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Evaluation Model for the Level of Service of Shared-Use Paths Based on Traffic Conflicts

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Abstract: As a product of urban motorized traffic, sharing roads between pedestrians and non-motor vehicles has been widely used in the world. In order to improve the service quality of slow traffic, it is necessary to evaluate the service level of the shared-use path to determine whether the road is suitable for setting up shared forms. Therefore, the purpose of this study is to provide an analytical framework to quantify and accurately express the service level of shared-use paths. Considering the direct impact of traffic conflicts on service quality, fuzzy clustering analysis is used to analyze traffic conflicts. Then, the corresponding relationship between traffic conflict events and service levels is established, and the classification criteria of the service levels at all levels and the corresponding range of conflict events are determined. By judging the interval in which the number of conflict events belongs, we can determine the service level of the shared-use path, and then determine whether the slow-moving road is suitable for sharing between pedestrians and non-motor vehicles. The research results can provide a reference for traffic management departments to determine the service level and applicability of shared roads.

Keywords: shared-use paths; traffic conflicts; service level; isolation facilities

1. Introduction

Slow traffic usually refers to manually driven traffic, such as walking or non-motorized vehicles, which is an important part of urban residents' travel. However, with the rapid improvement of the degree of motorization, urban transportation resources tend to be excessively motor vehicles, the slow-moving space is severely compressed, and pedestrians are mixed with bicycles and electric cars. This study calls it a shared-use path used by pedestrians, cyclists, and electric bicycle riders. Shared-use path is a road resource that pedestrians and non-motor vehicles can use simultaneously. In this design mode, there is no height difference between sidewalks and non-motor vehicle lanes, and space can be utilized mutually (as illustrated in Figure 1).

It is a product of urban motorization. Through lane sharing, non-motor vehicle traffic can use sidewalk space during peak hours, while pedestrian traffic can use non-motor vehicle lane space during normal hours, thus saving urban space resources and alleviating lane congestion. However, when mixed traffic flow is too large, the conflicts between different modes of transportation will be greater, and the service quality of shared roads will be worse. At this time, it is necessary to consider taking reasonable isolation measures to isolate non-motor vehicles and pedestrians with different operations to ensure traffic efficiency and safety. Therefore, it is necessary to discuss whether shared-use paths are used in road sections, and then determine the reasonable application scope of the shared road to ensure the rationality of its planning and design.

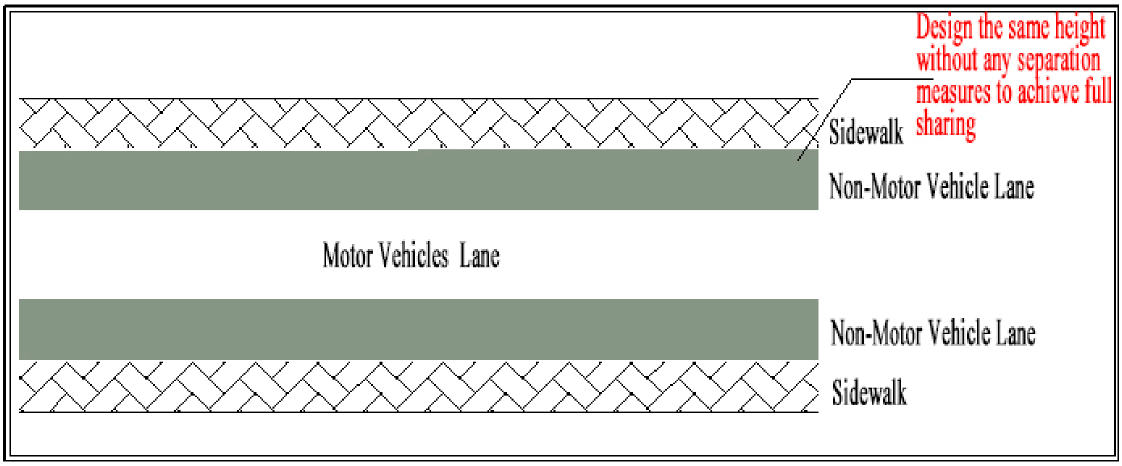

Figure 1. Schematic diagram of urban shared-use paths.

Service level is a comprehensive description of the running state and the feelings of road users [1]. It is typically used as an important index to evaluate the quality of shared-use paths. Reasonable evaluation of the service level of shared-use paths is of great significance for determining the applicable scope of shared lanes, improving the slow-moving traffic environment, and increasing the utilization rate of road space.

Existing research on the service level of shared-use paths mainly focuses on various independent slow traffic modes, paying attention to pedestrians and bicycles. Many studies have analyzed the factors affecting the service level of bicycle lanes, including speed, traffic volume, the width of bicycle lanes, road conditions, and riding experience [2–5]. Generally speaking, there are two classical methods to evaluate the service level of bicycle lanes, namely, the Bicycle Compatibility Index (BCI) and the Bicycle Level of Service (BLOS). Numerous studies have compared and analyzed the similarities and differences between the two models, summarized their advantages and disadvantages, pointed out the applicability of the models [6–8], and optimized the evaluation models [5,8–10]. This review investigates the variables and indices employed in the BLOS area in relation to the field of bicycle flow and comfort research [11].

The service level is also related to the capacity of bicycle lanes [12,13]. Some scholars also put forward the concept of user's psychological space, and regard its influence rate and duration as the evaluation index of bicycle lane safety service level [14]. Studies have used the number of bicycle traffic conflicts as the basis for dividing the service level of bicycle lanes, including two types of conflicts: The number of encounters in reverse traffic flow and the number of overruns in the same direction [15,16]. Survival analysis of the risk perception sensitivity of cyclists is proposed. The cumulative probability of survival serves as an index of risk perception sensitivity, and a Cox regression model is established to evaluate bicyclists traffic conflicts [17].

