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Speed Characteristics and Safety Risk Level Evaluation for Nighttime Roadway Work Area

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Abstract

More and more roadway projects are conducted during nighttime to satisfy heavy travelling demands in the daytime. However, the Nighttime Roadway Work (NRW) produces several safety problems. As a developing region of China, these problems expose later than some developed countries, and there is scarcely any valid crash samples for NRW safety analysis. Therefore, a surrogate safety assessment philosophy is adopted in the paper. Firstly, the field survey and statistical analysis approaches are adopted to acquire percentile speed characteristics of vehicles passing through work-zones during nighttime. Secondly, a kind of safety risk evaluation model is established to assess NRW safety levels. The results reveal that 1) speeding problems severely exist in the NRW zone and safety risk levels are comparatively high; 2) from speed characteristics of NRW in a city expressway by lanes, speeding ratio in the activity area is higher than 90% and in the lane in transition area the ratio is higher than 30%; 3) from speed characteristics of NRW in a city expressway by vehicle types, speeding ratios of all type vehicles in the activity and transition area are higher than 90% and 30% respectively; 4) the speeding ratio in freeway NRW area is close to 100%; 5) the safety risk analysis indicates that risk levels of lanes in transition area are comparatively high, and also the safety risk level of large vehicles is higher compared to other type vehicles. Finally, several useful tips for the prevention of speeding in the NRW area are suggested.

Keywords: Nighttime roadway work; Speed characteristic; Speeding; Safety Risk; Risk Model;

1. Introduction

Both developed and developing countries are encountering a great quantity of roadway work activities, such as roadway construction, maintenance, roadside planting and facility maintenance. These activities usually lead to roadway occupation and are designated as Roadway Work (RW). RW tends to have a negative influence on

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traffic operation efficiency, like forming traffic bottlenecks and worsening traffic congestion conditions. Therefore, more and more RW projects are conducted during the nighttime. In the daytime the working equipment are removed and the occupied traffic lanes are restored to accommodate large travelling demand to reduce traffic delay. The research of Gerald *et al.* (2004) has demonstrated a positive relationship between the number of Nighttime Roadway Work (NRW) and the average daily traffic.

Generally, the NRW has several advantages over the Daytime Roadway Work (DRW). Firstly, compared with large traffic volume in the daytime, the considerable low volume in nighttime lessens traffic delay and restriction of resident trip. Secondly, the NRW brings a lower impact on construction and is more convenient for equipment setting and removing. Additionally, the low volume in nighttime ensures the efficiency and accessibility of transportation of construction equipment and materials.

However, the NRW also has some disadvantages. One of the most remarkable disadvantages is the lower level of traffic safety service. For example, Arditi *et al.* (2003) adopted an empirical analysis method to acquire traffic casualty characteristics through the 1996 to 2001 traffic crash datum occurring in work-zone area in Illinois. The result shows a five times higher traffic safety risk of the NRW than the DRW. Besides, Walter (2009) found out that over speed and lacking attention were primary reasons for the NRW crashes through the comparison analysis of advantages and disadvantages between the NRW and the DRW.

Since the safety problems of the RW, especially the NRW, has not been exposed until recently in China, and the RW traffic crashes have the features of inadequate sample, long period and randomness. These reasons lead to scarce published systematic literatures about traffic behaviors and risk characteristics in the NRW area for the developing region of China. Based on field survey, this study focuses on the analysis of speeding behaviors and safety risk characteristics in the NRW area. The conclusions are expected to provide basis for the making of corresponding countermeasures. The specific objectives are targeted as follows:

1) To acquire speed characteristics of vehicles passing through the work-zone area during nighttime by field survey and statistical analysis.

2) To establish a risk evaluation model to assess traffic safety risk levels of the functional area of the work-zone during the nighttime.

3) To propose several useful tips for the prevention of speeding in the NRW area.

The remainder of this paper is organized as follows. The next section reviews current research on traffic crash features and primary crash cause excavation of speeding behaviors for the NRW area. Section 3 describes field survey scheme and corresponding implementation process. Section 4 analyses speeding behavior characteristics. The safety risk model establishment and safety level assessment of the NRW area are stated in section 5. The conclusions are drawn and several tips for prevention of speeding are provided in section 6.

