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Preempt or yield? An analysis of driver's dynamic decision making at unsignalized intersections by classification tree

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ABSTRACT

For developing countries and regions, due to less construction of stop signs and roundabouts, as well as limited regulation of driving courtesy, safety issues at unsignalized intersections require harder concern. In China, drivers rarely stop completely at unsignalized intersections, but gradually enter and dynamically make their decisions to yield or preempt by gaming with other vehicles. Wrong decisions made in this quick process often lead to accidents. In this study, we aimed to explore how straight drivers dynamically made decisions when encountered merging vehicles at unsignalized intersections in China. By video graphing traffic scenarios, 150 cases of merging traffic were selected at a 4-legged unsignalized intersection in Kunming City. Motion parameters of the vehicles were extracted from video detection software. By modeling the motion parameters to a classification tree, the decision moment of straight drivers' yielding/preemptive decision and the motion parameters which influenced drivers' decision significantly were identified. Results showed that straight drivers made yielding/preemptive decisions 1.3–1.5 s before reaching the merging point. Speed difference between the straight vehicle and the turning vehicle was the most important factor to impact straight driver's decision-making. Turning vehicle's speed and distance to the merging point also impacted straight driver's decision. Moreover, a U-shape curve was found when plotted the minimum gap between the two vehicles by the speed difference of the two vehicles at the decision moment (1.3 s). The accurate motion parameters found in this study helped to develop driver's thorough behavior model at unsignalized intersections, and suggest safety measures further.

1. Introduction

Traffic safety at intersections has become a critical issue in urban transportation system. According to the statistics from Fatality Analysis Reporting System (FARS) and National Automotive Sampling System-General Estimates System (NASS-GES), about 40% of the total 5,811,000 crashes in the United States in 2008 were occurred at intersections (NHTSA, 2009). The International Steering Committee of the American Institute of Transportation Engineers (ITE) has announced that road intersection safety was an important issue to be solved urgently (Elmitiny et al., 2010). At intersections of two or more roads, traffic conflicts between moving objects from different directions are easily to be generated. These conflicts can lead to traffic delay, congestion, crash, even accident with injury and fatality. Therefore, appropriate measures to control or limit traffic from different directions are essential for each intersection. Popular measures have been used worldwide today include traffic light, stop sign, roundabout, etc. (Prasetijo and Ahmad, 2012). Although signalized intersections with traffic lights have been constructed intensively in urban area, unsignalized intersections are still frequently seen in most of urban and rural areas. When stop signs are absent at unsignalized intersections, most countries and regions implement the right-hand priority rule, such as Norway (Elvik et al., 2009).

However, in developing countries and regions, due to less construction of stop signs and roundabouts, traffics are difficult to be controlled, limited or guided at unsignalized intersections. Meanwhile, drivers' driving courtesy was not well regulated, so the right-hand priority rule almost fails to take effect. Consequently, safety issues at unsignalized intersections in developing countries and regions require harder concern. In China, when two vehicles encounter at unsignalized intersections, drivers rarely stop completely, but gradually approach and dynamically make their decisions to yield or preempt by gaming with another vehicle. This uncertain process generates more traffic conflicts and increases accident probability. As a result, safety problem at unsignalized intersections in China was found more serious (Wang and Yang, 2008). In 2010, about 25% of the total 290,000 road accidents in China occurred at unsignalized intersections (Statistical yearbook of China, 2010). Since drivers' yielding/preemptive decision primarily impact the occurrence of traffic conflict at unsignalized

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intersections, it is important to understand drivers' dynamic decision-making behavior while moving across the unsignalized intersection.

In this paper, we aimed to study how straight drivers dynamically made their preemptive/yielding decisions when encountered turning vehicles from the orthogonal directions at unsignalized intersections. Based on the analysis of classification tree, three questions have been illustrated and answered:

(1) When did drivers complete their preemptive/yielding decisions?
(2) What factors influenced drivers' decision?
(3) In what situation a near-collision was possible to happen?

It was expected to discover drivers' decision pattern at unsignalized intersections in China and provide appropriate motion parameters to develop driver's thorough behavior model, and then suggest safety measurements to control drivers' behavior by this study.