Pedestrian Level of Service (PLOS) is widely used to evaluate the comfort of pedestrian facilities on shared-use paths, which defines the performance level of pedestrian facilities [18,19]. In the research process of evaluation models of pedestrian service level, many methods have been applied to obtain the classification standard of service level, such as Highway Capacity Manual (HCM), Affinity Propagation (AP), Self-Organizing Map (SOM) in Artificial Neural Network (ANN), and Genetic Algorithm-fuzzy (GA-fuzzy) clustering [20,21]. Many studies have described the running state, comfort, and security of pedestrians during walking as evaluation indexes for the service level of walking facilities [22–25]. At the same time, scholars have put forward a calculation method of pedestrian service level considering the comfort of walking facilities from the perspective of visual inconvenience person [26].

Scholars have done further research on the service level of shared roads under mixed traffic flow. At first, Botma put forward the concept of blocking probability for two traffic entities, namely, bicycle and pedestrian, taking the frequency of overtaking and meeting between different traffic entities on the shared-use path as the evaluation index of the service level of a shared road. After that, many studies have studied the classification and determination of the service level of shared-use paths based on the obstacle model proposed by Botma. The concept of traffic conflict intensity was also adopted to describe the service level of shared roads [27–30]. On the macro level, Zohreh Asadi-Shekari discussed the challenges faced by the walking level of service and bicycle service level on shared-use paths and provided some development suggestions [31]. Fan Wei has qualitatively discussed the advantages, disadvantages, and applicable conditions of shared-use paths [32].

Scholars have further studied the service level of shared roads under mixed traffic conditions. Firstly, Botha put forward the concept of congestion probability of bicycle and pedestrian traffic entities. The frequency of overtaking and meeting between different traffic entities on the shared-use path is taken as the evaluation index of service level [33]. Since then, based on the obstacle model put forward by Botha [27,34,35], many studies have studied the classification and determination of the service level of shared-use paths. The concept of traffic conflict intensity has also been adopted to describe the service level of shared roads [26,29–31]. On the macro level, Zohreh said, Shekari has discussed the challenges faced by the walking level of service and bicycle service level on shared-use paths and provided some development suggestions [32]. Fan Wei has qualitatively discussed the advantages, disadvantages, and applicable conditions of shared-use paths.

However, the existing research on the service level of shared-use paths mostly focuses on the sharing of pedestrians and bicycles, while ignoring the influence of electric vehicles. Secondly, the establishment of the service level evaluation system of shared-use paths is only aimed at a certain type of road users, and it lacks a comprehensive consideration of the service quality of all slow traffic users under the mixed slow traffic flow.

Here, we propose a method for evaluating the service level of shared-use paths. This method takes into account three slow traffic modes: Pedestrians, bicycles, and electric vehicles. In this method, we study the influence of traffic conflict events on service level. Through fuzzy clustering analysis of traffic conflict events, the corresponding relationship between traffic conflict events and service levels is established, and the quantitative expression of service level of shared lanes is realized.

The organizational structure of this study is as follows: Section 2 analyzes and clusters traffic conflict events. Section 3 establishes the corresponding relationship between service levels at all levels and different types of traffic conflict events. The discussion and conclusion are given in Sections 4 and 5, respectively.

2. Materials and Methods

2.1. Data Definition

In this paper, Traffic Conflict Events are introduced as the index of dividing road service levels. Firstly, it is defined as follows: On an urban shared-use path, each road user occupies a certain amount of time and space resources. If two or more road users approach each other at the same time and space, at least one road user must change his running state, otherwise, collision or danger may occur. This phenomenon is called the Traffic Conflict Event. It is defined as a traffic conflict occurring in each traffic entity per unit time on a given shared-use path [36].

On shared-use paths, traffic conflict events refer to overtaking or meeting events that have a great psychological impact on traffic participants. The specific performance is the avoidance action caused by overtaking, being overtaken, or meeting. In the actual investigation, it is defined as follows.

(1) All conflict events only consider the overtaking (meeting) events occurring in adjacent lanes (1 m is specified as the width of a single lane). For several traffic entities that overtake (meet) in parallel at the same time, it is considered that the overtaking (meeting) events will not affect

them. Overtaking (meeting) traffic users on one side of adjacent lanes is counted as a conflict event (Figure 2a).

(2) Figure 2b shows that overtaking (meeting) traffic entities in adjacent lanes on both sides is regarded as two conflicting events.

(3) If the overtaking (meeting) event occurs at a lateral distance greater than l meter, the number of events is not counted (Figure 2c).

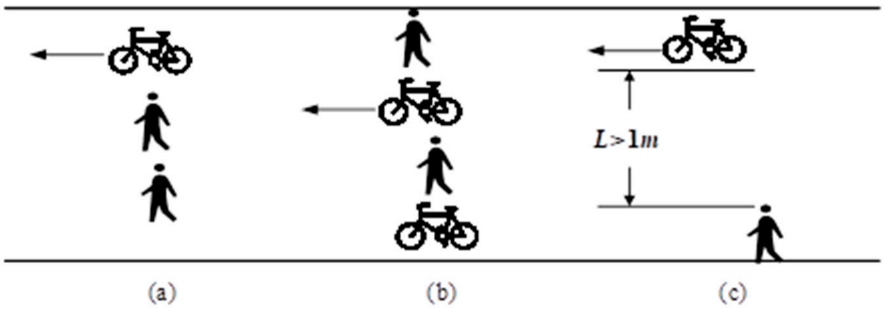

Figure 2. Schematic diagram of traffic conflicts on Shared-use path. (**a**) All conflict events only consider the overtaking (meeting) events occurring in adjacent lanes (1 m is specified as the width of a single lane). For several traffic entities that overtake (meet) in parallel at the same time, it is considered that the overtaking (meeting) events will not affect them. Overtaking (meeting) traffic users on one side of adjacent lanes is counted as a conflict event (Figure 2a); (**b**) Figure 2b shows that overtaking (meeting) traffic entities in adjacent lanes on both sides is regarded as two conflicting events; (**c**) If the overtaking (meeting) event occurs at a lateral distance greater than l meter, the number of events is not counted (Figure 2c).

