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Modeling crossing behavior of drivers at unsignalized intersections with consideration of risk perception

Miaomiao Liu [a,*], Yongsheng Chen [a], Guangquan Lu [b], Yunpeng Wang [b]

[a] Research Institute of Highway, Ministry of Transport, 8 Xitucheng Road, Haidian District, Beijing 100088, China
[b] Beijing Key Laboratory for Cooperative Vehicle Infrastructure Systems and Safety Control, School of Transportation Science and Engineering, Beihang University, 37 Xueyuan Road, Haidian District, Beijing 100191, China

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ABSTRACT

Studying driver awareness of information, particularly risk perception, is vital to understanding driving behavior and improving traffic safety. In the dynamic interaction of a driver-vehicle-environment system, risk perception of drivers changes dynamically. In this study, we focused on drivers' risk perception at unsignalized intersections in China and analyzed their crossing behavior with consideration of risk perception. Based on cognitive psychology theory and an adaptive neuro-fuzzy inference system, quantitative models of drivers' risk perception were established for the crossing processes between two straight-moving vehicles from the orthogonal direction. Drivers' acceptable risk perception levels were identified using a self-developed data analysis method. On the basis of game theory, the relationship among the quantitative value of drivers' risk perception, acceptable risk perception level, and vehicle motion state was analyzed, then the crossing behavior models of drivers were established. Finally, the behavior models were validated using data collected from real-world vehicle movements and driver decisions. The results showed that the developed behavior models had both high accuracy and good applicability. This study would provide theoretical and algorithmic references for the microscopic simulation and active safety control system of vehicles.

1. Introduction

Traffic safety in intersections has attracted increasing attention. According to the National Highway Traffic Safety Administration (National Highway Traffic Safety Administration, 2015), approximately 47% of the total 10,064,000 crashes in the United States in 2013 occurred at intersections and nearby areas. The American Institute of Transportation Engineers have declared that road intersection safety was an important subject that required careful solutions (Elmitiny, Yan, Radwan, Russo, & Nashar, 2010). Moreover, previous researches showed that drivers' behavior at intersections could significantly affect the capacity and safety of intersections (Sharma, Bullock, & Peeta, 2011; Xiao, Ran, Yang, & Wang, 2011). Thus, conducting research on drivers' behavior at intersections is necessary.

Unlike signalized intersections, unsignalized intersections have no positive indication to inform drivers when it is appropriate to enter the intersection. Drivers' behavior at unsignalized intersections is more complex than that at signalized intersections. Each driver makes decisions about when, where and how to complete a required maneuver based on the elements

* Corresponding author.
E-mail address: liumiao-0605@163.com (M. Liu).

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of a decision context, including his/her perceptions of distance, velocity, and the performance of his/her vehicle (TRB., 1997). Accordingly, the number of vehicular conflicts and accidents at unsignalized intersections is higher than that at other intersections. According to National Highway Traffic Safety Administration (2015) statistical data, approximately 46% of intersection crashes in the United States in 2013 occurred at unsignalized intersections. In China, crashes also occurred at unsignalized intersections in 2013, accounting for approximately 60% of total intersection crashes (Statistical yearbook of China, 2014). Therefore, we mainly focused on drivers' behavior at unsignalized intersections and established drivers' behavior models in this study.

The information analysis of drivers, particularly risk perception, is notably a key problem in understanding driving behavior and improving traffic safety (McKenna, Horswill, & Alexander, 2006). The level of drivers' risk perception changes dynamically in the dynamic interaction of a driver–vehicle–environment system. Once a perceived risk is out of an accepted region (i.e., an acceptable risk perception level), a driver will accordingly speed up or slow down to adjust his/her perceived risk. That is, drivers' risk perception significantly influences driving behavior. Thus, establishing drivers' risk perception models and determining acceptable risk perception levels are important to analyze drivers' behavior at unsignalized intersections.