2. Literature review

The current studies on NRW, for instance, some researchers like Arditi *et al.* (2003), Wunderlich *et al.* (2003), and Gerald *et al.* (2008) try to evaluate nighttime and daytime work zone safety levels, and other researchers including Walter (2009), Cottrell (1999), David *et al.* (2007), focus on screening safety factors by adopting empirical data.

In the area of comparing safety levels between nighttime and daytime, Arditi *et al.* (2003) used Illinois fatality crashes from work zone to evaluate the relative safety levels of daytime and nighttime. Wunderlich *et al.* (2003) mentioned that state and local transportation agencies posted the estimation of exposure from a sampling process of predesigned work zone activity information. Based on these studies, the conclusion of a five times higher safety risk of the NRW than the DRW was acquired. However, Gerald *et al.* (2008) insisted that the NRW didn't necessarily lead to a significantly higher crash risk level for vehicles passing through the work zone than did roadway work in the daytime. This controversy continues and this paper doesn't focus on the right or wrong arguments for the controversy, but excavates speed characteristics and evaluates traffic safety risk levels for the NRW area from a surrogate viewpoints.

As for factors influencing the NRW safety, Walter (2009) compared both advantages and disadvantage of traffic safety between the NRW and DRW. Considering factors like higher speed, lower attention and visibility and potential alcohol and drug cases in the nighttime, the lane-close type of NRW was more dangerous than the counterpart of DRW, also the crashes happened in the nighttime were always severe. Cottrell (1999) designed a RW questionnaire objected to the administrators from the State Departments of Transportation in U.S and related traffic engineers. The 28 departments in 50 have responded the questionnaire, among which 17 states have adopted NRW. The 18 engineers of 45 have responded, among which 15 indicate NRWs have been implemented in their states. The results show that the administrators believed the top three ranking safety problems of NRW being low visibility, more and more drivers being short of enough skill, and high driving speed, while the viewpoints of traffic engineers were low visibility, high average speed and low attention of driver. Arditi *et al.* (2007) indicated that low visibility, increased speed and possibility of drunken or fatigued driving were the three most influential factors on traffic safety.

The aforementioned studies mention that high speed behaviour is an important factor inducing traffic safety problems of the NRW. A similar phenomenon, namely speeding being one of the primary causes to crashes for the NRW in Beijing municipality, was detected in this study by expert interviews and field investigations.

Some other studies in the Australia, the United States, the China, for example, the research of RTANSW 2000, NHTSA 2006, Chen 2010, et al., have also demonstrated the hazardous of speeding behaviour.

A study in the Australia showed that the accident rate doubles for each additional speed of 5 km per hour when the speed is higher than 60 km per hour and the accident severity presents an exponential growth diagram accompanying the increase of speed (RTANSW 2000). According to a statistical bulletin of the United States, nearly 30% of the fatality accidents in the whole country were related with speeding. Speeding was an uppermost cause to a traffic crash, especially for a crash with fatalities (NHTSA 2006). Chen (2010) conducted a systematic research on the mechanism how speeding influences traffic safety. The result shows that speeding leads to the reduced visual acuity and the narrowed field of vision of drivers, which decreasing the cognition distance and the reaction time. This causes misjudgements of distance and speed and makes driver more fatigable, increases the possibility of improper driving manipulation. Meanwhile, speeding extends the braking reaction distance, destroys the vehicle's manoeuvrability and stability, and aggrandizes the percussive force of vehicles in an accident, which worsening the crash hazardous consequences.

Based on the aforementioned studies and practical situations about NRW in the Beijing municipality, this study focuses on exploring speeding and traffic safety risk characteristics in the NRW area. The basic statistical analysis techniques in traffic engineering are adopted. The discovered features are expected to provide a quantitative basis for smooth traffic movements and useful safety tips for the NRW area.

