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# Research on Traffic Characteristics and Traffic Conflicts of the One-way-closure Work Zone on Freeway

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**Keywords:** freeway; one-way-closure; work zone; traffic characteristic; traffic conflict.

**Abstract.** By analyzing the traffic characteristics and traffic conflicts of the typical one-way-closure work zone on four-lane freeways, the queuing characteristics of vehicles are determined, and the Erlang distribution model which can describe the distribution of time headway is calibrated. The speed distribution characteristics of each component of the work zone are concluded, and the speed limit scales for these components are put forward based on the statistic analysis. The types of traffic conflicts are firstly concluded, and then the identification method of the rear-end conflicts' severity degree based on TTC technique as well as the prediction model of rear-end conflicts based on Negative Binomial distribution are put forward. The research results are useful to the analysis of traffic conditions of work zones, and they can also be used to evaluate the safety situations of freeway work zones.

## Introduction

Heavy repair or maintenance is one of the main problems for expressways which opened to operation for many years. To ensure the operation of the expressway, "constructing while operating" is the most common adopted way. Under this condition, it needs to close parts of lanes even one-way-closure, which caused the reduction of capacity as well as the traffic condition change for the lanes allowing vehicle to run, and this will bring traffic congestion, road traffic accident occurrence and other problems. Thus, it is very important to analyze the traffic organization and optimization method during the heavy repair or maintenance period, and then improve the traffic operating efficiency and the safety level of the expressway.

In the early 1980s, developed countries began to do research on expressway work zones, and the focus of that time is speed limits. To 1990s, there was much further research on the operating speed of vehicles[1,2], and capacity, queuing and delay became the research hot points[3,4]. Recently, the research on how queuing and delay influencing traffic operating efficiency and road safety becomes popular[5-7]. As the expressways constructed in early years in China beginning to heavy repair or maintenance, domestic researchers pay close attention to the traffic flow characteristics of work zones, and traffic characteristics and influence factors, speed distribution, time headway distribution and other related research works are conducted[8,9].

Road safety of work zones is one of the main problems, and foreign researchers have done a lot of research works, including relationships between accident rates and working time as well as length of work zone, influencing factors of accidents, safety assessment, and accident prediction[10-12]. Since there are systemic and completed accident data from work zones, their research results are more reliable and applicable. Based on the experience from abroad, the domestic researchers have get some achievements in recent years, e.g., the risk prediction model of work zones are put forward, the influence factors of hazardous locations in work zones are analyzed, and the counter measures to improve road safety level are developed[13,14]. Regarding to there is not enough accident data of work zones in China up until now, the road safety research based on traffic conflict technique is put forward in this paper.

## Field Investigation and Data Collection

Based on the project of "Research on traffic control and safety guarantee technique during the construction of expressway", which is authorized by Transportation department of Heilongjiang province, the field investigation were conducted at the Harbin to Yagou segment of Suiman highway, Beian to Wudalianchi segment of Qianfeng Farm to Nenjiang Expressway, and Hailun to Beian segment of Suihua to Beian Expressway. The contents of investigation includes traffic volume, speed, time headway, traffic conflict and travel time, et al. 8 work zones are investigated and traffic data of 12h or 24h are obtained for each work zone. Traffic investigation sites and investigation method are shown in Fig.1.

