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Research on management and control strategy of E-bikes based on attribute reduction method

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Abstract

The sports characteristics of E-bikes increase the conflict between traffic participants. In this paper, the criteria of E-bike traffic conflict are given according to time distance. Based on the rough set theory, the redundant rule reduction method is developed, and the following conclusions are drawn: 1. Signal lights and video monitoring points have little effect on alleviating the traffic conflict between e-vehicles and motor vehicles; 2. Setting isolation facilities, non-motor vehicle lanes and traffic police can effectively reduce the traffic conflict. The results show that this method can effectively analyse the main influencing factors of traffic conflict.

Keywords: mixed traffic, E-bike, Traffic conflict safety, management and control strategy, attribute reduction

1 Introduction

At present, the control strategy of urban mixed traffic is widely adopted by related departments. Some responsible researches shown that if pedestrians walk on the outermost lane, it would be beneficial to provide multiple channelised lanes for motor vehicles, and plan non-motorised roads for bicycle, motorcycles and electric bicycle. It is well known that traffic accidents often caused by these vehicles which were forced park on the motorised lanes because non-motorised vehicle lanes are often parked by motor vehicles. Hence, congestion is more likely to occur at peak periods; hidden danger increased greatly by traffic conflicts because the speed in both electric motor vehicles and non-motor vehicles are fast in flat peak and trough.

As some cities implement the 'Motorcycle Ban' policy in China, Traffic participant in the non-motorised lanes mainly are bicycle and electric bicycle, the E-bike is a weakly embedded alternative to mainstream auto mobility [1, 2]. On a substantial scale, E-bikes are not necessarily displacing cars, but are replacing walking,

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traditional bicycling, and the bus [3]. People use E-bikes to travel more than bicycle and most riders would travel by bus if E-bikes were unavailable [4]. Because the bicycles have low speed and flexible steering, the traffic conflicts often happen mainly between bicycles and the pedestrians [5,6]. Electric bicycle can always be seen in traffic accidents in flat peak period and low peak period. Therefore, electric bicycle has become an unavoidable traffic participant. Electric bikes need to be considered as an important factor in urban traffic planning and traffic control strategy formulation.

As one of the most likely alternative vehicles for fuel vehicles, the research of E-bikes has attracted the attention of researchers worldwide. In general, the research of Asian countries (such as China) is mainly focused on safety, environment and selection patterns with E-bikes [7]. In contrast, in western countries, the main use of electric bicycles is the older people with higher income. The purpose of their use is entertainment and leisure. Most of the studies in Europe and North America focus on the impact of E-bikes on emerging markets, user behaviour, health and ageing [8,9]. In recent years, for most urban decision-makers in China, pedalling models such as bicycles and E-bikes have been more and more attracted to people [10]. The E-bikes are electrically operated two-wheeled bicycles. Compared with traditional bicycles, people who need a long distance travel are more willing to choose it as their mode of travel [11]. In the field of urban transportation, compared with other modes of transport, E-bikes are more effective in reducing traffic problems, such as traffic jams, air pollution caused by traffic, lack of sports, excessive use of motor vehicles and so on [12]. According to ‘2017-2022 years China E-bike industry operation status and operation situation forecast report’, by the end of 2014, there were more than 200 million E-bikes in China. According to ‘the analysis of the current situation of the market demand of the E-bike industry in China for 2018-2023 years and the Research Report on the prospect of investment development’, in 2015 and 2016, the total output of E-bikes in China was 3080 and 32 million 150 thousand, respectively.

In Melbourne, Australia, 4,225 cyclists’ red-light crossing behaviour on videotape was used by Johnson, to analyse and summarise the factors affecting illegal crossing behaviour, including: driving direction, other cyclists, other vehicles and vehicle flow. Besides, for cyclists and pedestrians, personal characteristics such as gender and age are also the determinants of red-light crossing behaviour [13]. Field observation method was applied by Phillips et al., to study the factors and mitigation strategies about intersection conflicts between vehicles and bicycle [14].

