Transportation Research Part F 58 (2018) 133–144

Contents lists available at ScienceDirect

Transportation Research Part F

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

Evaluating the impact of adaptive signal control technology on driver stress and behavior using real-world experimental data

Zulqarnain H. Khattak [a,*], Michael D. Fontaine [b], Richard A. Boateng [a]

[a] Center for Transportation Studies, Department of Civil and Environmental Engineering, University of Virginia, Charlottesville, VA 22904, United States
[b] Virginia Transportation Research Council, 530 Edgemont Rd., Charlottesville, VA 22903, United States

ARTICLE INFO

Article history:
Received 16 November 2017
Received in revised form 6 June 2018
Accepted 7 June 2018

Keywords:
Human factors
Heart rate
Driver stress
Adaptive signal control technology
Driving behavior
Intelligent transportation systems
Traffic safety
GPS trajectories

ABSTRACT

While the operational and crash reduction benefits of adaptive signal control technology (ASCT) have long been investigated, the impact of this technology on driver behavior and stress is still uncertain. This study evaluated the impact of ASCT on driver behavior and stress in a real-world environment. Participants travelled through two arterial corridors, one equipped with ASCT and the other having traditional time-of-day coordinated signals. Driver stress was measured using a heart rate detector and a perceived stress scale while driver behavior was examined using vehicular trajectory data. Overall, driving behavior improved on the ASCT as compared to the non-ASCT corridor, as indicated by higher speeds and a fewer number of stops on the ASCT corridor relative to the non-ASCT corridor. Repeated measures ANOVA showed a statistically significant reduction in driver heart rate by −10 beats per minute over the ASCT corridor. A similar trend was observed for drivers' perceived stress, analyzed by Wilcoxon sign ranked test. Driving behavior also showed significant improvement with ASCT presence, and speed was found to be negatively correlated with stress. Furthermore, the participants' speed was controlled by the two systems i.e. ASCT and non-ASCT as expected. This study provides a significant proof of concept that ASCT can create positive improvements in driver stress and behavior that can be further investigated in the future.

1. Introduction

Traffic safety is one of the major concerns for transportation engineers across the world, and a common cause of traffic crashes is human error. Driving is a complex cognitive phenomenon and stress levels may affect drivers' abilities thus, leading to decision making errors and crashes (Hill & Boyle, 2007). One study estimated that 30 percent of road crashes are caused by driver stress, thus making stress a major contributor to crashes (Aworemi, Abdul-Azeez, Oyedokun, & Adewoye, 2010). Similarly, Desmond and Matthews (2009) also recognized the importance of drivers' stress as a potential safety problem, but noted that it may differ by individuals in response to the demands of driving.

Adaptive signal control technology (ASCT) is an emerging method for operating traffic signals using real-time data. ASCT relies on improved intersection detection to determine traffic demands in real time. These demand data are then processed through an algorithm to adjust timing plans on-the-fly based on real time traffic volumes. This is in contrast to traditional

* Corresponding author.
E-mail addresses: zk6cq@virginia.edu, zhkhattak@gmail.com (Z.H. Khattak), Michael.Fontaine@VDOT.Virginia.gov (M.D. Fontaine), ra3fb@virginia.edu (R.A. Boateng).

https://doi.org/10.1016/j.trf.2018.06.006
1369-8478/

time of day (TOD) timing plans, where signal timings and phase lengths are set based on historic intersection counts and timing plans that were developed off line. ASCT systems can change phase order, skip phases, or alter phase or cycle length based on observed demand at the intersection. Although these systems should theoretically improve traffic flow through optimization of the intersection, it is unclear whether the non-standard operation of the intersection may have adverse effects on driver behavior or stress levels. This paper sought to investigate whether there were noticeable differences in driver reactions and stress levels between a corridor equipped with ASCT and another equipped with a traditional coordinated TOD signal system.