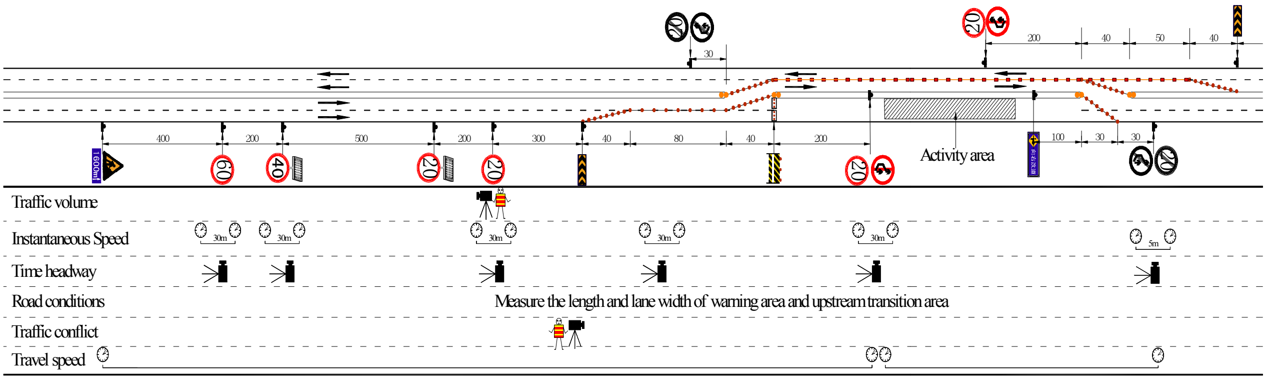



Fig.1 Investigation sites and investigation method

## Vehicle Queuing Characteristics and Time Headway Analysis

### Vehicle Queuing Characteristics

At the upstream transition area, vehicles on the two lanes need to merge into one lane, and then run into the opposite way, which will form an obvious bottleneck at this segment. Vehicles need to slow down and pass the bottleneck in a queue. By statistic analysis, the characteristics of vehicle queuing during the peak time are as follows: the proportion of queuing vehicles for all kinds of vehicles is 41.18%; the proportion of queuing vehicles for light-duty vehicles is 41.18%; the proportion of queuing vehicles for medium vehicles is 42.67%; the proportion of queuing vehicles for oversized vehicles is 52.84%. The queue length with a light-duty vehicle as leading is 3.72 vehicles; the queue length with a medium vehicle as leading is 3.04 vehicles; the queue length with an oversized vehicle as leading is 3.87 vehicles; the maximum queue length is 14 vehicles; the average queue length for all the vehicles is 4.96 pcu.

The queuing characteristics, especially the queue length, are very important to determine the proper length of transition area. If the average queue length is 4.96 pcu, and the speed limit is 20 to 40 km/h, the minimum length of transition area should be 45 to 70m, which is longer than 40m required by the "Safety Work Rules for Highway Maintenance".

### Time Headway Analysis

All the time headways less than 30s are taken as samples, and the statistic results are shown in Table 1. The average time headway is 5.75s, and 2s time headway is most frequent. Negative exponential distribution, shifting negative exponential distribution, Erlang distribution and Weibull distribution are employed to fit the data, and the result shows that Erlang distribution is the best for both the peak time period and the off-peak time period.

Table 1 Statistical Results of Time Spaces of Vehicles

| Average | Standard error | Median | Mode | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| 5.75 | 0.17 | 3.70 | 2.00 | 5.42 | 0.20 | 29.20 |

The function of Erlang distribution is as follows:

$$P(h \geq t) = \sum_{i=0}^{r-1} \frac{(\lambda t)^i}{i!} e^{-\lambda t} \tag{1}$$

where, $t$ is the time headway, s; $r$ is the order of the Erlang distribution( the larger the $r$, the traffic is more congested).

$r$ and $\lambda$ can be determined by the average(E) and variance ($S^2$) of the samples, and the calculation formula are $r = E^2 / S^2$ and $\lambda = E^2 / S^2$. The calculation results show that the time headways of peak time, off-peak time and all time agree with the Erlang distribution with $r$=2, $r$=1 and $r$=1, respectively. The Erlang distribution with $r$=1 is actually the negative exponential distribution. The fitting of the time headways for peak time and off-peak time are shown in Fig.2. The distribution of time headway can be used to identify the traffic conflict and determine the situation of traffic operation.

