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Speed, speed variation and crash relationships for urban arterials

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ABSTRACT

Speed and speed variation are closely associated with traffic safety. There is, however, a dearth of research on this subject for the case of urban arterials in general, and in the context of developing nations. In downtown Shanghai, the traffic conditions in each direction are very different by time of day, and speed characteristics during peak hours are also greatly different from those during off-peak hours. Considering that traffic demand changes with time and in different directions, arterials in this study were divided into one-way segments by the direction of flow, and time of day was differentiated and controlled for. In terms of data collection, traditional fixed-based methods have been widely used in previous studies, but they fail to capture the spatio-temporal distributions of speed along a road. A new approach is introduced to estimate speed variation by integrating spatio-temporal speed fluctuation of a single vehicle with speed differences between vehicles using taxi-based high frequency GPS data. With this approach, this paper aims to comprehensively establish a relationship between mean speed, speed variation and traffic crashes for the purpose of formulating effective speed management measures, specifically using an urban dataset. From a total of 234 one-way road segments from eight arterials in Shanghai, mean speed, speed variation, geometric design features, traffic volume, and crash data were collected. Because the safety effects of mean speed and speed variation may vary at different segment lengths, arterials with similar signal spacing density were grouped together. To account for potential correlations among these segments, a hierarchical Poisson log-normal model with random effects was developed. Results show that a 1% increase in mean speed on urban arterials was associated with a 0.7% increase in total crashes, and larger speed variation was also associated with increased crash frequency.

1. Introduction

Most traffic on urban road networks is carried by their arterials. These roads are, however, the least safe. In downtown Shanghai, urban arterials have several unusual characteristics including uneven and short signal spacing, and the absence of posted speed limits. Operational conditions are also complex on those arterials due to a large variation in speed by time of day; for example, speed might be lower during peak hours. Both higher and lower mean speeds have been found to be associated with increased crash frequency, and large speed variation has consistently been found to increase crash counts (Garber and Gadiraju, 1989; Solomon, 1964; Oh et al., 2001). Although speed management measures are generally implemented on suburban arterials and highways in Shanghai, speeding is currently not strictly enforced on urban arterials. Quantification of the relationships of mean speed and speed variation to crash frequency can be a guideline for authorities to improve traffic safety on urban arterials (Wang et al., 2015).

Speed data employed in developing speed-crash relationships have typically been collected with fixed-based sensors such as radar and loop detectors (Figueroa and Tarko, 2005; Poe et al., 1998). These methods only capture speeds at fixed points, failing to represent spatio-temporal distributions of speed along a road. Spatio-temporal speed data can be collected by probe vehicles, a method known as floating car data (FCD), in which vehicles (e.g., taxis) are equipped with global positioning systems (GPS) that can continuously record vehicle position, speed and direction at a high sampling frequency (normally 1 Hz). Speed measurements from sample vehicles are then employed to calculate both mean speed and speed variation by road segment at given intervals (Wang et al., 2014; Xie et al., 2013; Wang et al., 2016). There is a dearth of research, however, on the use of spatio-temporal GPS speed measurements in developing crash-speed relationships while controlling for other mediating factors (e.g., traffic volume). In addition, most of the previous studies on crash-speed relationships have been developed using data either from freeways or rural roads.

A recent study by Wang et al. investigated how road geometry and

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other traffic- related factors affect traffic safety in Shanghai (Wang et al., 2015). Their results showed that higher average speed was associated with higher crash frequency. However, there are some limitations in their study and others, which are addressed in this paper. First, although speed variation is widely reported to have an effect on safety, and existing studies indicate that the inclusion of speed variation in a model has a significant influence on the impact of speed on crashes (Quddus, 2013; Gargoum and El-Basyouny, 2016), speed variation was not considered by Wang et al. (2015). Second, it is apparent that traffic conditions on a road segment vary by the direction of traffic flow for a given time of day. Most existing studies aggregate traffic conditions (e.g., speed, volume, geometry) from both sides into a single measurement/observation and assume the crash generation process is the same in both directions at a given time period (Wang et al., 2015; Wang et al., 2016). Third, traffic conditions also vary by time of day. For example, the mean speed during peak hours tends to be lower than during off-peak hours because of congestion. Therefore, in modeling, the relationship between speed, speed variation and crashes should differentiate and control for time of day. Finally, the heterogeneity of segments with different signal spacing density was not accounted for in the mentioned research while, in this study, arterials were assigned into homogeneous groups by signal spacing density so as to obtain more rational modeling results.

The objective of this study is therefore to examine a relationship between mean speed, speed variation and crash frequency on urban arterials by overcoming the above mentioned limitations. While existing studies employed segment-based aggregated speed measurements in calculating speed variation, this study aims to use a more representative measure of speed variation from vehicle-level GPS speed data. In this study, 8 arterials consisting of 234 one-way segments were selected, representing a total length of about 77 km. Other mediating and exogenous factors were also considered, and their relationships with crash frequency were developed using a hierarchical Poisson lognormal (HPLN) model with random effects.

