Environmental and Traffic Effects on Incident Frequency Occurred on Urban Expressways

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Abstract

Traffic incidents are a major source of congestion and travel time uncertainty. Traditionally, extensive attention has been given to accidents in the view of safety when studying occurrence frequency. The regularity of incident frequency, however, deserves equal attention by practitioners and researchers, especially on urban expressways with dense ramps and high traffic volume. The objective of this study was to have a thorough exploration of environmental and traffic-related causative factors of incident rate on three urban expressways in central Shanghai City, including disability incidents and crash incidents. Incident data obtained by CCTV-monitoring system were used, which contain large quantities of minor and short-duration incidents. The disaggregation of expressway sections and time intervals of this study was rare in its scope: disability frequency is analyzed on an hourly basis and segment-hour aggregation is applied for crash frequency. To account for temporal correlation among different time intervals, Generalized Estimation Equation procedure was used in this paper. In particular, the effects of traffic interaction features on incident occurrence were analyzed by considering segment length, merging and diverging volume. Results showed that temporal correlation of crash incident occurrence was larger than that of disability occurrence. There is a significant relationship of disability rate with rain and temperature, and there was more risk of vehicle disability in dense-traffic and low-speed condition. It also pointed out that the regularity of crash incident occurrence is quite different from that of accidents on highways or rural freeways: Environmental factors exert little impact on crash occurrence except from visibility; Short segment, high merging and diverging volume increased crash rate remarkably.

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Selection and/or peer-review under responsibility of Chinese Overseas Transportation Association (COTA).

Keywords: incident rate; urban expressway; temporal correlation; traffic interaction features

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1. Introduction

Traffic incidents have long been recognized as the main contributor of congestion in roadway networks. Incidents cause approximately 25% of traffic congestion, and even a higher proportion for urban expressways (Giuliano G, 1989). A traffic incident is defined as any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand, such as traffic crashes, disabled vehicles and spilled cargo (US. Department of Transportation, 2010). In order to identify problems and implement more effective countermeasures to reduce the occurrence of incidents and optimize incident management, a better understanding of the factors associated with incidents is required.

In previous literature, much attention has been given to the occurrence frequency of those accidents by the police and incident frequency is far beyond full study. Incident data obtained by CCTV (Closed Circuit Television) monitoring system on urban expressways in Shanghai City are applied in this study to guarantee the completeness of indents. These incident data are quite different from those traditional incident (including accident) reports by the police or incident management personnel: the CCTV-monitoring incident dataset contains large quantities of minor crashes, which are always neglected in the field of safety analysis, and numerous short-duration vehicle disabilities, which does not need the help of rescue facilities before moving and thus left unrecorded. In this study, the average duration of an incident is only 9 min and 50% of incidents last shorter than 5 min. These incidents may be out the list of police’s and incident management personnel’s manual records, but must be considered in terms of congestion alleviation. It should be noted that distinction is made in this paper between accidents and crash incidents: accidents are relatively severe crashes traditionally recorded by the police, while crash incidents include those minor ones usually beyond the concern of traffic safety.

Urban expressways in this paper refer to a type of urban road facility similar to freeways. They are free of any at-grade crossings with other roads, railways, or pedestrian paths, which are instead carried by overpasses and underpasses across them. However, this type of roadways differs from freeways in traffic condition and some geometric features: 1) Urban expressways in many metropolitans are extremely congested and operate through much of the peak hours at or near design capacity. Take Shanghai as an example, the average daily turnover of urban expressways in the central city was 28.83 million pcu•km in 2009, accounting for 54% of the whole network and the average speed during peak hour is 25km/h (Office of the Fourth Comprehensive Traffic Survey in Shanghai, 2009). 2) The ramp density of urban expressways is much higher and traffic condition is severely impacted by merging and diverging traffic from ramps. Besides, there is no shoulder on the two sides and vehicles involved in a crash could not easily leave the lane before they are moving on. Therefore, traffic disruption caused by a minor incident may lead to a large congestion on urban expressways and the impact factors for incident occurrence may be quite different from that occurred on highways or rural freeways.

