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# DETERMINATION OF TRAFFIC IMPACT LEVEL IN URBAN CYCLING

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## *Highlights*

- Traffic impact level (bikted and bikkted) has been developed for bicycle use in urban roads in Turkey.
- Traffic impact level in bicycle use is considered in two situations: corridor and intersection.
- A bicycle prototype was developed that enabled field data to be collected during the study methodology.
- Originally, for the first time in a bicycle model, the gap between vehicles, the amount of noise and the amount of vibration were taken into consideration.

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**ABSTRACT:** In recent years, the habit of cycling has been increasing. Particularly when active mobility is gaining prominence, there is a global emphasis on healthy living and natural sustainability. Although the current rate of bicycle use in Turkey is quite low, there is significant potential for cycling in metropolitan areas and districts. The concept of bikted (Traffic Impact Level in Bicycle Usage) has been developed to enhance bicycle usage in Turkey, address infrastructure deficiencies, and ensure more comfortable cycling. This method, which consists of parameters related to traffic infrastructure, environmental factors, and user behavior, was evaluated using eight parameters in corridors and five parameters at intersections. In corridors, assessments were made for separated bicycle paths, bicycle lanes, and roads without infrastructure; at intersections, evaluations were conducted for signalized intersections, modern roundabouts, and intersections with traffic markings. In corridors; slope, noise level, curbside parking, vertical marking, surface vibration amount, main road-side road intersection situations, speed limit and bicycle-vehicle gap distance were examined. In intersections; parking at the intersection, intersection visibility, intersection crossing distance, vertical marking presence and bicycle path presence were examined. Additionally, an experimental e-bicycle was developed to aid data collection for bikted. The scoring system in the model was designed using data obtained from field studies and previous literature. For the first time in a bicycle model study, noise intensity, gap distance measurement, slope and vibration were combined for corridor assessment. Slope accounts for approximately one-third of the scoring in corridor assessments for each infrastructure type, and corridors with high slopes cannot reach the "comfortable use" classification. The measurements may not be as reliable at intersections as the numerical data analysis conducted for corridors, but they still provide valuable insights for analyzing intersections. This study aims to contribute to the current state of bicycle corridors in Turkey's traffic infrastructure and future bicycle infrastructure projects, thereby promoting increased bicycle use. Furthermore, bikted is expected to raise awareness among local governments when planning and implementing bicycle-related projects.

***Keywords:*** Cycleability, Cycling Safety, Traffic Stress Level, Cycling Infrastructure

## 1. INTRODUCTION

In recent years, countries worldwide have engaged in numerous social and technical efforts to promote bicycle use as part of active mobility initiatives. As urban traffic volumes in most countries have reached their maximum capacity, bicycles are increasingly being seen as an alternative, particularly for primary or multimodal transportation. This trend is especially noticeable in many European countries, where there is a marked shift away from private vehicle use toward bicycles, e-bikes, and scooters, all considered cleaner energy options [1].

In Turkey, the trend of bicycle usage has been increasing, especially since the global pandemic. However, despite the growing construction of bicycle paths in major cities, these efforts often lack comprehensive planning and integration into the broader transportation network. Furthermore, the existing bicycle paths (alongside roads and separate lanes) often fail to provide a well-planned network for cyclists. Insufficient infrastructure, a lack of adherence to cycling rules, and, most critically, errors by motor vehicle drivers hinder the widespread adoption of bicycles. In global cities, the utilization rates of

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bicycles have reached up to 45%, whereas in Konya, the city with the longest bicycle infrastructure in Turkey, the usage rate is only 2% [2]. Additionally, the impact of existing infrastructure on cyclists in Turkey has not been adequately studied, nor have these impacts been leveraged to promote cycling, which is a significant disadvantage. Globally, the bicycle has consistently maintained its place throughout history. Initially invented in the 1850s, bicycles were used mainly for recreation and transportation until the 1900s when the invention of motor vehicles led to a decline in their use [3].

In Turkish cities, the rate of bicycle use is closely linked to the level of investment in bicycle infrastructure, highlighting the importance of developing proper infrastructure. Turkey’s longest bicycle path network is in Konya, which is 650 km, as shown in Figure 1. In 36% of Turkish metropolitan areas, the length of bicycle paths ranges from 26 to 100 km, while in 46%, it ranges from 1 to 25 km [4].


**Figure 1.** The length of bicycle paths in cities across Turkey

Considering the number of fatal and injury-causing traffic accidents in Turkey, the country suffers significant financial and emotional losses every year. The most important of these losses is the psychological impact on individuals who feel unsafe and stressed during their daily commute, which affects their overall well-being and productivity. For better traffic psychology, urban planning should be designed to increase people's health and productivity. Infrastructure design in almost all cities in Turkey is planned with vehicle traffic in mind. Parameters such as intersections, road alignments, pedestrian regulations, speed limits and parking areas create negative effects for cities that have started or are already using bicycles.

