Analysis on Characteristics and Causes of Traffic Accidents in Interweaving Areas of Freeways

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Abstract

As the bottleneck section of a freeway, the interweaving area is the main point of accidents. The safety of the freeway interweaving section depends on the driver, road design, vehicle performance, and external environment, all of which result from the joint effects of various factors. Based on the traffic accident data collected from the city of Xi'an in China, this paper carries out mathematical statistics analysis to determine the distribution of accidents, including the accident types and the characteristics of spatial-temporal distribution. Then, based on the analysis of the causal mechanism of accidents, the paper analyzes the causes and main influencing factors of different types of accidents. Combined with the observed characteristics of traffic flow, the relationship between traffic accidents and traffic characteristics is also analyzed. Finally, this paper puts forward some suggestions to improve traffic safety in the freeway interweaving section.

Keywords: Freeway; Interweaving area; Traffic accident; Spatial-temporal characteristics.

INTRODUCTION

An important part of a freeway, an interweaving area is the main form of road convergence and diversion. Vehicles in the interweaving area run complex, and some vehicles need to complete lane changes to produce interweaving behavior. The convergence of the upstream ramp, the diversion of the downstream ramp, and the internal lane-changing behavior in the interweaving area are all confined to a limited space. Frequent vehicle lane-changing will lead to traffic flow disorder. From the analysis of the traffic characteristics of vehicles in operation, we see that traffic conflicts easily occur both in the process of car-following and lane-changing. The interweaving area is a bottleneck section of freeway because of its special configuration. It is also an accident-prone area of freeway. According to statistics, the

number of interchange accidents on Beijing-Tianjin-Tangshan Freeway from 2002 to 2004 accounts for 14% of the total number of accidents (Guo 2003).

Interweaving area analysis has always been an important and complex part of the analysis of road traffic safety systems. Traffic scholars all over the world continue to study it. Statistical regression method, fuzzy mathematics analysis method, graph method, and traffic conflict technology are generally used in the research of interweaving areas. Overseas, good research on interweaving zones was produced as early as the 1950s. The situation in China is different from that abroad. Because of the great difference between China and foreign countries in terms of facilities, vehicle characteristics, and driving habits in the interweaving area of a freeway, and the lack of sufficient recognition of the particularity of traffic flow operation at the beginning of the interweaving area, there is no definite design criterion in road design, and the safety research in the interweaving area in China started relatively late. In recent years, it has been recognized that the interweaving area is an accident-prone area of freeway, and great progress has been made in this area.

According to *Highway Capacity Manual*, the characteristics of traffic operation in the interlaced area are determined by the following factors: length, width, speed of vehicles, and flow rate in the interlaced area. Most foreign scholars have studied the traffic capacity of interwoven areas, and have made great achievements in the security of interwoven areas. Tiwari (1998) analyzed the relationship between fatal collision and conflict rate in 14 interlaced zones in Delhi, India, and compared the conflict data of different sections according to different traffic conflicts. After studying the mixed traffic in interlaced zones, it is suggested that traffic conflict rather than accident rate be used as an index to evaluate the safety of interlaced zones. Cirillo used statistical regression analysis of interlaced area accidents in 20 states of the United States in the 1960s. The study found that the shorter the deceleration lane in interlaced area, the higher the accident rate. Increasing the length of deceleration lane and interlaced area, the accident rate will decrease significantly. Golob et al. (2004) used traffic accident data from 55 interlaced areas of A, B, and C on a Southern California highway to conclude that there is no difference in the overall accident rate, but there are significant differences in the severity of these types of accidents, major collision locations, causes of accidents, and the time period during which accidents may occur. Golob (2015) of the University of Florida proposed a multi-level Bayesian logistic regression model to utilize collision, geometry, and weather data in the highway interlaced area. The conclusion shows that the main line speed at the beginning of the interlaced area and the speed difference between the beginning and the end of the interlaced area have a significant impact on the collision risk of the interlaced area in the next 5-10 minutes. In Tanak's study (2017), he observed and concluded that about 80% of interwoven vehicles changed lanes in the upstream 25% of the whole section. By developing a vehicle

algorithm to avoid the conflict of interwoven zones, the downstream throughput of two interwoven zones under different interwoven ratios and the lane change positions of each vehicle were studied experimentally. The results show that the vehicle control algorithm can be used effectively. Some infrastructure can reduce conflicts and thus improve the security of interwoven areas.

