining responses from experts and bicycle users, the evaluation criteria used to determine the suitability of bicycle paths were examined based on the averages. Road and sidewalk widths received the highest score (4.61), while factors such as road usage status, relationship with bicycle maintenance areas, and relationship with existing bike share stations received the lowest score (4.02) (Table 5). Based on these criteria, factor degrees for the suitability of roads for bicycle use were determined according to the following suitability levels.

Evaluation of the Suitability of Urban Roads for Establishing a Bicycle Lane Network

According to 14 evaluation criteria, the suitability of the roads in the study area for the creation of a bicycle path network was evaluated (Figure 3). In terms of road widths, 56.69% of the roads in the study area are suitable for bicycle use (Figure 3a). The widest road in the study area is 20.00 m, while the narrowest is 3.00 m. The proportion of roads with a width between 11.00 m and 20.00 m (very suitable) is 11.08% (47.00 km). Roads with a width of 5.50 m to 11.00 m are suitable (56.69%; 240.25 km).

Sidewalks are mostly not suitable for bicycle use in terms of width (Figure 3b). The rate of roads with a sidewalk width of less than 2.90 m is 79.23%. 12.48% of sidewalks are 2.90-4.00 m wide and 4.48% are 4.00-5.40 m wide. Only 1.42 km of sidewalks have a width (5.40 m and above) suitable for the creation of two-way bicycle lanes and green belts.

Regarding the slope-distance relationship, the percentage of roads considered very suitable is 83.12% (Figure 3c). Roads with a slope between 5.00%-7.00% and a length of up to 240 m are suitable. For roads with a slope of 7.00%-8.00%, the maximum distance was 120 m. For roads with a slope of 8.00%-9.00%, the maximum distance was 90 m, and these roads were classified as less suitable.

In a significant part of the study area (64.62%), roads have parking, while the percentage of roads without parking is limited to 31.85% (Figure 3d). During the evaluation of the suitability of roads for bicycle use, roads with vehicle parking were considered as less suitable and roads without vehicle parking were considered as suitable because they negatively affect bicycle use (Figure 3d).

Pedestrianized streets (0.71%), one-way vehicle roads (12.58%), and two-way vehicle roads (83.18%) are present in the study area (Figure 3e). The percentage of roads with a traffic speed of 50 km/h and above is quite high (91.61% less suitable, 1.27% not suitable) in terms of traffic speed, and these roads are considered less suitable for bicycle use (Figure 3f).