Therefore, this paper will make an attempt to identify and quantify factors influencing incidents (disability incidents and crash incidents) on urban expressways. Generally, geometric, environmental and traffic features are recognized as three major types of factors contributing to an incident. As geometric design of urban expressways in the study area is quite consistent for all segments, only environmental and traffic effects are analyzed here. Some geometric features, like ramp density and segment type, are considered as part of traffic interaction features in the form of segment length, merging volume and diverging volume in this study.

The current study is unique in its scope as detailed data for all incidents on urban expressways, minor and severe, are included (not only those manual reports). In addition, a much lower level of temporal aggregation is allowed to be applied here without the appearance of preponderant zero samples due to much higher occurrence rate of these complete incidents. For environmental effect analysis, estimation model is established on an hourly basis. Traffic effect is analyzed on a segment-hour basis: segments are classified by ramps and we aggregate incidents in the same hour of the year to consider the hourly variation of traffic. However, temporal correlation may affect the precision of parameter estimates if data are modeled in small time intervals (Lord, D. and F.
Mannering, 2010). To avoid this problem, Generalized Estimating Equation (GEE) procedure is used to take temporal correlation into account.

This paper is organized into six sections: The second section reviews the incident causative factors in the existing literature. The third section describes the studied expressways and data prepared for modeling in this research. Section 4 introduces the prediction model and model form applied. The calibration results are presented and the key findings are identified in section 5. Finally, conclusions are drawn.

2. Literature Review

In general, there are few studies on incident frequency. In contrast with incident frequency, accident frequency has been in study for decades and has undergone many transformations with more new variables incorporated in model. Here, causative factors for accident was also reviewed, aiming to establish a methodology for incident frequency analysis and have a comparison between results of previous literature with those in this research.

2.1. Geometric Features

In previous literature (Pardillo J. M. and Llamas R, 2003; Zhang, C., and J.N. Ivan, 2005; Cafiso S. and La Cava G., 2006), a large number of geometric factors were analyzed for accident occurrence on highways, including road width, lane width, shoulder width, type and condition of shoulders, sight distance on curves and road side hazards. In recent years, more and more researchers have focused on freeways and urban expressways. Freeways, both in urban and rural areas, have a higher design standard in curvature and there is no road shoulder on them. Most literature found that the frequent presence of on-ramps or off-ramps on freeways has a high potential for accidents since they involve a significant traffic conflict between vehicles entering and exiting (Byung-Jung Park, Kay Fitzpatrick, Dominique Lord, 2010). Although many researchers have identified the significance of ramps, the effect of ramps on accidents frequency was usually indicated by the explanatory variable “number of driveways”, and only ramp or driveway density was considered (Persaud B. and L. Dzbik, 1993). Our previous study (Tu Yingfei, Zhang, Jiangman, Yang, Chao and Chen Xiaohong, 2012) showed that segment types (merge segment, diverge segment, weaving segment and basic segment) must be considered, but how much the ramp flow volume changes frequency was not studied.

2.2. Traffic Features

Traffic characteristics mainly include traffic volume, speed characteristics and traffic composition. Studies concerning the relationship between accident frequency and traffic volume have showed a great variation in their results. Some literature indicated accident frequency increases with the increase of traffic volume but at a decreasing rate (Brodsky, H. and A. S. Hakkert, 1969), while other research arrived at the opposite conclusions (Cirillo J. A., 1968). Accident frequency is not completely proportional with traffic volume since variation in volume causes change in traffic condition. In terms of speed, studies showed that the relationship between vehicle speed and accident frequency was illustrated by a U-shaped curve (Garber N. J. and R. Gadiraju, 1998). Accident rates were lowest for travel speeds near the mean speed of traffic, and increased with greater deviations above and below the mean. In terms of traffic composition, Srinivas and Hiselius modeled road accidents under mix traffic conditions and their results both demonstrated minor accidents are significantly affected by the vehicle types and traffic composition (2007, 2004).