Turkey has a lower rate of bicycle use compared to European and other global countries, making all research and development efforts related to bicycles quite valuable. Bicycles in Turkey are mostly used in recreational areas, except for certain cities. The use of bicycles for transportation is minimal, almost non-existent. Although the concepts of micro-mobility and active transportation are increasing worldwide, their adoption in Turkey is increasing steadily, albeit more slowly. In this context, traditional bicycles and electric bicycles constitute the core of our study. In cities where the infrastructure is primarily designed for motor vehicles, this situation creates an unsafe user profile for cyclists. However, in order to encourage more active use of bicycle infrastructure and increase the number of cyclists, the concept of bikted (Traffic Impact Level of Bicycle Use) is essential for Turkey. This concept has been studied as 'traffic stress level' and 'bikebility' in many countries and cities around the world, emphasizing its importance for Turkey.

The aim of the study is to encourage safe and more bicycle use and to make recommendations to improve the infrastructure. The difference of the study from the examples in the world is that a model is created by combining noise, surface vibration amount, vehicle-bicycle distance, slope and parking parameters. In addition, while the studies in the world only examine traffic stress in corridors, our study also evaluates intersections.

### 1.1. Literature studies on the relationship between bicycles, the environment, and infrastructure

#### 1.1.1. General Studies

In recent years, infrastructure studies related to cycling have seen an increase. These studies have examined various parameters related to infrastructure, such as integrating bicycles with public transportation systems, which can influence route selection, traffic capacity, bicycle parking availability, and road gradients. Such analyses have been conducted to optimize cycling routes [5]. Other studies have emphasized the importance of dedicated bicycle lanes in traffic infrastructure [6]. For instance, a study on one of Turkey's leading micro-mobility organizations analyzed seasonal bicycle usage and various influencing factors in four cities offering bike-sharing services. A developed model predicted future trip numbers and their seasonal variations in these cities [7]. There are also studies on the status, planning, and implementation of bicycle use, particularly in Turkish cities like Konya and Antalya, where cycling is more prevalent [8],[9]. Several studies have been conducted at the city level to strengthen bicycle infrastructure to increase usage [10], [11].

Additionally, the impact of different types of bicycle infrastructure on usage has been examined [12], [13]. The strengths and weaknesses of bicycle infrastructure in Paris, France, have also been explored [14], [15]. To enhance cycling comfort, pavement analyses focusing on vibration have been conducted [16]. Some studies have compared comfort and safety parameters for better bicycle infrastructure design [17]. To understand the safety of bike lanes, the status of dedicated and shared bike lanes has been analyzed [18]. Additionally, some studies have evaluated safety from an accessibility perspective [19]. Naturalistic studies have analyzed near-miss situations using sensors to prevent bicycle accidents [20]. Another study comprehensively examined the impact of gradients, one of the most critical factors in bicycle use [21].

Another type of study focuses on cyclist behavior. These studies typically involve surveys that question users about their behavioral patterns, including hazard perception, evaluation of bike networks and facilities, the impact of traffic, the influence of road conditions, and factors that encourage or deter cycling [22], [23], [24], [25], [26].

For cyclists to comfortably use bicycles for transportation, environmental factors must also be conducive. Studies on environmental factors have highlighted noise levels, vibration, and bicycle path maintenance. For example, a study in Montreal, Australia, examined the impact of noise on cyclists [27], while another looked at the effect of noise levels on stress [28]. In Mumbai, India, the effects of vibration on cyclists were recorded along specific corridors [29]. Vehicle noise levels were measured and recorded in Thessaloniki, Greece, as environmental impacts [30]. An international study allowed for comparing noise levels in traffic in Copenhagen, Paris, and Montreal [31]. In Xi'an, China, the conditions caused by vibration were defined as dynamic cycling comfort, and measurements were conducted along corridors [32]. Some studies have measured vibration levels using various sensors placed on different parts of bicycles [33]. Another study explored the impact of different pavement types—such as asphalt, concrete, and pavers—on bicycle use by measuring and analyzing these surfaces [34]. Winter maintenance is also among the topics examined to ensure better bicycle use during winter [35].

Parking and passing distances, which significantly affect cyclists in bike lanes and mixed traffic, have been researched extensively in recent years [36], [37], [38]. Some studies specifically focus on a detailed analysis of all road types [39], while others attempt to correlate the impact of mixed traffic with passing distances [40].

As the use of electric bicycles has increased in recent years, some studies have examined the differences in riding and driving behaviors between conventional and electric bicycles [41]. Another study in Hangzhou, China, analyzed the behavior of e-bike riders at intersections using a survey method [42]. The e-bike program in the North Brabant province of the Netherlands has also provided benefits for promoting e-bike use [43].

Intersections are crucial structural elements for cyclists navigating through them. The literature on bicycle-intersection studies is limited. One study examined cyclists' tendencies to run red lights [44], while another looked at cycling behaviors at different roundabouts [45]. A study analyzing cyclists' comfort, stress levels, and riding behaviors across three different intersection types identified the impact of intersection types on cycling [46]. Another experimental study explored the effects of bike lanes at signalized intersections [47]. Two studies evaluated both vehicle-cyclist interactions and the types of infrastructure where cyclists feel safest at unsignalized intersections [48], [49]. The visibility of intersections, which is rarely observed, was examined through field studies conducted at urban intersections in Madrid, Spain [50].

