Accident Analysis and Prevention 108 (2017) 100–111

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Safety analysis of urban arterials at the meso level

Jia Li[a,b], Xuesong Wang[a,b,*]

[a] The Key Laboratory of Road and Traffic Engineering, Ministry of Education, China
[b] School of Transportation Engineering, Tongji University, Shanghai 201804, China

ARTICLE INFO

Keywords:
Urban arterial
Safety analysis
Meso level
Signal spacing
Street network pattern

ABSTRACT

Urban arterials form the main structure of street networks. They typically have multiple lanes, high traffic volume, and high crash frequency. Classical crash prediction models investigate the relationship between arterial characteristics and traffic safety by treating road segments and intersections as isolated units. This micro-level analysis does not work when examining urban arterial crashes because signal spacing is typically short for urban arterials, and there are interactions between intersections and road segments that classical models do not accommodate. Signal spacing also has safety effects on both intersections and road segments that classical models cannot fully account for because they allocate crashes separately to intersections and road segments. In addition, classical models do not consider the impact on arterial safety of the immediately surrounding street network pattern. This study proposes a new modeling methodology that will offer an integrated treatment of intersections and road segments by combining signalized intersections and their adjacent road segments into a single unit based on road geometric design characteristics and operational conditions. These are called meso-level units because they offer an analytical approach between micro and macro. The safety effects of signal spacing and street network pattern were estimated for this study based on 118 meso-level units obtained from 21 urban arterials in Shanghai, and were examined using CAR (conditional auto regressive) models that corrected for spatial correlation among the units within individual arterials. Results showed shorter arterial signal spacing was associated with higher total and PDO (property damage only) crashes, while arterials with a greater number of parallel roads were associated with lower total, PDO, and injury crashes. The findings from this study can be used in the traffic safety planning, design, and management of urban arterials.

1. Introduction

Urban arterials connect the main subareas of a city and form the primary structure of the city's street network. The road design of urban arterials often includes multiple lanes and diverse cross-section configurations (Sawalha and Sayed, 2001). These roadways carry most of the traffic on the urban street network (Xie et al., 2014), and crashes occurring on them play a significant role in the overall safety of the network. Since classical crash prediction models focus on the micro level, they separate roadways into intersections and segments, and treat them as two isolated research units when investigating the safety effects of road design and traffic characteristics (Lord and Mannering, 2010). Classical crash prediction models define an intersection as the area from its geometric center to the stop bar, including the safety influence area of the upstream approach (Joksch and Kostyniuk, 1998; Wang et al., 2008). A segment is defined as the road section between two adjacent intersections (Abdel-Aty and Radwan, 2000; Hauer et al., 2004; Gattis et al., 2005; Lord, 2006).

By this separation of segments and intersections, classical crash prediction models have not properly accounted for interactions between them. This problem becomes worse when signal spacing is short, as it so often is on urban arterials in dense street networks. By allocating crashes to road segments and intersections separately (Lord, 2006), classical models cannot estimate the full effects of signal spacing on the safety of the whole arterial. A recent study by Zeng and Huang (2014) found that spatial correlations between intersections and their adjacent road segments were greater than those solely between adjacent intersections or adjacent segments. This is further evidence that a new crash prediction model is needed.

Another problem with existing micro-crash prediction models is that the effects on arterial safety of the immediately surrounding street network pattern are not considered. Research on overall urban arterial crash occurrence has been studied at the macro level, where roadway network patterns over large geographic areas, such as a community or a traffic analysis zone (TAZ), have been shown to influence the total crash count of the studied area (Lovegrove and Sun, 2010; Marshall and

---

[*] Corresponding author at: School of Transportation Engineering, Tongji University, Shanghai, 201804, China.
E-mail address: wangxs@tongji.edu.cn (X. Wang).

http://dx.doi.org/10.1016/j.aap.2017.08.023
Received 28 March 2017; Received in revised form 19 July 2017; Accepted 20 August 2017
0001-4575/

Garrick, 2011; Wang et al., 2012; Rifaat et al., 2010). Macro-level analysis, however, like micro-level analysis, does not consider the specific influence of the street network patterns in close proximity to the arterials.

What is needed is a modeling approach to urban arterial safety that takes into account the interactions between segments and intersections as well as the relationship between signal spacing and safety while accounting for the influence of the surrounding street network on safety. These requirements necessitate the use of a meso-level model to examine arterial safety.

This study proposes such a meso-level approach by combining intersections and road segments into single higher units of analysis. To accomplish this, adjacent road segments with similar geometric design characteristics (cross-section designs) and operational conditions (travel speeds), were assembled with their linked intersections in the longitudinal direction of the arterial. The street network patterns on both sides of the arterial were also analyzed because they directly influence traffic flows on the arterial.

After the meso-level units were established, the effects of signal spacing and network pattern on urban arterial crash frequency were examined using CAR (conditional auto regressive) crash prediction models. A conditional autoregressive effect term was needed to correct for spatial correlations arising from geometric and traffic similarities along the arterials (Guo et al., 2010; Xie et al., 2014). Crash types were modeled separately by severity level because different crash severities have different influencing variables (El-Basyouny and Sayed, 2009a; Ma and Kockelman, 2006).