3. Field survey

Since traffic safety risk levels have strong positive relation with high speed, the entranceways and basic roadway sections of expressway with high design speed are selected for field survey to acquire speed behaviour characteristics of the NRW area. High resolution camera is used for video observation. The video observation contains three steps. The first step is to interview two primary roadway maintenance companies and visit the NRW area to pick out specific spots for field survey (Table 1). Meanwhile, the necessary safety and shooting training are implemented. The second step is to take scene videos with all observers in fluorescence suit. The last step is to extract the datum from videos in the laboratory.

The second step is very important for the reason that precise datum is hard to acquire and the safety problems of the observers should be paid special attention. The critical point is to select proper and safe video collection points. All three selected NRW zones are shown in Fig. 1. Since there is no advanced warning area in both

NRWA and NRWB, video collection points are arranged in the middle of the upstream transition area and the activity area. The NRWC has a complete functional composition of warning area, upstream transition area, activity area, downstream transition area and termination area (FHWA, 2009). Three points of warning area, upstream transition area, and upstream buffer area are selected for video collection in NRWC. Besides, the cameras are placed as near as the neighbouring streetlight for clear videos. The tripod stability and camera influence to drivers are also considered.

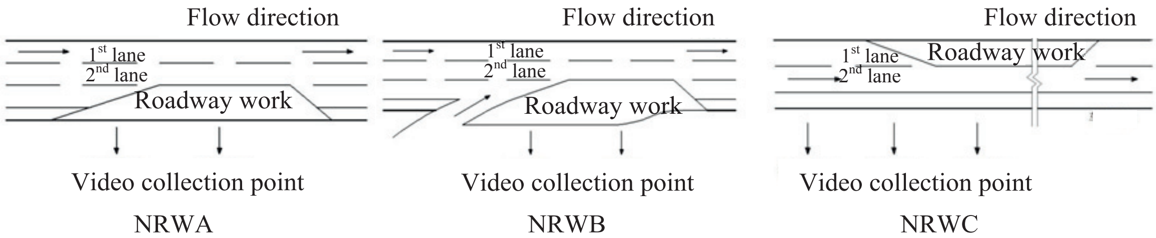


Fig.1 Settings of video collection points

Table 1 Basic conditions of field survey spots

	East of Anhua Bridge (Main road of 3rd Ring Rd.)	Anzhen Bridge (Main road of 3rd Ring Rd.)	Luyang Bridge (6th Ring Rd.)
Roadway class	Expressway	Expressway	Freeway
RW lane	Lane closure of the outside lanes	Lane closure of the outside lanes	Lane closure of the inside lanes
RW location	Basic section	Nearing ramp entranceway	Basic section
Restricted speed	60-40-60 (km/h)	60-40-60 (km/h)	60-40-60 (km/h)
Grade	No	No	No
Weather	Sunny	Sunny	Sunny
Time period	2:00～3:00	2:00～3:00	21:00～22:00
Symbol	NRWA	NRWB	NRWC

In the last step, the traffic stream parameter extraction method is explained as follows. An 8-10 meter long roadway section with starting point a and ending point b are marked before video taking. This roadway section could be clearly discerned in the videos. A video processing software is used to take each picture frame of the video. Then the arriving times at both point a and b are recorded for each vehicle, and the speed of each vehicle passing through this roadway section could be acquired. The other parameters like vehicle gaps and equivalent traffic flow rate can also be obtained, with vehicle gaps being computed by their arriving time differences at point a or point b and one hour equivalent traffic flow rate being conversed by counting the amount of vehicles passing through the marked section during a certain time.

4. Speed characteristics of NRW area

This section summarizes speed characteristics of the NRW area in different roadway types from a statistical analysis perspective.

4.1. Speed characteristics of city expressway during NRW

Take NRWA as an example, this section analyzes the traffic speed characteristics of expressway during NRW.

Speed frequency distribution

Speed frequency is calculated by four groups of speed under 40 km/h, from 40 to 50 km/h, from 50 to 60 km/h, and bigger than 60 km/h according to the transition and activity area respectively. The proportion of vehicles with speed over 50 km/h drops a little from the transition area to activity area, but almost all vehicles are driving over 50 km/h. The 44.7% vehicles in transition area and 41.7% in activity area are driving over 60 km/h.