#### 1.1.2.Traffic Stress Level for Cyclists

In recent years, active mobility in urban areas has gained global prominence regarding sustainable transportation. In this context, the concept of low-stress cycling and network connectivity, thoroughly explained by a group of researchers in the United States [51], was previously evaluated as an attempt to relate cyclists' perceptions of road types to specific geometric and traffic conditions under the concept of bicycle stress levels. The study's authors created a stress level rating from 1 to 5 by considering traffic variables such as volume, speed, and curb width. Additionally, a widely recognized model categorizes traffic stress levels into four distinct categories: LTS 1 (Low Traffic Stress Level 1) represents a level most children can tolerate; LTS 2 is suitable for the general adult population; LTS 3 is for the "enthusiastic and confident" cyclists; and LTS 4 is tolerated only by those characterized as "strong and fearless." The study examined various parameters: speed, annual average daily traffic, roadway classification, bike lane width, and parking conditions [52].

Another study analyzed LTS rankings by comparing parents' willingness to cycle with their willingness to allow their children to cycle [53]. Another study analyzed the relationship between bike network design and commuting mode shares in Franklin County, Ohio. Criteria for bicycle traffic stress levels were adopted to assess the bike network [54]. Another study classified bike network connectivity through two case studies to evaluate the adapted LTS system and demonstrate practical applications in infrastructure management [55]. Specifically, the study examined the levels of traffic stress for cyclists on street and trail networks in Toronto, Canada [56].

## 2. MATERIAL AND METHODS

Various methods have been developed to assess bikeability and traffic-induced stress levels. This study aims to build upon these existing models and methods by incorporating new elements and introducing a fresh perspective to develop a Traffic Impact Level Management System for Cycling (bikted). The study was conducted simultaneously: creating the bikted model and collecting data for bikted using an equipped experimental bicycle.

### 2.1. Material

As part of the study, a prototype bicycle was developed to collect field data. Volta A.Ş. and ISSD A.Ş supported this initiative. The hardware used in the field study includes an experimental bike equipped with various electrical components. A computer was used to record and store the data collected from the field and to conduct checks after each measurement. These components are essential for gathering and processing field data. The equipment was procured as part of the KTÜN BAP project. The bicycle and its components include one bicycle, one aluminum enclosed box for equipment storage, a mini panel, a regulator, a GPS module, a webcam, a mini P.C., 1 Micro SDXC 512 GB MicroSD card, a microcontroller, a sine inverter, temperature and acceleration sensors, ultrasonic and vibration sensors (Fig.2)

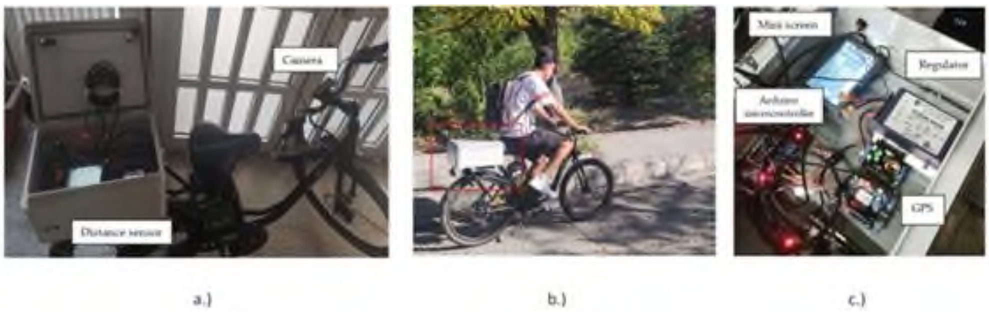


**Figure 2.** Experimental Bike a) Distance sensor and camera b) User collecting data in the field c) Display of main equipment components

The prototype consists of an electric bike with a bicycle equipment box mounted on the saddle, drawing power from the bike. The box contains all the necessary components for data analysis, including a mini PC, a power converter, an accelerometer, a GPS module, a camera capable of sound measurement, a sine inverter (useful for electrical conversion), a temperature sensor, ultrasonic sensors, a mini panel, and a vibration sensor. This setup enables comprehensive data collection and analysis directly in the field, providing valuable insights into the various parameters affecting cycling conditions.

**2.2. BikTED Methodology**

The bikted method was developed to classify and measure the impact of traffic on bicycle use in urban roads. Routes were examined in two categories: corridors and intersections (Fig.3).

