Transportation Research Part C 91 (2018) 156–175

Contents lists available at ScienceDirect

Transportation Research Part C

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

Exploring relationships between driving events identified by in-vehicle data recorders, infrastructure characteristics and road crashes

Victoria Gitelman[a], Shlomo Bekhor[a,*], Etti Doveh[b], Fany Pesahov[a], Roby Carmel[a], Smadar Morik[a]

[a] Transportation Research Institute, Technion – Israel Institute of Technology, Haifa 32000, Israel
[b] The Technion Statistical Laboratory, Technion – Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Keywords:
In-vehicle data recorder
Driving events
Infrastructure characteristics
Interurban roads
Road crashes

ABSTRACT

There is an increasing interest in technology-based solutions that can assist drivers in reducing their risk of involvement in road crashes. Previous studies showed that driving events produced by in-vehicle data recorders (IVDR) are applicable for identification of unsafe driving patterns, while combined examinations of driving events and road infrastructure characteristics are rare. This study explored the relationship between the IVDR-driving events, road characteristics and crashes, to examine a potential of the events for predicting crashes and identification of high-risk locations on the road network. The study database included 3500 segments of the interurban roads in Israel, for which the automatically produced IVDR events were matched with road infrastructure characteristics and crashes. Negative-binomial regression models were adjusted for the relationships between road characteristics and driving events, and subsequently, between events and crashes, given the exposure. Significant impacts were found, yet various event types showed different relations to the infrastructure characteristics and different effects on crashes, on various road types. Better road conditions were associated with a decrease in "braking" events and an increase in the "speed alert" events, where road layout constraints and junction proximity were associated with an opposite effect on events. "Braking" and total events showed better potential for predicting crashes on single-carriageway roads, with a positive link to crashes, where for other road types the "speed alert" events were stronger related to crashes, but with a negative link. The heterogeneity of findings indicates a need in further research of the above relationship, with a particular focus on definitions of driving events produced by the IVDR or other technologies.

1. Introduction

It is well known in the road safety literature that human factors contribute to the majority of road crashes, e.g. 93% as estimated by Treat et al. (1979). Given the importance of understanding the driver's interaction with road, vehicle and the environment for preventing crashes, naturalistic driving studies (NDS) are being conducted over the past decade to collect objective data. In a NDS, volunteer participants drive an instrumented vehicle, which continuously records their driving behavior, the vehicle behavior and the

* Corresponding author.
E-mail addresses: trivica@technion.ac.il (V. Gitelman), sbekhor@technion.ac.il (S. Bekhor), ierde01@ie.technion.ac.il (E. Doveh), fanyp@technion.ac.il (F. Pesahov), robyc@cv.technion.ac.il (R. Carmel), smadarm@technion.ac.il (S. Morik).

https://doi.org/10.1016/j.trc.2018.04.003
Received 2 April 2016; Received in revised form 20 December 2017; Accepted 6 April 2018
0968-090X/

behavior of other road users with whom they interact. Examples of such studies are the seminal “100-car naturalistic driving study” (Klauer et al., 2006), which explored factors leading to rear-end crashes, and the most recent the US Strategic Highway Research Program Phase 2 (SHRP 2) NDS, which deployed 2800 vehicles to explore and analyze a wide range of road safety problems (Antin et al., 2011; Hallmark et al., 2013; TRB, 2014) and is currently underway, on the stage of the NDS data analysis. Other large-scale efforts can be found in Japan (Uchida et al., 2010) and in Europe where the European Commission funded UDRIVE project (e.g. Twisk et al., 2012).

Regan et al. (2012) reviewed around 40 studies that used the NDS approach, and noted that most of them have been small-scale studies. Several research issues have been examined, including factors leading to rear-end crashes (e.g. Klauer et al., 2006); skill development in young drivers (Prato et al., 2010); skill loss in older drivers (e.g. Blanchard et al., 2010); young novice driver crash and incident types (e.g. Lee et al., 2011); distraction and inattention (e.g. Olson et al., 2009; Koppel et al., 2011); fatigue (e.g. Hanowski et al., 2009); interactions between light and heavy vehicle drivers (Hanowski et al., 2007); understanding driver interactions with new vehicle safety technologies (e.g. Sayer et al., 2007); and lane changing behavior (e.g. Lee et al., 2004). Recently, a large-scale study on driver performance and behavior crash risk factors was reported (Dingus et al., 2016).