Speed distribution by NRW roadway sections and lanes

Speed distribution by NRW sections and lanes are shown in Table 2. The restricted speed is 60 km/h in transition area and 40 km/h in activity area, but average speeds in these two areas are very close in practical conditions. Almost all vehicles in NRW area are speeding. The speeding ratio is 45.1% in the transition area and as high as 98.1% in the activity area. Although speeding may exist in these roadways at usual times, speeding in the NRW situations are more dangerous and drivers should obey the speed limitations for a low risk driving environment.

As the statistical results of different lanes show, though the speed in the 2nd lane is slightly smaller, they are generally the same and both lane speeds are over 60 km/h. Speeding in the NRW area could be very dangerous, especially on the lane close to the activity area. If there are not enough anti-collision equipment in the activity area, severe crash consequences would occur once the speeding vehicles crash or run into this area. Besides, the speed in lane 2 falls from the transition to activity area, while the speed in lane 1 even rises slightly. In the permitted error range, the speed in lane 1 and 2 from the transition to activity area could be regarded as no significant differences on the whole.

From viewpoints of speeding ratio, the ratio of lane 1 is much higher than lane 2 in transition area where the restricted speed is 60 km/h, which indicates less road work impact on lane 1. However, considering the changeable traffic environment and the potential traffic safety risk, there still should be necessary countermeasures to control the speed. In the activity area where restricted speed is 40 km/h, both lane 1 and lane 2 have a speeding ratio over 97%, which implies high safety risks and calls for strong speed control actions.

Table 2 Speed distribution by roadway sections and lanes of NRWA

Sections and lanes	**Transition area**		**Activity area**	
Speed(km/h)	1st lane	2nd lane	1st lane	2nd lane
Maximum	75	75	75	75
Minimum	37.5	20.5	37.5	25
85% speed	75	75	75	75
50% speed	56.3	75	56.3	56.3
15% speed	45.6	56.3	56.3	45
Average	64.8	61.0	62.6	61.8
Ratio of speeding (%)	50.9	38.8	98.5	97.2

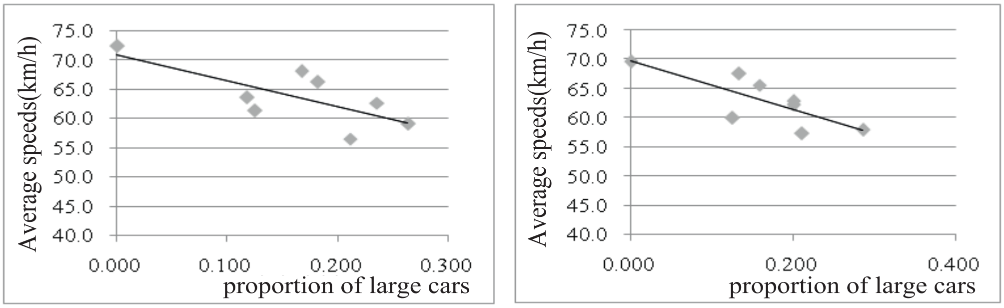
Speed distribution by vehicle types

Speed distribution by vehicle types is explained in Table 3. Considering that trip proportion of taxis during nighttime is large, we separate taxis from small cars and divide all vehicles into three types: private cars, taxis and large vehicles. Average speed of private cars and large vehicles falls when come from transition area to activity area, though in quite a small extent. While speeds of taxis increase and become the highest in all vehicle types both in transition and activity area. The reasons may be that taxi drivers are so skilful and familiar with NRW environment that they are unlikely to be alert and keep away from driving beside the activity area. As the index of speeding ratio, taxis remain highest of 55.3% compared to large vehicles of 18.2%. In activity area, however, the speeding ratio of large vehicles comes up to 90%, not to mention the 100% ratio of private cars and taxis.