Abdel-Aty and Wang (2017) in Europe tested several VSL strategies using VISSIM. The research shows that the location and speed value of VSL are very important. VSL installed upstream is safer than VSL installed downstream, so reducing the upstream speed is to improve the safety of a highway interlaced area. In addition, lower upstream speed limit will better improve the security of the whole interweaving area. Based on traffic conflict technology (TCT) and grey theory, Yue (2007) proposed a new method for safety assessment of interwoven areas, namely grey clustering evaluation method for traffic conflict.

Through the review, it can be found that in previous studies, few can accurately study the characteristics and distribution of accidents in the interweaving area. There are significant differences in the severity of accidents, the location of main collisions, the factors leading to accidents, and the most likely time period of accidents in the interweaving zone. These differences have significant impact on traffic engineering improvement.

DATA COLLECTION

The study was conducted with data collected from the city of Xi'an in China. The traffic accidents in a typical interweaving area of a freeway were collected over one year. After eliminating the invalid data, a total of 95 traffic accidents were obtained. The main data collected included the accident type, the distance between the accident location and the entrance triangle, the month of the accident, the specific time, and the number of vehicles in the interweaving area. Data statistics and system analysis of the above accident information are carried out to obtain the characteristics of the accident in the interweaving area.

DISTRIBUTION CHARACTERISTICS

This paper classifies the forms of traffic accidents for the following two purposes: a subdivision of traffic accidents is conducive to discovering the internal laws of the formation, occurrence, and development of various traffic accidents; and it is conducive to special statistics. On this basis, it is convenient to explore more effective traffic accident prevention countermeasures from different angles. Then, the paper describes the time distribution and spatial distribution characteristics of the accidents in the interweaving area, which is helpful for studying the traffic safety situation in different areas and at different times in the interweaving area of a freeway.

Traffic accidents can be divided into seven types: collision, rolling, scraping, rollover, car crash, explosion, and fire. Because of the one-way driving on a freeway and the special configuration of the interweaving area in our country, the collision in an interlaced area is usually a side collision or a rear collision. According to the statistical results, the main types of accidents in the interweaving area are side collision, rear-end collision, impact barrier, and rollover. The distribution of accident types is shown in Figure 1 and Figure 2.