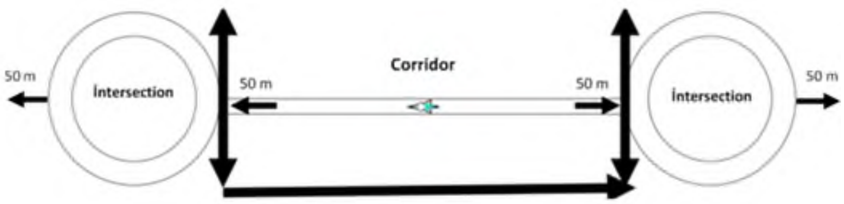


**Figure 3**. Illustration of corridors and intersections analyzed within the bikted model

For corridors, the physical conditions typically found in our country were considered: shared lanes next to vehicle lanes (bike lanes), mixed-use with vehicle lanes (shared lanes), and protected bike paths (separated bike paths). For intersections, classifications included signalized intersections, modern roundabouts, and traffic-sign-controlled intersections, encompassing various types of intersections. In the literature, traffic impact level has been discussed regarding traffic stress level and bikeability. Past studies have considered factors such as parking, vehicle speed, platform width, the presence of bike lanes, and bike lane width.

Unlike previous studies, this research evaluated corridors based on eight parameters: noise level, slope, rightmost lane parking, vertical signage, pavement surface vibration, side road intersections, speed limits, and vehicle spacing. Intersections were assessed using five parameters: parking, intersection visibility, crossing distance, vertical signage/signals for cyclists, and the presence of bike lanes. For separated bike paths, parameters like speed limits and vehicle spacing were not considered due to their physical separation from the roadway. Vertical signage for cyclists was not evaluated in mixed traffic as it does not typically exist.

The following indices were used in determining corridor and intersection parameters and determining (bikted) intervals.

Copenhagen Index; Established in Denmark, the Copenhagen Index provides the most comprehensive and holistic ranking of bicycle-friendly cities worldwide. Since 2011, it has evaluated cities based on categories like street scenery, culture, and passion, each rated on a scale of 1 to 4 points.

[57]. Munich Bicycle Availability Index; This index is used to identify areas of low bicycle accessibility across road networks with varying spatial extensions. Focusing on Munich, the index measures cycling capabilities by considering the presence and type of bike paths, speed limits, bicycle parking facilities, and the quality of bicycle intersection infrastructure. Parameters outside intersections are scored between 1 and 10 based on survey results, while intersections are examined in detail [58]. Bicycle Service Level; In the United States, a Bicycle Service Level was developed to measure the quality of service provided to cyclists traveling on urban road networks. The study found that road surface conditions and the presence of bike lanes are critical factors in determining the quality of service [59]. Bicycle Compatibility Index (BCI); The index was to identify and combine the key road and traffic variables that influence a cyclist's decision to cycle on a particular road [60].

By using the indexes mentioned above, as well as many demo studies conducted with experimental bikes in the field, the following scores and bikted impact levels were determined.

For corridors, separated bike paths, which are physically isolated from the roadway for safety, were scored out of 100 points. Bike lanes, which lose 20 points due to reduced infrastructure compared to separated paths, were scored out of 80. Cycling in mixed traffic without dedicated infrastructure, losing an additional 20 points for the lack of bike lanes, was scored out of 60 points. For intersections, signalized intersections were scored out of 100, modern roundabouts out of 90, and traffic-sign-controlled intersections out of 80. The scoring was entirely based on the author's review of past research, field experiences during the study, and technical expertise. In the bikted model, corridor or intersection evaluations are classified as bikted 1-6 for corridors and bikted 1-6 for intersections. A score of 1 represents very comfortable use or intersection crossing, while a score of 6 indicates that the corridor or intersection is unusable(Fig.4). Data collected using the prototype test bike should be averaged from at least two days of data collected during weekday rush hours in September-November or April-June to determine the level. For the method, 28 km of data collection was carried out in mixed traffic, roads with bicycle lanes and separated bicycle paths in Konya and Ankara cities.

| Corridor | | | | İntersection | | | |
|---|---|---|---|---|---|---|---|
| Category | View | Point | Class | Category | View | Point | Class |
| bikTED -6 | | 0-30 | Not used | bikKTED-6 | | 0-30 | Not used |
| bikTED -5 | | 30-50 | bad use case | bikKTED-5 | | 30-50 | bad transition state |
| bikTED -4 | | 50-60 | Very uncomfortable to use | bikKTED-4 | | 50-60 | Very uncomfortable transition |
| bikTED -3 | | 60-70 | uncomfortable use | bikKTED-3 | | 60-70 | uncomfortable transition |
| bikTED -2 | | 70-90 | Comfortable use | bikKTED-2 | | 70-90 | comfortable transition |
| bikTED-1 | | 90-100 | Very comfortable use | bikKTED-1 | | 90-100 | Very easy transition |

**Figure 4.** Classification and Symbolic Representation of the bikted Model

### 2.3. Parameters used in the methodology and methods of use

#### 2.3.1. Parameters for corridor

Corridors are linear road segments extending from 50 meters before an intersection structure to 50 meters after the intersection approach. This study considered three types of bicycle infrastructure within corridors: separated bike paths, bike lanes, and mixed-traffic roads without specific bicycle infrastructure. According to the bicycle path regulations published by the Ministry of Environment and Urbanization in 2019, separated bike paths should have a minimum width of 190 cm, and bike lanes should be at least 175 cm wide [61]. In Turkey, especially in cities like Konya, Düzce, Istanbul, Eskişehir, and Sakarya, some compulsory adjustments were made irrespective of the regulations or due to zoning conditions. These adjustments resulted in separated bike paths narrower than 1.5 meters, bike lanes narrower than 1.2 meters, and sometimes without edge markings. Because of these factors, a thorough analysis was conducted. As shown in Table 1, since separated bike paths are far from the roadway, parameters like speed limit and vehicle clearance are not considered. Conversely, the vertical signage parameter is disregarded on roads without infrastructure (mixed traffic).