2. Literature review

2.1. Safety effects of signal spacing

As mentioned above, in classical crash prediction models, components are shown in Fig. 1: D1 is the intersection inside area, which extends from the intersection's geometric center to the stop bar, and is used to designate at-intersection crashes; D2 is the approach safety influence area, which is measured upstream from the stop bar and is used to designate intersection-related crashes. D5 is the road segment, which does not include D1 and D2, whereas D6, signal spacing, is the full distance between the two adjacent intersections' geometric centers. More inclusive than the road segment measure, signal spacing adds factors that affect both road segment and intersection safety.

To consider the effect of signal spacing on road segment safety, Sawalha and Sayed (2001) used the road segments between two adjacent intersections as basic analysis units, and found that longer segment length was associated with higher road crash frequency. Wang et al. (2015) and Wang et al. (2016b) reported similar results, which may be attributed to longer segments allowing vehicles to attain higher speeds, which increases the potential for loss of vehicle control, thereby resulting in higher crash rates. These studies, however, were focused on the effect of segment length, not signal spacing, and the scale of the segment's safety influence area was not clearly defined. Conversely, Mauga and Kaseko (2010) found that shorter signal spacing was associated with higher crash frequency because drivers had to complete lane changes within short segments, and thus encountered a greater number of traffic conflicts. These opposing findings suggest that investigating the relationship between signal spacing and crash frequency for road segments at the micro level is not ideal because signal spacing is an arterial-level variable rather than a segment-level variable. Consistent with this view are the findings from an earlier study by Wang et al. (2014b). By treating signal spacing as a separate arterial-level variable, they concurred that increases in crash frequency on road segments were associated with shorter signal spacing.

To consider the effect of signal spacing on intersection safety, intersections closer to each other were with higher crash frequencies, were reached by Xie et al. (2014), who developed a hierarchical model to analyze safety influencing variables; and by Abdel-Aty and Wang (2006), who used the intersection as the analysis unit. While an opposite conclusion that longer signal spacing is associated with higher intersection crash frequency is reasonable since higher travel speeds of the vehicles on road are associated with more crashes at intersections. However, in these intersection studies the effects of signal spacing were only analyzed on signalized intersection crashes rather than on the whole arterial crashes. At this point, the relationship between signal spacing and arterial safety remains to be fully investigated.

2.2. Street network pattern and its relationship to traffic safety

Southworth and Ben-Joseph (2003) classified street network patterns into grid, fragmented parallel, warped parallel, loops and lollipops, and lollipops on a stick. Following this classification, Rifaat et al. (2011) added a mixed pattern. These network patterns were determined by visual inspection, a method that was both subjective and time consuming, so in recent years, studies have been conducted to explore the topological properties of street networks quantitatively (Wasserman and Faust, 1994). In one macro-level study, Wang et al. (2012) used the traffic analysis zone (TAZ) to develop a coefficient that measures the structure of circles in a graph. This coefficient, called the meshedness coefficient, was able to quantitatively distinguish street network patterns into sparse, loops and lollipops, mixed, and parallel and grid. Betweenness centrality has also been used to describe networks quantitatively, and in particular, as a metric to describe network centrality (Wasserman and Faust, 1994). In a more recent study, Wang et al. (2016a) used betweenness centrality, again with the TAZ as the research unit, and was able to distinguish street network patterns in a Shanghai suburban area into grid, irregular grid, mixed, and lollipops patterns.

These efforts at street network pattern quantification were needed because the network pattern is predictive of traffic operation characteristics and accessibility–two key elements that influence traffic safety (Lovegrove and Sun, 2010; Marshall and Garrick, 2011). But equally important, quantification provides a way to relate independent

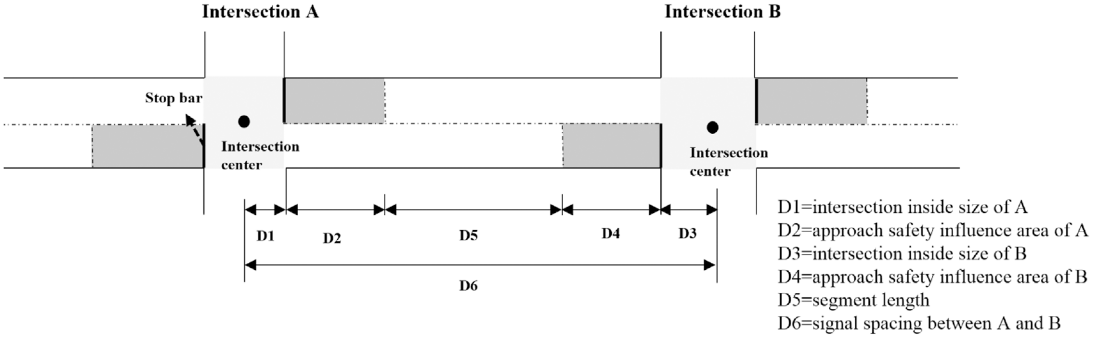

Fig. 1. Key road components.