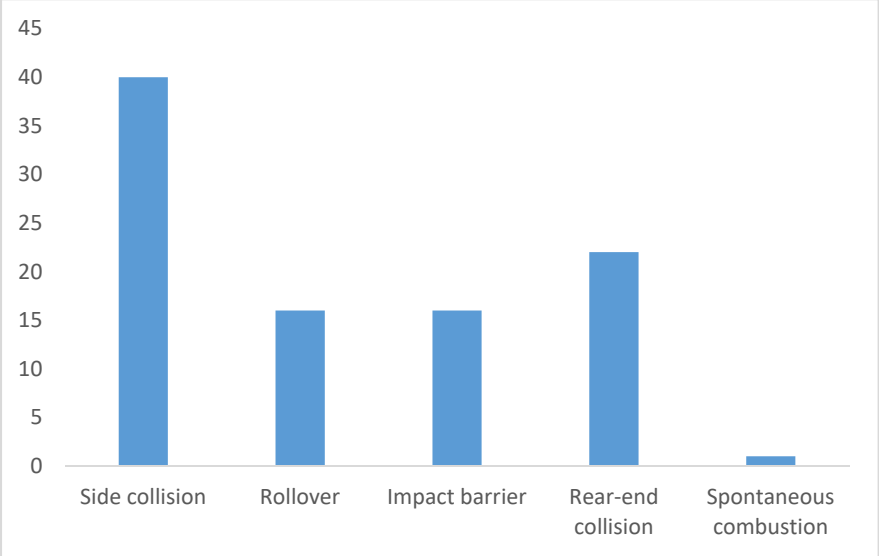

Figure 1. The distribution of accident type

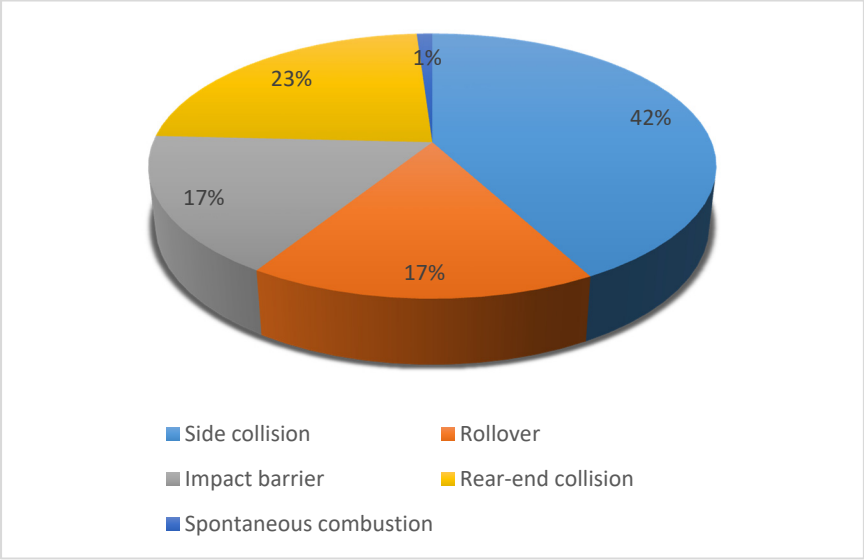

Figure 2. Accident type percentage

The statistical results show that in the whole interweaving area, side collision accounts for the largest proportion, or 42% of the total, followed by rear-end collision, accounting for 23% of the total. The cumulative frequency of the above two

types of accidents reaches 65%, which constitutes the main accident mode in the interweaving area. Impact barrier and rollover are other major accident types. This is because vehicles in the interweaving area need to change lanes frequently in order to complete the interweaving behavior. Vehicles in different lanes are prone to producing traffic conflicts, which leads to the occurrence of collisions. There is a big difference between the speed of vehicles on the main road and on the ramp, as well as between the speed and braking performance of cars and trucks, all of which are prone to rear-end accidents.

In order to reveal the characteristics of accident distribution in the interweaving area, this paper studies two dimensions of time and space. The study of temporal and spatial features shows that there are obvious differences in the accident distribution in different sections of the interweaving area, as well as in the time the accident occurs.

Spatial Distribution of Accidents

Based on the distance from the triangle end of the entrance, the interweaving area is divided into three parts, i.e. upstream merging area, midstream interweaving area, and downstream diverging area, with 120m as a statistical unit. The spatial distribution law of the number and type of accidents in each area of the interweaving area is statistically analyzed, and the results are shown in the Figure 3.

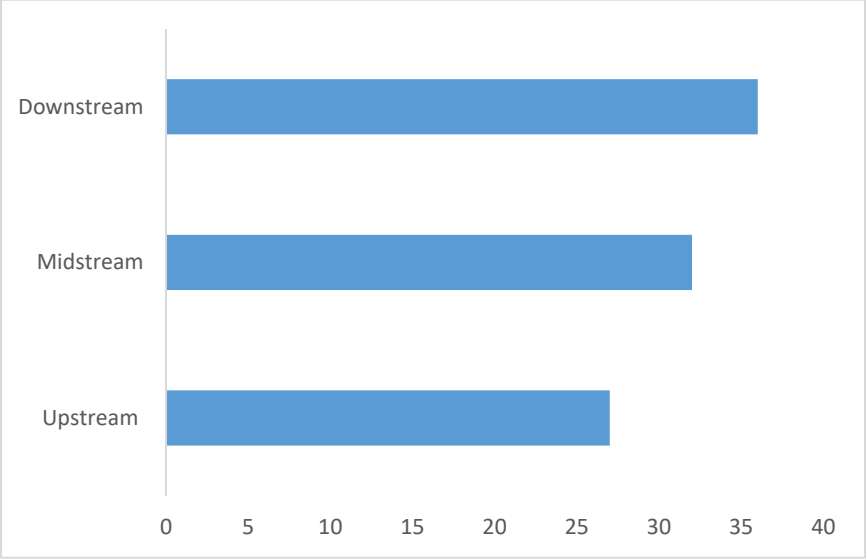

Figure 3. Spatial distribution of interweaving accidents

It can be seen from the statistical results that traffic accidents occur in each area of the interweaving area and the downstream diverging area is the most frequent area of the whole interweaving area. This is because many vehicles in the downstream area need to drive out of the freeway, and the vehicles on the ramp and