Table 3 Speed Distribution by Vehicle Types of NRWA

Sections and Vehicle types / Speed(km/h)	Transition area			Activity area		
	Small cars		Large vehicles	Small cars		Large vehicles
	Private cars	Taxis		Private cars	Taxis	
Maximum	75	75	75	75	75	75
Minimum	45	45	20.5	45	45	25
85% speed	75	75	72.2	75	75	56.3
50% speed	65.6	75	56.3	56.3	75	56.3
15% speed	56.3	56.3	45	56.3	56.3	45
Average speed (km/h)	64.6	66.3	54.1	63.2	67.4	52.8
Ratio of speeding (%)	50.0	55.3	18.2	100.0	100.0	91.3

In field survey, a phenomenon is found that the proportion of large vehicles bring a certain effects on the speed of a platoon. Therefore, the relationship between proportions of large vehicles and average speeds is depicted as Fig.2. The average speed decreases accompanying the proportion increase of large vehicles both in transition and activity area.



a) Transition area b) Activity area

Fig. 2 Diagram of Speed Distribution with the Proportion of Large vehicles in NRWA Area

4.2. Speed characteristics of city expressway with ramp entrance during NRW

Speed datum are collected in the upstream transition area and activity area of NRWB. Conclusions of speed characteristics in NRWB area are as follows.

(1) Speeding is common in both transition and activity area. Majority vehicles, namely 78.3% vehicles in transition area and 86.6% in activity area, are driving at a speed of 50 to 60 km/h or even over 60 km/h. The speeding ratios are 58.4% in transition area where the restricted speed is 60 km/h and 96.0% in activity area with the restricted speed of 40 km/h.

(2) Speeds of large vehicles are comparatively low in transition and activity area. Also the average speed decreases with the increase of proportions of large vehicles. Speeds of taxis are the highest among the small cars. Average speeds of all types of vehicles are stated in Table 4.

(3) Average speed decreases with the increase of volume of traffic flow.

(4)Proportions of large vehicles during the nighttime are large. Equivalent volume of large vehicles in NRWB area exceeds 40% of total traffic flow.

Besides, the NRWB is located approaching a ramp entranceway. The 18.4% vehicles passing through NRWB are merging from the ramp road and majorities are driving at a low speed in lane 2. Therefore, vehicle speeds in lane 1 are higher than in lane 2 and speeds in activity area is higher than in transition area. Average speeds in lane1 and lane 2 of functional sections in NRWB are shown in Table 5. Obviously, the driving speeds, especially in the 2nd lane, increase greatly when come to the activity area, which is totally opposite with the requirement of driving slower in the activity area than the transition area. Over 90% vehicles are speeding. These drivers accelerate right after passing the entrance. Apparently, the speed control facilities in this condition nearly don't work at all.

Table 4 Speed Distribution by Vehicle Types of NRWB

Sections and vehicle types	**Transition area**			**Activity area**		
	Small cars		Large vehicles	Small cars		Large vehicles
Speed(km/h)	Private cars	Taxis		Private cars	Taxis	
Maximum	90	90	90	83.3	83.3	83.3
Minimum	15	27	24.5	33.3	22.2	25.6
85% speed	67.5	67.5	67.5	83.3	83.3	83.3
50% speed	67.5	67.5	54	66.6	66.6	66.6
15% speed	45	45.9	38.6	55.5	55.5	47.6
Average speed(km/h)	62.7	63.2	53.5	69.1	70.7	63.2
Ratio of speeding (%)	65.9	72.0	31.1	97.2	97.4	93.4

Table 5 Speed Distribution by Sections and Lanes of NRWB

Sections and lanes	**Transition area**		**Activity area**	
Speed(km/h)	1st lane	2nd lane	1st lane	2nd lane
Maximum	90	90	83.3	83.3
Minimum	19.3	15	30.3	22.2
85% speed	69.8	67.5	83.3	83.3
50% speed	67.5	54	83.3	66.6
15% speed	54	38.6	66.6	47.6
Average speed(km/h)	68.0	53.1	73.7	61.6
Ratio of speeding (%)	82.2	36.0	98.1	93.8

4.3. Speed characteristics of freeway during NRW

Take NRWC as an example to analyze the speed characteristics of freeway during NRW. NRWC is a 24 hour RW area. Three time period of the daytime off peak and peak hour, and the nighttime are selected for video observations and comparative analysis. The datum of transition area in the three time periods are refined and selected for speed characteristic analysis after video processing.