In the past, the causes of traffic jams and accidents were often explained and described based on people’s subjective cognition and judgement. These deficiencies will affect the evaluation based on traffic accidents [15]. With the development of computer video recognition technology, the video detection technology is used to automatically identify the traffic conflict data in the video [15]. Since videos are recorded at certain angles, it is necessary to convert the distance through the mathematical formula using the field reference to achieve more accurate data [16]. There have been studies on automatic conflict detection by video recognition after taking video by UAV flying high above the research object [17]. Some scholars believe that the most important thing in traffic safety research is to prevent accidents rather than to predict accidents. Traffic collision technology can be used as a tool to diagnose and evaluate road traffic congestion and safety [18]. The traffic conflict prediction models widely used at home and abroad are established according to the traffic accident prediction model, including regression model, generalised linear model (Poisson distribution, negative binomial distribution, zero pile-up probability distribution), BP neural network, time series, probability model etc. Traffic conflict prediction models mainly focus on the number of conflicts, and the severity of conflicts is less. The accident prediction models based on traffic conflict mainly include regression model, causal model and probability model of trajectory based on video [19–22].

There have also been some studies on participants in multiple traffic conflicts [23,24]. For vehicles running in non-free flow, when a conflict occurs between a pair of participants, the driver immediately takes the avoidance behaviour, resulting in the change of vehicle movement state, which is likely to affect the adjacent vehicles in the lane and other lanes, causing other vehicles to have traffic conflicts, which is a ‘regional chain reaction’. Expansion of the traditional pair of participants in traffic conflict to a larger scope and the mechanism

of interaction among more participants may provide a basic model for the regional Internet of Vehicles (ROV) early warning system [25].

On the basis of the above research, this paper plans to analyse the types of human-vehicle conflicts involving E-bikes, and study the judgement criteria of traffic conflicts involving E-bikes based on time interval. Based on the field survey data, a statistical table summarising the number of conflicts under various road traffic conditions was formed. Then, the redundancy attribute reduction method based on rough set theory is used to analyse the main influencing factors of traffic conflicts of E-bikes under the traffic conditions. It provides a scientific decision-making basis for the development of traffic conflict control strategies.

2 Mixed traffic flow conflict

A. Types of Human-Vehicle Conflict Involving E-Bikes

This paper mainly analyses the impact of human-vehicle conflicts involving E-bikes on the safety of road traffic operations. The definition of traffic conflicts is as follows: Under observable conditions, when one or more bicycle flows are close to each other at the same time and space, there is a danger of collision if the motion state of one of the vehicles is not changed [26]. In the traffic simulation process, the conflict can be divided into three types of conflicts according to the angle of the advancing direction of the two agents (referred to as the collision angle) [27].

Forward traffic conflict

The traffic conflict angle $\theta \in [135^\circ, 225^\circ]$ is called forward traffic conflict, which is mainly manifested by the collision traffic agents approaching each other in opposite directions, which is the collision of oncoming conflicts.

Fig. 1 Forward traffic conflict diagram.

Fig. 2 Rear-end conflict diagram.

(1) Rear-end conflict

The traffic conflicts at the collision angle $\theta \in [-45^\circ, 45^\circ]$ are called rear-end collisions. The main manifestation is that traffic agents approach each other in the same direction, which is a collision of collisions.

Fig. 3 Cross conflict diagram.

(2) Cross conflict

The traffic conflict angle $\theta \in [45^\circ, 135^\circ]$ is called cross conflict, the main manifestation is that the traffic agents approach each other in a staggered manner, and one forward collision hits the other side. When a motor vehicle and an E-bike are in a positive conflict, it is generally difficult for the driver to accurately detect the lateral cyclist, especially when the vehicle turns. In addition, the relative speed between motor vehicles and bicycles in the event of a conflict is significantly greater than the situation of rear-end conflicts. Therefore, the positive consequences of accidents caused by positive conflicts are far greater than those of rear-end conflicts and cross-conflicts.

When the E-bikes pass through the intersection, it does not follow the vehicle path and strictly maintains a certain lateral distance, but travels in a ‘group’ manner [28]. In addition, for E-bikes riders, traffic regulations are much less binding than motor vehicle drivers. Cyclists often ignore safety rules and drive with motor vehicles during driving. As a result, individual bicycles in group-type E-bikes show strong randomness, so they are not limited to conflicting positions. There is a ‘conflict zone’ around each conflict point. A large number of E-bikes and motor vehicles are mixed and turned in the conflict zone, which makes the conflicts in the area dense and constitutes conflict points within the road [28]. This is the most obvious difference between non-conflict and motor vehicle conflicts at the intersection.

