Research of Road Intersection Safety Evaluation Based on Driver’s Workload

Li Gao[1, a], Liting Hou[2, b *] and Xiaoting Yu[3, c]

[1, 2, 3] School of Mechanical Engineering, Beijing Institute of Technology; Beijing 100081, China

[a] ligaobit@bit.edu.cn, [b] leetinghou@163.com, [c] 1103272535@qq.com

Keywords: Road intersection; Safety evaluation; Driver’s workload;

Abstract. In order to evaluate the safety of the road intersection more reasonable and humanity, the driver’s workload was added into the current evaluation system in this paper. The new safety evaluation system which aimed at providing theory basis for safety management decision, was established based on 4 indexes, including driver’s workload, traffic conflict, intersection geometry design and intersection facilities, and then respectively analyzes the concrete influence factors of the four indexes. The weight of each index was given by using the method of Analytic Hierarchy Process and Expert Scoring.

Introduction

Intersection traffic system is a dynamic system composed of human, vehicle, road and environment. In this system, any factor unreliable, unbalanced and unstable can lead to conflict, then evolve into a traffic accident. Domestic and foreign statistics showed that in the factors affecting traffic safety, the human factor accounted for 80%~85%, the vehicle factor accounted for 5%~10%, the road and the environmental factor accounted for about 10% [1]. It showed that human factor play a leading role in the traffic systems, especially for the drivers, who had an important influence on intersection safety.

At present, most domestic intersection safety evaluation studies were based on objective. These safety evaluations mainly aimed at the intersection of facilities and management means, and overlooked the impact of these factors on drivers [2]. The driver's physiological and psychological characteristics of the operation would affect the driving safety. Therefor it was necessary and important to add the driver’s workload index into current evaluation systems.

In this paper, the intersection safety evaluation index system was established by using 4 indexes, including driver’s workload, traffic conflict, intersection geometry design and intersection facilities, and then on the basis of AHP and Expert Scoring, the road intersection safety evaluation method based on driver's workload is put forward, which provide a more scientific and humane evaluation method for intersection safety research.

Construction of intersection safety evaluation index system

The main factors of the intersection safety evaluation were introduced through the discussion with several experts and scholars in the field of transportation. Under the guidance of systematic, concise and flexible principles, three levels of Road intersection safety evaluation index system was constructed. The first level was the target level, namely, the comprehensive index of the road intersection safety evaluation; The second level were the four specific factors, including the driver’s workload, traffic conflict, intersection geometry design and intersection facilities; The third one were the subdivided factors associated with them, as shown in Tab.1.

Tab.1 Road intersection safety evaluation index system

The first level	The second level	The third level
Road intersection safety evaluation index A_1	Driver’s workload B_1	Heart rate variability, HRV C_1 NASA-TLX C_2
	Traffic conflict B_2	Morning rush TC/MPCU C_3 Evening rush TC/MPCU C_4 Flat rush TC/MPCU C_5
	Intersection geometry design B_3	Longitudinal slope C_6 Cross angle C_7 Line of sight C_8 Lane Setting C_9 Channelization C_{10}
	Intersection facilities B_4	Signal lamp C_{11} Mark C_{12} Marking C_{13} Road conditions C_{14} Lighting C_{15}

Driver’s workload. As the main traffic involved, the driver’s work was a continuous process of perception of information and processing information. In this process, the driver's driving ability was limited because of the limitation of the capacity of the channel capacity. As the traffic safety control of the driver was controlled by the central controller of its brain, then the processing capacity was relatively limited, which is known as the “Driver's workload”.

Professor Hu Jiangbi of Beijing University of Technology put forward the concept of “Driver’s standard workload” [3], and showed the relationship between driver’s workload and accident rate, as shown in Fig.1. When the driver’s workload is lower than the standard, the driver’s operation was too easy, work negligence will cause the road information loss, processing information ability is abate, and the increasing error rate will easily lead to traffic accidents; When the driver’s workload exceeds the standard, due to the large amount of processing information or mental stress, the ability to work reduced and the risk of traffic accidents increased; when the driver’s workload is consistent with the standard, the driver drives normally and the accident rate is the lowest.