**Noise Intensity:** Studies on cycling across various countries have found noise levels between 45 and

85 dB. Numerous analyses indicate that a noise level of 65 dB or above is uncomfortable for cyclists [62], [63], [64], [65]. This study assesses noise intensity based on the average sound levels throughout a corridor. The basic noise levels are categorized as follows: 0-50 dB, 50-65 dB, and above 65 dB.

**Slope:** One of the most critical parameters in cycling is the slope, which has been examined in many studies, establishing specific criteria [66], [67]. The Dutch Bicycle Infrastructure Guide (2017), referenced in this study, adjusts slope values based on ride comfort. Accordingly, the criteria used in our study are +0-3% (unlimited), +3-5% (up to 222 meters), and above +5% (56-80 meters).

**Curbside Lane Parking:** Parking along the road is a negative condition for cyclists. Using roadside lanes as parking spaces, especially where legally prohibited, causes problems for cyclists. Various parking scenarios exist, such as perpendicular, angled, and parallel. In a survey, respondents were asked about physical cross-sections in areas with parking. A notable finding was that in areas with parking, a 3.5-meter-wide bike lane should have a 25 cm edge line, whereas a 2-meter-wide bike lane should maintain a 75 cm gap between the parked cars and the bike lane [13]. In our study, parking is expressed as a percentage of the road length along the entire corridor, with evaluations made at 0-10%, 10-30%, and 30-50% parking rates.

**Vertical Signage:** Vertical signage is essential for bicycle infrastructure, particularly for separated bike paths and roadside bike lanes. Vertical signage ensures cyclists feel safe in corridors and can approach, stop, and leave intersections more comfortably. These signs are necessary after every intersection and side road connection to increase driver awareness of cyclists. The study evaluated vertical signage using a 0-100% scale based on traffic signs and side road connections.

**Road Pavement Surface Vibration Effect:** The surface on which a bicycle is ridden is vital for safe and comfortable cycling. In Turkey, asphalt, concrete, and curb materials are generally used for bike paths, whereas asphalt is used for bike lanes and mixed traffic due to shared road use. On asphalt road platforms, minimal undulation, smoothness, and compatibility between the bicycle tire and the pavement enhance comfort. Poor pavement conditions can distract cyclists from environmental factors and require more effort. Some studies have explored different road types using experimental bicycles [33], [34]. In our study, bicycle comfort level was assessed based on the ISO-2631-1 standard, evaluating accelerations of 0-0.5 $m/s^2$, 0.5-1 $m/s^2$, 1-2.5 $m/s^2$, and greater than 2.5 $m/s^2$.

**Main Road-Secondary Road Intersection:** High intersections with side roads along a cyclist’s route can compromise safety. Since separated bike paths are designed on sidewalks, intersections with side roads can pose obstacles due to height differences between the sidewalk and the road, hindering smooth cycling. The study classified side road intersections along a corridor as 0-2, 2-6, and more than six intersections.

**Speed Limit:** One of the most important factors for cyclists is the speed limit on the road. Speed limits vary according to road width and classification, and vehicle speeds must be considered to ensure cyclists feel safe. Speed has been particularly emphasized in past studies [51], [52], [59], [60]. Our study categorized speed into 0-30 km/h, 30-50 km/h, 50-82 km/h, and over 82 km/h.

**Vehicle Clearance Distance:** Another factor affecting cyclists, especially in bike lanes and mixed traffic, is the distance between them and passing vehicles. Although this distance varies with speed, anything below 100 cm is considered dangerously close, while 150 cm is considered more acceptable. This study assessed clearance distances in ranges of 0-50 cm, 50-100 cm, and 100-150 cm.

**Table 1.** Increasing efficiency according to the classification of bicycles in corridors

| Parameters | Seperated Cycle Path | Bike Line | Mixed Traffic |
|---|---|---|---|
| Amount of Noise | ● | ● | ● |
| Slope | ● | ● | ● |
| Bicycle Path Parking | ● | ● | ● |
| Vertical Sign | ● | ● | |
| Coating Surface Vibration | ● | ● | ● |
| Secondary Road | ● | ● | ● |
| İntersection Status | | | |
| Speed Limit | | ● | ● |
| Vehicle-Bicycle Distance | | ● | ● |

#### 2.3.2. Parameters for intersection

Intersections are one of the two types of infrastructure examined in this study. In Turkey, intersections are mostly traffic-marked and signalized. In recent years, the number of modern roundabouts has increased globally and in Turkey, which has also been evaluated in this study. However, relatively few studies specifically investigate the impact of bicycle infrastructure at intersections worldwide. For example, the Munich Bicycle Usability Index [58] examines parameters such as vertical bicycle traffic lights and bicycle infrastructure.