Speed frequency distribution histogram is drawn in Fig.3. During the peak hour in daytime, majority traffic flow move slow for the large traffic flow rate, and 52.4% vehicles have a speed within 40 km/h. In the off peak hour in daytime and selected time in nighttime, the average speeds increase significantly, and the proportions of vehicle speed over 60 km/h amount to 85.2% and 76.5% respectively.

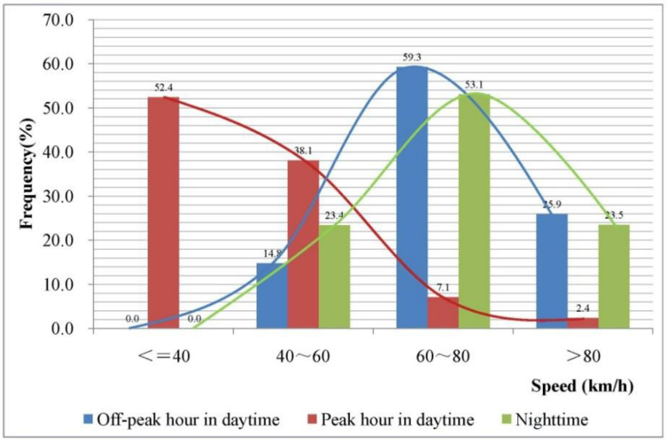


Fig. 3 Speed Frequency Distribution Histogram of NRWC

For further exploring of speed behaviors in freeway NRW, speed distributions in different time ranges are calculated in Table 6. Apart from peak hour in daytime, where average speed is close to restricted speed of 40 km/h and has a low over-speeding ratio under 50%, speeds in any other time range are about 70 km/h and speeding ratios are 100%.

Compared with the aforementioned city expressway, both nighttime average speeds and lane flow rates in freeway NRWC are much higher than in NRWA and NRWB. Safety risks in NRWC will greatly increase because of the increasing speed and flow rate simultaneously. In addition, the poor illumination conditions in freeway NRWC would make it hard for drivers to identify the outline position of work zone functional areas and the distances of vehicles ahead. Thus latent safety problems in freeway NRW are particularly serious.

Table 6 Comparative Analysis of Speed Distribution of NRWC

Time period Speed(km/h)	**Off-peak hour in daytime**	**Peak hour in daytime**	**Night-time**
Maximum	104.4	87	87
Minimum	52.2	13.4	43.5
85% speed	87	55.4	87
50% speed	74.6	37.3	65.2
15% speed	64.9	29.8	52.2
Average speed	73.9	42.1	67.2
Restricted Speed	40.0	40.0	40.0
Ratio of speeding (%)	100.0	47.6	100.0

5. Traffic safety risk analysis

Based on current safety risk analysis studies, a traffic safety risk model to assess the risk levels in functional areas of NRW is established.

5.1. Establishing traffic safety risk evaluation model

Time-to-collision (TTC) indicator is widely used to assess the safety risk levels in many regions. TTC is defined as the time required for two vehicles to collide if they continue at their present speed and on the same path. TTC was put forward by Hayward and is a safety assessment approach developed with the improvement of modern detecting techniques (Hayward, 1972). It only needs vehicle trajectory data to assess traffic safety risk levels and eliminate the dependence that conventional ways have on historical crash records. TTC is depicted as Equation 1.

$$TTC_{n-1}^{n}(t)=\frac{s_n^{n-1}(t)}{V_n(t)-V_{n-1}(t)} \qquad \forall V_n(t)>V_{n-1}(t) \qquad \text{Equation 1}$$

Where $s_n^{n-1}(t)$ is defined as the distance between the nth and the (n-1) th vehicle at moment t. $V_n(t)$ and $V_{n-1}(t)$ are defined as the speed of the n th and the (n-1) th vehicle at moment *t*. TTC is defined as infinite when $V_n(t)<V_{n-1}(t)$.