In practice, the number of events corresponding to different modes of transportation includes not only the number of times of overtaking (meeting) but also the number of times of being overtaken (met). However, it has been stipulated that the number of overtaking (meeting) events is only the number of overtaking (meeting) events between two road users, so strictly speaking, the number of overtaking is equal to the number of being overtaken, and the number of meetings is equal to the number of being met. Using transcendental number and encounter number to express the number of events accords with the actual situation, which is convenient for statistical operation.

In the process of traffic conflict, road users are required to pay extra attention to the events of overtaking, being overtaken, or meeting. Therefore, the more traffic conflict events road users encounter during operation, the more blocked the operation, the worse the travel comfort, and the lower the service level. In other words, the number of conflict events is a comprehensive indicator of the comfort of shared-use paths, which is closely related to the definition of road service level. Therefore, taking traffic conflicts as indicators, this paper establishes the standard of service level division.

2.2. Data Investigation

2.2.1. Data Interpretation

This study needs the following data in the subsequent analysis (Table 1):

Table 1. Survey data summary table.

Data Type	Data Content	Acquisition Method
Static Data	The width of shared-use paths	Tape measure
	The width of road sections	
Dynamic Data	Traffic composition	Video recording or manual counting
	Traffic flow in all modes	
	Traffic conflict events	

2.2.2. Investigation Scheme

(1) Investigation period

According to the analysis results of pre-investigation, the pedestrian and non-motor vehicle traffic generally presents the trip rule that the morning peak distribution is concentrated, the evening peak is relatively scattered, and the morning peak traffic volume is larger than the evening peak traffic volume. The peak period lasts 20 min.

Restricted by objective factors such as driving speed and distance, the morning peak of slow traffic is generally 15–30 min earlier than that of motor vehicle traffic, and the evening peak is later than that of motor vehicle traffic. Therefore, drawing on the existing experience of motor vehicle investigation, it is considered that it is more appropriate to choose 7:00 am–8:30 am for investigation.

(2) Source of data

Researchers investigated four typical shared-use paths in Nanjing city in China. The survey point is located in the central area of the city. See Table 2 for details.

Table 2. Basic information of survey sections.

Road Number	Road Name	Road Grade	Width (m)	Section Length (m)	Road Surrounding Environment
1	Jinxiang River Road (East Side)	Secondary trunk road	3.5	195	Hotels, schools, and military regions
2	Zhujiang Road (north side)	Main road	5	205	Electronics, business
3	Beijing East Road (south side)	Main road	3.6	334	Leisure and entertainment
4	Taiping North Road (East Side)	Main road	5.5	167	Business, entertainment

2.2.3. Data Statistics

(1) Select typical sections in each road section and take 5 min as a statistical interval, and then obtain the two-way pedestrian, bicycle, and electric bicycle traffic flow on shared-use paths from 7:00 a.m. to 8:30 a.m. Finally, we need to extend the short-time traffic in 5 min to hourly traffic.

(2) Taking the bicycle as the test vehicle, the tester rode continuously at 5-min intervals during the investigation and recorded the corresponding real-time traffic operation through the camera, so as to obtain the number of traffic conflict among pedestrians, bicycles, and electric vehicles (Table 3).

Table 3. List of traffic conflict types of different modes of transportation.

Main Object of Conflict	Conflict Type
Pedestrians	Overtaken by bicycles
	Overtaken by electric vehicles
	Meeting opposite pedestrians
	Meeting opposite bicycles
	Meeting opposite electric vehicles
Bicycles	Overtaking pedestrians
	Overtaking bicycles
	Overtaken by electric vehicles
	Meeting opposite pedestrians
Electric vehicles	Overtaking pedestrians
	Overtaking bicycles
	Overtaking electric vehicles
	Meeting opposite pedestrians

2.3. Data Processing

2.3.1. Traffic Composition Analysis

Through the comparative study of the forward and reverse traffic flows of three slow-moving traffic modes on shared-use paths, it is found that the reverse traffic volume ratio of electric vehicles and bicycles on each road section is small (less than 10%), which can be ignored. Except Beijing East road, the reverse pedestrian flow in other sections is relatively large, accounting for 36–62% of the total pedestrian flow in this sections, which is related to the characteristics of pedestrians and the nature of the land around the sections. Based on this, this paper focuses on electric vehicles, bicycles, and two-way pedestrians.

2.3.2. Data Classification

In the actual investigation, due to the constant change of the speed of the test car, the random sampling value of the number of events has great discreteness, so it is not suitable for fitting with the original data directly. Therefore, firstly, the raw data are classified and processed according to the following methods, and the average interval value of each group is taken as the unified flow of the data in this group.

(1) Bicycle hourly flow rate Q_{cb} distribution has a minimum interval of [0, 100], a maximum interval of [800, 900], and a step size of 100, which are divided into 9 groups.
(2) The minimum and maximum interval of pedestrian flow Q_p rates are [0, 100] and [900–1000], respectively, with a step size of 100, which are split into 10 groups.
(3) The minimum interval of the total flow rate Q of the road section is [200, 400], the maximum interval is [3400, 3600], and the step size is 200, which are divided into 17 groups.

When processing, all data samples are divided into 83 categories according to different lane widths, electric vehicle flows, bicycle flows, and pedestrian flows. The average measured number of events is regarded as the new value of the number of events after classification. Each category includes information such as lane width, flow rate, and number of conflict events. Table 4 gives a summary.

Table 4. Aggregated data of traffic conflicts events on shared-use paths.