It is noticeable that the majority of the studies examined the interaction between drivers and the surrounding environment and/or driver characteristics, while the examination of driving events and road infrastructure characteristics are still rare. Hallmark et al. (2011) performed a comprehensive review of the roadway, driver, environmental and vehicle data needs to address lane departures using NDS data. Their study identified the following roadway elements as important for addressing the issue: horizontal and vertical curves, roadway cross section, driveway density, roadway lighting, rumble strips, roadway delineation and sighting, and pavement edge drop-off. Cannon and Sudweeks (2011) used NDS data to compare driver behavior between high-crash and low-crash rural road sites and found a few significant differences, without a consistent pattern. Using the “100 cars” NDS data, Guo et al. (2010) explored near-crash versus crash events and demonstrated similarity in factors contributing to both events, including road conditions such as road surface, lighting, road alignment. Further inputs on the topic are expected from the SHRP 2 NDS, based on combined analyses of driver behavior and detailed roadway data (Hallmark et al., 2013).

Jovanis et al. (2011) noted that comparatively few NDS studies have emphasized exposure-based analyses. In this respect, Shankar et al. (2008) formulated exposure-based risk measures that can be derived from NDS data to perform surrogate analyses. They comment that an essential starting point for analyzing NDS data is to establish and define surrogates beyond the conventionally considered events such as near-crashes. Wu and Jovanis (2012, 2013) further explored the definitions suggesting a distinction between safety-related and surrogate events. The former includes events that were traditionally collected and examined by road safety behavioral studies and referred to as near crashes, risky driving or near misses, while the latter includes both crashes and near crashes with common etiologies to crashes. In any case, a surrogate measure is considered as an indirect measure of safety, where the need in the use of surrogate measures is explained by rareness of crash events that limits the possibilities of studying crash contributing factors (Guo et al., 2010; Hallmark et al., 2013; Wu et al., 2014).

It is worth mentioning that examples of using surrogate measures to evaluate traffic safety were provided by traffic conflict techniques (TCT) that were introduced several decades ago (Perkins and Harris, 1968; Hyden, 1987). Studies applying such techniques demonstrated relationships between traffic conflicts and crashes and, particularly, when exploring road infrastructure impacts. For example, Sayed and Zein (1999) validated the relationship between crash frequencies and observed conflicts at signalized intersections; Retting and Greene (1997) used traffic conflicts to examine the impact of traffic signal timing at urban intersections; Hanowski et al. (2004) demonstrated the application of modified TCT (critical incidents) to ascertain the needs in re-design of existing urban road infrastructure. As stated (Guo et al., 2010; Wu et al., 2014), naturalistic driving approach has much in common with TCT, except for that the instrumentation is vehicle-based rather than road site-based, where NDS approach is much more powerful and promising. Yet, it should be noted that both approaches are not well-controlled studies.

1.1. In-vehicle data recorders

There has been an increased interest in technology-based solutions that can assist drivers in reducing their risk of involvement in car crashes. One class of solutions that were proposed is the installation of in-vehicle data recorders (IVDRs), which monitor and provide feedback on driver behavior (Toledo et al., 2008; McGehee et al., 2007; Musicant et al., 2014). IVDRs can be viewed as a component to NDS, which focuses on data acquisition and processing related to the vehicle. The IVDR system is typically based on measuring gravitational forces and GPS location of the vehicles. The type of data stored by an IVDR system may range from full acquisition of all vehicle sensor measurements to concise representation of main indices, e.g. speed, event type. Some systems log data continuously, others store data related to undesirable driver events. The key advantages of commercial IVDRs are the low cost and the “ready to use” package of identification, logging and reporting capabilities (Musicant et al., 2014). IVDR does not include video records and thus, unlike most naturalistic driving studies, it does not require substantial data processing enabling large-scale data collection at a reasonable cost (Toledo et al., 2014). However, IVDR pattern recognition procedures are typically proprietary, thus not permitting to focus on detailed data and possibly reducing comparability of findings received based on various systems.

In Israel, an IVDR system referred to as “green box” collected naturalistic data in private vehicles driven by novice young drivers and their family members (Lotan et al., 2010; Farah et al., 2013). This is a g-force based system developed by Green-Road technologies. The system tracks all trips made by the vehicle and records: trip start and end times; vehicle and driver identification, using magnetic keys; vehicle location measured by a GPS receiver; events of excessive maneuvers defined by patterns of g-forces measured in the vehicle. For example, the accelerations of the vehicle, both in the lateral and longitudinal directions, are measured by accelerometers at a sampling rate of 40 measurements per second. Using raw information, the system defines over 20 driving