Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Determining the criteria for bicycle infrastructure in developing countries via delphi technique: The case of Denizli (Türkiye)

Gelişmekte olan ülkelerde bisiklet altyapisi kriterlerinin delphi tekniği ile belirlenmesi: Denizli (Türkiye) örneği

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Received/Geliş Tarihi: 17.05.2025 Revision/Düzeltme Tarihi: 10.11.2025 doi: 10.65206/pajes.83668
Accepted/Kabul Tarihi: 12.11.2025 Research Article/Araştırma Makalesi

Abstract

The continued expansion of urban areas in the coming years will lead to rapid growth in the size and density of cities. Consequently, facing severe transportation challenges in the future will be inevitable. Addressing this issue requires increasing and diversifying transportation options. Bicycles can play a crucial role in this regard. Since bicycles are suitable for many urban transportation needs, they can significantly contribute to sustainable land-use planning, transportation, recreation, and economic development initiatives. In addition, the expansion of cycling will contribute to the formation of sustainable cities with more environmentally friendly and healthy uses by reducing energy consumption in transportation. However, despite the rapidly growing literature on bicycles in transportation and transportation planning, there is insufficient research on how to prioritize, select, and decide on investments in bicycle infrastructure. This study aims to identify criteria that can be considered in creating bicycle infrastructure systems in Turkey, where the benefits and importance of urban cycling are acknowledged, but a comprehensive national strategy for sustainable transportation and bicycles has yet to be fully developed. To achieve this, a comprehensive study emphasizing the importance of developing policies based on a holistic planning approach and the principle of participation was conducted. The study utilized the Delphi technique, which adopts a participatory planning approach. Over three rounds, criteria to consider in determining bicycle routes were categorized under three main headings: physical, visual, and social factors. As a result, several recommendations were developed for promoting bicycle use and establishing bicycle infrastructure in developing countries.

Keywords: Sustainable Transportation, Delphi Technique, Participation, Bicycle Roads.

Öz

Önümüzdeki yıllarda kentsel alanların genişlemeye devam etmesi, şehirlerin büyüklüğünde ve yoğunluğunda hızlı bir artışa yol açacaktır. Sonuç olarak, gelecekte ciddi ulaşım sorunlarıyla karşılaşmak kaçınılmaz olacaktır. Bu sorunun üstesinden gelmek için ulaşım seçeneklerinin artırılması ve çeşitlendirilmesi gerekmektedir. Bisikletler bu konuda çok önemli bir rol oynayabilir. Bisikletler birçok kentsel ulaşım ihtiyacı için uygun olduğundan, sürdürülebilir arazi kullanımı planlaması, ulaşım, rekreasyon ve ekonomik kalkınma girişimlerine önemli ölçüde katkıda bulunabilir. Ayrıca bisiklet kullanımının yaygınlaşması, ulaşımda enerji tüketimini azaltarak daha çevre dostu ve sağlıklı kullanımlara sahip sürdürülebilir kentlerin oluşmasına katkı sağlayacaktır. Ancak ulaşımda bisiklet ve ulaşım planlaması üzerine hızla büyüyen literatüre rağmen, bisiklet altyapısı yatırımlarının nasıl önceliklendirileceği, seçileceği ve karar verileceği konusunda yeterli araştırma bulunmamaktadır. Bu çalışma, kent içi bisiklet kullanımının faydaları ve öneminin kabul edildiği, ancak sürdürülebilir ulaşım ve bisiklet için kapsamlı bir ulusal stratejinin henüz tam olarak geliştirilmediği Türkiye'de bisiklet altyapı sistemlerinin oluşturulmasında dikkate alınabilecek kriterleri belirlemeyi amaçlamaktadır. Bu amaçla, bütüncül planlama yaklaşımına ve katılımcılık ilkesine dayalı politikalar geliştirmenin önemini vurgulayan kapsamlı bir çalışma yürütülmüştür. Çalışmada katılımcı planlama yaklaşımını benimseyen Delphi tekniği kullanılmıştır. Üç tur boyunca bisiklet rotalarının belirlenmesinde göz önünde bulundurulması gereken kriterler fiziksel, görsel ve sosyal faktörler olmak üzere üç ana başlık altında toplanmıştır. Sonuç olarak, gelişmekte olan ülkelerde bisiklet kullanımının teşvik edilmesi ve bisiklet altyapısının oluşturulması için çeşitli öneriler geliştirilmiştir.

Anahtar kelimeler: Sürdürülebilir Ulaşım, Delphi Tekniği, Katılımcılık, Bisiklet Yolları

1 Introduction

Today, more than 50% of the global population resides in urban areas [1]. Urban areas worldwide are expected to nearly triple in size from 2000 to 2030 [2],[3]. For this reason, the development of transportation infrastructure is encouraged worldwide in line with urbanization [4], [5]. Motor vehicles dominate urban transportation globally.

Transportation has multidimensional importance in terms of historical, social, political, environmental and economic aspects [6],[7]. The importance of transportation is growing due to trends such as increasing demand, reducing costs, and developing infrastructures. However, ideal transportation should be instant, free, have unlimited capacity, and always be accessible [7]. In recent years, the shift from motor vehicle dominance to sustainable transportation modes has become a societal goal. As urban areas continue to expand and cities grow rapidly in size and density, there is a growing need to expand and diversify transportation options.

Bicycles are a suitable mode of transportation in urban areas, playing a key role in sustainable land use planning, recreation, and economic development, as well as in urban transportation.

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Despite the widespread adoption of automobiles, bicycles have remained one of the most fundamental modes of transport for over a century [8]. Particularly in urban and peri-urban areas where the majority of trips are shorter than 5 kilometers, bicycles can reduce traffic congestion and serve as a safe, efficient, low-cost, healthy, and environmentally friendly mode of transport. Additionally, bicycles can be integrated into urban transportation plans to complement public transport systems, public transit, enhancing connectivity and accessibility.