2.3. Environmental Features
A number of studies investigated the relationship between weather and safety. Precipitation was consistently found to increase traffic accidents. Several studies, in fact, conclude that accidents increase during rainfall by 100% or more (H. Brodsky and A.S. Hakkert, 1988), while others find more moderate (but still statistically significant) increases (L.A. Sherretz and B.C. Farhar, 1978). There is an ongoing discussion on the effects of snowfall on accident risk. Some studies found increased rates of accidents to be associated with snowy days (Andrey J, 2010), whereas, other studies noted fewer collisions during winter (Fridstrom L., Liver J, Ingebrigtsen S., Kulmala R., and Thomsen, L, 1995). Temperature and wind gust speed were also analyzed in some literature, but found to be insignificant or only significant for a certain type of accidents (M. Andreescu and D.B. Frost, 1998).

In addition, most existing models are calibrated using aggregate data (in temporal or spatial level). Usually, highly aggregated data will lead to loss of significant causative factors and reduction in sample size (Chang M, 1982). However, few literature uses the disaggregated data and this could be because of the lack of disaggregate traffic related and environmental data or to avoid too many zero samples of the dependent variable.

From the literature review, we can see that: 1) incident frequency analysis is conducted in a relatively simple way in both variables and techniques. Explanatory variables in incident frequency analysis are usually categorical variables (snowy or not, rainy or not); Traffic features are indicated by considering time of day or day of week, as a result, whether it is the effect of traffic volume, traffic condition or effects combined by both leaves unknown; A similar problem exists in terms of temperature effect, which is indirectly analyzed by monthly change or seasonal effect. 2) The main geometric characteristics contributing to accidents or incidents are segment type and ramp density, and they will be considered in the form of traffic interaction features in this research. 3) Data aggregation is used in frequency analysis due to low probability of occurrence. Usually multi-year/yearly aggregation is used in spatial study and Monthly/Daily aggregation is used in temporal study, both of which lead to ignorance of some temporal variation. With the above findings in mind, additional efforts are needed in incident frequency analysis, especially on urban expressways. This paper focuses primarily on environmental and traffic-related variables on two types of incidents, vehicle disabilities and crashes, on urban expressways in the central city of Shanghai at a low temporal aggregation level.

3. Data Collection

In this research, portions of three urban expressways are analyzed in central Shanghai: Inner-ring Expressway, North-South Expressway and Yan’an Expressway, which form the basic structure of Shanghai expressway network and play a backbone role for the inner-city traffic. Incident frequency analysis for these three expressways involves three datasets: incident data, environmental data and traffic data.

3.1. Incident data

Incident data used in this paper were obtained from Expressway Monitoring Center of Shanghai (EMCS). The incident data studied is from April 1st, 2010 to March 31st, 2011. Since February 2010, EMCS has implemented an incident record system. Through the cameras set on the portal frame on urban expressways or the tall buildings near expressways, the traffic conditions on each section of expressways could be thoroughly observed all the time. The incident information includes occurrence time (with the accuracy of minute), location (between two consecutive ramps), incident type, weather condition etc. In this paper, frequency of two types of incidents is analyzed, disability incidents and crash incidents, which account for 99% of the total. Since the majority of incidents occurred during the daytime, only incidents from 7:00-19:00 are studied in this research.

3.2. Environmental data
The historical environmental data were obtained from the records of Shanghai Hongqiao Airport Weather Station, where the record is updated at 1 hour intervals. The environmental information contains temperature, visibility, humidity, atmospheric pressure, precipitation, wind speed, wind direction and weather condition (sunny, rainy or snowy). Based on the literature review in section 2, only temperature, visibility, precipitation and weather condition are selected to establish the model. As snow depth is unrecorded, the effect of snow is implied by snow indicator, while rain effect is implied by precipitation.

3.3. Traffic data

Traffic volume and speed data were extracted from loop data provided by EMCS. Each expressway segment has at least one dual-loop detector on each lane. The average speed and traffic volume are recorded every 20 seconds. However, data were only available from July 1st to July 31st 2010. Since traffic flow data of the whole year can be obtained by multiplying the monthly data with a variation coefficient, stretching data of July for the entire study period will only cause a change in intercept value of the prediction model. The difference of Traffic composition is considered by accounting for the proportion of large vehicles.