As shown in Table 2, the study evaluates parking, intersection sight distance, intersection crossing distance, vertical bicycle signage/signaling, and the presence of bicycle infrastructure at signalized intersections, traffic-marked intersections, and modern roundabouts.

**Intersection Parking:** Parking within intersection areas is a condition that complicates cyclist crossings and creates safety risks. In Turkey, parking on approaches and within intersections is a major problem. Despite regulations under the Traffic Law stating that parking within intersections is not allowed, illegal parking is common in many cities. The approach and departure distance for intersections is taken as 50 meters. In this study, parking is expressed as a percentage of the road length throughout the intersection crossing distance, evaluated at 0-10%, 10-30%, and 30-50%.

**Intersection Sight Distance:** The sight distance and visibility at intersections are crucial for cyclists. Vertical curves, such as hills or valleys, or structures obstructing the view within the intersection pose a safety threat to cyclists approaching the intersection. While there have been no specific studies on intersection sight distance for cyclists, an urban intersection in Madrid, Spain, was evaluated for visibility from different angles, providing a reference for this study [50]. This study categorizes visibility as poor, normal, or good.

**Intersection Crossing Distance:** The intersection crossing distance is defined as the total distance a cyclist covers from a point 50 meters before entering the intersection to a point 50 meters after exiting it. Intersections with long crossing distances typically expose cyclists to greater danger due to vehicle traffic. Distances at modern and signalized intersections usually exceed 100 meters. Longer crossing distances imply more conflicts with other road users. Particularly in bike lanes and mixed traffic situations, these intersection and vehicle interactions can put cyclists in challenging positions. This study evaluated crossing distances as 0-50 meters, 50-100 meters, 100-150 meters, and over 150 meters.

**Vertical Signage or Signaling for Bicycles:** At modern roundabouts and traffic-marked intersections, vertical mini-traffic signs for bicycles should be installed to prevent cyclists' violations while crossing and alert drivers. At signalized intersections, bicycle-specific traffic signals are necessary to ensure that cyclists have their separate light system for safety, independent of vehicle signals. The Munich Bicycle Usability Index [58] considers the right-turn radius, bicycle-specific signals, horizontal markings, and designated areas for cyclists at intersections. In this study, the presence or absence of these parameters is evaluated.

**Presence of Bicycle Path:** A bicycle path at intersections is crucial for the controlled and safe crossing of cyclists, allowing them to stop and wait safely. In many instances, pedestrians and cyclists share the same crossing paths. Especially at traffic-marked and modern roundabouts, providing a dedicated bicycle path helps ensure that cyclists do not feel endangered by drivers. In this study, a bicycle path's presence is considered present or absent, depending on the infrastructure. A study mentions the importance of having separated bicycle lanes at intersections. A separated bicycle lane at an intersection has significantly reduced accidents in terms of visibility, attention, and ease of passage [68].

**Table 2.** Parameters scored according to bicycle infrastructure at intersections

| Parameters | Signalized İntersection | Modern Roundabout | İntersection with Traffic Signs |
|---|---|---|---|
| Parking in the intersection | ● | ● | ● |
| Sight at the intersection | ● | ● | ● |
| İntersection passing distance | ● | ● | ● |
| Bicycle Vertical Sign | ● | ● | ● |
| Bicycle Path | ● | ● | ● |

## 3. RESULTS AND DISCUSSION

This study developed a method for bikted, which differs from previous studies by assigning weights and scores to each type of infrastructure to create a specific bikted class. This method allows for assessing how risky a particular urban road is for cycling, whether it has a dedicated bike lane, and how much of this risk can be tolerated by the user. In Turkey, there is still no standardization for urban road classification. Globally, recent studies have often referenced the Level of Traffic Stress (LTS) management system, focusing on road width and speed. Other model studies emphasize speed, curb lane volume, and width [51]. Additional models consider factors such as the type of bike lane, parking availability, and the percentage of heavy vehicles [59], [60].

The model developed in the study was examined in 2 categories. Corridors and intersections on the route where cyclists pass. Infrastructure conditions in corridors; roads without infrastructure, bicycle lanes or separated bicycle paths encountered in urban bicycle use in our country. In these 3 main road structures, different measurements were evaluated for each road structure type and parameters were determined. These are; noise, slope, parking, vertical marking, pavement vibration status, main road-secondary road junction status, speed limit and bicycle-vehicle distance status.Corridors were divided into three types according to their usage and safety status: dedicated bike lanes, shared bike lanes and protected bike paths. Dedicated bike paths were rated with 100 points (P), bike lanes with 80 points (P) and mixed traffic roads without dedicated bike infrastructure were rated with 60 points (P). Each parameter was weighted according to its impact on the infrastructure (Figure 5).