2. Literature review

There are currently two schools of thought in developing speed, speed variation and crash relationships: (1) using the temporal aggregation of speed measurements (e.g., mean speed) of an entity (e.g., segment, link or area) over a given time period and then calculating the number of crashes occurring on the same entity over the same time period (Quddus, 2013); this is normally known as a segment-based analysis; (2) employing speed measurements just before the crash occurrence and then synthesizing the speed data into bins and calculating the number of crashes by speed bin (Imprialou et al., 2015); this is known as a scenario-based analysis. Both approaches have advantages and disadvantages (Imprialou et al., 2015); this paper, however, employs the former approach as the objective is to develop segment-based safety management measures.

The balance of this review is devoted to speed, speed variation and crash relationships, as well as the statistical methods employed in developing these relationships.

2.1. Mean speed and crashes

In a meta-analysis performed by Finch et al. (1994) of rural roads in Finland, Denmark, Switzerland and the United States, a linear function was constructed and it was reported that a 1 mph increase in speed would lead to a 4.9% increase in crash rate. Similarly, in a study of Swedish rural roads with speed limits from 90 km/h to 110 km/h, Nilsson (1982) found that a reduction in mean speed was accompanied by a reduction in crashes. The author explained that from a kinetic point of view, stopping distance was greater at higher speeds, thus more dangerous.

Inconsistent findings were reported in the literature. When looking into the speed-crash relationship on rural European single carriageways with speed limits between 70 km/h and 100 km/h, Baruya (1998) found that when mean speed was low, crash frequency was high, and inferred that poor road environment and road design caused serious congestion. Another cross-sectional study on Hong Kong freeway segments conducted by Pei et al. (2012) reached the same conclusion. Using GPS data from 480 taxis, they inferred that higher mean speed was associated with shorter time exposure; thus crash frequencies decreased.

In a recent study, Cameron and Elvik (2010) suggested that the safety effect of mean speed would vary with road types. They inferred that Nilsson's model appeared satisfactory for rural highways and freeways, but was not applicable on urban arterials because speed limit changes were fewer on arterials. In order to study a variety of road types, Garber and Gadiraju (1989) developed generalized linear models using spot-collected vehicle speeds on interstate roads, arterial roads and major rural collector roads. They found that the crash rate was higher at lower mean speeds, which may be a result of different geometric characteristics. More in accord with relationships found on rural roads, a cross-sectional study focusing on urban arterials conducted by Wang et al. (2015) found that an increase of 10 km/h in mean speed was associated with a 3% rise in crash frequency during peak periods.

Although mean speed is widely adopted as an important indicator of crash frequency, its safety effects are not consistent. This inconsistency may result from the use of different research approaches, different data sources and low data quality. According to a study by Garber and Gadiraju (1989), the total accident rate and fatal accident rate on urban arterials were both much higher than on other road types studied, indicating that the safety conditions on urban arterials require more attention.

In summary, most research on speed and crash frequency has been based on rural roads or freeways. Urban arterials however are different, characterized by small and uneven signal spacing, heavier traffic load, higher speed variation throughout the day and significant difference between peak and off-peak periods due to the large proportion of commuter traffic. This paper, therefore, aims to investigate the relationship between mean speed and crash frequency on urban arterials.

2.2. Speed variation and crashes

Speed variation is used to represent the inconsistency of vehicle speed along a segment. Despite a variety of research methods and speed collection methods, crash frequency has consistently been found to rise as speed variation increases (Garber and Gadiraju, 1989; Solomon, 1964; Oh et al., 2001). However, this conclusion is to a great extent based on research on rural roads and freeways, while the relationship between speed variation and safety on urban arterials remains unclear.

Based on freeway spot speed data, Oh et al. (2001) found that speed variation was the most significant indicator for potential crash frequency. Solomon (1964) studied 600 miles of rural highways, measuring single vehicle speeds of 10,000 drivers. The author found a U-shaped curve relationship between speed variation and crash frequency. That is, crash counts were the lowest for travel speeds near the mean speed, and increased with greater differences as they moved away from the mean speed in either direction. In a cross-sectional study of highways and arterials, Garber and Gadiraju (1989) found that speed variation on a segment was greater when the difference between design speed and speed limit was greater. Another study on highway safety conducted by Pei et al. (2012) used FCD to calculate speed variation as the standard deviation of speed for vehicles travelling through a highway segment. In their study, speed variation was not significantly associated with crash occurrence. They argued that their results conflicted with the usual findings because the speed variation calculation could not accurately represent speed differences in a mixed traffic flow with various types of vehicles.

Although the speed variation-safety relationship has been demonstrated as generally consistent, previous studies have mainly