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Heterogeneity in the effectiveness of cooperative crossing collision prevention systems

Kai Liu[a,*], Jie Jia[a], Zhi Zuo[b], Ryosuke Ando[c]

[a] School of Transportation and Logistics, Dalian University of Technology, Dalian 116024, China
[b] Xinjiang University, Urumqi 830046, China
[c] Toyota Transportation Research Institute (TTRI), Aichi 471-0024, Japan

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ABSTRACT

The adoption of a vehicle-to-infrastructure (V2I) cooperative crossing collision prevention system (CCPS) has been recognized as an option for reducing accident risk at intersections. However, the effects of driver characteristics on the general design of CCPSs have remained relatively unexamined. This study was conducted based on a field operational test (FOT) conducted in 2014 that included 64 monitored drivers receiving input from a CCPS and a driving style questionnaire (DSQ) that was administered to all 64 monitored drivers. To provide a better understanding of the various reactions of each driver with different driving styles, we employed both a logistic regression model and a time-series cross-sectional Prais-Winsten regression model with panel-corrected standard errors (PCSEs). The impacts of the driver characteristics and driving styles on a surrogate safety measure, namely, time-to-collision (TTC) risk, were modeled. The results revealed that both CCPS information displays and alarms significantly affect the TTC, whereas limited differences were observed when the serial correlations were removed during the FOT. For drivers younger than 65, only drivers who exhibited a natural worrier driving style (one of the eight DSQ classifications) did not benefit from the CCPS; thus, safety at intersections can be improved in practice with a higher CCPS penetration ratio. However, the evaluated CCPS had a limited effect on elderly drivers due to the significant negative effects of most driving styles on the TTC risk; thus, CCPSs should be specifically designed for elderly drivers with various driving styles.

1. Introduction

Collision avoidance systems, such as auditory warning information for relative safe distances, have been shown to reduce the crash involvement rate (Spence and Ho, 2008; Straughn et al., 2009). Since the beginning of the 21st century, the Japanese government has implemented the design and establishment of a vehicle-to-infrastructure (V2I) cooperative crossing collision prevention/avoidance system (CCPS/CCAS), which was expected to significantly reduce the risk of accidents at intersections (Furuta et al., 2014). The CCPS uses vehicle-based and infrastructure-based technologies to provide drivers approaching an intersection with information on the activities within that intersection; thus, this system has the potential to warn drivers of potential traffic control device violations and to help them safely pass through cross traffic (Becic et al., 2013; Farah and Koutsopoulos, 2014). Prior CCPS-related research has investigated the effectiveness of various environments and the acceptance of these systems by drivers in practice.

Human factors, such as human error, are the main factors of traffic accidents. Among all common causes, human factors may be

* Corresponding author.
E-mail address: liukai@dlut.edu.cn (K. Liu).

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reduced or avoided through an elaborately designed CCPS, thereby improving the safety conditions at intersections. However, CCPSs may have different effects on drivers with various personal characteristics and driving styles. Few papers have focused on field operational tests (FOTs) of the effects of CCPSs, and few researchers have considered the impact of individual characteristics, such as driving style, age and gender, on the efficiency of CCPSs. Thus, the key factors that affect the efficiency of CCPSs must be identified, and contributing factors must be compared among different application environments to fill the gap between the need for elaborately designed CCPSs and the current generally designed CCPSs that do not account for personal heterogeneity. Moreover, with the increasing rate of elderly drivers worldwide, especially when considering the possible decline of their cognitive, perceptual and physical senses, the effectiveness of CCPSs requires a more thorough examination. This paper attempts to fill such gaps by exploring the effectiveness of CCPSs via an FOT designed in Japan.

Toyota Motor Corporation in cooperation with Japanese police authorities installed an experimental V2I cooperative CCPS at non-signalized intersections in Toyota City. This study evaluates the effect of the applied field tests in 2014 and verifies the effect on reducing active right-of-way violations (Parker et al., 1995) based on the impact of the drivers' driving style. This paper examines the effects of various driving styles on the surrogate safety measures and time-to-collision (TTC). The heterogeneity in the effectiveness of the CCPS among elderly and non-elderly drivers is also examined.