Parameters \ Data Number	1	2	3	4	5	6	7	8	9	...
W (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	...
Q (units/h)	900	900	900	1100	1100	1100	1300	1300	1500	...
Q_{eb} (units/h)	350	350	350	350	450	550	550	550	450	...
Q_{cb} (units/h)	150	250	350	150	150	250	250	250	250	...
Q_p (units/h)	150	150	150	350	150	250	150	250	350	...
Q'_p (units/h)	150	150	150	250	250	150	350	250	450	...
Bicycle conflict events (pieces)	17.0	10.8	8.2	24.4	24.6	16.4	24.3	25.4	22.9	...

Note: (1) The number of bicycle conflicts here is the sum of the number of bicycles overtaking pedestrians, the number of bicycles overtaken by bicycles and electric vehicles, and the number of bicycles encountering opposite pedestrians. (2) Details of 83 types of summary data are shown in Appendix A.

2.4. Fuzzy Cluster Analysis

To establish the corresponding relationship between conflict events and service levels, it is necessary to classify the number of events obtained from the investigation, to obtain the standard value for dividing the number of service-level events.

2.4.1. Classification Index

Considering that bicycle traffic flow usually occupies the middle lane of the road section and conflicts with neighboring pedestrians and electric vehicles to a certain extent, it can be considered that the number of bicycle traffic conflict events per minute is the largest [37]. Therefore, the service level of bicycles is regarded as the service level of shared-use path, and the number of various traffic conflicts of bicycles is regarded as the classification index of fuzzy clustering analysis.

In this paper, the clustering analysis method of the bicycle service level is cited [16]. Cluster analysis classifies a group of things according to their similarity in essence, and classifies individuals with similar attributes into one class, so that individuals in the same class have a high degree of homogeneity. In the systematic clustering method, a given sample is just one class attribute, which belongs to the hard clustering method. However, in a practical application, the boundaries between different bicycle service levels are fuzzy, so fuzzy clustering analysis should be carried out according to the objective characteristics and the degree of closeness between samples. Different from the systematic clustering method, the fuzzy clustering method is a mathematical method to classify objective things by establishing fuzzy equivalence relation according to their characteristics, the degree of affinity, and similarity.

The principle of "minimizing the similarity between classes and maximizing the similarity within classes" should be followed when using fuzzy cluster analysis to divide the bicycle service level on shared-use paths.

The specific steps of fuzzy clustering are as follows.

2.4.2. Data Standardization

According to the requirements of the fuzzy matrix, the standard deviation transformation and range transformation are carried out on the data, and the sample data are compressed to the interval [0, 1]. Assume that the original data matrix is as follows:

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \cdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}$$

where x_{nm} represents the original data of the m-th index of the n-th classified object

Equations (1)–(3) shows the transformation formula of standard deviation:

$$\overline{x_k} = (1/n)\sum_{i=1}^{n} x_{ik} \quad (1)$$

where $\overline{x_k}$ represents the average value of each classified object.

$$s_k = \sqrt{(1/n)\sum_{i=1}^{n}(x_{ik} - \overline{x_k})^2} \quad (2)$$

$$x'_{ik} = (x_{ik} - \overline{x_k})/s_k, i = 1, 2, \ldots, n; k = 1, 2, \ldots, m; \quad (3)$$

where x'_{ik} represents the standard deviation of each classified object.

Equation (4) shows the range transformation formula:

$$x''_{ik} = \left[x'_{ik} - \min_{1\le i\le n}\{x'_{ik}\}\right] / \left[\max_{1\le i\le n}\{x'_{ik}\} - \min_{1\le i\le n}\{x'_{ik}\}\right], k = 1, \ldots, m; \quad (4)$$

where x''_{ik} represents the range of each classified object.

2.4.3. Fuzzy Similarity Matrix

The fuzzy similarity matrix R (1) is established by absolute value subtraction-Euclidean distance, and it is shown in Equation (5):

$$r_{ij} = \left\{ \begin{array}{c} 1, i = j \\ 1 - c \times \sum_{k=1}^{m} |x_{ik} - x_{jk}|, i \neq j \end{array} \right\} \quad (5)$$

where r_{ij} indicates the similarity between x_j and x_i. $r_{ij} = R(x_i, x_j)$, and $0 \le r_{ij} \le 1$.

2.4.4. Fuzzy Similarity Equivalent Matrix

The square self-synthesis method is used to find the fuzzy similarity equivalent matrix, which is also called the dynamic clustering graph. Let the value of the fuzzy similarity matrix, which is greater than or equal to λ, be set to 1, otherwise set to 0, and merge the elements set to 1 into a class. We can control the number of clustering results by adjusting the value of λ (0 < λ < 1). Since the service level is usually divided into six levels, to facilitate the connection between the number of bicycle conflict events and the service levels, the value of λ is required to ensure that the number of event samples can be separated into nearly six categories.

3. Results

3.1. Clustering Results

After constant adjustment, it is finally determined that the value of λ is 0.9250. At this time, the number of events is subdivided into eight categories. Then, according to the above four steps, the program is compiled and calculated, and the results of sample fuzzy clustering can be obtained (Table 5).

Table 5. Sample fuzzy clustering results.

Conflict Number Interval	Category
[0.18, 1.28]	1
[5.03, 6.77]	2
[7.59, 8.79]	3
[10.19, 11.06]	4
[12.34, 19.27]	5
[20.05, 22.14]	6
[22.90, 22.91]	7
[23.92, 28.59]	8

Note: Sample statistics of various intervals of traffic conflict events are shown in Appendix A.

3.2. Research on Service Levels Corresponding to Conflict Events in Each Catagory

This study analyzes road conditions and traffic flow conditions corresponding to each conflict event classification to obtain the service level represented by such conflict events. This paper describes the service level according to the following indicators.

(1) Riding freedom: According to the descending order of riding freedom, it can be divided into free riding, basic free riding, restrictive riding, and obstructive riding. Among them, free riding means that the rider can freely choose the riding route and riding speed, and overtaking (meeting) events can occur; restricted riding means that the rider's behavior of choosing the route, speed, and overtaking (meeting) is limited to some extent; obstructive riding means that riders cannot freely choose riding routes, riding speeds, overtaking (meeting) events, and other behaviors.

