Crash Risk Monitoring Method for Highways in Rain Conditions

Minggang Liu[1, a], Jiuping He[2,3, b], Shiyu Liu[2,3, c], and Feng Zou[1, d]

[1]Sichuan Communication Surveying and Design Institute Co., Ltd., China;

[2]The Engineering Design Academy of Chang'an University Co., Ltd., China;

[3]Chang'an University, China.

[a] 834225869@qq.com, [b] 624239763@qq.com, [c] 470718414@qq.com, [d] 47115583@qq.com

Abstract. The slick road surface during rainy days necessitates an increased braking distance, posing prominent safety hazards for driving. Consequently, this paper researched on the monitoring method of collision risk posture of highway in rainy days. The impact of rain on the driving risk of vehicles is mainly the braking distance. In this paper, the ratio μ, defined as the quotient of stopping sight distance (S_t) and the spacing (S_r) between the front of a trailing vehicle and the rear of a leading vehicle, was adopted as the collision risk assessment metric. Employing the Expressway A-Rain segment from the Citysim dataset as the subject of investigation, traffic risk probability statistics diagrams and heatmaps had been generated. The results showed that the ratio μ>1 has accounted for nearly 10% of the roadway, the traffic risk of this roadway is high, and the risk is mainly distributed on the middle lane of the freeway and entrance ramp.

Keywords: Expressway; Rainfall Condition; Crash Risk; Stopping Sight Distance

1. Introduction

Expressway is an important infrastructure serving urban transport needs[1], which plays an important role in the development of the country and the region. However, while the rapid development of transportation networks has brought immense socio-economic benefits, the traffic accident rate remains stubbornly high. Traffic crashes on expressways are one of the world's largest public health problems[2], and the risk of highway collisions during rainfall is particularly acute. Therefore, accurate monitoring of the collision risk posture of highways under rainfall weather is of great significance for preventing traffic accidents and ensuring driving safety.

Hwang et al [3] found that rainfall leads to a significant increase in the accident rate based on the different characteristics presented by highway accidents under both normal and rainfall weather conditions. Agarwal M et al.[4] found that water slide is one of the main factors affecting the high risk of traffic accidents in rainy days. Sherretz L A et al.[5] found a positive linear relationship between rainfall and the number of traffic accidents by studying traffic weather data for seven cities, including Southern Illinois. Jackson T L. et al.[6] analyzed the traffic accident data and geospatial data in previous years, and obtained the correlation between rainfall and collision accidents. Zhang M et al.[7] evaluated the traffic operation of several cities in China by using the data of traffic operation and rainfall in previous years, and the results showed that the traffic operation of 13 cities, including Chongqing, was significantly affected by rainfall. Burchett[8] studied 16,533 accidents that occurred on a two-lane rural highway in Kentucky in one year, of which 3,785 accidents occurred in rainy weather. And a linear relationship was found between pavement skid resistance and traffic accident rate by function fitting. Numerous scholars have analyzed the correlation between rainy days and traffic accidents, but have not studied traffic accidents caused by abnormal parking on rainy days.

In view of this, this paper proposed a method for monitoring traffic risk situations on expressways during rainfall to effectively monitor the collision risk associated with abnormal stopping on expressways under rainy weather conditions. The approach was grounded in ensuring adequate stopping sight distance for safety, utilizing the ratio of stopping sight distance to actual vehicle distance as evaluation index for traffic risk. Furthermore, a traffic risk heatmap was adopted as a representation of traffic risk postures. This method aims to provide a real-time and effective solution for monitoring the collision risk situation on expressways. Ultimately, the weaving segment in the CitySim dataset was selected for case verification and analysis.

2. Methodology

2.1 Calculation of Braking Distance

The sight distance is divided into parking sight distance, overtaking sight distance, meeting sight distance and identification sight distance. The highway adopts the driving method of divided lanes in different directions. There is no need for meeting and overtaking in opposite directions, so drivers should meet the requirements of stopping sight distance when driving on the highway.

Stopping sight distance (SSD) refers to the shortest driving distance required for the driver to stop safely before reaching the obstacle from the moment he sees the obstacle in front of the vehicle at a certain speed. The stopping sight distance consists of two parts, including the driving distance and braking distance of the driver during the reaction time, which are calculated according to Formula(1).

$$S_t = \frac{v}{3.6}t + \frac{(vt/3.6)^2}{2gf_1} \quad (1)$$

Where v denotes vehicle speed(km/h); f_l is the longitudinal friction coefficient, depending on the speed and road conditions; t is the driver 's reaction time(s), take 2.5 s, including judgment time 1.5s, running time 1.0s.