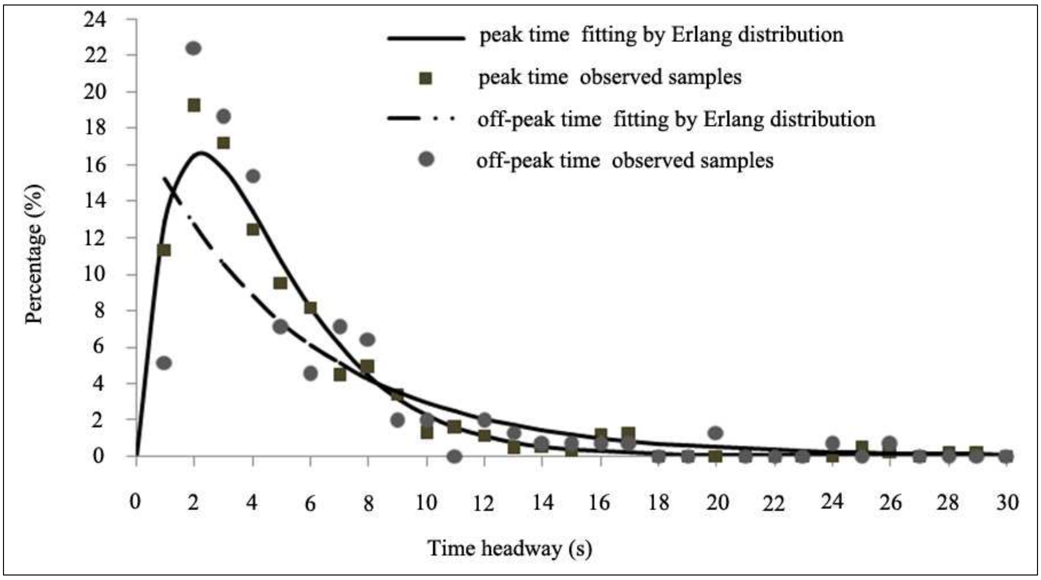



Fig.2 Time headways on peak and off-peak time

## Speed Distribution and Speed Limit Scale based on Statistic Analysis

### Speed Distribution of Work Zones

The speed frequencies of the investigate sites at the speed limit signs of 80km/h (60km/h), 60km/h (40km/h), 40km/h (20km/h) in upstream of work zones, buffering spaces, activity areas, and downstream segments are listed in Table 2.

Table 2 Statistical results of speeds on each component of work zone

| No. | Statistic indexes | 80 (60)km/h | 60 (40)km/h | 40 (20)km/h | Buffering space | Activity area | Downstream segment |
|---|---|---|---|---|---|---|---|
| 1 | Average（km/h） | 91.697 | 72.345 | 61.273 | 38.354 | 61.763 | 87.310 |
| 2 | Median（km/h） | 90.0 | 70.054 | 61.463 | 38.710 | 61.685 | 87.273 |
| 3 | Standard error | 1.347 | 0.956 | 0.69 | 0.46 | 0.95 | 1.15 |
| 4 | Standard deviation | 22.1 | 16.6 | 12.3 | 8.8 | 17.3 | 18.0 |
| 5 | Variance | 489.91 | 275.85 | 150.99 | 77.87 | 299.14 | 325.35 |
| 6 | Number of samples | 270 | 300 | 314 | 371 | 334 | 245 |
| 7 | e+δ | 113.797 | 88.945 | 73.573 | 47.154 | 79.063 | 105.31 |
| 8 | e-δ | 69.597 | 55.745 | 48.973 | 29.554 | 44.463 | 69.31 |

### Speed Limit Scale based on Statistic Analysis

The speed limit scales of each component of the work zone can be calculated by the formula below:

$$V_i^{upper} = E_i + 1 \times \delta_i \tag{2}$$

$$V_i^{lower} = E_i - 1 \times \delta_i \tag{3}$$

where, $V_i^{upper}$ is the upper speed limit of segment *i*; $V_i^{lower}$ is the lower speed limit of segment *i*; $E_i$ is the average speed of segment *i*; $\delta_i$ is the standard deviation of speeds at segment *i*.