(2) Comfort degree: It is a comprehensive index to express riding comfort, which is divided into comfortable, relatively comfortable, normal feeling, uncomfortable, and very uncomfortable according to the descending order of comfortable degree.

(3) Smooth degree: According to the order of smooth degree of road sections from big to small, it can be divided into smooth, relatively smooth, and not smooth.

According to the sample data of various conflict events and the traffic load coefficient V/C, the road conditions and bicycle riding conditions corresponding to each interval are described, and the relationship between traffic conflict events and the service level is established.

Conflict events of the first category: The interval of events is [0.18, 1.28]. Investigation statistics of this kind of conflict events include 11 groups of samples, and the details are shown in Table 6.

Table 6. Sample statistics of conflict events of the first category.

Parameters \ Data Number	39	40	41	43	44	45	63	64	65	67	68
W (m)	5	5	5	5	5	5	5.5	5.5	5.5	5.5	5.5
Q (units/h)	700	700	700	900	900	900	700	700	700	900	900
Q_{eb} (units/h)	350	350	350	450	550	550	350	350	350	450	550
Q_{cb} (units/h)	150	250	250	250	250	250	150	250	250	250	250
Q_p (units/h)	50	150	150	50	50	150	50	150	150	50	150
Q'_p (units/h)	50	50	150	150	250	150	50	50	150	150	150
Bicycle conflict events (pieces)	1.2	1.0	0.7	1.0	1.1	1.3	0.2	0.2	0.9	0.7	0.3

In the table above, the total traffic flow rate of this set of data is less than 900 units/hour. Among them, the pedestrian flow is very small, basically kept below 150 units/hour, and the flow of electric vehicle does not exceed 550 units/hour. All data are measured on the road sections with a width of 5 m or more, and the number of lanes exceeds 4. According to the traditional calculation method of the traffic load coefficient, the v/c ratio of bicycles is distributed in [0.27, 0.38], with an average value of 0.32. The corresponding cycling conditions can be characterized as follows: Free riding, basically without interference, cyclists feel comfortable and the road condition is smooth.

The analytical principles of the other seven categories are similar to those of the first category. In summary, Table 7 illustrates the relationship between the bicycle service level and traffic conflict events of each category. Each service level corresponds to conflict events in a certain interval.

Table 7. Division standard of initial bicycle service level.

Category	Conflict Number Interval	Traffic Load (V/C)	State Description
1	[0.18, 1.28]	[0.27, 0.38]	Free riding, basically without interference, cyclists feel comfortable and the road condition is smooth
2	[5.03, 6.77]	[0.34, 0.57]	Basic free riding, with little interference, cyclists feel normal, and the road condition is relatively smooth
3	[7.59, 8.79]	[0.40, 0.67]	Restricted riding, with much interference, cyclists feel uncomfortable, and the road is not smooth
4	[10.19, 11.06]	[0.52, 0.58]	Restricted riding, with much interference, cyclists feel uncomfortable, and the road is not smooth
5	[12.34, 19.27]	[0.44, 0.97]	Restricted riding, with great interference, cyclists feel uncomfortable, and the road is not smooth
6	[20.05, 22.14]	[0.61, 1.03]	Restricted riding, serious interference, cyclists feel very uncomfortable, and the road is not smooth
7	[22.90, 28.59]	[0.70, 1.08]	Obstructive riding, serious interference, cyclists feel very uncomfortable, the road is not smooth

3.3. Optimized Classification

Table 7 only reflects the traffic characteristics of the sample itself, but in practical application, the physical characteristics of the shared-use path and the feelings of cyclists are taken into account, so we need to adjust the clustering results. The following principles should be observed during adjustment.

(1) Give full consideration to the continuity and integrity of the number of events.
(2) Avoid situation where the number of incidents is similar but the service level is very different, or the number of incidents is very different but the service level is similar. We need to combine and adjust the data intervals with similar traffic conditions.
(3) Avoid abrupt changes in service levels between adjacent grades and similar service levels between different grades.

To sum up, the adjusted service level classification standards is shown in Table 8.

Table 8. Recommended bicycle service level standards on urban shared sections.

Service Level Grade	Event Number Range	State Description
Level 1	[0, 2.5)	Riding freely, basically without interference, cyclists feel comfortable and the road condition is smooth
Level 2	[2.5, 5.0)	Riding freely, with little interference, cyclists feel more comfortable and the road condition is smooth
Grade 3	[5.0, 7.0)	Riding is basically free, with little interference, cyclists feel comfortable and the road condition is smooth
Level 4	[7.0, 12.0)	Restricted riding, with much interference, and cyclists feel uncomfortable and the road condition is not smooth
Grade 5	[11.0, 20.0)	Restricted riding, with great interference, cyclists feel uncomfortable and the road condition is not smooth
Grade 6	[20.0, +∞)	Restricted riding, serious interference, cyclists feel very uncomfortable and the road condition is not smooth

Note: The number of events refers to the average number of events per minute experienced by each bicycle in the bicycle traffic flow on a given urban road section.

3.4. Application of Service Level Evaluation Model

Combined with Table 8, it can be seen that the bicycle riding state corresponding to the service level of level 4 and below is restricted riding and is greatly interfered with by other traffic modes on the road section. Traffic safety is also reduced and the rider feels uncomfortable. Therefore, it is considered to set up separation facilities to separate pedestrians from non-motor vehicles, so as to reduce interference, ensure safety, and improve comfort.

At the same time, considering the geometry and traffic conditions of the road, it is found that it is not suitable to set up separation facilities under the following conditions.

(1) Slow traffic space does not meet the set conditions: When the road section width is less than 2.5 m (two lanes), the width of independent sidewalks or non-motor vehicle lanes cannot meet the minimum traffic space requirements, and the traffic efficiency and comfort are low.