2. Literature review

Reducing the number of deaths and injuries in traffic accidents is a global societal concern. In recent years, ITS technology has been widely applied, and information has been provided by cooperative vehicle infrastructure systems (CVISs) and advanced driver assistant systems (ADASs), which have been implemented at a variety of intersections. To improve the application and popularity of these technologies, actual FOTs that consider various types of factors present increased importance. Lee et al. (1999) simulated various in-vehicle message characteristics that affect driving safety and compliance and focused on human factors that help explain the influence of in-vehicle messages on driving behavior. Xiang et al. (2016) found that early in-vehicle warning information is more effective for reducing brake response time and collision rates than late warning information. However, late warnings can still reduce the collision rate by approximately 37%.

To our knowledge, the first CCPS experimental tests at intersections were conducted at PATH in 2003 (Misener et al., 2007). A CCPS mainly consists of three parts: vehicle-based technologies and systems, including sensors, processors, and driver interfaces installed within the vehicle; infrastructure-based technologies and systems, including roadside sensors and processors to detect vehicles and identify hazards and signal systems, messaging signs, and/or other interfaces to communicate various warnings to drivers; and communications systems, including dedicated short-range communications (DSRCs) to communicate warnings and data between the infrastructure and equipped vehicles. Farah and Koutsopoulos (2014) showed that the cooperative V2I system had a positive safety impact on drivers' car-following behavior. Although the situational awareness of older drivers has been reported as poor (Kaber et al., 2012) or equivalent to that of younger drivers (Key et al., 2016), the performance of older drivers in conjunction with a CCPS has seldom been reported.

Several methods are available to measure collision risk (Li et al., in press), among others, distance-based measurement methods and time-based measurement methods are most commonly used. Tang et al. (2017b) examined the impacts of a vehicle's front safety distance and rear safety distance on traffic safety and improved the car-following model via increased consideration of traffic safety. Recently, the TTC-based measurement method proposed by Hayward (1972) has attracted increased attention because it is a more feasible measurement given existing technology. The original definition of TTC proposed by Hayward (1972) is the time required for two vehicles to crash if they continue moving at their present speeds and in the same direction. Li et al. (2017) used two surrogate safety measures related to TTC to quantify collision risk and evaluate the impacts of a cooperative adaptive cruise control system on reducing rear-end collision risks. The TTC method has been applied and is widely accepted as a surrogate safety measure and can be used to quantify the risks of collision (Yi et al., 2007; St-Aubin et al., 2013; Ward et al., 2015; Mwesige et al., 2016). TTC can be employed in various research objectives, such as determining the risk associated with passing maneuvers (Mwesige et al., 2016) and designing adaptive cruise control systems (Yi et al., 2007). The method can also be implemented at various locations, such as protected highway ramps (St-Aubin et al., 2013) and inner-city streets and intersections (Chandra, 2014). TTC can be measured by video (Ismail et al., 2012) or from vehicle trajectory data (Oh and Kim, 2010).

Furuta et al. (2014) presented a detailed review of Toyota CCPS projects, and their FOT results revealed that the TTC distribution is improved when CCPS information is provided compared with the TTC distribution without CCPS information. The statistical results from post surveys indicated that a large percentage of participants positively evaluated the system and revealed relatively high acceptance.

In general, the published articles and reports on FOT post evaluations of CCPSs remain limited, and few researchers have examined the effect of driver characteristics. Personal driving styles, especially personal bounded rationality, are one of the key issues faced by current CCPS models and numerous other in-vehicle driving assistance systems. Drivers' bounded rationality exists and affects traffic flow (Tang et al., 2015, 2017a); however, heterogeneous drivers' bounded rationality is difficult to observe and model. Farah et al. (2012) collected physiological data and acceptance attitudes of drivers on in-vehicle cooperative systems to determine whether driving behavior in general changed and whether the system had general positive impacts based on a field test in Austria. However, it is also difficult to identify heterogeneity regarding the effectiveness of the V2I cooperative system among various drivers. To our knowledge, this paper is the first attempt to examine the heterogeneous effects of the drivers' personal driving styles on the general design of a V2I CCPS.

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