4. Model Development

4.1. Time Division and Segmentation

In total, 10030 crash incidents and 5477 disability incidents occurring on 109 segments for the daytime (7:00-19:00) of 365 days were recorded. Because incidents rarely occur, small spatial and temporal division cannot be made at the same time to avoid preponderance of zeros in dependent variables. Once traffic features were accounted for, no systematic differences in incident frequency could be found related to differences in environmental factors (6). This is caused by data aggregation, leading to the lack of detailed data within the time period or spatial areas (5). Thus, this paper applies different aggregations and establishes models for environmental and traffic effect analysis respectively. Moreover, data in this study contain numerous minor incidents and have a higher occurrence frequency, which allows us to have a much lower temporal aggregation than previous research.

When investigating the impact of environmental effects on safety, the variations of environmental variables over short periods of time is likely to be highly influential in generating incidents. In this research, an hourly aggregation is used: no spatial segmentation is made and incident count is summed up for all three expressways; incident data is considered on an hourly basis. Thus, there are 365*12 observations.

For traffic effect analysis, a segment-hour aggregation is applied: segmentation is made by the two consecutive ramps connecting a segment, the traffic features of which is quite homogeneous; in the temporal scale, data were aggregated of the same hour in a whole year together. The precondition of this way of aggregation is as follows: for urban expressways, the variance of traffic mainly lies in hourly change. In this case, a sample in the traffic effect analysis is described as the number of vehicle disabilities or crashes on segment i (i=1,2,...,109) in hour j (j=1,2,...12). Thus, there are 109*12 observations.

4.2. Generalized Estimation Equation

Generalized Estimating Equations (GEEs) are applied in order to account for temporal correlation among observations on the same day (in environmental effect analysis) and observations on the same segment (in traffic effect analysis). The methods of modeling correlation in GEEs and the working correlation structure used in this study are described, followed by the type III analysis to identify the relative effects of variables in the GEE models. The following description is exampled by the case of environmental effect analysis.
4.3. Model structure and variables

To explain the exclusive effect of causative factors, exposure measures should be combined with incident data so that the effects of various environmental, segment and traffic elements on incident frequency can be explicitly compared within or between classifications of interest. Similar to most other incident or accident prediction models (8, 9), the proposed model expresses incident frequency as a function of a variety of traffic and environmental characteristics as follows:

\[
\ln(y) = \beta_0 + \ln(\text{Exposure}) + \sum_{j=1}^{m} \beta_j \cdot x_j
\]  

(1)

The log form of the model is expressed as:

\[
\text{Incident count} = e^{\beta_0} \cdot \text{Exposure} \cdot \exp(\sum_{j=1}^{m} \beta_j \cdot x_j)
\]  

(2)

where

- \(y\): Expected incident frequency;
- \(\text{Exposure}\): the product of traffic volume and travel distance (million pcu\*km);
- \(x_j\): Environmental or traffic explanatory variables;
- \(\beta_j\): Model parameters;
- \(m\): Number of explanatory variables included in the model.

Some literature also estimated the effect size of exposure by adding a parameter for it (11, 12, 13). The non-linear relationship between crash frequency and exposure is actually caused by the variation of traffic condition and interaction area when traffic volume and travel distance changes in exposure. To investigate how much traffic features and segment length affect the individual incident risk, the parameter of exposure is set to be 1 by default in modeling. Thus, this paper actually aims to assessing the environmental and traffic effects on incident rate.

The explanatory variables in environmental effect analysis are listed below with explanation. The effect of rain is expressed by precipitation, while snow depth is unrecorded by the Shanghai Hongqiao Airport station and thus snow indicator is used rather than the continuous variable. Whether it has rained or snowed in the previous two hours are taken into account in this research because it impacts surface condition for a relatively long time.

- **Temperature**: average temperature of the hour (0C);
- **Precipitation**: total precipitation of the hour (mm);
- **Snow**: whether it has snowed or not in the hour (1 yes, 0 no);
- **Visibility**: the distance could be clearly seen in the hour (km);
- **Pre. Rain**: whether it has rained or not in the previous two hours (1 yes, 0 no);
- **Pre. Snow**: whether it has snowed or not in the previous two hours (1 yes, 0 no).