Bicycle paths in the study area constitute only 3.52% of all

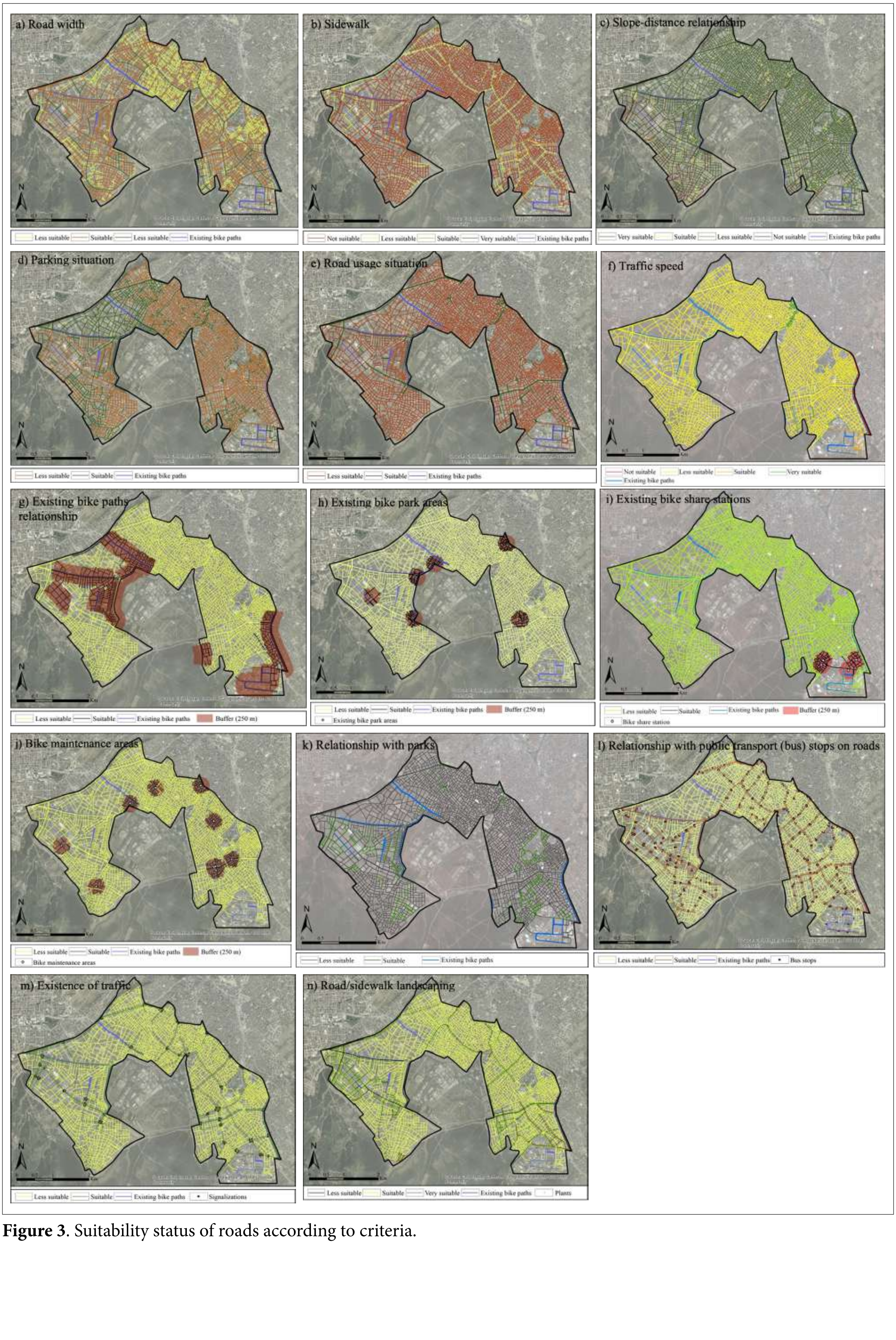

Figure 3. Suitability status of roads according to criteria.

roads (Figure 3g). Due to the inadequacy of existing bicycle paths (14.96 km) in Denizli city, the percentage of suitable roads related to existing bicycle roads is also quite low (19.03%). A total of 22.68 km (5.35%) of roads related to existing bicycle parking areas were identified as suitable for bicycle use (Figure 3h). Due to the low number of bicycle parking areas, the rate of unsuitable roads (91.11%) is quite high. Bike share stations within the study area cover 2.93% (12.44 km) of the roads according to the suitability zone (Figure 3i).

In terms of the relationship with bicycle maintenance/repair facilities that bicycle users may need at any time, 8.31% of the roads evaluated are suitable (Figure 3j). As a component of the urban green infrastructure system, the relationship of bicycle paths with existing green spaces should be taken into consideration (Figure 3k). In this context, roads that are connected to existing green spaces are considered suitable for bicycle use (11.66%), while roads that are not directly connected are considered less suitable (84.80%).

The public transportation (bus) vehicle route is considered suitable for bicycle use with the aim and objective of integrating bicycles into public transportation (Figure 3l). In this context, 20.27% of the roads within the boundaries of the study area (on which there is a bus stop) are considered suitable.

Roads with signalization are preferred by cyclists as they feel safer. Therefore, 70.66 km (16.67%) of roads with signalization in the study area are suitable for cycling (Figure 3m). In the study area, roads with vegetation suitable for cycling (13.49%) are very suitable. Roads with no planting were considered suitable (80.29%), and roads with faulty planting (2.68%) were considered less suitable (Figure 3n).

In the specific context of Denizli city, the suitability of roads for bicycle use was determined using a weighting technique based on the 14 evaluation criteria (Figure 4). In terms of bicycle use, there is 5.74 km (1.35%) of very suitable roads, 65.63 km (15.48%) of suitable roads, 242.89 km (57.30%) of less suitable roads, and 94.65 km (22.32%) of unsuitable roads in the research area.

CONCLUSION AND DISCUSSION

In this study, the natural and socio-cultural features of Denizli city were comprehensively evaluated using a landscape planning approach, and the suitability of roads for bicycle use was determined based on the criteria identified through the Delphi technique and a survey. Suitability maps for 14 criteria influencing bicycle use in Denizli were created, and these maps were evaluated using a weighting method to determine the suitability of roads for bicycle use in the city. As a result, the suitability of roads for bicycle use in the city center was revealed. In this context, urban roads were classified into four groups (not suitable, less suitable, suitable, and very suitable) based on their suitability levels. However, this classification alone was not sufficient. Considering the goal of creating comprehensive and safe cycling areas in the city, a systematic bicycle route network proposal was developed for the study area covering Denizli, considering the connection of the identified roads with existing bicycle paths. Criteria identified through the Delphi technique and user surveys were used in the development of the proposed bicycle route network, which considered factors such as the centrality of the route, the number of intersections, access to educational institutions (schools, education centers), readability, access to desired destinations (official buildings, squares, historical and cultural sites/structures, parks), and compatibility with existing bicycle infrastructure systems. The proposed bicycle route network is presented in Figure 5. A total of 26.49% of the roads within the study area are prioritized for