When an E-bike is driving in the conflict zone of the intersection, apart from maintaining a safe distance from other E-bikes, it must also deal with the straight-moving vehicles, the right-turn vehicles and the left-turn motor vehicles and also the relationship of position and speed between straight-moving vehicles. When the motor vehicle is driving, the attention should be paid not only to prevent the scratching from the same-way motor vehicle, but also to the side-to-side collision [29]. It is also necessary to pay attention to the group movement of the surrounding E-bikes and the discrete movement of the individual E-bikes.

B. Determination Traffic Conflict

As a method of studying road traffic safety, traffic conflict technology can measure the safety of traffic operation by determining the number of traffic conflicts [30]. Assume that traffic individual A reaches the conflict point first, and it has the necessary conditions to conflict with traffic individual B:

Table 1 Critical gap observation statistics of conflict between motor and non-motor vehicles

Table 1 Critical gap observation statistics of conflict between motor vehicles and E-bikes.

	Observing through conflict Average time (seconds)		Observing through conflict Average time (seconds)
Left turn bicycle through straight large car	5.65	Straight bicycle through the right turn large car	2.15
Left turn bicycle through straight small car	4.55	Straight bicycle through right turn small car	1.15
Left-turning motor vehicle crossing straight bicycle	3.79		

When $t_a \geq t_b$ and $t_a \leq t_b + \Delta t_b$

It means B comes first, but there is no conflict point in the tail, and A is here. Or when $t_a < t_b$ and $t_a + \Delta t_a \geq t_b$, it means A arrives first, but there is no conflict point in the tail, and B will arrive.

where:

t_a, t_b are the time when traffic individuals A and B advance from the current position to the conflict point;

$\Delta t_a, \Delta t_b$ are the time when the heads of traffic individuals A and B reach the conflict point to the tail of the vehicle leaving the conflict point.

Dean Taylor and Hani Mahmassani observed the non-conflict critical gap of some machines, and the observation results are shown in Table 1 [31]. There are few measured data on the non-conflict critical gap of the domestic machine. In practical applications, the above conclusions can be referred to and the values should be appropriately selected according to the specific conditions.

As is known, the acceleration capability and average driving speed of E-bikes are higher than that of human bicycles. Therefore, Table 1 is revised as Table 2, the conversion factor is set to 1.2295 [32].

Table 2 Critical gap observation statistics of conflict between motor vehicles and E-bikes.

	Observing through conflict Average time (seconds)		Observing through conflict Average time (seconds)
Left turn E-bike through straight large car	4.6	Straight E-bike through the right turn large car	1.75
Left turn E-bike through straight small car	3.7	Straight E-bike through right turn small car	0.94
Left-turning motor vehicle crossing straight E-bike	3.08		

3 Mixed traffic flow control strategy

A decision-making table is established to reflect the influencing factors of road traffic conflicts and the amount of conflicts. The attribute reduction method of rough set theory is used to remove redundant rules in decision tables, and the main factors causing traffic conflicts in the concerned road section are found. This method can effectively analyse the important factors of mitigating traffic conflicts, and provide a scientific decision-making basis for formulating effective control strategies and facility planning schemes to reduce road traffic conflicts.

A. Rough Set Data Analysis

Z. Pawlak uses rough set methods for knowledge-based decision support [33]. It is a more promising method of soft computing. It is not necessary to give relevant knowledge and subjective experience information such as probability distribution, fuzzy membership function and credibility distribution in which data knowledge representation and knowledge reasoning is based on rough set method. The simplification and reduction of knowledge can be derived from existing data, providing a new mathematical method for dealing with inaccurate, uncertain, ambiguous, incomplete, inconsistent information and knowledge. This theory is an important theoretical basis for data mining, knowledge fusion, information computing and expert control systems.

(1) Theory of rough Sets

Several concepts are given.