In the traffic effect analysis, segment length, segment type and traffic flow on ramps were considered as part of traffic data because they are indirect indicators of interactions between vehicles. Segment length has a two-side effect: On the one hand, it contributes to the exposure of traffic incidents, and on the other hand, segment length may affect the frequency of vehicle interactions. Segment type (on-and-on-ramp segment, off-and-off-ramp segment, on-and-off-ramp segment and off-and-on-ramp segment) and ramp flow were considered together in the form of merging and diverging volume. In the direction of traffic flow, if the first ramp of a segment is an on-ramp, the traffic volume on the ramp is defined as merging volume; if an off-ramp, the merging volume is zero. Similarly, if the second ramp is an off-ramp, the traffic volume on the off ramp is defined as diverging volume; if an on-ramp, the diverging volume is zero. The interaction between vehicles on segment with different ramp types is illustrated in FIGURE 1. Segment One and Segment Two have a merging volume of \(q_1\) and \(q_2\) respectively, while Segment Two and Segment Three have a diverging volume of \(q_3\) and \(q_4\) respectively. For Segment Four,
merging and diverging volume from the ramp are zero. If the segment length is too short, as shown in Segment Two in FIGURE 1, the merging flow and diverging flow may combine together to form a weaving flow, which cause more frequent and severe vehicle interactions.

![Fig. 1 Illustration of Merging and Diverging Flow of Segments with Different Ramp Types](image)

The variables in traffic effect analysis are listed below with explanation. Traffic density can be obtained by traffic volume/speed/number of lanes.

- Density: Traffic flow density per lane (pcu/km/lane);
- Speed: Average spot speed (km/h);
- Segment length: length of a segment between two consecutive ramps (km);
- Merging volume: traffic volume on the first on-ramp of a segment (100pcu/h);
- Diverging volume: traffic volume on the second off-ramp of a segment (100pcu/h);
- PLV: Proportion of large vehicles (%);

5. Results and Analysis

The GEE models with a Negative Binomial link function for the incident frequency with autoregressive correlation structure were fitted. Table 1 presents the calibration results with the major findings summarized in the following section.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Vehicle disability</th>
<th>Crash</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Standard Error</td>
<td>Pr&gt;ChiSq (type III)</td>
<td>Estimate</td>
<td>Standard Error</td>
<td>Pr&gt;ChiSq (type III)</td>
</tr>
<tr>
<td>Intercept</td>
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<td>0.074</td>
<td>--</td>
<td>1.788</td>
<td>0.060</td>
<td>--</td>
</tr>
<tr>
<td>Precipitation</td>
<td>0.007</td>
<td>0.002</td>
<td>0.020</td>
<td>0.000</td>
<td>0.001</td>
<td>0.979*</td>
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<tr>
<td>Snow</td>
<td>0.402</td>
<td>0.155</td>
<td>0.137*</td>
<td>-0.005</td>
<td>0.170</td>
<td>0.981*</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.009</td>
<td>0.002</td>
<td>&lt;.001</td>
<td>-0.004</td>
<td>0.002</td>
<td>0.130*</td>
</tr>
<tr>
<td>Visibility</td>
<td>0.030</td>
<td>0.018</td>
<td>0.132*</td>
<td>-0.013</td>
<td>0.006</td>
<td>0.042</td>
</tr>
<tr>
<td>Pre. rain</td>
<td>0.095</td>
<td>0.054</td>
<td>0.076</td>
<td>-0.013</td>
<td>0.045</td>
<td>0.774*</td>
</tr>
<tr>
<td>Pre. snow</td>
<td>-0.245</td>
<td>0.179</td>
<td>0.252*</td>
<td>0.186</td>
<td>0.203</td>
<td>0.414*</td>
</tr>
<tr>
<td>Dispersion</td>
<td>0.811</td>
<td>0.179</td>
<td>0.252*</td>
<td>0.186</td>
<td>0.203</td>
<td>0.414*</td>
</tr>
<tr>
<td>Correlation parameter α</td>
<td>0.223</td>
<td>0.240</td>
<td>0.414*</td>
<td>0.203</td>
<td>0.240</td>
<td>0.414*</td>
</tr>
</tbody>
</table>
### Traffic effect analysis: segment-hour aggregation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Vehicle disability</th>
<th></th>
<th>Crash</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Standard Error</td>
<td>Pr&gt;ChiSq (type III)</td>
<td>Estimate</td>
</tr>
<tr>
<td>Intercept</td>
<td>4.269</td>
<td>0.644</td>
<td>--</td>
<td>5.338</td>
</tr>
<tr>
<td>Density</td>
<td>0.038</td>
<td>0.005</td>
<td>0.003</td>
<td>-0.045</td>
</tr>
<tr>
<td>Speed</td>
<td>-0.017</td>
<td>0.006</td>
<td>0.021</td>
<td>-0.010</td>
</tr>
<tr>
<td>Length</td>
<td>-0.462</td>
<td>0.319</td>
<td>0.123*</td>
<td>-1.001</td>
</tr>
<tr>
<td>Merging Volume</td>
<td>0.015</td>
<td>0.058</td>
<td>0.796*</td>
<td>0.139</td>
</tr>
<tr>
<td>Diverging Volume</td>
<td>-0.108</td>
<td>0.092</td>
<td>0.274*</td>
<td>0.059</td>
</tr>
<tr>
<td>PLV</td>
<td>-3.352</td>
<td>3.949</td>
<td>0.256*</td>
<td>0.073</td>
</tr>
<tr>
<td>Dispersion</td>
<td>0.673</td>
<td></td>
<td>0.729</td>
<td></td>
</tr>
<tr>
<td>Correlation parameter $\alpha$</td>
<td>0.705</td>
<td></td>
<td>0.770</td>
<td></td>
</tr>
</tbody>
</table>