2.2 Crash Risk Assessment Indicators

When the distance between the front vehicle and the rear vehicle is less than the stopping sight distance, if the leading vehicle brakes suddenly, the following vehicle may not have sufficient braking distance to stop, posing a certain risk of rear-end collision. Especially under rainy weather conditions, the road surface becomes wet, resulting in a decreased friction coefficient. Compared to dry road conditions, vehicles require a longer braking distance to ensure the need for safe stopping. Therefore, from the perspective of safe stopping sight distance, this paper selects the ratio μ, defined as the quotient of stopping sight distance (S_t) and the spacing (S_r) between the front of a trailing vehicle and the rear of a leading vehicle as an evaluation index for collision risk. As shown in the following equation.

$$\mu = \frac{S_t}{S_r} \quad (2)$$

$$S_r = x_l - x_t \quad (3)$$

Where S_t is stopping sight distance(m); S_r is the spacing between the front of a trailing vehicle and the rear of a leading vehicle(m); x_l is the coordinates of the front end of the rear car; x_t is the coordinates of the rear end of the front car. The greater the μ value, the greater the risk of collision. When $\mu < 1$, it is considered that there is no security.

2.3 Risk Situation Representation

Assume that the leading vehicle Car 2 stops abnormally due to vehicle failure at time t as shown in figure1. The distance between Car 1 and Car 2 is S_r, and the stopping sight distance of Car 1 is S_t. When $S_t > S_r$, the driver of Car 1 has insufficient reaction braking distance and will collide with vehicle 2.

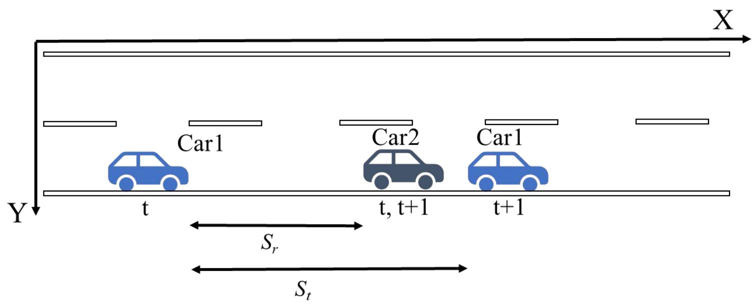

Fig. 1 Illustration of Abnormal Parking Lot Scenarios

3. Results

3.1 Data Collection and Preprocessing

Citysim is an open vehicle trajectory data set based on UAV aerial photography. It records detailed driving data, vehicle data and trajectory information of vehicles passing through specific road sections within a certain period of time, including vehicle ID, vehicle position coordinates, driving lane and driving speed, etc. The base data used in this paper is the Expressway A-Rain (Weaving Segment) roadway in the Citysim dataset, and the study roadway is shown in Fig.2.

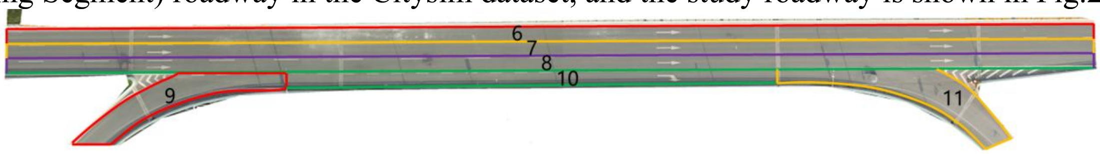

Fig. 2 Study Section

A detailed description of the main variables of the raw data for the Expressway A-Rain (Weaving Segment) section is shown in table1.