Universe: a non-empty finite set of objects.

Concept: any set X belongs to the universe and u is a concept.

Empty concept: an empty set is regarded as an empty concept.

Knowledge: any cluster of such x forms abstract knowledge in the universe, which is the ability to classify objects.

Object: any entity, object, attribute, probability, etc.

Undefined set: for any subset x on the universe u , X may not be expressed accurately by the knowledge in the knowledge base.

Information system $\text{Quad}(U, Q, V, f)$, where:

U is the collection of objects,

Q is the attribute set (including condition attribute C and decision attribute d),

V is the value range of the attribute,

f is a kind of mapping, reflecting the values between sets of objects [34].

Table 3 An information system instance.

U	a	b	c	d	e
1	1	0	1	2	0
2	0	1	1	1	2
3	2	0	0	1	1
4	1	1	0	2	2
5	1	0	1	0	1
6	2	2	0	1	1
7	2	1	1	1	2
8	0	1	1	0	1

$$U = \{1, 2, 3, 4, 5, 6, 7, 8\}$$

$$Q = \{a, b, c, d, e\}$$

$$V = \{0, 1, 2\}$$

$$\frac{U}{\text{Ind}(a)} = \{(1, 4, 5), (2, 8), (3, 6, 7)\}$$

The partition of U is determined by condition attribute a .

$$\frac{U}{\text{Ind}(a, b, c)} = \{(1, 5), (2, 8), (3), (4), (6), (7)\}$$

If $(x, y) \in \text{Ind}(P)$, then x and y are said to be indistinguishable, that is, x and y cannot be distinguished according to the properties contained in P . For example, 2 and 8 in Table 3 cannot be separated by attribute a .

It is assumed that properties and attribute values are used to describe objects in the universe. If two objects (or sets of objects) have the same attributes and attribute values, they have indistinguishable relations.

If a subset B of the conditional attribute set C in decision table $T = (U, P, C, D)$ is independent of D and $\text{Pos}_B(D) = \text{Pos}_C(D)$, then B is said to be a D reduction of C . The effect of B and C on D is the same. The core of attribute set C can be obtained by intersection of all reduction subsets like B .

Therefore, the meaning of core is as follows:

(1) because the core is included in all reductions, the core can be used as the basis of all reductions.

(2) the core is a feature set that cannot be eliminated in knowledge reduction.

(2) Attribute Reduction Method Based on Rough Set Theory

In rough set theory, all concepts and calculations are based on unresolvable relations, defined by set operations by introducing upper and lower approximation sets. This is often referred to as the algebraic view of rough set theory. Since the concepts of rough sets are abstract and difficult to understand, the concepts hinder their popularity and development, especially for the combination of practical applications in other fields. As a research tool, simulation technology can improve the efficiency of development and research systems. This paper uses MATLAB functions for basic concepts and methods of rough concentration.

The functional simulation is implemented as follows.

(1) The function $\text{pos} = \text{posCD}(a, d)$ is positive field, saving the index value of condition attribute matrix.

"a" is the conditional attribute matrix, the data is in Table 4. C_6 and C_7 represent the traffic condition. "d" is the decision attribute vector, the data is from (D) in Table 4.

(2) The function $\text{dismat} = \text{dismatrix}(a, d, \text{pos})$ is Unprocessed discrimination matrix.

(3) The function $\text{dism}=\text{disbe}(\text{dismat})$ is to simplify a discernible or reduced matrix, that is, to remove the inclusion relation.

(4) The function $\text{core}=\text{cor}(\text{dism})$ is the kernel of the differentiated matrix that has been processed.

(5) The function $[\text{red}, \text{row}]=\text{redu}(\text{dism})$ is a knowledge reduction of the differentiated matrices that have been processed. "red" is the kernel matrix. "row" is the number of rows in a nuclear matrix.

B. Traffic Control Analysis Based on Attribute Reduction

The data from the simulation results under different traffic control measures is used as the domain while the factors affecting traffic conflict as the condition attribute set and the urban road traffic congestion as the decision attribute set. Seven factors such as isolation guardrails, signal lights, non-motor vehicle lanes, video surveillance camera points, setting duty traffic police or traffic assistants, motor vehicle flow and E-bikes flow, are used as conditional attributes, denoted by C1, C2,..., C9 respectively; The amount of traffic conflict between E-bikes and motor vehicles is the decision attribute. Establish a traffic congestion decision table, as shown in Table 4.