*The variable is not significant at a 0.10 level of significance.

#### 5.1. Dispersion and Temporal Correlation

There is a strong evidence of over-dispersion for all models, which is indicated by the significant estimated dispersion value in the Negative Binomial regression as shown in Table 1: 0.811, 0.667 for vehicle disabilities and crashes in environmental effect analysis, and 0.673, 0.770 for two types of incidents in traffic effect analysis respectively.

Since the number of observations for each day is 12 and for each segment is also 12, the correlation structure is a symmetric matrix and its dimension is 12 with one in each diagonal position. The autoregression structure assumes that the correlations between the multiple observations for a certain day will decrease as the time-gap increase and the correlation is multiplied by the parameter $\alpha$ for one more hour gap. In this case, the correlation estimated is 0.223 in environmental analysis models for vehicle disabilities. That is to say, the autoregression structure has correlation of 0.223 for each successive two hours and correlation 0.050 for time periods with one-hour gap. This conclusion in turn has proved the rationality of choosing weather condition in previous two hours in “Pre. Snow” and “Pre. Rain” variables, since the correlation could be ignored for hours with two-hour gap or more. The correlation parameter is 0.240 for crashes, and a similar conclusion could be drawn. In traffic effect analysis models, the correlation parameter values are 0.705, 0.770 for vehicle disabilities and crashes, much higher than those in environmental analysis. This may be because the correlation of traffic condition among different hours is more closely. As a result, the effect of traffic condition on incident occurrence could last 4 hours or more (the correlation of time periods with three-hour gap is about 0.25).

Moreover, it is found that, both in environmental and traffic effects assessment, the estimated correlation parameters of vehicle disabilities are lower than those of crashes. This indicates the occurrence of crashes is more correlated in a temporal scale.

#### 5.2. Causative Factors Analysis

In order to examine the relative effect of the explanatory variables included in the model, the type III analyses were performed for different correlation structures and for each variable as shown in Table 1. For example, the type III chi-square value for the variable Precipitation is the difference between the generalized score statistic for
the model with all the variables included and the generalized score statistic for the model with the variable Precipitation excluded. The hypothesis tested in this case is the significance of the variable Precipitation given that all the other variables are in the model (i.e., it tests the additional contribution of Precipitation). The small p-value for Precipitation indicates that the effect of this variable is highly significant. Based on the p-value of type III analysis, the effects of causative factor are assessed for disability incidents and crash incidents respectively as followed.