2. Literature review

Previously, most of studies on decision-making behaviors at unsignalized intersections have focused on driver's gap acceptance (Weng and Meng, 2011; Moshe et al., 2002; Hamed et al., 1997). While no positive signal indication to control traffic at the unsignalized intersections, Troutbeck and Brilon (1992) pointed out that drivers were always seeking the right opportunities to cross the intersections by themselves. They call this sort of behaviors "gap acceptance". In the following years, many researchers have modeled driver's gap acceptance behaviors in various ways. By using the logit-modeling techniques to develop gap acceptance functions at a stop controlled intersection and the stochastic queuing theory to evaluate the capacity of this intersection, Madanat et al. (1994) found that gap length, the stop bar delay, the queuing delay and the number of rejected gaps were significant predictors of driver's gap acceptance behavior. In 1997, Hamed et al. developed a set of disaggregate models to recognize the major factors affecting driver's critical accepted gap at unsignalized T-intersections, then established a crossing behavioral model to predict driver's decision on either accepting the current gap and crossing the intersection or rejecting the current gap and waiting for the next one. They also found that the waiting time of the front car in the queue, the driver's socioeconomic characteristics and the time of day had significantly impacted driver's gap acceptance. On the bases of the risk evaluation associated with not accepting small gaps against the potential benefit of their acceptance, Moshe et al. (2002) present a microscopic decision model for driver gap-acceptance behavior when waiting at an unsignalized intersection on the secondary road and also to estimate the resulting intersection capacity. And the model also took individual preferences (riskloving vs. cautious) into account. The results show that different populations had different critical gaps, and this difference would result in different capacities on the minor road. Guo and Lin (2011) designed a survey designed method of rejected and accepted gaps based on the earlier gap acceptance theory and preceding assumptions. Four methods for calculating critical gap were proposed. The probability density function of the rejected and the accepted gap was deduced by introducing the exponential rejected proportion function. The relation among variables of these functions was also established. It concluded that the exponential model of rejected proportion was more practical than the linear model, and the typical capacity functions were improved by using the accepted proportion function.

Though conventional gap acceptance theory was applied in many researches, Brilon and Wu (2002) stated that the gap-acceptance method had a few drawbacks, which did not consider the driver behavior, particularly the compliance with priority rules. In other words, as for gap-forcing caused by aggressive driver, driving behaviors were not in accordance to the priority rules. The conventional gap-acceptance method could not be used to explain them. The situation would be aggravated by heterogeneous traffic, a mix of motorized and non-motorized modes (Prasetijo, 2007).

According to Troutbeck and Kabo (1999), in Brisbane of Australia, the ratio of gap-forcing behavior to all merging behavior at unsignalized intersection was approximately 9%. But in China, due to the lack of control measures for right-of-way and the limited regulation of driving courtesy at unsignalized intersections, gap-forcing behaviors are more common. A one hour early morning field observation was conducted to observe vehicles condition at an unsignalized intersections on the campus of Beihang University. The results showed that 51 driving behaviors not in accordance to the priority rules accounted for 49.3% of the total merging behaviors. In addition, there was less research about drivers' decision-making behaviors when facing to conflicting streams at unsignalized intersection in China. Therefore, it is necessary to understand when did drivers complete their preemptive/yielding decisions and what factors influence their decisions while encountering conflicting vehicles in China.

Various mathematical methods have been used in previous studies about decision-making behaviors, including classification tree method (Elmitiny et al., 2010; Wang and Yang, 2008), logistic regression method (Chiang et al., 2006), fuzzy theory method (Dheena and Mohanraj, 2011), artificial neural network (Lin, 2009) and expert system (Su and Lin, 1998), etc. Among them, the classification tree method has a special flexibility of assigning objects in one or more steps based on the similarity of the observation (Yan and Radwan, 2006). Most other methods have to assign the variables to pre-defined groups in a single step. Besides, as a nonparametric model, the classification tree does not require to assume the nature of the data. Most other methods assume that there's a function can link the probabilities of group membership to predictor variables. Another advantage of the classification tree method is that it easily explains the complex patterns associated with decision-making behaviors, while other models are less capable to analyze the interaction effect with more than two independent variables. Consequently, this paper adopted the classification tree method to analyze the decision-making behaviors of the straight moving drivers and turning drivers at unsignalized intersections.

Classification tree, also called decision tree, is one of the popular statistical tools emerged from machine learning and data mining. A classification tree classifies observations by recursively partitioning the predictor space. The resultant model can be expressed as a hierarchical tree structure. Due to its nonparametric nature and easy interpretation, decision tree method has been very popular in diversified research fields, especially after the introduction of the Classification and Regression Trees (Simon et al., 2003). In the research field of traffic safety, the application of decision tree has also been extended, such as a classification analysis of driver's stop/go decision and red-light running violation (Elmitiny et al., 2010), an analysis of driver injury severity in truck-involved accidents (Chang and Chen, 2012), identifying key factors of transit service quality (Juan de et al., 2012), etc. However, the decision tree method has not been applied to analyze drivers' merging decision behaviors at unsignalized intersections in China.

3. Method

3.1. Field observation site

A typical unsignalized intersection (latitude: 25°3′N, longitude: 102°44′E, see Fig. 1) in Kunming, Yunnan province of China was