Infrastructure conditions in intersections were examined in 3 categories as signalized, modern roundabout and traffic marked. Here, different parameter evaluations were made for different types of intersections. These are; parking percentage, visibility of the intersection, distance of cyclists passing the intersection, presence of bicycle vertical markings and presence of bicycle path. Signalized intersections were rated the highest at 100 points (P) for intersections, as they are considered the safest design for cyclists in literature. Modern roundabouts, which lack a stopping system but provide a physical slowing effect, were rated at 90 points (P). In contrast, intersections regulated solely by traffic signs, without any physical slowing mechanisms, were rated at 80 points (P) (Fig. 6).

In addition, the most studied parameters in the literature for corridors in the world; parking, speed and slope were further developed in this model with field data, observations and extensive literature source studies sampling and a new model study was presented by combining road vibration status, vehicle-bicycle gap distance and sound level measurements in corridors. Similarly, although there are few studies examining the intersection crossing status of cyclists at field and model levels, in our study, the parameters of crossing distance, sight distance and parking at intersections were evaluated and the concept of safety impact level was developed.

a.)

| Parameters | 100 | |
|---|---|---|
| | Separated Cycle Path | |
| | 1 m-1.5 m (10P)<br>L≤1.5 m (20P) | 20% |
| Amount of Noise | Point | Weight |
| 0-50 db | 7 | 7% |
| 50-65 db | 4 | |
| 65 db and above | 0 | |
| Slope | Point | Weight |
| (+) 0-3 % | 30 | 30% |
| (+) 3-5 % 0-222m (CROW) | 10 | |
| (+) 5% and above | 1 | |
| Bicycle Path Parking | Point | Weight |
| 0<P<10% | 7 | 7% |
| 10<P<30% | 5 | |
| 30<P<50% | 1 | |
| Vertical Sign<br>Traffic Sign / Secondary Road Intersection | Point | Weight |
| 1 | 9 | 9% |
| 0,7 | 7 | |
| 0,5 | 5 | |
| 0 | 1 | |
| Coating Surface Vibration | Point | Weight |
| 0-0,5 m/s2 | 15 | 15% |
| 0,5-1 m/s2 | 10 | |
| 1-2,5 m/s2 | 5 | |
| 2,5≤ T m/s2 | 1 | |
| Secondary Road Intersection Status | Point | Weight |
| 0-2 K | 12 | 12% |
| 2-6 K | 5 | |
| 6-15 K | 1 | |

b.)

| Parameters | 80 | |
|---|---|---|
| | Bike Lane | |
| | 1.00 m -1.30 m (7P)<br>(0.25 Çizgi) 1.30 m ≤L≤1.95 m (10P)<br>1.30≤L≤1.95 m (14P) | 18% |
| Amount of Noise | Point | Weight |
| 0-50 db | 8 | 10% |
| 50-65 db | 4 | |
| 65 db and above | 1 | |
| Slope | Point | Weight |
| (+) 0-3 % | 16 | 20% |
| (+) 3-5 % 0-222m (CROW) | 5 | |
| (+) 5% and above | 1 | |
| Curbside Strip Parking | Point | Weight |
| 0<P<10% | 6 | 7% |
| 10<P<30% | 4 | |
| 30<P<50% | 2 | |
| Vertical Sign<br>Traffic Sign / Secondary Road Intersection | Point | Weight |
| 1 | 4 | 5% |
| 0,7 | 3 | |
| 0,5 | 1 | |
| 0,3 | 0 | |
| Coating Surface Vibration | Point | Weight |
| 0-0,5 m/s2 | 8 | 10% |
| 0,5-1 m/s2 | 5 | |
| 1-2,5 m/s2 | 3 | |
| 2,55 T m/s2 | 1 | |
| Secondary Road Intersection Status | Point | Weight |
| 0-2 K | 8 | 10% |
| 2-6 K | 3 | |
| 6-15 K | 1 | |
| Speed limit | Point | Weight |
| 0-30 | 6 | 7% |
| 30-50 | 4 | |
| 50-82 | 1 | |
| 82-ve üzeri | 0 | |
| Vehicle-Bicycle Distance | Point | Weight |
| 100-150 cm | 10 | 13% |
| 50-100 cm | 4 | |
| 0-50 cm | 2 | |

c.)