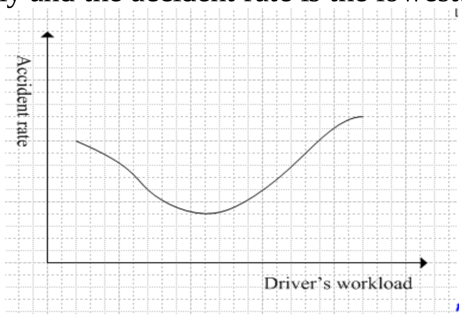

Fig.1 The relationship between Driver’s workload and Accident rate

The driver's workload mainly includes two aspects: the psychological workload and the mental workload. The psychological workload can be measured by physiological measurement, and the mental workload can be measured by the NASA-TLX scale. Therefore, the paper selects the heart rate variability (HRV) and NASA-TLX as the subdivided index of the driver's workload.

HRV is a measure to characterize the mental workload of the driver through physiological measurements. It is a simple, real-time and quantitative index that reflects the activity of the vague nerve system and its balance and coordination. Generally speaking, the lower the HRV value, the higher the workload. And it can be collected by physiological measurement instrument, the normal reference value is 39 ± 15.0ms.

NASA-TLX has been widely used in the assessment of driver's mental workload with its good reliability and validity. NASA-TLX mainly contains six dimensions: Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort and Frustration [4]. As shown in Tab.2.

Tab.2 NASA TLX scale dimension description

Dimension	Description
Mental Demand	The brainpower to complete the driving task, including thinking, decision-making? Such as: thinking and other mental activity is difficult or not?
Physical Demand	Physical strength to complete the driving tasks, including the driving behavior? Such as: muscles are relaxed or tense, the action is easy or difficult?
Temporal Demand	The time pressure on drivers to complete the driving tasks? Such as: is the time pressure large or small? How big is it? Is nervous or deliberate?
Own Performance	The satisfaction degree of drivers after completing the task? Such as: Self feeling is good or bad? Feel a sense of accomplishment or not?
Effort	Effort required to complete the task?
Frustration	The degree of frustration in the process of completing the task? Such as: insecurity during driving and irritability level is high or low?

In general, when evaluate the mental workload through NASA-TLX scale after completing the driving tasks, follow the following steps:

Firstly, choose two pairs from the six dimensions and compare which one is more associated with actual task workload. After comparing all, the number of a dimension selected as "more related dimensions" will be used as the weight.

Then, score each dimension from 0 to 100(minimum interval of 5) by using the two-stage rating scale. In addition to Own Performance, The score of the other five dimensions from small to large means increased gradually, while the Own Performance score was the opposite.

Finally, the comprehensive mental workload score=the score of each dimension*the weight/15.

Traffic conflict. Traffic conflict technology has been widely used in the fields of transportation, research showed that the traffic conflict technology is effective for the intersection safety evaluation [5].

In the paper, the ratio of traffic conflict and mixed passage car unit (TC/MPCU) was used as the evaluation parameter. MPCU reflects the traffic level, and TC reflects the absolute traffic safety level. The lower the parameter, the less traffic conflicts, and the more safe of the intersection.

As the traffic volume of road intersection has time varying characteristics, so the TC/MPCU of the morning rush, the evening rush and the flat rush these three period are used as the evaluation index. The TC refers to the serious conflict, the exchange among different type vehicle of MPCU is as shown in Tab. 3. These indexes can be obtained by observation on site.

Tab.3 The exchange among different type vehicle of MPCU

Vehicle type	Large truck	Large Passenger car	Medium passenger car	Small truck	Small passenger car	Motorcycle
MPCU	1.5	1.5	1.5	1.0	1.0	0.3

Intersection Geometry Design. The main factors influencing the Intersection Geometry Design include longitudinal slope, Cross angle, Line of sight, Lane Setting, Channelization. These factors criteria can be obtained through Expert Scoring. The safety status of intersection is divided into safe, general safe and unsafe, corresponding standard is as shown in Tab.4.