Name	Description	Unit
frameNum	Frame number of the vehicle waypoint captured at 30 frames per second	
carId	Vehicle unique identifier that remains consistent for all vehicle waypoints across the entire video	
carCenterX	Pixel x-coordinate of vehicle bounding box center point	Pixel
carCenterY	Pixel y-coordinate of vehicle bounding box center point	Pixel
headX	Pixel x-coordinate of vehicle bounding box front center point	Pixel
headY	Pixel y-coordinate of vehicle bounding box front center point	Pixel
tailX	Pixel x-coordinate of vehicle bounding box front center point	Pixel
tailY	Pixel y-coordinate of vehicle bounding box rear center point	Pixel
speed	Pixel x-coordinate of vehicle bounding box front center point	Miles per Hour
laneId	Waypoint lane number according to the supplementary lane map	

Table 1. Raw data description

It should be noted that the abscissa X of the vehicle trajectory data is the positive direction of the vehicle 's driving direction, and the ordinate Y is the positive direction of the change from the inner lane to the outer lane. The length unit of the original data is ' foot '. In this paper, it is converted according to 1 foot = 0.3048 m, so that the length unit of each variable is represented by 'm'.

3.2 Collision Risk Evaluation

In this section, we draw the probability map and cumulative frequency distribution map of the ratio μ of stopping sight distance S_t to the spacing (S_r) between the front of a trailing vehicle and the rear of a leading vehicle. It can be seen that the proportion of the ratio $\mu > 1$ is close to 10%, and the traffic risk is large.

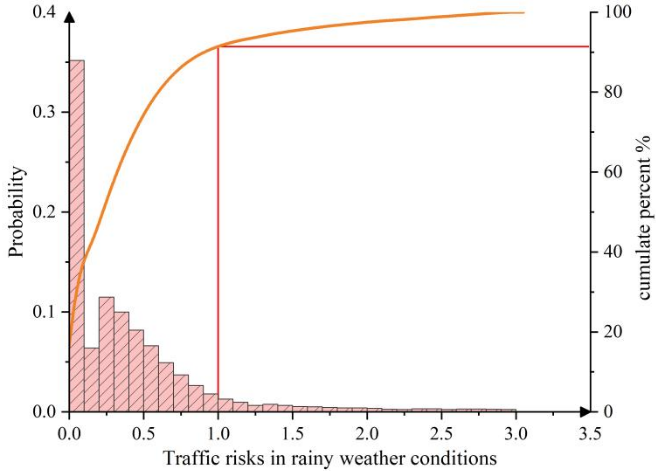

Fig. 3 Traffic risk probability statistics

3.3 Visualization of Results

Fig.4 shows the collision risk situation of the study section. It can be seen that the collision risk of the middle lane and the entrance of the expressway is higher, and the collision risk of the outer lane is lower.

Fig. 4 Traffic risk distribution heat map

4. Conclusion

This paper took the Expressway A-Rain (Weaving Segment) section of the Citysim data set as the research object, and used μ as the evaluation index to analyze the traffic risk. The main conclusions are as follows:

The roadway has close to 10% of the cases μ>1. When μ>1 S_t is greater than S_r , and collisions are prone to occur.

Traffic risks are primarily located in the middle lane of the freeway and on entrance ramps.

Acknowledgements

This research was funded by the Sichuan Communication Surveying and Design Institute Co., Ltd. science and technology projects(232022007).

REFERENCES

[1] Qu X B., Yang Y, Liu Z Y, et al. Potential crash risks of expressway on-ramps and off-ramps: A case study in Beijing, China. Safety Science, 2014 70, 58-62.

[2] Qu X, Kuang Y, Oh E, et al. Safety Evaluation for Expressways: A Comparative Study for Macroscopic and Microscopic Indicators. Traffic Injury Prevention, 2013 15(1), 89–93.

[3] Hwang T, Chung K, Ragland D,et al. Identification of High Collision Concentration Locations Under Wet Weather Conditions. Institute of Transportation Studies, Research Reports, Working Papers, Proceedings, 2008.

[4] Agarwal M, Maze T H, Souleyrette R R. Impacts of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity.In Mid-Continent Transportation Research Symposium, 2005, 20(5):1121-1134.
[5] Sherretz L A, Farhar B C. An Analysis of the Relationship Between Rainfall and the Occurrence Of Traffic Accidents. Journal of Applied Meteorology, 1978, 17(5): 711-716.
[6] Jackson T L, Sharif H O. Rainfall impacts on traffic safety: rain-related fatal crashes in Texas. Geomatics, 2016.
[7] Zhang M, Liu Y, Sun W, et al. Impact of Rainfall on Traffic Speed in Major Cities of China. Sustainability, 2021, 13(16): 9074.
[8] Burchett J L, Rizenbergs R L. Frictional performance of pavement and estimates of accident porbility. ASTM Special Technical Publication, 1982, 763. 73-97.