Despite a rapidly growing literature on bicycles in transportation and planning, there is a lack of studies on how to prioritize, select, and decide on bicycle infrastructure investments [9]. Of particular importance are social studies that aim to promoting increased bicycle usage in cities characterized by high cycling prevalence, which are grounded in an analysis of the distinct characteristics of cyclists and their user groups. Establishing criteria to ensure safe and comfortable travel for cyclists are essential when planning and designing bicycle transportation systems. A systematic integration of bicycles into urban transportation is possible only with appropriate planning approaches. According to NCDOT (1994) [10], the bicycle transportation planning process can be simple or complex depending on community characteristics and needs, but fundamental planning principles should be followed regardless of scope.

Literature indices such as the Bicycle Environmental Quality Index (BEQI) (SFDPH, 2014) [11], (Nuñez et al., 2020) [12], the Bikeway Quality Index (BQI) (Renfro and Voros, 2011) [13], Patterson and Fadum, (2013) [14], Chang et al., (2021) [15], and the Bicycle Compatibility Index (BCI) Jones and Carlson, (2003) [16], Ilie et al., (2016) [17], Kwigizile et al., (2019) [18], Abdullah et al., (2020) [19] are commonly used to evaluate and/or determine the quality of bicycle routes. However, these indices primarily assess the condition of existing infrastructure or identify potential visual improvements for encouraging bicycle use, rather than addressing planning and design needs for new bicycle infrastructure in urban areas lacking sufficient systems.

There is a pressing need to identify criteria for planning and designing transportation infrastructure in urban areas where cycling is not yet widespread but is a critical factor in promoting its use. While multi-criteria decision-making methodologies have been extensively utilized within the broader field of transportation research. The most widely used of these methods is the *Analytical Hierarchy Process* (AHP). AHP was developed to solve complex multi-criteria decision-making problems. It is a method that requires the opinions of decision-makers (experts) to determine the relative importance levels of all criteria [20]. In this method, decision makers evaluate criteria and sub-criteria based on Saaty's (1994) [21] 1-9 scale [22]. Another method is the *Nominal Group Technique* (NGT). In NGT, a group of people are prepared to express their opinions and write about a specific situation face-to-face. Opinions are expressed strictly individually and independently of other group members. Ultimately, participants are asked to pool their individual judgments based on a predetermined statistical criterion and reach a group decision. The criteria are ranked or graded at a later stage [23]. *The Interacting Group Method (IGM)* is a process in which participants openly discuss their ideas with each other, provide feedback, and analyze each other's work. The Delphi technique is similar in nature to NGT, but it has different characteristics from NGT and IGM. First, individuals generate ideas not only individually and independently, but also in isolation and anonymously [24]. Second, communication between individuals is managed by a moderator and takes place through written questionnaires and feedback reports. The Delphi technique is primarily used as a planning and consensus technique in situations where it is difficult to use other techniques based on objective information [25]. All of this demonstrates that the Delphi technique requires more comprehensive research. In particular, the participation of the expert group within the framework of anonymity, the manager's role in providing feedback, and the inclusion of participants from different professional disciplines were decisive factors in the selection of the method. Furthermore, the lack of studies in the literature on the use of the Delphi technique in determining bicycle infrastructure criteria also influenced its use.

Existing studies conducted internationally, as well as within Türkiye, have delineated and assessed various characteristics to the development of bicycle transportation systems. Such as (Yedla and Shrestha, 2003) [26]; Tudela et al., 2006) [27], (Macharis and Pekin, 2009) [28], (Chow et al., 2013) [29], their application to bicycle transportation remains comparatively limited. Nevertheless, there exists a pronounced gap in the literature concerning research that employs participant-supported, comprehensive, and multifaceted data collection approaches in this area. However, there is limited consensus on which criteria are most applicable for planning and designing bicycle transportation infrastructure, as cities have unique natural, cultural, and social characteristics that influence cyclists' needs.

Therefore, this study aims to identify criteria for developing bicycle infrastructure systems in Türkiye, where the benefits and importance of urban cycling are recognized, but a comprehensive national strategy for sustainable transportation and cycling has not yet been fully developed. A comprehensive study emphasizing holistic planning and participatory principles for policy development was conducted.

The study employed the Delphi technique, which adopts a participatory planning approach. Conducted in three rounds, it identified criteria under three main categories-physical, visual, and social factors-that should be considered when planning bicycle routes. As a result, several recommendations were developed to promote cycling and establish bicycle infrastructure in developing countries.

2 Materials and methods

The study area is Merkezefendi and Pamukkale districts of Denizli city center. Denizli stands out as an industrial city, it is also an important tourism center. There are 22 ancient cities, including sites such as Hierapolis-Pamukkale World Heritage Site and Laodikea Archaeological Site. The city population, at the time the study was completed (in 2022), is 684,744 people. Considering the number of cars (215,984) and motorcycles (77,472) registered in the city, the rate of motor vehicle ownership in the city (28.29%) is quite high. In addition, there are approximately 15 km of bicycle roads in the city center [30]. However, one-third of these roads are used for recreational purposes. This situation shows that motorized transportation is dominant in the city. It can be said that the existing bicycle lanes in the city are not related to each other and do not meet the transportation network requirement. All these and the transportation problem of Denizli were effective in the selection of the city as the study area.

Consecutive questionnaire forms used in the Delphi technique application are among the materials of the study. IBM Statistics SPSS Version 20.0 and Microsoft Office programs used in the evaluation of the data obtained were also used as materials. In addition, national and international literature on the subject and study area, maps, plans and reports prepared by local governments for the study area, and national legislation on the subject are the materials of the study.

The research aimed to identify the criteria to be considered in improving bicycle infrastructure and promoting bicycle use for sustainable transportation in the city center of Denizli. It was conducted in four stages: i) Data Collection, ii) Qualitative and Quantitative Research (Formation of the Expert Group, Application of the Delphi Rounds), iii) Evaluation of Criteria, iv) Discussion and Conclusion.