the main road are prone to "conflict," resulting in traffic disorder. Further, the accident types of each area are counted and compared, so as to obtain the distribution features and analyze the specific causes of accidents, as shown in Figure 4.

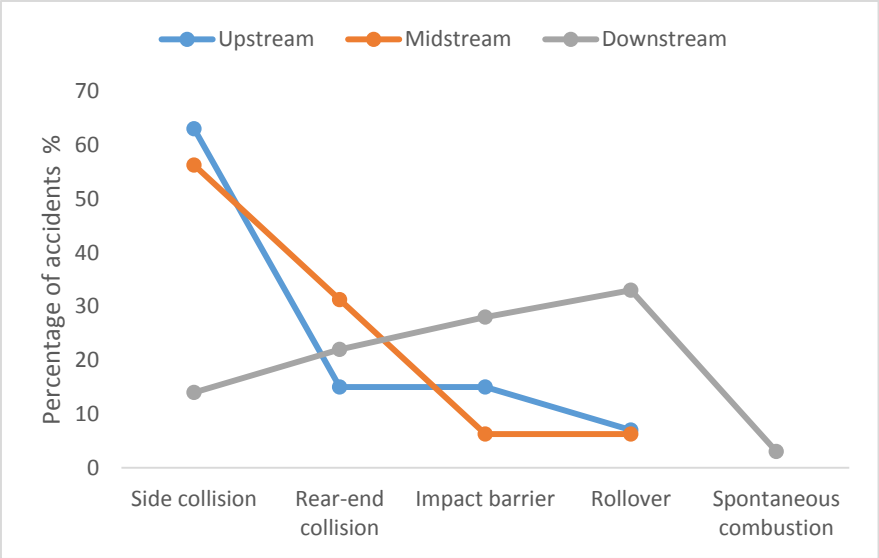

Figure 4. Percentage of accidents in different areas

It can be concluded that there are significant differences in the distribution characteristics of accidents in different regions of the interweaving area. The distribution characteristics of upstream and midstream segments are similar, mainly side collision and rear-end collision, both of which are more than 78%, and the total of the two in the midstream interweaving area is as high as 87.5%. Meanwhile, in the downstream diversion area, rollovers and impact barriers are the main accident patterns, and rear-end collision and side collision occupy only a small part. This is different from the accident distribution in the upstream merging area and the middle interweaving area due to the different running characteristics of vehicles in different regions. The main influencing factors of accidents are not the same, specifically the traffic flow characteristics, road environment, weather conditions, etc., so the accidents in each region show different distribution features. The specific causes of accidents will be explained in detail in the next section.

Temporal Distribution of Accidents

According to the accident data, the monthly distribution and hour distribution of accidents in the interweaving area are analyzed, as shown in Figure 5 and Figure 6.