(2) The road section needs to meet certain traffic conditions: When the traffic flow of the road section is low, the proportion of pedestrians and non-motor vehicles is unbalanced or the distribution in peak hours is not synchronized, the sharing management model is more conducive to the effective use of road resources, and separation is not recommended. Therefore, the process of judging the setting conditions of isolation facilities in shared-use paths is given (Figure 3).

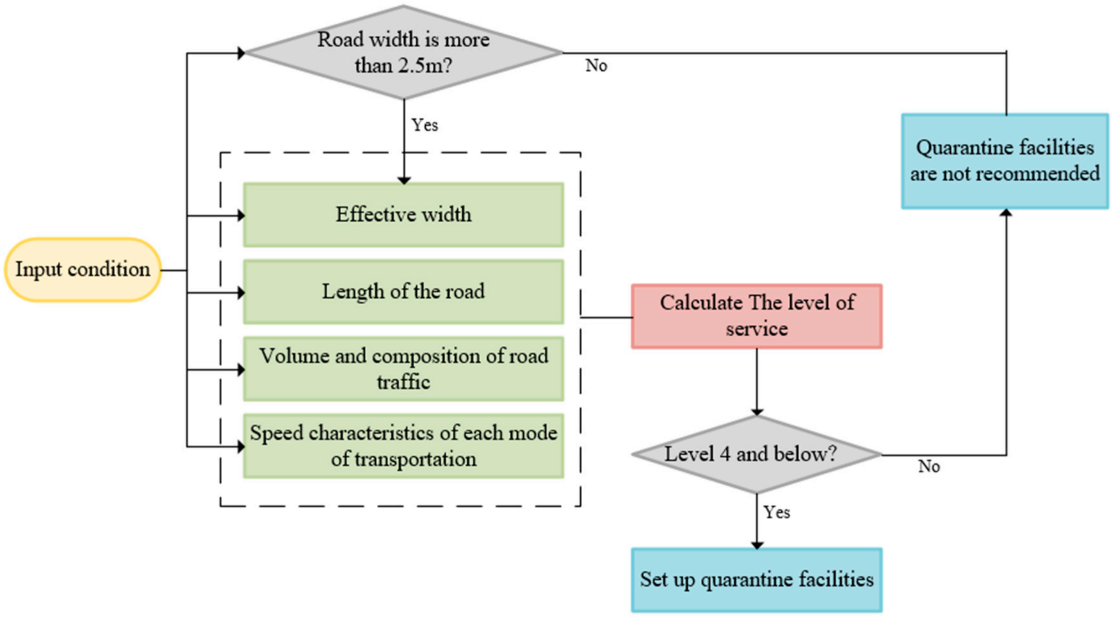

Figure 3. Flow chart of judging conditions for setting isolation facilities on shared-use paths.

(1) Find out the exact conditions of road sections, such as road width, effective width, length of road section, traffic volume, and composition of traffic mode. Then, it is judged whether the width of the road section is larger than 2.5.

(2) If the width is less than 2.5 m, it is not recommended to set up pedestrian and non-motor vehicle separation facilities on the shared roads. Otherwise, it is necessary to judge the service level of road sections and further determine whether it is necessary to set up separation facilities.

(3) Determine the number of bicycle conflict events on the road section, find out the corresponding event interval, and determine the corresponding service level according to Table 8. Then, judge whether the service level is Grade 4 or lower. If it belongs to Grade 4 or below, the sidewalks must be separated from non-motor vehicle lane. Otherwise, it is recommended not to divide shared lanes.

4. Discussion

In this study, the service level evaluation of shared-use paths under mixed flow conditions, including pedestrians, bicycles, and electric vehicles, is studied. Traffic conflicts that have a direct impact on the quality of road service are taken as the criteria for dividing the service level. Then, the correspondence between the number of conflict events and service levels is established, and the interval of the number of conflict events corresponding to each service level is found.

This study realizes a quantitative description of the traffic comfort of shared-use path, which makes the evaluation of service level more accurate. At the same time, the service level evaluation model can be applied to the setting conditions of pedestrian and non-motor vehicle isolation facilities, which indicates that the research has practical application ability and popularization value.

5. Conclusions

The setting of shared-use paths used by pedestrians, cyclists, and electric bicycle riders can effectively improve utilization efficiency of the slow-moving system. However, at present, the setting of this lane lacks a comprehensive and quantitative judgment on the service level of road sections.

In this study, the shared-use path used by pedestrians and non-motor vehicles was regarded as the research object, and the service level evaluation model of a shared lane was established based on the number of traffic conflicts. We chose four typical shared roads in Nanjing to carry out traffic investigation. Considering the occupation characteristics of different modes of transportation on shared roads, bicycles are selected as the evaluation object, and fuzzy cluster analysis was carried out on the survey samples, and the correlation between the number of conflict events and service levels is established according to the measured data. In addition, according to the actual traffic conditions of road sections, the classification standards of service levels at all levels and the corresponding range of incidents are discussed and adjusted. Then, we put forward the six-level classification standards for service levels. The corresponding relationship between the number of conflict events and the service level of a shared channel is established, and the service level can be quantitatively evaluated.

In this study, mixed traffic conditions were considered, and the traffic comfort of shared-use path was quantitatively described, which made the service level evaluation of road sections more accurate. At the same time, the evaluation model of service level can be applied to the setting conditions of isolation facilities. The research results of this paper provide a basis for the organization and optimal management of slow traffic.

This paper mainly studies the shared-use path from the perspective of traffic safety, and evaluates the service quality of road sections with the number of traffic conflicts, but does not deeply analyze the traffic efficiency of different traffic modes. However, the occurrence of conflicts is often accompanied by changes in speed and running track, which will bring certain changes in inefficiency to road users, and further research can be undertaken in this regard in the future.

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Appendix A

Table A1. Aggregated data of traffic conflicts events on shared-use paths.