**Environmental Effects on Vehicle disabilities**

Table 1 shows that both the estimated coefficients of Precipitation and Pre. Rain are positive with small p-values, which indicates more vehicle disability incidents occurred when it is rainy. The calibration result also implies that disability rate will increase by 0.7% with each additional mm in precipitation on average (the coefficient is 0.007). The effect of rain on vehicle disability is probably due to the negative effect that rain has on a vehicle's brake system. As perceived, it is usually difficult for old vehicles to maintain a low speed in bumper-to-bumper traffic conditions when it is raining. Snow, however, causes less hazard conditions as described above for rain since there is a high-efficient maintenance team for Shanghai Expressways and Shanghai is a city rarely troubled by heavy snow weather, and thus snow is not as significant as rain. Further, there was a significant increase of 0.9% each additional degree Celsius in mean temperature (the coefficient is 0.009). This is understandable: high temperature is the direct cause of vehicle disabilities occurrence since driving in this condition may lead to overheating of oil tank.

**Environmental Effects on Crashes**

The effect of weather condition (rain and snow) on crash occurred on urban expressways is surprisingly quite inconsistent with the results of highway accidents in previous literature (23, 24, 25, 26). The rain indicators (including precipitation and Pre. rain) show little effect on crash frequency with p-values of Precipitation and Pre. Rain 0.979 and 0.477 respectively. Rain has long been considered as a significant factor for accidents because rain reduces both visibility and friction that are needed for vehicle tires. On urban expressways, however, traffic density is much higher and the average speed is much lower than that on rural freeways and highways. In this case, friction reduction caused by rain may be less significant since speed is more easily to control. Moreover, drivers may be more cautious in rainy days to avoid crashes. The complexity of rain effect on crash incidents has also been mentioned in some literature on incident study (8, 9). Similar to the results of disability incidents, Snow and Pre. Snow are not significant indicators for crash incidents either. Visibility is the only significant environmental factors with a negative correlation, and the crash incident rate will decrease by 1.3% with additional km in visibility (the coefficient is -0.013).

**Traffic Effects on Vehicle Disabilities**

Traffic-interaction-related variables, including segment length, merging volume and diverging volume, do not significantly impact disability incidents. The result is as expected because there seems no obvious correlation between vehicle performance and merging, diverging or weaving behaviors. Although vehicle disability occurrence is usually more of the result of environmental effects, it has significant correlations with certain traffic features as indicated by the p-values of density and speed (0.003 and 0.021). High traffic density will contribute to more disability incidents, which may be caused by more frequent braking-and-starting behaviors in this condition. Average spot speed, on the contrary, has a significant negative effect on disability incident rate, which indicates that when speed increases, disability rate decreases. When vehicles are travelling at relatively high speed, the driving process is smoother and vehicle disability is less likely to occur. It is also found the occurrence rate will decrease by 1.7% with 1 km/h increase of speed (the coefficient is -0.017).

**Traffic Effects on Crashes**

The occurrence of crashes is the usually result of the interaction between two or more vehicles (except from one-car collision with the guard rail), and thus segment length, merging volume and diverging volume are all
significant explanatory variables for crash incident rate, with p-values 0.002, 0.069 and 0.049. Low distance between ramps implies that there may be more areas for merging, diverging and weaving on the roadway. In can be conceivable that these interaction behaviors among vehicles increases the probability of crash incidents. Since this paper has supposed exposure has a linear relationship with incident frequency and focuses on individual incident risk, it is reasonable that segment length is estimated to have a negative effect on crash incident occurrence (the coefficient is -1.001). This indicates crash incident rate will decrease by 63.2% with additional 1 km in length. This result highlights the benefit of long segment length design in terms of safety improvement and congestion alleviation although short segments and dense ramps will make urban expressways available to more traffic in urban area. The volumes of merging and diverging vehicles are also taken into account and they are both significant as expected. For merging volume, crash rate increases by 14.9% with additional 100 pcu (the coefficient is 0.139), while there is 6.1% increase of crash rate with 100 more pcu of diverging volume (the coefficient is 0.059). The effect size of merging volume is larger than that of merging volume, which indicates that merging behavior contributes more to crash occurrence.