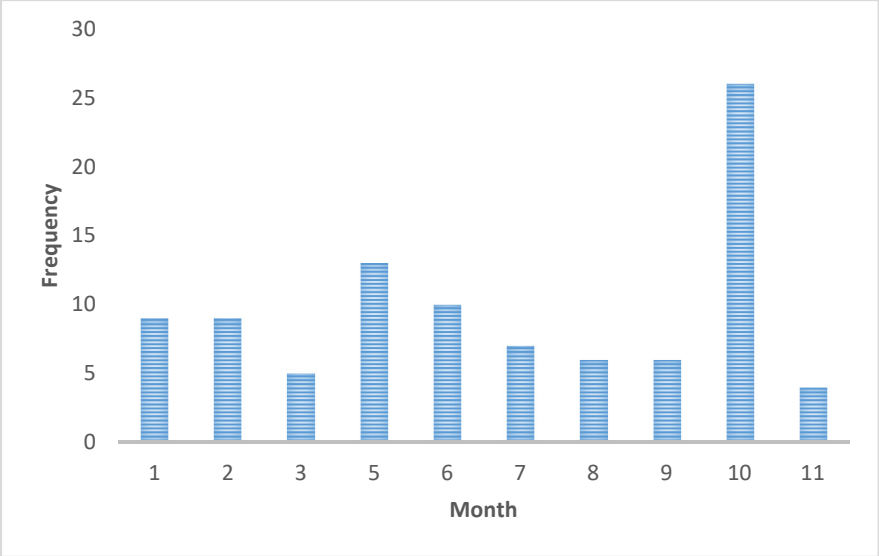

Figure 5. Monthly distribution of accidents

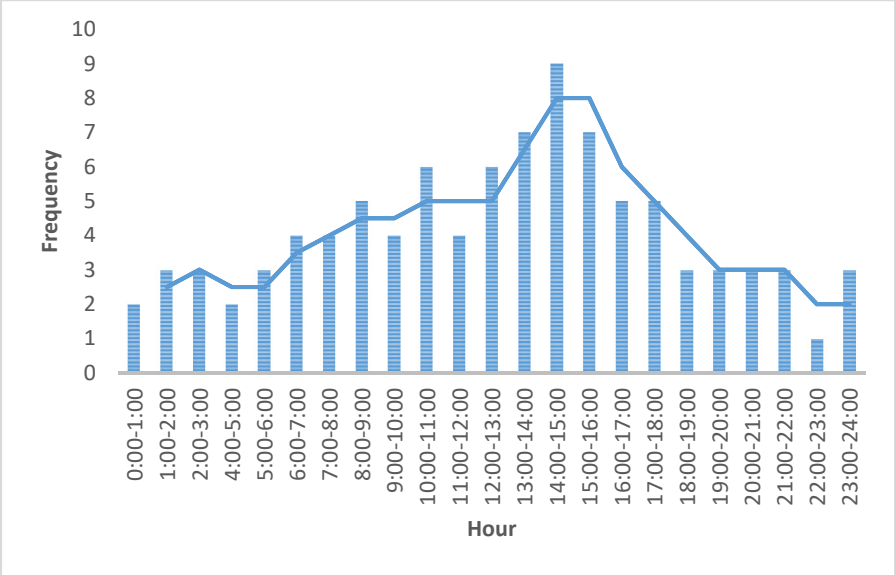

Figure 6. Hourly distribution of accidents

The overall distribution of traffic accidents in the interweaving area is concentrated in spring and autumn. October has the highest incidence of accidents, accounting for 27% of the total. The time period between 13:00 and 16:00 is the concentration period of traffic accidents in interweaving areas. According to the research, drivers are prone to fatigue and drowsiness between 14:00 and16:00 p.m., and distraction is an important cause of traffic accidents (Wang 2016). The sunshine in the afternoon is dazzling, which can cause the driver to be dazed, thus inducing the traffic accident. From 18:00 to 6:00 at night, the traffic accident rate is relatively stable, with an average of two to three accidents per hour. In addition, the number of

traffic accidents (6:00-18:00) in the interweaving area accounts for 69.5% of the total number of accidents, which is higher than at night.

ANALYSIS OF ACCIDENT INFLUENCING FACTORS

Because of its special structure, the freeway interweaving area has some particularity compared with the ordinary road section, and the characteristics of vehicles running in the interweaving area are also different. In order to obtain strategies for reducing the accident rate and improving the safety level of the interweaving area, the causes of several main types of accidents are analyzed.

Side collision is mainly caused by the interweaving of ramp vehicles and main road vehicles, which usually occurs when vehicles change lanes. In order to meet the inherent lane change requirements, some vehicles caused a collision by forcing a lane change when looking for a gap in traffic. When the driver who needs to merge into the main line sees that there is no vehicle behind him, he will directly change lanes merge. Due to insufficient acceleration in the acceleration lane, the vehicle speed difference between the ramp and main road will be large, resulting in a collision. This explains why side collisions domninate in the upstream interweaving segment.