Table 4 Traffic conflict and influencing factors data.

U	C							D	U	C							D
	C1	C2	C3	C4	C5	C6	C7			C1	C2	C3	C4	C5	C6	C7	
1	0	1	0	0	0	0	0	0	12	0	0	1	0	1	0	1	0
2	0	0	0	1	0	1	1	2	13	0	1	1	1	0	2	1	1
3	0	0	0	0	0	2	1	2	14	1	1	1	1	0	2	0	1
4	0	1	0	0	1	2	1	2	15	0	1	1	1	0	2	0	1
5	0	0	0	1	1	1	1	2	16	0	0	0	0	0	1	0	2
6	0	1	0	0	1	2	1	2	17	1	0	1	0	1	0	0	1
7	0	0	1	1	0	1	0	0	18	0	0	1	1	0	1	0	1
8	0	1	0	1	0	2	0	0	19	0	0	1	0	1	1	1	0
9	1	1	1	1	0	0	1	0	20	1	1	1	1	0	2	1	0
10	0	0	0	0	1	0	1	1	21	0	1	0	0	0	2	1	2
11	0	0	1	0	1	1	1	0	22	1	1	1	1	1	0	0	0

Wherein, C1:0 means that no isolation guardrail is set, and 1 means that an isolation guardrail is set;

C2:0 means that no signal light is set at both ends of the road section, and 1 means that the signal light is set at both ends of the road section;

C3:0 means that no non-motorised vehicle lane is set, and 1 means that the non-motorised vehicle lane is set on the road section;

C4:0 means that the video surveillance camera point is not set on the road segment, and 1 indicates that the video surveillance camera point is set on the road segment;

C5:0 means there is no traffic police or traffic assistant, 1 means that there is a traffic police or traffic assistant;

C6:0 means light traffic (less than 200 vehicles/hour), 1 means moderate traffic (200 vehicles/hour to 800 vehicles/hour), and 2 means moderate traffic (800 vehicles/hour or more);

C7:0 means that the E-bikes have a small flow rate (less than 500 vehicles/hour, no clustering phenomenon), and 1 indicates that the E-bikes have a dense flow rate (more than 500 vehicles/hour, and the cluster phenomenon is serious);

D:0 means no traffic conflict occurs, 1 means there is a small amount of traffic conflict (1 time or more, 3 times or less), and 2 means more traffic conflicts (more than 3 times).

The attribute reduction is performed, and the rules are as shown in Table 5.

C. Data Analysis Conclusions

According to the results in Table 5, we can draw the following conclusions:

Table 5 Analysis of factors affecting traffic conflicts.

The kernel matrix						
C1	C2	C3	C4	C5	C6	C7
Empty					0	0
0	0	1	0	0	0	1
0	0	1	0	0	1	0
0	0	0	1	0		
0	0	1	0	0	1	1
0	0	0	1	0		
0	0	1	0	0	2	0
1	0	1	0	0	2	1
1	0	0	1	0		

The setting of the signal lights at both ends of the road section on the road has little effect on alleviating the traffic conflict between the E-bikes and the motor vehicle;

When motor vehicles and E-bikes flow are very small, it can be seen whether the isolation guardrail, the non-motor vehicle lane, the duty traffic police and the traffic assistant have no influence on the traffic conflict;

When the motor vehicle flow is small and the E-bikes flow is large, non-motorised lane or video monitoring can effectively reduce traffic conflict and double settings are more effective.

When the motor vehicle flow is large and the traffic volume of the E-bikes is small, non-motorised lane can effectively reduce traffic conflict;

When the motor vehicle flow is large and the E-bikes flow is large, the traffic police or traffic assistants on duty can effectively reduce the traffic conflict. The double setting effect is better, and the isolation guardrail has little effect;

When the motor vehicle flow is large and the E-bikes flow is also large, the installation of the isolation guardrail and the non-motor vehicle lane and video monitoring can effectively reduce the traffic conflict. If any item is missing, the collision amount will increase significantly. Failure to set up will result in a sharp increase in the conflict between E-bikes and motor vehicles.