Density is a significant impact factor of crash incident rate with estimated coefficient -0.045, as shown in table 1. This implies that the individual crash risk decreases as the density increases and it is less dangerous for a driver to travel under heavy flow conditions than under light flow conditions on urban expressways (in terms of occurrence rate). The possible reasons can be that as the flow increases the variance of the speed becomes lower and drivers are more alert. The result is in harmony with conclusions in previous literature (17), which found that with the increase of traffic on roadway, the total crash count is increasing but with a decreasing rate. Speed is found significant and the relationship between crash incident rate and speed is negative. This indicates the higher the speed is, the less likely the crash occurs and each additional km/h in speed will decrease the crash rate by 1.0% (the coefficient is 0.010). The possible reasons can be when speed is high, the traffic volume is at a low level and less interference between vehicles exists. Moreover, the proportion of large vehicles impacts the crash rate significantly. This is due to heterogeneity imparted on the traffic flow by higher proportion of large vehicles: they usually move slower and have lower maneuverability than standard small cars. 1% increase of large vehicle proportion will make crash incident rate increase by 7.6% (the coefficient is 0.073).

6. Conclusion

This paper has attempted to provide a thorough investigation of environmental and traffic effects on incident occurrence on urban expressways in central Shanghai City, including disability incidents and crash incidents. Environmental effects are assessed on an hourly basis and segment-hour aggregation was applied in traffic effect analysis, using the Generalized Estimation Equation procedure. The covariates in the environmental effect model represent hourly precipitation, snow indicator, previous rain indicator, previous snow indicator, mean temperature and visibility. Segment length, merging volume, diverging volume, density, speed and the proportion of large vehicles are considered in traffic effect model. The temporal correlation of incident rates between two different hours of a day was also analyzed. The main findings are as follows:

This study has shown that temporal correlation exists between crash rates of two different hours: in general, the temporal correlation of crash occurrence is more remarkable than that of disability occurrence; When assessing environmental effects, correlation of incident rate with two-hour gap or more can be ignored and the temporal correlation is more obvious in traffic effect analysis.

Most environmental features exert significant impact on disability occurrence risk, but with a moderate degree. For example, Precipitation, Pre. Rain and Temperature are significant and the disability rate only increase by 0.7% and 0.9% with additional 1mm in precipitation and 1 Celsius degree in temperature respectively. The effect of rain on crash rate is quite complex because although rain worsens surface condition of the roadway, it causes the change in driving behaviors, especially in congested urban expressways. Thus, neither Precipitation nor Pre. Rain is significant. Snow indicator is not significant, which is also different from highway safety analysis, this
result, however, is consistent with several researches on incident frequency. A negative correlation was identified between crash rate and visibility with 1.3% decrease effect.

Traffic-interaction related factors have a significant effect on crash rate but do not have an obvious correlation with disability occurrence rate. Shorter segment length implies more areas of lane-changing behaviors and more frequent interactions, and thus increasing crash rate. The estimate value of segment length is -1.001, implying that a segment with 1km longer design will have 63.2% less risk of crash occurrence. Moreover, the crash rate will decrease by 14.9% and 6.1% if there is a 100pcu increase in merging and diverging volume. These quantified results can provide strong support for the optimism of segment design and ramp control in terms of crash reduction. Dense traffic will increase the risk of crashes but decrease the individual probability of crash occurrence, with a degree of 3.9% and 4.4% respectively when density increases 1pcu/km/lane. Low speed on urban expressways will cause an increase for both disability and crash rate, because unsmooth condition will impair the braking system and contribute to more vehicle interaction. The existence of more large vehicles will cause more risk for crashes.

In summary, the CCTV-monitoring data gives us a new source of dataset when analyzing incident frequency and guarantees its completeness compared with previous manual records by containing both traditional manual records and minor incidents with short duration. This enables lower level of data aggregation when modeling incident frequency. The disaggregation of both expressway sections and time intervals of this study is rare in this field. Urban expressways have shown a lot of differences with freeways and highways and thus the effects of environmental and traffic features are sometimes inconsistent with results of research on freeway or highway. In addition, the effect of highly-dense ramps should be considered by involving the interaction area (segment length) and interaction volume (merging and diverging volume). Another topic for further research is the incident duration analysis, which will assist in understanding incident regularity better and managing incidents more efficiently.

REFERENCES


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