Tab.4 Scoring criteria of the Intersection Geometry Design influencing factors

Influencing factors	Safety status		
	Unsafe(40~60)	General safe(60~85)	Safe(85~100)
Longitudinal slope	>6%	3%~6%	<3%
Cross angle	<70	70~80	80~90
Line of sight	As the visible triangle with obstacles, the line of sight is very obvious blocked.	The line of sight is quite obvious blocked.	No visible triangle obstacle.
Lane Setting	The lane No. and the width setting is not reasonable and no accommodation lane setting.	The lane No., the width and the accommodation lane setting is quite reasonable.	The lane No., the width and the accommodation lane setting is very reasonable.
Channelization	The channelization does not match with traffic.or no channelization.	The channelization does not match with traffic, but Vehicles in different directions are less affected.	The channelization is reasonable.

Intersection facilities. The domestic and foreign related research showed that, Signal lamp, Mark, Marking, Road conditions and Lighting have a significant impact on intersection safety. These influencing factors criteria, can be obtained through Expert Scoring. The safety status of intersection can be divided into safe, general safe and unsafe, corresponding standard is as shown in Tab.5.

Tab.5 Scoring criteria of the intersection facility influencing factors

Influencing factors	Safety status		
	Unsafe(40~60)	General safe(60~85)	Safe(85~100)
Signal lamp	The signal phase and time setting is not reasonable, and the signal lamp is blurred.	The signal phase and time setting is relatively reasonable, but it’s a little difficult to distinguish .	The signal phase and time setting is reasonable and can be easily distinguished.
Mark	Mark setting isn’t reasonable, the sign has poor visibility, and the inf is complicated that difficult to understand.	Mark setting is reasonable with poor visibility and the information is complicated that difficult to understand.	Mark setting is reasonable with strong visibility and the information is moderate.
Marking	Marking with poor reflecting can‘t be seen clearly.	Most marking can be seen, but with slight discolor.	Marking with good visibility.
Road conditions	Pavement roughness and skid resistance is very poor, the vehicle suddenly stopped or slowed down on the road.	Pavement roughness and skid resistance is poor, and only little vehicle suddenly stopped or slowed down .	Pavement roughness and skid resistance is good.
Lighting	It’s hard to see the intersection at night.	It’s a little difficult to see the intersection at night.	It’s easy to see the intersection at night.

Calculation of the evaluation index weight

In this experiment, the relevant experts in the field of transportation are invited to evaluate the importance of each index of the intersection safety evaluation system. Based on AHP, the weight of each index is calculated through the comparison and judgment matrix, the calculation of weight vector and consistency test. The calculation are as shown from Tab. 6 to Tab.10.

Tab.6 Comparison and judgment matrix of A_1-B

A_1	B_1	B_2	B_3	B_4	$w^{(2)}$	
B_1	1	1	2	2	0.338	$l_{max} = 4.031$
B_2	1	1	3/2	3/2	0.293	$C_I^{(2)} = 0.010$
B_3	1/2	2/3	1	2/3	0.166	$R_I^{(2)} = 0.09$
B_4	1/2	2/3	3/2	1	0.203	$C_R^{(2)} = 0.011$

Tab.7 Comparison and judgment matrix of B_1-C

B_1	C_1	C_2	$p_1^{(3)}$	$l_{max} = 2.002$
C_1	1	1/2	0.333	$C_{I1}^{(3)} = 0.002$
C_2	2	1	0.667	$R_{I1}^{(3)} = 0$

Tab.8 Comparison and judgment matrix of B_2-C

B_2	C_3	C_4	C_5	$p_2^{(3)}$	$l_{max} = 3.018$
C_3	1	1	1	0.331	$C_{I2}^{(3)} = 0.009$
C_4	1	1	3/2	0.379	$R_{I2}^{(3)} = 0.58$
C_5	1	2/3	1	0.290	$C_{R2}^{(3)} = 0.016$

Tab.9 Comparison and judgment matrix of B_3-C

B_3	C_6	C_7	C_8	C_9	C_{10}	$p_3^{(3)}$	
C_6	1	1/2	1/3	1/3	1/2	0.087	$l_{max} = 5.207$
C_7	2	1	1/2	1/2	1	0.158	$C_{I3}^{(3)} = 0.052$
C_8	3	2	1	2	2	0.331	$R_{I3}^{(3)} = 1.12$
C_9	3	2	1/2	1	1/2	0.215	$C_{R3}^{(3)} = 0.046$
C_{10}	2	1	1/2	2	1	0.208	