4 Conclusions

Conflicts between E-bikes and motorists and pedestrians increase the chances of causing congestion and increasing traffic safety risks. This paper analyses the types of human-vehicle conflicts involving electric vehicles and puts forward a conflict determination method for designing E-bikes in mixed traffic. Then, in terms of traffic control strategy, the relationship decision table reflecting the influencing factors of road traffic conflicts and the number of conflicts was established. Based on the attribute reduction method of rough set theory, the redundant rules were removed from the decision table, so as to find the main influencing factors of road traffic conflicts. The results show that this algorithm can effectively analyse the important factors for mitigating traffic conflicts, and provide a scientific decision-making basis for making effective control strategies and facility planning schemes to reduce the amount of traffic conflicts.

Limitations and Future Research Plan

In the E-bikes driving behaviour simulation model, the violations caused by the subjective factors of the rider such as the rush time and the huge changes in the collision of people and vehicles are not considered. In the next step, the collected data will be distinguished according to rush hours, etc. and the statistical characteristics among them will be statistically analysed, and efforts will be made to apply them to the formulation of traffic control strategies. At present, the phenomenon of collision between people and vehicles in the three-dimensional traffic (overpass, overpass intersection, etc.) that exists in the city is not considered.

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References

- [1] Deng, Xingdong , X. U. Jianmin , and B. Wang. "Traffic Countermeasures Research for Guangzhou City in Traffic Mode Transferring Period after "Motorcycle Forbidden Ban" Effect." *Journal of Transportation Systems Engineering & Information Technology* 9.4(2009):145-150.
- [2] Wells, Peter , and X. Lin . "Spontaneous emergence versus technology management in sustainable mobility transitions: Electric bicycles in China." *Transportation Research Part A Policy and Practice* 78.AUG.(2015):371-383..
- [3] Lin, Xiao , P. Wells , and B. K. Sovacool . "Benign mobility? Electric bicycles, sustainable transport consumption behaviour and socio-technical transitions in Nanjing, China." *Transportation Research Part A Policy & Practice* 103.sep.(2017):223-234.
- [4] Cherry, Chris , and R. Cervero . "Use Characteristics and Mode Choice Behavior of Electric Bikes in China." *Institute of Transportation Studies, Research Reports, Working Papers, Proceedings* (2006).
- [5] Pein, and Wayne. "BICYCLIST PERFORMANCE ON A MULTIUSE TRAIL." *Transportation Research Record Journal of the Transportation Research Board* 1578(1997):127-131.
- [6] Taylor, Dean , and W. Davis . "Review of Basic Research in Bicycle Traffic Science, Traffic Operations, and Facility Design." *Transportation Research Record Journal of the Transportation Research Board* 1674(1999):102-110.
- [7] Elliot, et al. "E-bikes in the Mainstream: Reviewing a Decade of Research." *Transport Reviews* (2016).
- [8] Jones, Tim , L. Harms , and E. Heinen . "Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility." *Journal of Transport Geography* 53.May(2016):41-49.
- [9] Popovich, Natalie , et al. "Experiences of electric bicycle users in the Sacramento, California area." *Travel Behaviour and Society* 1.2(2014):37-44.
- [10] Macarthur, John , J. Dill , and M. Person . "Electric Bikes in North America." *Transportation Research Record Journal of the Transportation Research Board* 2468(2014):123-130.
- [11] Ziwen, Ling , et al. "Differences of Cycling Experiences and Perceptions between E-Bike and Bicycle Users in the United States." *Sustainability* 9.9(2017):1662.
- [12] Yang, Chih Wen , and Y. L. Ho . "Assessing carbon reduction effects toward the mode shift of green transportation system." *Journal of Advanced Transportation* 50.5(2016):669-682.
- [13] Johnson, Marilyn , et al. "Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists." *Accident Analysis & Prevention* 43.1(2011):323-328.
- [14] Ross, et al. "Reduction in car-bicycle conflict at a road-cycle path intersection: Evidence of road user adaptation?." *Transportation Research Part F Traffic Psychology & Behaviour* (2011).
- [15] Paul St-Aubin, et al. Large-scale automated proactive road safety analysis using video data. *Transportation Research Part C* 58.(2015).
- [16] Zhang X.W. Researchon the Conflict Between Pedestrians and Right-turning Vehicles at Signal-con-trolled Intersections.Diss.Southwest Jiao-tong University,2016.
- [17] Wang, Chen , C. Xu , and Y. Dai . "A crash prediction method based on bivariate extreme value theory and video-based vehicle trajectory data." *Accident Analysis & Prevention* 123.FEB.(2019):365-373.
- [18] GUO Yan-yong. Safety Evaluation Technology of Signalized Intersection Basedon Traffic Conflict Theory. Diss. South-east University,2016.
- [19] GAO Zhi-jun,MA Lu,YAN Xue-dong."Researchon Models for Traffic Conflicts Involving Non-motor Ve-hiclesat City Intersection and Their Severity".*China Safety Science Journal* 27.03(2017):31-36.
- [20] WANG Xin.Research on Discrimination and Prediction Methods Between Vehicle and Bicycle Conflictat Signal Intersection.Diss.Beijing Jiaotong University,2017.
- [21] Sacchi, Emanuele , and T. Sayed. "Bayesian Estimation of Conflict-Based Safety Performance Functions." *Journal of Transportation Safety & Security* (2015):66-99.
- [22] GUO Yan-yong, et al."Traffic Conflict Model Based on Bayesian Multivariate Poisson-lognormal Normal Distribution". *China Journal of Highway and Transport*.31.01(2018):101-109.
- [23] YANG Lan, MA Jia-rong, ZHAO Xiang-mo,etal. A Vehicle Collision Warning Modelin Expressway Scenario Based on Vehicle-infrastructure Cooperation. *Journal of Highway and Transportation Research and Development*,34.09(2017):123-129.