Parameters \ Data Number	1	2	3	4	5	6	7	8	9	10
W (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Q (units/h)	900	900	900	1100	1100	1100	1300	1300	1300	1300
Q_{eb} (units/h)	350	350	350	350	450	550	550	550	550	650
Q_{cb} (units/h)	150	250	350	150	150	250	250	250	350	250
Q_p (units/h)	150	150	150	350	150	250	150	250	250	150
Q'_p (units/h)	150	150	150	250	250	150	350	250	250	350
Bicycle conflict events (pieces)	17.0	10.8	8.2	24.4	24.6	16.4	24.3	25.4	17.8	21.4
Parameters \ Data Number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
W (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Q (units/h)	1500	1500	1500	1500	1500	1500	1500	1700	1700	1700
Q_{eb} (units/h)	450	450	450	550	550	650	650	750	750	850
Q_{cb} (units/h)	250	250	250	350	350	250	250	350	350	350
Q_p (units/h)	350	350	550	150	250	250	250	250	350	250
Q'_p (units/h)	450	550	250	350	250	250	350	350	350	350
Bicycle conflict events (pieces)	22.9	28.0	27.7	21.9	23.9	26.7	24.3	22.1	27.1	25.1

Table A1. *Cont.*

Parameters \ Data Number	21	22	23	24	25	26	27	28	29	30
W (m)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Q (units/h)	1300	1300	1500	1500	1500	1500	1500	1500	1500	1500
Q_{eb} (units/h)	850	950	850	950	1050	1050	1050	1150	1150	1150
Q_{cb} (units/h)	350	350	450	450	250	350	450	250	250	350
Q_p (units/h)	150	50	150	150	250	150	50	50	150	50
Q'_p (units/h)	50	50	50	50	50	50	50	50	50	50
Bicycle conflict events (pieces)	16.5	17.0	17.0	18.4	26.1	19.3	18.8	28.6	27.6	21.4
Parameters \ Data Number	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
W (m)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	5	5
Q (units/h)	1500	1700	1700	1700	1700	1700	1700	1700	700	700
Q_{eb} (units/h)	1150	950	950	950	1050	1050	1150	1150	350	350
Q_{cb} (units/h)	350	350	450	450	350	450	350	450	150	250
Q_p (units/h)	150	250	150	250	250	250	50	150	50	150
Q'_p (units/h)	50	50	50	50	50	50	50	50	50	50
Bicycle conflict events (pieces)	21.2	28.0	22.9	21.0	26.4	24.1	25.2	20.1	1.2	1.0
Parameters \ Data Number	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
W (m)	5	5	5	5	5	5	5	5	5	5
Q (units/h)	700	900	900	900	900	1100	1100	1100	1100	1300
Q_{eb} (units/h)	350	450	450	550	550	450	550	550	750	550
Q_{cb} (units/h)	250	150	250	250	250	150	250	250	150	250
Q_p (units/h)	150	50	50	50	150	150	50	150	150	150
Q'_p (units/h)	150	50	150	250	150	250	150	50	150	250
Bicycle conflict events (pieces)	0.7	7.6	1.0	1.1	1.3	15.2	6.8	6.7	13.5	10.6
Parameters \ Data Number	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
W (m)	5	5	5	5	5	5	5	5	5	5
Q (units/h)	1300	1300	1300	1500	1500	1500	1500	1500	1500	1500
Q_{eb} (units/h)	550	550	650	650	650	650	650	650	650	750
Q_{cb} (units/h)	250	250	250	150	450	250	250	250	250	250
Q_p (units/h)	250	350	150	350	150	250	250	350	350	250
Q'_p (units/h)	150	150	250	250	250	250	350	250	350	150
Bicycle conflict events (pieces)	10.9	12.7	11.1	20.4	7.6	15.3	16.1	15.3	13.7	14.1

Table A1. *Cont.*

Data Number / Parameters	61	62	63	64	65	66	67	68	69	70
W (m)	5	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Q (units/h)	1500	1500	700	700	700	900	900	900	1100	1100
Q_{eb} (units/h)	750	750	350	350	350	450	450	550	450	550
Q_{cb} (units/h)	250	250	150	250	250	150	250	250	150	250
Q_p (units/h)	250	350	50	150	150	50	50	150	150	50
Q'_p (units/h)	250	150	50	50	150	50	150	150	250	150
Bicycle conflict events (pieces)	14.8	14.2	0.2	0.2	0.9	6.3	0.7	0.3	12.3	5.0
Data Number / Parameters	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
W (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Q (units/h)	1100	1100	1100	1300	1300	1300	1500	1500	1500	1500
Q_{eb} (units/h)	550	650	750	550	550	650	650	650	650	650
Q_{cb} (units/h)	250	250	150	250	250	150	250	250	250	450
Q_p (units/h)	150	150	150	250	350	350	250	350	350	150
Q'_p (units/h)	250	250	150	150	150	250	350	250	350	250
Bicycle conflict events (pieces)	5.3	5.4	12.5	8.8	10.2	14.3	12.6	14.0	13.7	6.0
Data Number / Parameters	**81**	**82**	**83**							
W (m)	5.5	5.5	5.5							
Q (units/h)	1500	1500	1500							
Q_{eb} (units/h)	750	750	750							
Q_{cb} (units/h)	250	250	250							
Q_p (units/h)	250	250	350							
Q'_p (units/h)	150	250	150							
Bicycle conflict events (pieces)	12.5	13.3	15.4							

Table A2. Sample statistics of conflict events of the first category.

Data Number / Parameters	39	40	41	43	44	45	63	64	65	67	68
W (m)	5	5	5	5	5	5	5.5	5.5	5.5	5.5	5.5
Q (units/h)	700	700	700	900	900	900	700	700	700	900	900
Q_{eb} (units/h)	350	350	350	450	550	550	350	350	350	450	550
Q_{cb} (units/h)	150	250	250	250	250	250	150	250	250	250	250
Q_p (units/h)	50	150	150	50	50	150	50	150	150	50	150
Q'_p (units/h)	50	50	150	150	250	150	50	50	150	150	150
Bicycle conflict events (pieces)	1.2	1.0	0.7	1.0	1.1	1.3	0.2	0.2	0.9	0.7	0.3

Table A3. Sample statistics of conflict events of the second category.