Based on the aforementioned definition of TTC, Cheol *et al.* (2010) adopted exponent attenuation function of TTC. The general formation of exponent attenuation function is $y=a+b\times \hat{e}$. Define safety risk level as a quantitative parameter varying from 0 to 1, where 0 represents no possibility of collision and 1 represents collision being likely to occur in the next moment. Then a=0 and b=1 can be acquired. On the premise of clearly defined $TTC_{n-1}^{n}(t)$, the risk of latent crashes between the nth and the (n-1) th vehicle can be computed as equation 2.

$$R_t\left(C_n^{n-1}\right)=\exp\left(-\frac{1}{c}\left(\frac{s_n^{n-1}(t)}{V_n(t)-V_{n-1}(t)}\right)\right) \qquad \text{Equation 2}$$

Because it is possible for the nth vehicle to collide with the (n-1) th vehicle or the (n+1) th vehicle, the probability of latent crash of the nth vehicle equals to 1 minus the probability that the nth vehicle does not collide with vehicles neither forward nor backward. Thus the latent crash risk of the nth vehicle can be defined as Equation 3.

$$R_t\left(C_n\right)=1-\left(1-\exp\left(-\frac{1}{c}\left(\frac{s_n^{n-1}(t)}{V_n(t)-V_{n-1}(t)}\right)\right)\right)\left(1-\exp\left(-\frac{1}{c}\left(\frac{s_{n+1}^{n}(t)}{V_{n+1}(t)-V_n(t)}\right)\right)\right) \qquad \text{Equation 3}$$

Where the symbols of $s_n^{n-1}(t), V_n(t)$ and $V_{n-1}(t)$ have the same meaning with Equation 1. The Equation 3 is restricted to the range when $V_n(t)>V_{n-1}(t)$. TTC is defined as infinite when $V_n(t)<V_{n-1}(t)$. There is an undetermined coefficient c in the function. Since $R_t\left(C_n\right)$ is a monotone increasing function about c, the value of c will not change the relative relationship value of $R_t\left(C_n\right)$. The absolute value of $R_t\left(C_n\right)$ varies between 0 and 1. For observing and comparing convenience, the parameter c is set with value 100, which makes the distribution of $R_t\left(C_n\right)$ more evenly between 0 and 1.

5.2. Traffic safety risk level evaluation of NRW in expressway

Traffic safety risk analysis by lanes

The Equation 3 is used to quantify traffic safety risk levels of NRWA and NRWB areas according to lanes. In NRWA area, the average safety risk levels of the 1st and 2nd lane in the transition area are 0.332 and 0.548 respectively, and the counterpart in the activity area are 0.430 and 0.398 respectively. In NRWB area, the average safety risk levels of the 1st and 2nd lane in the transition area are 0.301 and 0.459 respectively, and the counterpart in the activity area are 0.416 and 0.550 respectively.

In NRWA area, the 2nd lane in the transition area has the highest average safety risk level. This indicates that flow density and speed dispersion in the 2nd lane close to activity area in upstream transition area are large, which results in a large TTC value and a high risk of latent crash.

Besides, the average safety risk level of the 1st lane increases from the transition area to the activity area. The possible reasons are that lane change behaviors frequently occur from upstream transition area to activity area, then some vehicles transit from the 2nd lane into the 1st lane, leading to increase of flow rate in the 1st lane and decrease of space headway, only to result in a large TTC value and high safety risks.

For NRWB area, the 1st lane in the activity area has the highest safety risk levels. This is because NRWB located near a ramp entranceway and the average speed is low in transition area, but increase in buffer and activity area from the aforementioned speed characteristics, additionally, the speed in the 1st lane in the activity area has a big dispersion. These factors cause high crash risk levels. Besides, the results indicate that the risk level in the 2nd lane in transition area is higher than the 1st lane, which once again proves the poor continuity in the 2nd lane that close to the activity area in the transition area. From the analysis above, it can be seen that it is necessary to reinforce safety facilities in upstream transition area such as speed guiding signs and anti-collision equipment.