2.1 Qualitative and quantitative research

In the second stage, opinions of participant groups were analyzed within the framework of qualitative and quantitative research. This stage consisted of two sub-steps and employed the Delphi technique to gather expert opinions. The Delphi technique was chosen primarily because no comprehensive study adopting a participatory planning approach for determining criteria for bicycle infrastructure has been extensively studied in the literature. Moreover, the technique facilitated data collection for practical implementation through a holistic planning approach by integrating the views of experts from diverse disciplines.

2.1.1 The Delphi technique

The Delphi technique, introduced by Dalkey and Helmer (1962) [31], is widely used in fields such as economics, education, healthcare, politics, tourism, sport science, sociology, technology, and urban and regional planning. It serves as a planning and consensus-building tool, particularly when objective data-driven techniques are difficult to apply.

Linstone and Turoff (2002) [32] noted that while initially considered a simple and easy-to-apply method, improper use led to disappointing results. Failures in the Delphi process include inadequately exploring alternative perspectives, poorly prepared questionnaires, inappropriate selection of expert groups, introduction of biases, limited feedback, ineffective summary of group responses, and expert fatigue due to the method's iterative nature [32], [33].

The key components of the Delphi process include anonymity, iteration, controlled feedback, and statistical analysis of results [34], [35]. Ideally, the process involves 10-20 participants, with surveys conducted in at least three successive rounds. Statistical analyses of responses are carried out after each round. The analytical outcomes derived at the conclusion of each iterative phase are systematically conveyed to the participants through successive surveys administered in the subsequent round, thereby elucidating prevailing trends in collective opinions on the subject matter. This iterative feedback mechanism facilitates participants' critical reappraisal of their initial positions by enabling comparative reflection against the communicated results and the spectrum of diverse viewpoints and methodological approaches.

2.1.2 Formation of the expert group

In selecting the expert group (architect, landscape architect, cartographer, urban planner, or civil engineer), priority was given to the professions mentioned in the Bicycle Roads Regulation (2019) [36]. In addition, in the planning decisions to be made for bicycle roads, the opinions of other stakeholders (public health experts, sociologists, civil society organizations, bicycle users, and local residents) were also considered, and importance was given to developing a multidisciplinary approach. Thus, the expert group was formed by considering technical disciplines (e.g., landscape architects, architects, civil engineers, and city planners) and stakeholders (e.g., public health specialists, sociologists, NGOs, bicycle users, and local residents). Initially, the expert group was constituted to include one representative from each of the following sectors-university, Denizli Metropolitan Municipality, and the private sector-selected from the specified professional disciplines. Moreover, to account for the potential withdrawal of participants during subsequent stages of the study, expert panels comprising four members were established. Participants were selected from academia, the public sector, and the private sector to ensure a balanced interdisciplinary approach. Initially, 24 experts were targeted; however, 18 participated in the first round. Subsequent rounds saw participation numbers decline to 17 and 15, respectively (Fig. 1). Some researchers [37]-[42] encountered a similar situation and concluded the study because the number of experts who provided feedback was more than the minimum acceptable number of experts (7 experts).

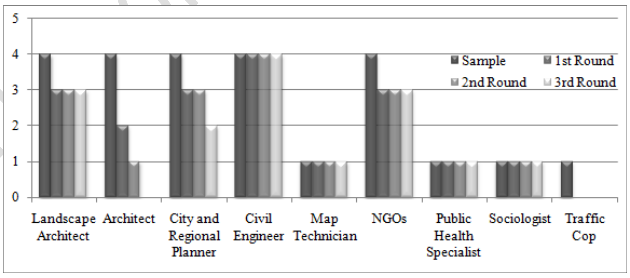

Figure 1. Response number by occupation and round throughout the Delphi process.

2.1.3 Application of the Delphi rounds

<u>1. First Round:</u> A semi-structured survey was prepared, including demographic questions and 12 criteria related to urban bicycle comfort. The results were consolidated to form the basis of the second-round questionnaire.

<u>2. Second Round:</u> A 5-point Likert Scale was used, and participants were asked to rate and justify their agreement with the criteria. Statistical analyses identified areas of consensus and disagreement.

<u>3. Third Round:</u> The third-round survey was tailored to individual participants, presenting first- and second-round results and explanations of statistical findings. Participants were asked to re-evaluate their responses, especially for criteria lacking consensus.

2.2 Evaluation criteria

In the evaluation of the expert forms, the consensus evaluation criteria used by Şahin (2010) [43], Akar (2015) [44], and Kalaycı Önaç and Birişçi (2019) [40] were utilized (Table 1). In the third stage, consensus was determined based on median scores (≥4) and interquartile ranges (≤1.5). Disagreement or indecision were identified when median scores were ≤3 or if interquartile ranges indicated significant variability (Table 1). Results from each round refined the criteria for developing sustainable bicycle infrastructure in Denizli. Thus, by taking the majority opinion into consideration, we aimed to eliminate the propositions that were completely irrelevant, misunderstood, and/or misinterpreted.

Median (Md): The value where 50% of the responses are to the left and 50% of the responses are to the right.
First quartile (Q1): The value where 25% of the responses are to the left and 75% of the responses are to the right.
Third quartile (Q3): The value where 25% of the responses are to the right and 75% of the responses are to the left.
Range (R): The difference between the first quartile and the third quartile (R = Q3 - Q1). A low difference indicates a consensus, whereas a high difference indicates a lack of consensus [43].

Table 1. Response number by occupation and round throughout the Delphi process.

Reconciliation status	Description
Consensus	Median ≥ 4, Interquartile ranges (R) ≤ 1.5
	Median ≥ 4, Interquartile ranges (R) ≤ 2.5 and 4-5 score ≥ 70%
Disagreement	Median ≤ 3, Interquartile ranges (R) ≤ 1.5
	Median ≤ 3, Interquartile ranges (R) ≤ 2.5 and 1-2 score ≥ 70%
Indecision	Median = 3, Interquartile ranges (R) ≤ 2.5

3 Findings

3.1 Characteristics of the expert group

Among the 18 experts participating in the study, 16.7% were women, and 83.3% were men. Of these, 72.3% were married, 11.1% were single, and 5.6% were divorced. Average ages of participants were 41. The distribution of participants by age group is shown in Figure 2. Most of them (44.4%) were member of Pamukkale University. Others work in the public sector (33.3%), private sectors (33.3% are). The rate of PhD (44.4%) and bachelor's degree (33.3%) holders are higher than associate (11.1%) and master's degree (11.1%) graduates.