Parameters \ Data Number	47	48	66	70	71	72	80
W (m)	5	5	5.5	5.5	5.5	5.5	5.5
Q (units/h)	1100	1100	900	1100	1100	1100	1500
Q_{eb} (units/h)	550	550	450	550	550	650	650
Q_{cb} (units/h)	250	250	150	250	250	250	450
Q_p (units/h)	50	150	50	50	150	150	150
Q'_p (units/h)	150	50	50	150	250	250	250
Bicycle conflict events (pieces)	6.8	6.7	6.3	5.0	5.3	5.4	6.0

Table A4. Sample statistics of conflict events of the third category.

Parameters \ Data Number	3	42	55	74
W (m)	3.5	5	5	5.5
Q (units/h)	900	900	1500	1300
Q_{eb} (units/h)	350	450	650	550
Q_{cb} (units/h)	350	150	450	250
Q_p (units/h)	150	50	150	250
Q'_p (units/h)	150	50	250	150
Bicycle conflict events (pieces)	8.2	7.6	7.6	8.8

Table A5. Sample statistics of conflict events of the fourth category.

Parameters \ Data Number	2	50	51	53	75
W (m)	3.5	5	5	5	5.5
Q (units/h)	900	1300	1300	1300	1300
Q_{eb} (units/h)	350	550	550	650	550
Q_{cb} (units/h)	250	250	250	250	250
Q_p (units/h)	150	150	250	150	350
Q'_p (units/h)	150	250	150	250	150
Bicycle conflict events (pieces)	10.8	10.6	10.9	11.1	10.2

Table A6. Sample statistics of conflict events of the fifth category.

Parameters \ Data Number	1	6	9	21	22	23	24	26	27	46
W (m)	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	5
Q (units/h)	900	1100	1300	1300	1300	1500	1500	1500	1500	1100
Q_{eb} (units/h)	350	550	550	850	950	850	950	1050	1050	450
Q_{cb} (units/h)	150	250	350	350	350	450	450	350	450	150
Q_p (units/h)	150	250	250	150	50	150	150	150	50	150
Q'_p (units/h)	150	150	250	50	50	50	50	50	50	250
Bicycle conflict events (pieces)	17.0	16.4	17.8	16.5	17.0	17.0	18.4	19.3	18.8	15.2

Table A6. *Cont.*

Data Number / Parameters	49	52	56	57	58	59	60	61	62	69
W (m)	5	5	5	5	5	5	5	5	5	5.5
Q (units/h)	1100	1300	1500	1500	1500	1500	1500	1500	1500	1100
Q_{eb} (units/h)	750	550	650	650	650	650	750	750	750	450
Q_{cb} (units/h)	150	250	250	250	250	250	250	250	250	150
Q_p (units/h)	150	350	250	250	350	350	250	250	350	150
Q'_p (units/h)	150	150	250	350	250	350	150	250	150	250
Bicycle conflict events (pieces)	13.5	12.7	15.3	16.1	15.3	13.7	14.1	14.8	14.2	12.3
Data Number / Parameters	**73**	**76**	**77**	**78**	**79**	**81**	**82**	**83**		
W (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5		
Q (units/h)	1100	1300	1500	1500	1500	1500	1500	1500		
Q_{eb} (units/h)	750	650	650	650	650	750	750	750		
Q_{cb} (units/h)	150	150	250	250	250	250	250	250		
Q_p (units/h)	150	350	250	350	350	250	250	350		
Q'_p (units/h)	150	250	350	250	350	150	250	150		
Bicycle conflict events (pieces)	12.5	14.3	12.6	14.0	13.7	12.5	13.3	15.4		

Table A7. Sample statistics of conflict events of the sixth category.

10	14	18	30	31	34	38	54	
W (m)	3.5	3.5	3.5	3.6	3.6	3.6	3.6	5
Q (units/h)	1300	1500	1700	1500	1500	1700	1700	1500
Q_{eb} (units/h)	650	550	750	1150	1150	950	1150	650
Q_{cb} (units/h)	250	350	350	350	350	450	450	150
Q_p (units/h)	150	150	250	50	150	250	150	350
Q'_p (units/h)	350	350	350	50	50	50	50	250
Bicycle conflict events (pieces)	21.4	21.9	22.1	21.4	21.2	21.0	20.1	20.4

Table A8. Sample statistics of conflict events of the seventh and eighth category.

Data Number / Parameters	4	5	7	8	11	12	13	15	16	17
W (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Q (units/h)	1100	1100	1300	1300	1500	1500	1500	1500	1500	1500
Q_{eb} (units/h)	350	450	550	550	450	450	450	550	650	650
Q_{cb} (units/h)	150	150	250	250	250	250	250	350	250	250
Q_p (units/h)	350	150	150	250	350	350	550	250	250	250
Q'_p (units/h)	250	250	350	250	450	550	250	250	250	350
Bicycle conflict events (pieces)	24.4	24.6	24.3	25.4	22.9	28.0	27.7	23.9	26.7	24.3

Table A8. *Cont.*

Parameters \ Data Number	19	20	25	28	29	32	33	35	36	37
W (m)	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Q (units/h)	1700	1700	1500	1500	1500	1700	1700	1700	1700	1700
Q_{eb} (units/h)	750	850	1050	1150	1150	950	950	1050	1050	1150
Q_{cb} (units/h)	350	350	250	250	250	350	450	350	450	350
Q_p (units/h)	350	250	250	50	150	250	150	250	250	50
Q'_p (units/h)	350	350	50	50	50	50	50	50	50	50
Bicycle conflict events (pieces)	27.1	25.1	26.1	28.6	27.6	28.0	22.9	26.4	24.1	25.2

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