- [24] RONG Yin, WEN Hui-ying, ZHAO Sheng Study on Driving Risk Measurement for Two-lane Freeway Vehicle group. *Journal of Chongqing Jiaotong University: Natural Science*, 38.09(2019):95-100, 121.
- [25] ZHU Shun-ying, et al. "Review of Research on Traffic Conflict Techniques". *China Journal of Highway and Transport*. 33.2(2020).
- [26] Jiang, et al. Safety evaluation of signalized intersections with left-turn waiting area in China. *Accident Analysis & Prevention* (2016).
- [27] Yuan, Quan , Y. Li , and B. Mei. "Comparative Study of Characteristic Parameters of Vehicle-Pedestrian Accidents and Vehicle-bicyclist Accidents." *Journal of Transportation Systems Engineering and Information Technology* 3.3(2005):92-99.
- [28] Kim, Karl , and L. Li . "Modeling Fault Among Bicyclists and Drivers Involved in Collisions in Hawaii, 1986–1991." *Transportation Research Record Journal of the Transportation Research Board* 1538.1(1996):75-80.
- [29] Shinar, D . "PSYCHOLOGY ON THE ROAD. THE HUMAN FACTOR IN TRAFFIC SAFETY." *Driving* (1978).
- [30] Liu Xiaoming, Ren Futian, Wang Gencheng, Duan Liren. Research On Urban Road Traffic Accident Generation. *China Journal of Highway and Transport*, 8.1(1995):110-114.
- [31] Wang, Yinhai , and N. L. Nihan . "Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections." *Accident Analysis & Prevention* 36.3(2004):313-321.
- [32] YE Xiaofei, CHEN Jun, GU Shanshan. Conversion coefficient of Electric-bike into Bicycle on Urban Road Section. *Journal of Highway and Transportation Research and Development*, 29.10(2012):109-116.
- [33] Zdzisław Pawlak. Rough set approach to knowledge-based decision support. *European Journal of Operational Research* , 99.1(1997):48-57.
- [34] Li, Qingfu , et al. "Safety Risk Analysis of Bridge Rhombic Hanging Basket Construction Based on WBS-RBS and Rough Set Theory." *IOP Conference Series Materials Science and Engineering* 780(2020):072033.