The cause of rear-end collisions is similar and due to the speed difference caused by interweaving. The rear-end collision usually occurs in the same lane, while the side collision occurs between adjacent lanes. The rear-end accident at the downstream is usually caused by an emergency stop or forced reverse of the vehicle missing the exit.

Impact barrier accident refers to a collision between a vehicle and freeway structure. In order to avoid side impact with the vehicle changing lanes or rear-end collision with the vehicle in front, the rear vehicle takes emergency measures, causing impact with the guardrail. In addition, at many exit ramps, the unreasonable linear design and poor sight distance will cause the vehicle to hit the guardrail. Similarly, when the exit of the interweaving area is located on a curve, the poor sight distance will cause the vehicle to decelerate urgently, which can cause rollover. This is consistent with the results in Figure 4 of this study.

A significant factor affecting the number of accidents in the interweaving area is the traffic volume. We used Excel to graph and analyze the relationship between accident data and traffic volume data. Figure 7 compares the growth rate curve of monthly traffic volume and the growth rate curve of monthly traffic accident numbers. It can be found that the correlation between the two growth rates is strong and basically changes synchronously. Taking October as an example, when the traffic volume in the interweaving area is 1.78 times higher than the monthly average, the number of traffic accidents is 1.74 times higher than the monthly average. It is concluded that traffic volume has a significant impact on accident frequency, and there is a linear fitting relationship.

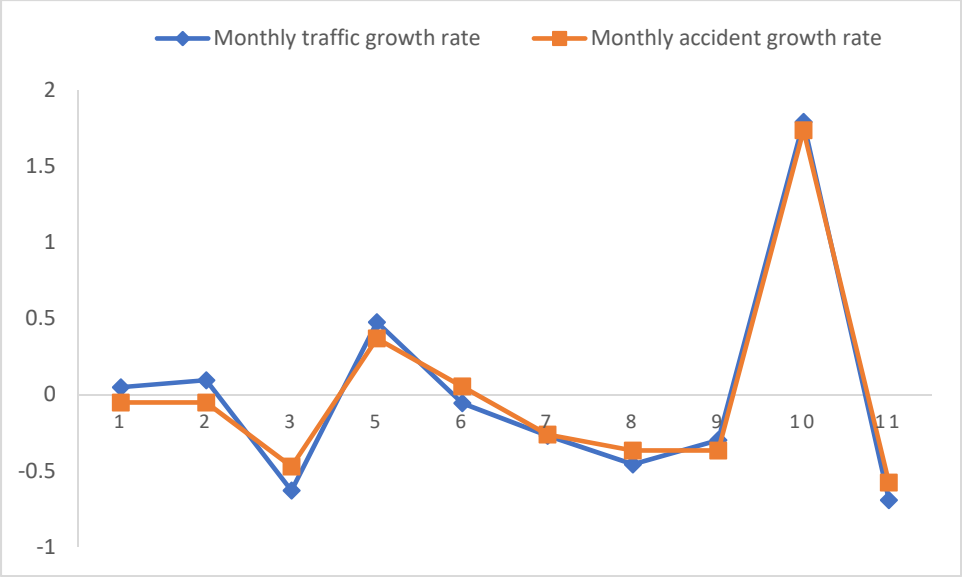

Figure 7. Comparison curve of accident growth rate and traffic growth rate

CONCLUSION

Side collision and rear-end collision are the main types of interweaving accidents in this study. Because of the interweaving of traffic flow, side collision and rear-end mainly occur in the upstream merging area and the middle interweaving area, while the downstream diverging area shows different characteristics, with rollover and collision with guardrail being the most common accidents. The high incidence time of interweaving accidents is between 13:00 and 16:00.

Based on the discussion of traffic accident distribution features and accident influencing factors, this paper puts forward some suggestions from several angles in order to maximize the safety level of the interweaving area. First, the linear design of the entrance and exit ramps should be as reasonable as possible. Second, the driver should abide by the regulations and make full acceleration and deceleration before changing lanes. In addition, when the traffic volume is large, sufficient traffic control measures should be in place.

In the analysis of the distribution characteristics of traffic accidents and various influencing factors, this paper only focuses on the frequency of traffic accidents. However, the severity of accidents, another important attribute of accidents, is not reflected in this paper. This is the limitation of this study and also the focus of our next stage of research.

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