The determined speed limit values are shown as Row 7 and 8 in Table 2. When the traffic volume is low, the upper limits can be taken as the speed limit values, while the traffic volume is high, the lower limits should be taken as the speed limit values.

## Traffic Conflict Characteristics Analysis and Prediction

### Categories of traffic conflicts of work zone

Because of the lane merging or changing, vehicles running in the work zone are often very close to each other. There will be a traffic conflict even a traffic accident, if any of the two approximating vehicle does not take counter measures such as slowing down or changing the direction.

The categories of traffic conflicts of work zone mainly include rear-end conflicts and side conflicts, and the detailed forms are rear-end conflicts in passing carriageway of warning areas, rear-end conflicts in carriageway of warning areas, side conflicts in upstream transition areas, rear-end conflicts in activity area, and rear-end conflicts in downstream transition area. The locations where the five traffic conflicts occurred are shown in Fig.3.

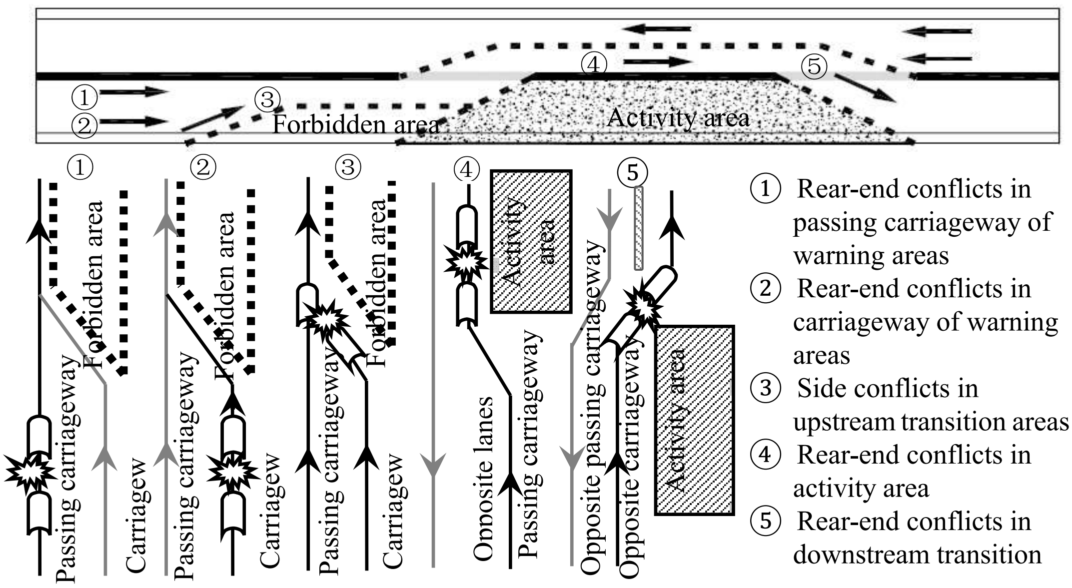



Fig.3 Types of traffic conflict of work zone

### Identification of Rear-end Conflict Severity based on TTC

The first thing to apply traffic conflict technique is to determine the identification method of traffic conflict severity, and the identification method based on TTC is employed in this paper. Given two vehicles running while queuing on the same lane, if the speed of the follower is faster than that of the leader and the distance between them is short, there will be a rear-end conflict. The time TTC (time to collision) for the follower vehicle hit the leader is calculated as follows:

$$TTC_i = \frac{x_{i-1}(t) - x_i(t) - l_{i-1}}{\dot{x}_i(t) - \dot{x}_{i-1}(t)} \quad \forall \dot{x}_i(t) > \dot{x}_{i-1}(t) \tag{4}$$