2. Literature review

2.1. Safety effects of ASCT

Various studies have evaluated the safety effects of adaptive signal control technology, but very few have been able to find statistically significant results. Two recent studies (Khattak, 2016; Ma, Fontaine, Zhou, Hale, & Clements, 2015) found significant reductions in crashes using an Empirical Bayes analysis, while the rest have suffered from inconclusive results or methodological limitations. Ma et al. (2015) evaluated one type of ASCT system using an Empirical Bayes method with before and after crash data from 47 urban/sub-urban intersections in Virginia. That study found a reduction in both total and fatal + injury crashes, with a crash modification factor (CMF) of 0.83 for total crashes and a CMF of 0.92 for fatal + injury crashes. The study was later published as (Ma et al., 2016). Similarly, the other study (Khattak, 2016) evaluated 41 urban/suburban intersections in Pennsylvania equipped with two different types of ASCT systems. Their Empirical Bayes analysis concluded that both systems showed safety benefits, with CMF values of 0.87 and 0.64 for total and fatal + injury crashes, respectively. The study was published as (Khattak, Magalotti, & Fontaine, 2018). Since various types of ASCT systems are available that use different optimization methods, a study was conducted on one of the adaptive signal control technology known as InSync for its safety benefits (Clark, 2010). InSync uses four video detection cameras to collect real time data at each intersection. The signalization parameters such as state, sequence, and amount of green time are selected based on the collected data to best service the prevailing conditions second by second. Optimization is based on minimizing the overall delay and reducing stops. That study used a simple observational before and after crash data analysis on different corridors and found reductions in the total number of crashes observed after deployment of the system. Since each type of ASCT system has its own unique algorithm, another study (Dutta, Bodke, Dara, & Lynch, 2010) analyzed a different type of ASCT system known as SCATS (Sydney Coordinated Adaptive Traffic System), that uses real time vehicular data from detectors to develop optimum plans for an entire network rather than individual intersections by minimizing vehicular delays through optimization of cycle length, splits, and offsets every cycle (NSW, 2018). The study used intersection and segment crash data before and after installation of the SCATS system and observed a reduction in injury severity, but statistical tests were not able to identify any significant differences at the 95% confidence level.

2.2. Measurement of driver stress and behavior

The impact of human factors on road safety (Khattak & Fontaine, 2018) has been a common research area, and different methods have been used to investigate these effects (NHTSA, 2006). Simulators (mainly driving simulators and microsimulations) and real-world observational studies are among the two most commonly used methods to assess the interaction between human factors and safety. Traffic simulations and driving simulators have been used by researchers such as (Brooks et al., 2011; Kergaye & Haigwood, 2011; Khattak, Park, Hong, Boateng, & Smith, 2018; Sabra, Gettman, Henry, & Nallamothu, 2010; Sabra, Gettman, Henry, & Nallamothu, 2013; Shahdah, Saccomanno, & Persaud, 2015; Yamaguchi, Wakasugi, & Sakakima, 2006; Zeuwts et al., 2016) mainly because of the ease with which a simulator can imitate real-world conditions while controlling external factors as much as possible. However, simulators do have limitations and may not always precisely replicate real-world conditions and behaviors since there are no consequences to poor performance in the simulator. For example, Zeuwts et al. (2016) analyzed behavior of cyclists on a real world and a simulated track and observed that behavior between the two conditions was somewhat different. They concluded that simulated lab studies can provide valuable information only under certain conditions (Zeuwts et al., 2016). Kergaye and Haigwood (2011) compared real world data from two sites in Utah to relevant safety surrogate measures from microsimulation to find correlations between the two datasets. They concluded that SCATS generated fewer rear end and total conflicts than traditional signalized traffic control and that field crashes increased as a consequence of road construction activities, not the ASCT. Similarly, Sabra et al. (2010) and Sabra et al. (2013) also developed a crash prediction method using field data from ASCT and actuated signals. After training the network with around 150 signal timing scenarios, the crash prediction method produced an average conflict prediction error of 17%. Hence, a real-world traffic study, if carefully conducted, could provide a better indication of actual driver reactions and safety effects.

In recent years, the use of sensors in transportation systems evaluation has been on the rise, and these sensors have enabled the collection of huge amounts of data easily and in a short amount of time. Some of the real world studies that measured driver behavior using sensors include (Lum and Halim, 2006; Salai, Vassányi, & Kósa, 2016; Zhu, Hu, & Chiu, 2013; Birrell and Fowkes, 2014). Salai et al. (2016) used a low-cost heart rate sensor to detect stress and proposed that their