| Parameters | 60 | |
|---|---|---|
| | Mixed Traffic | |
| | No Infrastructure | |
| Amount of Noise | Point | Weight |
| 0-50 db | 4 | 7% |
| 50-65 db | 2 | |
| 65 db and above | 1 | |
| Slope | Point | Weight |
| (+) 0-3 % | 16 | 27% |
| (+) 3-5 % 0-222m (CROW) | 7 | |
| (+) 5% and above | 2 | |
| Curbside Strip Parking | Point | Weight |
| 0<P<10% | 8 | 13% |
| 10<P<30% | 4 | |
| 30<P<50% | 2 | |
| Coating Surface Vibration | Point | Weight |
| 0-0,5 m/s2 | 9 | 15% |
| 0,5-1 m/s2 | 6 | |
| 1-2,5 m/s2 | 3 | |
| 2,55 T m/s2 | 1 | |
| Secondary Road Intersection Status | Point | Weight |
| 0-2 K | 6 | 10% |
| 2-6 K | 3 | |
| 6-15 K | 1 | |
| Speed limit | Point | Weight |
| 0-30 | 9 | 15% |
| 30-50 | 6 | |
| 50-82 | 3 | |
| 82-ve üzeri | 0 | |
| Vehicle-Bicycle Distance | Point | Weight |
| 100-150 cm | 8 | 13% |
| 50-100 cm | 5 | |
| 0-50 cm | 2 | |

**Figure 5.** Bikted corridor Scoring a) Dedicated Bike Path b) Curbside Bike Lane c) Mixed Traffic (Without Bike Lane Infrastructure)

| Parameters | 100 | | 90 | | 80 | |
|---|---|---|---|---|---|---|
| | Signalized İntersection | | Modern Roundabout | | Intersection with Traffic Signs | |
| Parking at the intersection | Point | Weight | Point | Weight | Point | Weight |
| 0<P<10% | 20 | 20% | 20 | 22% | 18 | 20% |
| 10<P<30% | 12 | | 12 | | 10 | |
| 30<P<50% | 6 | | 6 | | 4 | |
| View at the intersection | Point | Weight | Point | Weight | Point | Weight |
| Poor Sight | 6 | 26% | 6 | 24% | 4 | 24% |
| Normal Sight | 16 | | 12 | | 12 | |
| GoodSight | 26 | | 22 | | 18 | |
| Intersection Passing Distance | Point | Weight | Point | Weight | Point | Weight |
| 0-50m | 26 | 26% | 24 | 27% | 14 | 18% |
| 50-100m | 24 | | 20 | | 12 | |
| 100-150m | 18 | | 18 | | 10 | |
| 150m and above | 16 | | 14 | | 6 | |
| Bicycle Vertical Sign | Point | Weight | Point | Weight | Point | Weight |
| Yes | 12 | 12% | 10 | 11% | 14 | 18% |
| No | 2 | | 2 | | 2 | |
| Bicycle Path | Point | Weight | Point | Weight | Point | Weight |
| Yes | 16 | 16% | 14 | 16% | 16 | 20% |
| No | 2 | | 4 | | 2 | |
| | a.) | | b.) | | c.) | |

**Figure 6.** Intersection Parameters and Scoring for bikted a) Signalized Intersection b) Modern Roundabout c) Sign-Controlled Intersection

## 4. CONCLUSIONS

In this study, a bicycle model that aims to increase bicycle use, make urban infrastructure bicycle-friendly or improve current conditions, and a bicycle specially equipped to collect data for the model were developed.

The following conclusions can be drawn regarding the Bikted model:

• The scoring system in the model was designed by the authors using data obtained from field studies and previous literature.

•For the first time in a bicycle model, corridor evaluation was performed by combining noise intensity, bicycle-vehicle gap, slope and vibration values, and the traffic impact status of the corridors at 6 levels was revealed.

•In the corridor evaluations of our study, the slope constitutes approximately one third of the score for each type of infrastructure, and corridors with high slopes cannot reach the "comfortable use" classification.

• In the corridor evaluations, separated (physical separation) bicycle paths can reach the "very comfortable use" classification, bicycle lanes can reach the "comfortable use" classification, but corridors with mixed traffic (without bicycle infrastructure) are rated as "extremely uncomfortable use". This shows that roads without bicycle infrastructure are dangerous in terms of use.

• Measurements made with equipped bicycles may not be as reliable at intersections as the numerical data analysis presented for corridors, but still provide valuable insights for analyzing intersections.

•BikTED-3 and bikKTED-3 impact levels can be considered as acceptable levels for corridors and intersections in terms of safety, comfort and bicycle use on an urban road. However, situations below these levels are roads that need infrastructure development.

• The study may benefit municipalities, universities, provincial administrations and private institutions in terms of bicycle infrastructure investments and improvements.

This study presents a method for assessing traffic infrastructure and environmental factors in the context of urban bicycle use in Turkey. The method may require more reliable surveys or additional field studies to score infrastructure parameters. Future research should focus on collecting more user data that will contribute to the further development of the bicycle methodology.

**Declaration of Ethical Standards**

Authors must follow all ethical guidelines, including authorship, citation, data reporting, and publishing original research.

**Credit Authorship Contribution Statement**

**R.AYDAR:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - Original Draft, Visualization, Prototype development

**O.N.ÇELİK:** Investigation, Resources, Writing - Review & Editing, Supervision, Project administration, FunXding acquisition

**Declaration of Competing Interest**

Competing Interest is a set of conditions in which professional judgment concerning a primary interest, such as the validity of research, may be influenced by a secondary interest, such as financial gain.

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**Data Availability**

If you have made your research data available in a data repository, you can link your article directly to the dataset.

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