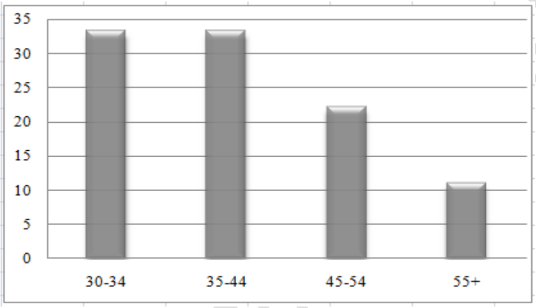

Figure 2. Age groups of participants.

Participants' distances to their workplace vary. The respondent who lives closest to his/her home stated that the distance was 1 km. He stated that his transportation preference is on foot. The participant, who lives the longest distance, 25 km, provides transportation by private vehicle. The distances between the experts' homes and workplaces were as follows: 0-5 km (44.4%), 6-10 km (44.4%), and 11 km or more (11.2%). 72.3% of the experts used private vehicles, 16.7% used public transport, 5.6% walked (1 km), and 5.6% used bicycles (6 km).

3.2 Evaluation of expert opinions

3.2.1 Delphi technique 1st round survey results

In the study, experts provided their opinions on 12 main topics that influence bicycle use in Denizli, including driving difficulty, intersection density, traffic density, traffic speed, noise, legibility, natural environment/visual quality, structural environment/route surroundings, centrality, accessibility to city parks, shadowing on roads, and other factors. Experts provided responses based on 54 different criteria, of which 33 were physical factors and 21 were visual and social factors, according to literature reviews and user experiences (see Tables 2 and 3).

Table 2. Delphi technique 1st round expert opinions according to Physical Factors (PHY).

Topic	Expert Responses	Code
Driving Difficulty	Slope-distance relationship	PHY1
	Road Width (boulevard, street, etc.)	PHY2
	Bicycle characteristics	PHY3
	Route insufficiency	PHY4
	Vehicle user behavior	PHY5
	Age	PHY6
	Slope	PHY7
	Elevation difference	PHY8
	Road surface features	PHY9
	Road humps	PHY10
	User Profile (age, gender, etc.)	PHY11
	Traffic rules	PHY12
	Climate characteristics	PHY13
	Travel Time (start-end duration)	PHY14
	Individual physical activity coordination	PHY15
	Chronic illness	PHY16
	Obstacle condition	PHY17
Intersection Density (Number of Intersections)	Safety	PHY18
	Bridge-underpass	PHY19
	Signalization	PHY20
Traffic Density	Shared bicycle lanes	PHY21
	Separated bicycle lanes	PHY22
	Scheduling adjustments for work hours	PHY23
	Reducing the number of vehicles by encouraging public transportation	PHY24
	Air pollution due to vehicle traffic	PHY25
Traffic Speed	Ensuring speed control	PHY26
Noise	In-city transportation noise	PHY27
	Recreational use noise	PHY28
Legibility	Number of turns to reach destination	PHY29
	Signage/information boards	PHY30
	Bicycle riding training	PHY31
	Safe route identification systems	PHY32
	Linear routes	PHY33

During the evaluation of expert opinions, members of non-governmental organizations (NGOs), particularly those who are bicycle users, highlighted the practical challenges encountered by cyclists, including factors such as slope, distance, climatic conditions, the behavior of motor vehicle operators, as well as bicycle and user characteristics. Landscape architects, adopting a technical standpoint, underscored the critical importance of the relationship between slope and distance, asserting that slope should not be considered in isolation but rather evaluated in conjunction with distance. Additionally, these experts emphasized the need to account for criteria such as noise levels, environmental influences, and the connectivity of bicycle routes. Civil engineers concentrated on infrastructural elements including road width (e.g., boulevards, streets), signalization, pavement characteristics, speed control measures, underpasses and bridges, and overall network connectivity. Urban planners and architects emphasized the significance of the interaction between the built environment and its surroundings. Public health experts and sociologists highlighted the imperative of ensuring user safety and the creation of secure cycling environments.

Table 3. Delphi technique 1st round expert opinions according to Visual and Social Factors (ViSo).

Topic	Expert Responses	Code
Natural Env./ Visual Quality	In-urban transportation	ViSo1
	Recreational use	ViSo2
Structural Env./ Route Surrounding Quality	Building density-road width relationship	ViSo3
	Building height-road width relationship	ViSo4
	Density of young population	ViSo5
	Numerous institutions along the route	ViSo6
	Socio-economic structure of the route environment	ViSo7
Centrality	Access to city center	ViSo8
	Access to malls	ViSo9
Accessibility to City Parks	In-urban transportation	ViSo10
	Recreational use	ViSo11
Shadowing of Route	Bioclimatic comfort	ViSo12
	Regulate natural and artificial light	ViSo13
Others	Access to historical and cultural sites	ViSo14
	Connecting to tourism facilities and areas	ViSo15
	Negative ımpact of stray animals	ViSo16
	Access to markets and other locations during travel	ViSo17
	Availability of safe bicycle parking	ViSo18
	Expansion of bicycle rental service or bike sharing systems	ViSo19
	Bicycle accommodation on public transport	ViSo20
	Bicycle carriage on intercity vehicles	ViSo21

3.2.2 Delphi technique 2nd round survey results

In the second round of Delphi surveys, experts were asked to evaluate the responses from the first round using 5-point Likert scale. Statistical methods were used to assess consensus. The results are presented in Table 4, showing that consensus was reached on 19 physical factors affecting bicycle use. Physical factors, slope-distance relationship (PHY1), road width (PHY2), etc. are among the most important factors on which there is consensus. The slope-distance relationship delineates the degree of cycling difficulty by integrating two critical parameters: slope gradient and road length. In other words, it is shown that cycling comfort can vary depending on the length of the slope. The high level of consensus on the slope-distance relationship is important because it is one of the topics emphasized in the Bicycle Roads Regulation. For example, according to the relevant regulations, if the slope of the route where the bicycle road will pass is less than 5%, the distance of the road is not important; however, for slopes between 5% and 7%, the distance must not exceed 240 meters. This concordance evidences the experts' comprehensive familiarity with regulatory standards and their provision of consistent and substantiated evaluations.