Tab.10 Comparison and judgment matrix of B_4-C

B_4	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	$p_4^{(3)}$	
C_{11}	1	1	2	3	3	0.323	$l_{max} = 5.099$
C_{12}	1	1	1	2	2	0.240	$C_{I4}^{(3)} = 0.025$
C_{13}	1/2	1	1	2	2	0.208	$R_{I4}^{(3)} = 1.12$
C_{14}	1/3	1/2	1/2	1	2	0.132	$C_{R4}^{(3)} = 0.022$
C_{15}	1/3	1/2	1/2	1/2	1	0.098	

According to the Tab.6 to Tab.10, the synthetic weight has been calculated and the overall consistency has been tested, as shown from Eq.1 to Eq.3.

$C_I^{(3)} = (C_{I1}^{(3)}, C_{I2}^{(3)}, C_{I3}^{(3)}, C_{I4}^{(3)})w^{(2)}$ = (0.002, 0.009, 0.052, 0.026)*(0.338, 0.029, 0.166, 0.203)^T=0.017 (1)

$R_I^{(3)} = (R_{I1}^{(3)}, R_{I2}^{(3)}, R_{I3}^{(3)}, R_{I4}^{(3)})w^{(2)}$ = (0, 0.58, 1.12, 1.12)* (0.338, 0.029, 0.166, 0.203)^T=0.583 (2)

$C_R^{(3)} = C_I^{(3)} / R_I^{(3)}$ =0.017/0.583=0.029<0.10 (3)

It is been proved that the Comparison and judgment matrix is satisfied.

The method of road intersection safety evaluation

The method of road intersection safety evaluation will be obtained by the combination of the score and the weight of each index, and the concrete evaluation method is as shown in Tab.11. By comparing the final score of each intersection, we can sort the safety level of them, so as to determine the order of the intersection, and provide scientific basis for the reasonable arrangement.

Tab.11 The road intersection safety evaluation method

The first level：The road intersection safety evaluation					
Safe：85~100 General safe：60~85 unsafe：40~85					
The second level	Weight N_i	The third level	Weight K_i	Method	Score M_i
Driver's workload	0.338	HRV	0.333	Physiological measurements and Export scoring	
		NASA-TLX	0.667	NASA-TLX scale and Export scoring	
Traffic conflict	0.293	Morning rush TC/MPCU	0.331	Observation on site and Export scoring	
		Evening rush TC/MPCU	0.379		
		Flat rush TC/MPCU	0.290		
Intersection geometry design	0.166	Longitudinal slope	0.087	Observation on site and Export scoring	
		Cross angle	0.158		
		Line of sight	0.331		
		Lane Setting	0.215		
		Channelization	0.208		
Intersection facilities	0.203	Signal lamp	0.323	Observation on site and Export scoring	
		Mark	0.240		
		Marking	0.208		
		Road conditions	0.132		
		Lighting	0.098		
Comprehensive intersection safety score					

Conclusions

Intersection is an important node of the road network. In this paper, the factors affecting the safety of intersection are classified into 4 indexes, including driver's workload, traffic conflict, and intersection geometry design and intersection facilities. Based on these 4 indexes, the new safety evaluation system was established. However, due to the limited data, the specific relationship between the driver's workload and the accident rate remains to be studied in the future research.

References

[1] Xiaofeng Wu. Highway Geometry Safety Evaluation Based on Driver workload [D].Xi'an: Chang'an University, 2009.

[2] Weifeng Long. Safety Evaluation research of freeway research of horizontal alignment design and safety based on driver's workload [D].Beijing: Beijing University of Technology, 2009.

[3] Jiangbi Hu. Research on forming mechanics and method for hazardous location of highway [D].Beijing: Beijing University of Technology, 2004.

[4] Shihui Zhang. Driver mental workload analysis and experimental test of urban intersection driving scenarios [D], 2010.

[5] Zhu Sheng-Xue, Jian Lu, Xiang Qiao-Jun, Lin Li-Yan. Intersection safety evaluation method based on Bayesian network[C].2009 International Conference on Measuring Technology and Mechatronics and Mechatronics Automation.2009(3):234-237 .