In addition, the lack of stop signs and roundabouts at unsignalized intersections in China causes difficulty in controlling or guiding traffic. In most cases, when one vehicle encounters another vehicle at an unsignalized intersection in China, neither of the drivers will completely stop their vehicle. Instead, one driver will gradually approach the intersection and adjust his/her driving behavior by gaming with the other vehicle. That is, the encounter between the two vehicles is actually a game process between the two drivers, and thus, can be analyzed using game theory.

In this study, we selected typical crossing cases at unsignalized intersections in China (in each case, one straight-moving vehicle encountered another straight-moving vehicle from the orthogonal direction) and developed drivers' behavior models based on risk perception and game theory. The models were expected to possibly reflect drivers' psychological characteristics and describe drivers' behavior at unsignalized intersections with improved accuracy.

2. Literature review

2.1. Drivers' risk perception

Drivers' risk perception has been defined as the ability to anticipate dangerous situations on the road ahead (Wilde, 1982; McKenna et al., 2006). It is one skill which has been found to be associated with crash risk (Darby, Murray, & Raeside, 2009). In recent years, many researchers have focused on drivers' risk perception and conducted numerous studies, which included analyzing the differences of risk perception in various situations and counties, identifying the risk perception ability of drivers, and finding the relationship between drivers' risk perception and road traffic safety, etc. For example, Whelan, Groeger, Senserrick, and Triggs (2002) recorded the response times of drivers to hazards or potential hazards appearing in photographed traffic scenes by using a laptop-based mouse-driven computer program; then, they analyzed the risk perception abilities of novice and experienced drivers. Pradhan et al. (2005) collected drivers' eye movement characteristics in an advanced driving simulator, and then analyzed drivers' scanning behavior and their deficits to perceive potential risks. In addition, many studies have highlighted the importance of risk perception in safe driving, as well as the feasibility of using hazard perception tests to evaluate the risk perception of drivers (Darby et al., 2009; McKenna et al., 2006; Pollatsek, Fisher, & Pradhan, 2006; Queensland Department of Transport, 2010).

Although previous studies have comprehensively analyzed drivers' perception characteristics and risk perception ability, and have made considerable achievements, research on quantifying drivers' risk perception and identifying the relationship between risk perception and drivers' decision behavior remains lacking. Drivers' risk perception exhibits nonlinear characteristics because of the effects of various factors. Thus, describing the risk perception of drivers using one particular formula is difficult. Previous studies have demonstrated the general use of neural networks in nonlinear mapping, reasoning, and prediction (Pao, 1989). However, a neural network has one disadvantage, that is, we cannot effectively obtain the implicit rules in a network structure. For a fuzzy logic system, it can be used to model human perception in an uncertain and imprecise environment. However, the fuzzy logic system is more complex; thus, it is difficult for the human brain to understand the causality existing in such system (Xiao, Sun, & Ran, 2004). According to recent literature (Sangole & Patil, 2014), an adaptive neuro-fuzzy inference system (ANFIS) is a combination of neural network and fuzzy logic approaches; hence, it inherently has the advantages of both, such as having a good learning mechanism and reasoning capability. Accordingly, we adopted ANFIS to model drivers' risk perception at unsignalized intersections in China in this study.

2.2. Drivers' behavior models at unsignalized intersections

Many researchers have conducted studies on divers' behavior at unsignalized intersections; most of these studies have focused on drivers' gap acceptance. For example, Madanat, Cassidy, and Wang (1994) developed gap acceptance functions at a stop-controlled intersection and evaluated the capacity of this intersection on the basis of logit-modeling techniques and stochastic queuing theory. Considering the risk evaluation results associated with accepting or denying small gaps, Pollatschek, Polus, and Livneh (2002) presented a model of driver gap-acceptance behavior when waiting at an unsignalized intersection. In addition, traffic conflict analyses and cellular automaton models have been applied to model driver behavior