In addition, another issue on which experts have a consensus is the statements related to traffic rules. There was a consensus on traffic rules such as, signalization (PHY20), speed control (PHY26), direction and information signs (PHY30). This shows that experts emphasize the importance of traffic rules for cyclist safety. However, 12 factors did not achieve a consensus, with bicycle characteristics (PHY3) and linear routes (PHY33) remaining unclear (Table 4). The absence of consensus regarding bicycle characteristics is attributed to the wide variety of bicycles currently available to consumers, which are designed to accommodate diverse user preferences and demands-such as city bikes, road bikes, mountain bikes, and suspension bikes.

Table 4. Delphi technique 2nd round expert opinions according to Physical Factors (PHY).

	Q1*	*M*	Q3	*R*	1-2 F (%)	4-5 F (%)	Consensus
PHY1	4.00	4.00	5.00	1.00	5.90	94.20	YES
PHY2	4.00	5.00	5.00	1.00	0.00	94.10	YES
PHY3	2.00	3.00	4.00	2.00	47.00	35.30	UNCLEAR
PHY4	4.00	4.00	5.00	1.00	5.90	82.40	YES
PHY5	4.00	5.00	5.00	1.00	5.90	88.20	YES
PHY6	2.00	3.00	4.00	2.00	35.30	41.10	NO
PHY7	4.00	4.00	5.00	1.00	5.90	94.10	YES
PHY8	4.00	4.00	5.00	1.00	5.90	88.20	YES
PHY9	2.50	4.00	5.00	2.50	23.50	58.80	NO
PHY10	3.00	4.00	5.00	2.00	17.70	58.80	NO
PHY11	2.00	3.00	4.50	2.50	35.30	41.10	NO
PHY12	4.00	5.00	5.00	1.00	0.00	100.0	YES
PHY13	3.50	4.00	5.00	1.50	11.80	76.50	YES
PHY14	2.00	4.00	4.50	2.50	35.30	52.90	NO
PHY15	1.50	3.00	4.00	2.50	47.00	35.20	NO
PHY16	2.00	2.00	3.50	1.50	64.70	23.50	NO
PHY17	2.00	4.00	4.50	2.50	47.10	52.90	NO
PHY18	4.00	5.00	5.00	1.00	41.20	58.80	NO
PHY19	4.00	5.00	5.00	1.00	0.00	88.20	YES
PHY20	4.00	5.00	5.00	1.00	0.00	100.0	YES
PHY21	4.00	4.00	5.00	1.00	0.00	100.0	YES
PHY22	4.00	5.00	5.00	1.00	0.00	100.0	YES
PHY23	3.00	4.00	5.00	2.00	11.80	58.80	NO
PHY24	4.00	5.00	5.00	1.00	0.00	100.0	YES
PHY25	4.00	5.00	5.00	1.00	5.90	94.10	YES
PHY26	4.00	5.00	5.00	1.00	0.00	94.10	YES
PHY27	3.50	4.00	5.00	1.50	17.70	76.50	YES
PHY28	2.50	4.00	4.50	2.00	23.50	70.60	NO
PHY29	2.50	4.00	4.50	2.00	23.50	58.80	NO
PHY30	4.00	5.00	5.00	1.00	0.00	100.0	YES
PHY31	4.00	4.00	5.00	1.00	11.80	88.20	YES
PHY32	4.00	4.00	5.00	1.00	5.90	82.40	YES
PHY33	3.00	4.00	5.00	2.00	11.80	70.60	UNCLEAR

* *Q1: First quartile, Q3: Third quartile, M: Median, R: Range, F: Frequency*

At the end of the 2nd round, a consensus was reached on 16 criteria among the visual and social factors affecting cycling. The number of criteria for which there was no consensus was 2 (ViSo4 and ViSo5) (Table 5).

Table 5. Delphi technique 2nd round expert opinions according to Visual and Social Factors (ViSo).

	Q1*	*M*	Q3	*R*	1-2 F (%)	4-5 F (%)	Consensus
ViSo1	3.00	4.00	5.00	2.00	11.80	70.60	UNCLEAR
ViSo2	3.50	4.00	5.00	1.50	17.70	76.50	UNCLEAR
ViSo3	4.00	4.00	5.00	1.00	0.00	94.10	YES
ViSo4	2.00	4.00	4.00	2.00	29.40	58.80	NO
ViSo5	3.00	4.00	4.00	1.00	17.70	58.80	NO
ViSo6	4.00	4.00	5.00	1.00	5.90	88.30	YES
ViSo7	3.00	4.00	5.00	2.00	17.60	70.60	YES
ViSo8	4.00	5.00	5.00	1.00	5.90	88.20	YES
ViSo9	3.00	4.00	5.00	2.00	11.80	70.60	YES
ViSo10	4.00	5.00	5.00	1.00	0.00	100.0	YES
ViSo11	4.00	4.00	5.00	1.00	5.90	88.30	YES
ViSo12	4.00	4.00	5.00	1.00	0.00	82.40	YES
ViSo13	4.00	4.00	5.00	1.00	5.90	88.20	YES
ViSo14	4.00	4.00	5.00	1.00	5.90	88.20	YES
ViSo15	4.00	4.00	5.00	1.00	5.90	88.20	YES
ViSo16	2.50	3.00	4.00	1.50	23.50	41.10	UNCLEAR
ViSo17	3.50	4.00	5.00	1.50	11.80	76.50	YES
ViSo18	4.00	5.00	5.00	1.00	0.00	100.0	YES
ViSo19	4.00	4.00	5.00	1.00	5.90	88.30	YES
ViSo20	4.00	4.00	5.00	1.00	0.00	100.0	YES
ViSo21	3.50	4.00	5.00	1.50	0.00	76.50	YES