Traffic safety risk analysis by vehicle types

The Equation 3 is used to quantify traffic safety risk levels of NRWA and NRWB areas according to vehicle types. The results are stated in Table 7.

Average risk levels of large vehicles are comparatively high in both NRWA and NRWB area, especially in the transition area. However, it can be inferred from speed characteristics that average speeds of large vehicles are usually slow and also there is a low speeding ratio. The possible explanation for large vehicles having a low speed but a high risk is that speeds of all type vehicles in activity area are high and there are a high speeding ratio. The low speed large vehicles bring huge speed dispersion, which increase the risk for large vehicles to collide with the other vehicles in the front or the back.

Risk level of taxis in activity area is close to 0.5 which is higher than risk level of other vehicles in the same section. The possible explanation is that taxi drivers are usually so skillful and familiar with the environment of activity area that they drive with a low vigilance, big speed difference and small space headway. From speed characteristics it can be also inferred that taxi drivers usually don't slowdown from transition area to activity area but contrarily accelerate slightly.

Table 7 Traffic Safety Risk Levels according to Vehicle Types

Location		**Transition area**			**Activity area**		
		Small cars		Large vehicles	Small cars		Large vehicles
		Private cars	Taxis		Private cars	Taxis	
NRWA	Average safety risk level ($\overline{R_t(C_n)}$)	0.424	0.386	0.548	0.342	0.491	0.456
NRWB	Average safety risk level ($\overline{R_t(C_n)}$)	0.427	0.374	0.588	0.491	0.428	0.533

5.3. Traffic safety risk level evaluation of NRW in freeway

The same safety risk level evaluation method is utilized in the NRWC area. The statistics analysis of $R_t(C_n)$ shows that the safety risk levels of transition area in NRWC during the valid observing period in the daytime off-peak and peak hour and the night time are 0.468, 0.491 and 0.449 respectively. The differences of average safety risk levels in the three periods are quite small and the relative deviations of each two are within 10%. It can be inferred that the speed distribution and space headway in two daytime periods have a much close similarity, consequently the average risk levels are approximately equal. Despite of the small speed dispersion in daytime peak hour, the large flow and small headway make the safety risk level approximate with risk levels in off-peak hour and nighttime. In general, the average safety risk levels in freeway NRWC are higher than risk levels in the city expressway during NRW like NRWA and NRWB.

6. Conclusions

Through field survey and statistical analysis, this study acquires the speed behaviors and safety risk characteristics of NRW in both the city expressway and the freeway having high driving speeds. The main conclusions are as follows:

Speeding problems severely exist in the NRW zone and safety risk levels are comparatively high. Although speeding problems may exist at usual times, speeding in the NRW situations should be paid special attention.

From speed characteristics of NRW in city expressway by lanes, average speeding ratio in the activity area is higher than 90% and in the lane close to the activity area in transition area the ratio is higher than 30%.

From speed characteristics of NRW in city expressway by vehicle types, average speeding ratios of all type vehicles in the activity area and transition area are all higher than 90% and 30% respectively.

The average speeding ratio in freeway NRW area is close to 100%.

The safety risk analysis indicates that traffic risk levels of lanes close to the activity area in transition area are comparatively high. The safety risk levels of large vehicles are higher compared to other type vehicles.

The above conclusions provide references to NRW of city expressway and freeway, more useful tips should be paid to during the NRW as follows.

Necessary engineering countermeasures should be adopted to compel vehicles driving under the restricted speeds in all functional areas of NRW.

The facilities in transition and activity area should be strengthened for the safety promotion of NRW as far as possible, such as the speed guiding signs and anti-collision equipment in the transition area, the lane guiding signs, anti-collision equipment and lighting facilities in the activity area.

The comprehensive management of speeding behaviours for large vehicles and taxis is in urgent need.

The education and training of safety driving during the NRW environment is also indispensable.

The future research shall aim at the sensitivity analysis in all kinds of speed reduction measures and explore the safety risk model establishment considering more influencing factors.

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