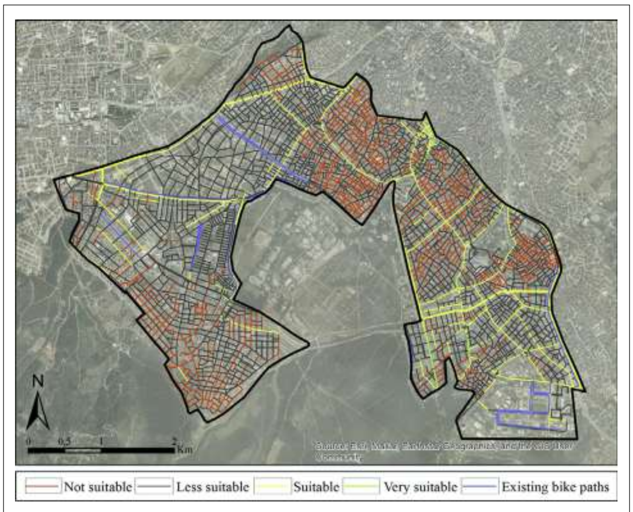

Figure 4. Suitability of roads for bicycle use.

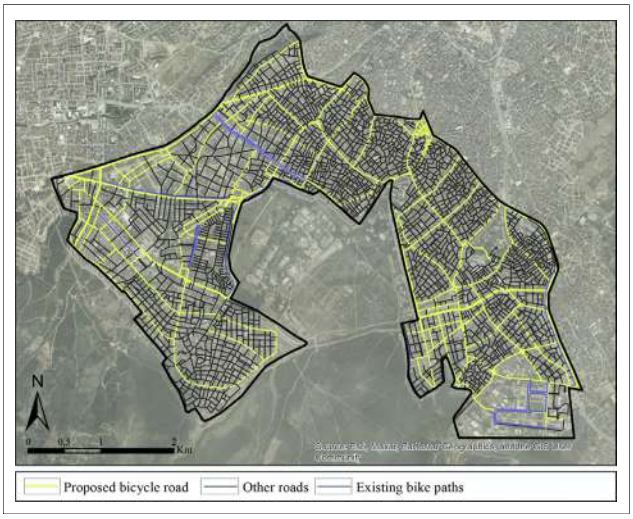

Figure 5. Proposed bicycle road network.

the proposed bicycle route network. The proposed bicycle route network exhibits a comprehensive structure covering the study area (Figure 5).

In this study, the weighting method of evaluation criteria used to determine the suitability of roads for bicycle use differs from previous studies. In the weighting of roads, Milakis & Athanasopoulos (2014) consulted the opinions of 10 professional cyclists, Altunkasa et al. (2006) consulted 10 design experts, 10 bicycle users, and 10 decision-makers (local government authorities), Cengiz & Kahvecioğlu (2016) consulted 10 cyclists, and Sönmez (2019) consulted the opinions of 5 landscape architects, 5 architects, 5 urban planners, and 5 cyclists. Alkılınç et al. (2021), Özkan et al. (2020), and Hsu & Lin (2011) did not provide any information about the number and characteristics of the expert group in their studies that mentioned relying on expert opinions for the weighting of criteria. Çeyiz & Koçak (2015) conducted interviews with 12 professionals, and Mansuroğlu & Dağ (2019) interviewed 30 professional cyclists to identify problems encountered in bicycle use. In the scope of this study, an interdisciplinary approach was followed in determining and weighing the criteria used to evaluate the suitability of roads for bicycle use, as stated in the Bicycle Paths Regulation (Official Gazette, 2019). In this context, both user (public) surveys and expert opinions were consulted.

The route selection model for bicycles is much more complex than the model used for motorized vehicles. This is because there are many criteria that influence cyclists' route selection decisions (Ryu et al., 2021). The evaluation criteria used in the research were determined through Delphi technique expert surveys and evaluations conducted in Denizli, in line with the opinions of bicycle users. In this context, compared to other studies, a comprehensive study has been conducted both in terms of the stages of determining the criteria and the versatility of the criteria used. Comprehensive participatory principles were utilized, and all roads were experienced by the researcher by bicycle. Such a comprehensive study has not been encountered in previous research. Many studies have focused on limited evaluations (explained in the introduction section), which allows limited evaluations. Criteria such as the relationship with bicycle maintenance places and the relationship with existing bike share stations were evaluated for the first time within the framework of comprehensive planning methodology in this study.

In conclusion, it is considered that the bicycle infrastructure system in Denizli is insufficient; there are limited safe and comfortable cycling areas within the city, and for the fulfillment of the increasing transportation needs in the city, the bicycle should be seen as a means of transportation. It is thought that this can be achieved by implementing the bicycle infrastructure system as a transportation network model. It is crucial to consider ecological and technical data prepared with landscape plans that preserve these values and contribute to the preparation of transportation plans in cities with important values in terms of natural, cultural, and social features. This is important for ensuring urban integrity, and it is essential to consider the participatory demands of urban residents.

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