* *Q1: First quartile, Q3: Third quartile, M: Median, R: Range, F: Frequency*

The divergence in expert opinions concerning the building height-to-road width ratio criterion (ViSo4) is attributable to the existing urban planning framework. The ratio as delineated in current city plans reflects an absence of consensus on this parameter. Despite the demographic predominance of younger populations within the city, the persistently low rates of cycling usage contribute to the discord observed in relation to ViSo5. Additionally, a lack of consensus was evident regarding urban transportation dynamics (ViSo1), recreational utilization (ViSo2), and the detrimental impact of stray animals (ViSo16) (refer to Table 5). Of particular concern is the presence of groups of stray domestic dogs, which exhibit aggressive behavior toward pedestrians and cyclists, thereby posing substantive safety risks.

3.2.3 Delphi technique 3rd round survey results

In the 3rd round, where the answers were asked to be re-questioned, it is seen that the number of undecided criteria related to physical factors decreased to 1 (PHY3). The number of criteria with no consensus also decreased to 7. Nevertheless, it was concluded that consensus was achieved in 25 criteria (Table 6).

Table 6. Delphi technique 3rd round expert opinions according to Physical Factors (PHY).

	Q1*	*M*	Q3	*R*	1-2 F (%)	4-5 F (%)	Consensus
PHY1	4.00	5.00	5.00	1.00	6.7	93.3	YES
PHY2	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY3	2.00	3.00	4.00	2.00	26.7	40.0	UNCLEAR
PHY4	4.00	5.00	5.00	1.00	6.7	93.3	YES
PHY5	4.00	5.00	5.00	1.00	0.0	93.3	YES
PHY6	2.00	2.00	3.00	1.00	53.4	20.0	NO
PHY7	4.00	5.00	5.00	1.00	6.7	93.3	YES
PHY8	4.00	4.00	5.00	1.00	6.7	86.6	YES
PHY9	3.00	4.00	5.00	2.00	20.0	53.3	NO
PHY10	4.00	4.00	5.00	1.00	6.7	80.0	YES
PHY11	2.00	3.00	3.00	1.00	46.7	20.0	NO
PHY12	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY13	3.00	4.00	5.00	2.00	20.0	73.4	YES
PHY14	3.00	4.00	5.00	2.00	20.0	60.0	NO
PHY15	2.00	3.00	3.00	1.00	40.0	20.0	NO
PHY16	1.00	3.00	5.00	4.00	46.7	26.7	NO
PHY17	2.00	4.00	4.00	2.00	40.0	20.0	NO
PHY18	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY19	4.00	5.00	5.00	1.00	0.0	93.3	YES
PHY20	5.00	5.00	5.00	0.00	0.0	100.0	YES
PHY21	4.00	4.00	5.00	1.00	0.0	100.0	YES
PHY22	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY23	4.00	4.00	5.00	1.25	0.0	80.0	YES
PHY24	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY25	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY26	5.00	5.00	5.00	0.00	0.0	100.0	YES
PHY27	4.00	4.00	5.00	1.00	6.7	80.0	YES
PHY28	4.00	4.00	4.00	0.00	6.7	80.0	YES
PHY29	3.00	4.00	5.00	2.00	13.4	73.3	YES
PHY30	4.00	5.00	5.00	1.00	0.0	100.0	YES
PHY31	4.00	4.00	5.00	1.00	6.7	93.3	YES
PHY32	4.00	4.00	5.00	1.00	0.0	86.7	YES
PHY33	4.00	4.00	5.00	1.00	6.7	80.0	YES

** Q1: First quartile, Q3: Third quartile, M: Median, R: Range, F: Frequency*

Notably, criteria PHY10, PHY18, PHY23, and PHY28, which failed to achieve consensus in the second round, attained consensus in the third round. It was unanimously agreed that the implementation of road humps (PHY10) contributes to bicycle safety by effectively reducing vehicular speed. Similarly, the correlation between the scarcity of intersections (PHY18) and enhanced cyclist safety was confirmed with full consensus, evidenced by a 100% participation rate at a frequency level of 4-5. Consensus was also reached regarding criterion PHY23, predicated on its potential to mitigate traffic density. Moreover, the reduction of external disturbances, such as noise during recreational cycling (PHY28), was recognized as a significant factor in promoting cycling comfort.

Regarding visual and social factors, the number of undecided criteria in Round 3 is 1 (ViSo16 - Negative impact of stray animals). There was no consensus on this criterion in the previous (2nd) round. The number of criteria for which there was no consensus was 2. These criteria are related to the route environment, including building height-road width relationship (ViSo4) and socio-economic structure of the route environment (ViSo7). The number of agreed criteria is 18 (Table 7).

Table 7. Delphi technique 3rd round expert opinions according to Visual and Social Factors (ViSo).