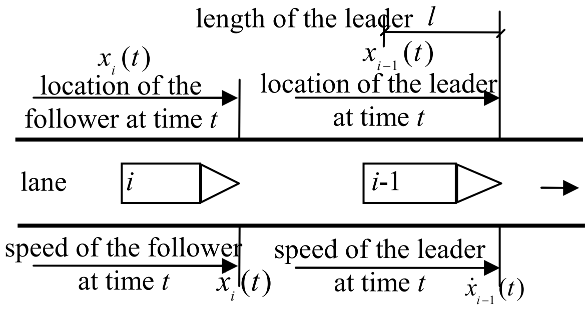
where, $x_{i-1}(t)$ and $x_i(t)$ is the location of the leader vehicle and the follower vehicle at time $t$, respectively, shown in Fig.4; $l_{i-1}$ is the length of the leader vehicle; $\dot{x}_{i-1}(t)$ and $\dot{x}_i(t)$ is the instantaneous speed of the leader vehicle and the follower vehicle, respectively.

Since the vehicles are always moving, it is much easier to get the time headway than the space headway. Thus, the formula is adjusted as follows:

$$TTC_i = \frac{\dot{x}_i(t)}{\dot{x}_i(t) - \dot{x}_{i-1}(t)} \left( h_i - \frac{l_{i-1}}{\dot{x}_i(t)} \right) \tag{5}$$

where, $h_i$ is the time headway, s.

The samples with short time headways as well as the follower vehicle faster than leader one are selected from the data, and the TTCs are calculated by formula (5). After the statistic analysis of the TTC data, TTCs less than 2s are defined as the severe conflicts, and TTCs more than 2s and less than 6s are defined as normal conflicts. The proportion of severe conflict, normal conflict and no conflict are 2.73%, 5.12% and 92.15%, respectively, shown in Fig.5.



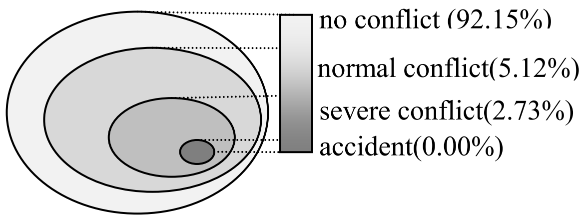




Fig.4 Schematic diagram of rear-end conflict of work zone

Fig.5 Safety situation of work zone

**Traffic Conflict Prediction Model of Rear-end Conflict in Work Zone**

The statistic analysis shows that the variance of the samples is much higher than the mean, so the negative binomial distribution is adopted to model the occurrence of traffic conflicts. Combining the traffic flow and traffic conflict data, applying the maximum likelihood estimation, the prediction model is calibrated as follows:

$$P_i(n) = \frac{\Gamma(\frac{1}{0.328} + n)}{\Gamma(\frac{1}{0.328}) \cdot n!} \cdot \left(\frac{1}{1 + 0.328\lambda_i}\right)^{\frac{1}{0.328}} \cdot \left(\frac{\lambda_i}{\frac{1}{0.328} + \lambda_i}\right)^n \tag{6}$$

$$\lambda_i = \exp(2.812 + 0.00734 x_q + 4.889 x_b + 0.0346 x_{\Delta v} - 0.538 x_h) \tag{7}$$

where, $P_i(n)$ is the probability of $n$ rear-end t conflicts at site $i$; $\lambda_i$ is the expectation number of rear-end conflicts at site $i$; $x_q$ is the traffic volume of the lane, pcu/15min; $x_b$ is the percentage of oversized vehicles, %; $x_{\Delta v}$ is the speed difference of two vehicles, m/s; $x_h$ is the time headway, s.

## Summary

The one-way-closure work zone is selected as the research focus, and the field investigation of traffic flow and traffic conflict are conducted. The queuing characteristics, time headway distribution, and speed distribution of each component of the work zone are analyzed base on the investigation data and statistic analysis. Then the traffic conflict prediction model based on TTC technique is put forward. The research results of this paper can provide reference to the analysis of work zones' traffic characteristics and traffic conflicts.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