	Q1*	*M*	Q3	*R*	1-2 F (%)	4-5 F (%)	Consensus
ViSo1	4.00	4.00	5.00	1.00	13.3	80.0	YES
ViSo2	4.00	4.00	5.00	1.00	13.3	80.0	YES
ViSo3	4.00	4.00	5.00	1.00	0.0	93.4	YES
ViSo4	2.00	4.00	4.00	2.00	33.3	60.0	NO
ViSo5	3.00	4.00	4.00	1.00	13.3	73.3	YES
ViSo6	4.00	4.00	5.00	1.00	6.7	86.7	YES
ViSo7	2.00	4.00	5.00	3.00	26.7	60.0	NO
ViSo8	4.00	5.00	5.00	1.00	6.7	86.6	YES
ViSo9	4.00	4.00	5.00	1.00	6.7	86.7	YES
ViSo10	4.00	5.00	5.00	1.00	0.0	100.0	YES
ViSo11	4.00	4.00	5.00	1.00	0.0	93.3	YES
ViSo12	4.00	4.00	5.00	1.00	0.0	93.4	YES
ViSo13	4.00	4.00	5.00	1.00	6.7	93.4	YES
ViSo14	4.00	4.00	5.00	1.00	6.7	86.7	YES
ViSo15	4.00	4.00	5.00	1.00	6.7	86.6	YES
ViSo16	2.00	3.00	4.00	2.00	26.7	46.6	UNCLEAR
ViSo17	4.00	4.00	5.00	1.00	6.7	80.0	YES
ViSo18	4.00	5.00	5.00	1.00	0.0	100.0	YES
ViSo19	4.00	4.00	5.00	1.00	0.0	100.0	YES
ViSo20	4.00	5.00	5.00	1.00	0.0	100.0	YES
ViSo21	4.00	4.00	5.00	1.00	6.7	80.0	YES

** Q1: First quartile, Q3: Third quartile, M: Median, R: Range, F: Frequency*

4 Discussion and conclusion

This study used the Delphi technique to identify criteria for the development of bicycle infrastructure. It aimed to conduct a multifaceted evaluation of the city's natural, cultural, and social characteristics through a landscape planning approach and establish relevant criteria within this context. While various studies employing qualitative (Çeyiz and Koçak, 2015) [45], (Mansuroğlu and Dağ, 2021) [46] and quantitative research techniques have identified problems encountered in bicycle usage, no studies were found that utilized the Delphi technique. In this study, a multifaceted approach was undertaken in determining the criteria used to evaluate the suitability of roads for bicycle use, as specified in the Bicycle Roads Regulation (2019) [36]. The expert group in this study was carefully selected. The prior knowledge of the researchers about the subject matter and study area was influential in the determination of the expert group. Participation of all professional groups that can be effective in the development of cycling and cycling transportation in cities is targeted. The expert group in this study, which utilized the Delphi technique, consists of 15 members: landscape architects (3), architects (1), urban and regional planners (2), civil engineers (4), map technicians (1), NGO representatives (professional cyclists) (3), public health experts (1), and a sociologist (1), representing various professional disciplines. It is noted that in previous studies related to the identification and/or evaluation of the suitability of bicycle paths, the expert groups were not created to address the topic from such a wide range of fields. Moreover, in studies involving experts, a single-round consultation method was used, unlike the three-stage approach used in the Delphi method. Milakis and Athanasopoulos (2014) [47] consulted 10 professional cyclists, Altunkasa et al. (2006) [48]

consulted 10 design experts, 10 cyclists, and 10 decision-makers (local government officials), Cengiz and Kahvecioğlu (2016) [49] consulted 10 cyclists, and Sönmez (2019) [50] consulted 5 landscape architects, 5 architects, 5 urban planners, and 5 cyclists, Yılmaz and Gerçek (2014) [51] consulted 42 different experts. Çeyiz and Koçak (2015) [45], who used a qualitative research method to identify issues related to bicycle use, interviewed 12 professional cyclists, while Mansuroğlu and Dağ (2021) [46] interviewed 30 professional cyclists. Dağ and Mansuroğlu (2024) [30] stated that in their research on the determination of bicycle paths, they based their evaluation criteria and weighting on findings from the Delphi expert group, surveys with cyclists, and the researcher's own experiences of the roads. Saplıoğlu and Aydın (2018) [52], determined effective parameters on route choice, a Questionnaire Survey (QS) was carried out on 460 participants who are cycling for a long time in Isparta City/Turkey.

Although the expert group was carefully and rigorously selected, a major challenge encountered in the process was that some experts who initially indicated their participation did not participate in later stages of the study. Additionally, the extended response time from experts became a significant limiting factor that prolonged the study. Some expert surveys, originally planned as face-to-face sessions, were conducted via email due to the COVID-19 pandemic, posing a limitation in this study. However, it should be noted that the Delphi technique inherently allows for the collection of expert opinions remotely. Taking all these challenges into consideration, it was explained in detail in the Methods section (2.2) that the study began with an expert group of 24 members, but it was completed with 15 experts. Similar situations have been encountered in other studies that applied the Delphi technique, such as Karacaoğlu (2009) [37], Gencturk and Akbas (2013) [38], Meijering et al. (2015) [39], Kalaycı Önaç and Birişçi (2019) [40], Adu-McVie et al. (2021) [41], and Lei et al. (2023) [42], where the number of experts who provided feedback exceeded the minimum acceptable number (7 experts), and the research was concluded. In future studies, considering that similar issues might arise, it will be beneficial to have a larger expert group as initially planned. There were no issues during the face-to-face or remote surveys in the 1st and 2nd rounds. However, in the 3rd-round surveys, despite examples and explanations provided at the beginning of the surveys, some experts required researcher support to understand certain technical terms. In face-to-face surveys, necessary explanations were given, but in email surveys, feedback from experts led to the need for phone clarification. Therefore, it is suggested that, whenever possible, expert opinions in Delphi technique studies should be gathered face-to-face to facilitate faster completion of the study and minimize such issues.

Existing literature highlights several methodologies developed for the planning of bicycle paths, the evaluation of road quality, the determination of their suitability for bicycle use, and the promotion of cycling. These methodologies are predominantly quantitative and observation-based survey techniques aimed at characterizing existing bicycle infrastructure and identifying potential visual enhancements on urban streets to encourage cycling. The Bicycle Environmental Quality Index (BEQI) encompasses the assessment of 21 empirically derived indicators that promote bicycle use. These indicators are categorized based on physical and environmental factors pertinent to bicycle safety, including intersection safety, traffic density, street design, overall safety, and land use. Similarly, the Bikeway Quality Index (BQI) incorporates ten factors such as road surface quality (assessed via the Pavement Surface Rating (PSR) scale), road connectivity, intensity of bicycle use, vehicular traffic density, topography, permeability (drainage capacity), land use, potential for bicycle use, existing bicycle network infrastructure, and general site conditions. The Bicycle Compatibility Index (BCI), on the other hand, evaluates the suitability of specific urban and suburban road segments (excluding intersections) for bicycle use, considering variables such as road width, sidewalk width, traffic density, and vehicle speed, supplemented by user experience data obtained through video evaluations. An examination of the criteria identified through the Delphi technique indicates that, beyond the physical characteristics of roads, visual and social factors are essential considerations. Indeed, these factors directly impact the user experience and perceptions of safety and comfort.

The present study, which employed the Delphi technique to determine criteria for assessing road suitability for bicycle use, identified 54 relevant criteria. While consensus was reached on many of these criteria by the conclusion of the third round, several remained undecided or failed to achieve consensus. The decision to utilize criteria lacking consensus or characterized by uncertainty should be guided by the specific attributes of the decision-making context, alongside the researcher's observations and analyses. Among criteria with established consensus, the determination of their applicability and prioritization at various stages should incorporate contextual considerations such as area characteristics, user demands, regulatory frameworks, and professional judgment. For instance, the combined use of slope (PHY7) and the slope-distance relationship (PHY1)-both of which achieved consensus-would be redundant; preference should be given to the slope-distance relationship due to its capacity to reduce uncertainty and enable more granular analysis, in alignment with regulatory guidelines. Conversely, criteria such as the negative impact of stray animals (ViSo16), which remains undecided, may warrant consideration in regions where interactions with aggressive dogs pose significant risks to cyclists. Similarly, the criterion pertaining to obstacle presence that does not impede bicycle use (PHY17), lacking consensus, should be deliberated in the design of bicycle paths adhering to universal accessibility principles.

Despite a consensus on the density of the young population (ViSo5) at 86.7%, there was no consensus on criteria related to age (PHY6, 20%) and user profile attributes (age, gender, etc.) (PHY11, 20%), which arguably convey similar concepts. This discrepancy is likely attributable to differences in the interpretation of terminology, as the term "young population" is commonly associated with a higher propensity for bicycle use.

Among criteria achieving consensus, those prioritizing cyclist safety are particularly salient. These include the presence of signalization (PHY20) (100%), a reduced number of intersections from a safety standpoint (PHY18) (100%), road humps (PHY10) (80%), elevation differences between bicycle lanes and adjacent transportation routes (PHY8) (86.6%), and motor vehicle user behavior (PHY5) (93.3%). Furthermore, road width (e.g., boulevards, streets) (PHY2) achieved unanimous agreement (100% at frequency level 4–5), reflecting expert consensus on the necessity for dedicated bicycle lanes. In developing countries such as Türkiye, the negative influence of motor vehicle user behavior (93.3%)

underscores this priority. However, as stipulated in bicycle lane regulations, bicycles may also be operated on shared lanes with pedestrians and/or vehicles.

Collectively, these findings suggest that research on assessing and planning bicycle infrastructure suitability is predominantly conducted within the disciplines of Landscape Architecture, Urban and Regional Planning, and Transportation Sciences. To establish robust criteria and sub-criteria for evaluating road suitability for bicycle use, it is imperative to adopt multifaceted decision-making processes grounded in landscape planning principles. Such processes should incorporate the natural and socio-cultural characteristics of the study area, the perspectives of cyclists and subject-matter experts, empirical observations and experimental data, as well as pertinent regulations and standards. For example, the assessment of road suitability in terms of width should integrate specifications from the Bicycle Roads Regulation (2019) [36] and relevant Turkish Standards Institution (TSE) guidelines. Suitability evaluations for shared and dedicated bicycle lanes should be conducted by considering the minimum and maximum road widths present within the study area, with appropriate weighting assigned to relevant criteria. The final determination of road suitability may be effectively facilitated through a two-stage multi-criteria decision-making methodology, such as the Analytic Hierarchy Process (AHP) or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

In addition to planning decisions, there are many criteria that influence cyclists' route selection decisions [53]. Some studies [47-49, 52, 54,55], the most commonly used criteria for route determination are road width, road usage status, traffic (flow) speed, parking and green areas, and the relationship of roads to public transportation (bus) stops. In addition to these criteria, some studies [30, 51, 54, 56, 57] have also used criteria such as vehicle parking status on roads, presence of traffic signals, road/sidewalk greening, relationship with existing bicycle lanes, slope-distance relationship, and sidewalk width. Criteria such as the relationship with bicycle maintenance locations and the relationship with existing bicycle rental stations were evaluated for the first time by Dağ and Mansuroğlu (2024) [30] within the scope of a comprehensive planning method.

In conclusion, it is suggested that the criteria influencing bicycle use and cyclists in the city center should not be limited to literature reviews but should be determined through multi-faceted decision-making processes, including expert opinions using the Delphi technique, surveys with bicycle users in the city center, and the researcher's own experiences and observations. This approach would allow for more accurate plans, designs, and decisions to be made, by using criteria that are suited to the city's natural, cultural, and socio-economic structure, moving beyond the direct use of criteria used in other cities or even countries as seen in previous studies. In the selection of the expert group, it is thought that taking the opinions of those who are directly related to the subject as well as those who are indirectly related to the subject will enable problems and solutions to be defined from a broad perspective, especially in broad-based and application-oriented studies.

5 Authors Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper. Material preparation [first author], data collection [first author] and analysis were performed by [1st] and [2nd]. The first draft of the manuscript was written by [1st] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

6 Ethical Approval

Researchers state that in the study based on human data, they received an ethical approval certificate from ……., and that the study was completed within the framework of ethical principles. The study was initiated after obtaining ethical consent from all participants in the study.

7 Statements & Declarations

The authors have no relevant financial or non-financial interests to disclose. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript. Additionally, there are no conflicts of interest in connection with this paper.

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