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Factors contributing to commercial vehicle rear-end conflicts in China: A study using on-board event data recorders

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ABSTRACT

Introduction: In the last 30 years, China has undergone a dramatic increase in vehicle ownership and a resulting escalation in the number of road crashes. Although crash figures are decreasing today, they remain high; it is therefore important to investigate crash causation mechanisms to further improve road safety in China. *Method:* To shed more light on the topic, naturalistic driving data was collected in Shanghai as part of the evaluation of a behavior-based safety service. The data collection included instrumenting 47 vehicles belonging to a commercial fleet with data acquisition systems. From the overall sample, 91 rear-end crash or near-crash (CNC) events, triggered by 24 drivers, were used in the analysis. The CNC were annotated by three researchers, through an expert assessment methodology based on videos and kinematic variables. *Results:* The results show that the main factor behind the rear-end CNC was the adoption of very small safety margins. In contrast to results from previous studies in the US, the following vehicles' drivers typically had their eyes on the road and reacted quickly in response to the evolving conflict in most events. When delayed reactions occurred, they were mainly due to driving-related visual scanning mismatches (e.g., mirror checks) rather than visual distraction. Finally, the study identified four main conflict scenarios that represent the typical development of rear-end conflicts in this data. *Conclusions:* The findings of this study have several practical applications, such as informing the specifications of in-vehicle safety measures and automated driving and providing input into the design of coaching/training procedures to improve the driving habits of drivers.

1. Introduction

Over the past 30 years, China has dramatically increased vehicle ownership. In the period 1985–2013, the number of passenger vehicles increased from 284,900 to 105,016,800 and the number of trucks increased from 264,800 to 12,754,900 (National Bureau of Statistics of China, 2016). The boom of motorization in the last three decades has caused the number of crashes to increase, although in the last few years there has been some decline. In total about 4.22 million road traffic crashes occurred in China in 2011, resulting in a total of 62,387 deaths and 237,421 injuries (Zhang, Yau, Zhang, & Li, 2016). Even with the decrease, it is important to continue the efforts to understand causation mechanisms of Chinese crashes to address the most critical aspects of traffic safety.

Analyzing accident records from 192 Shanghai roads in the year 2009, Deng, Wang, Chen, Wang, and Chen (2013) showed that rear-end crashes were the most frequent crash scenarios on urban expressways. Although they accounted for only 13.7% of the crash fatalities in 2009 in China (Zhang, Yau, & Chen, 2013), rear-end crashes are known to provoke several types of injuries — especially neck injuries and other whiplash-associated disorders (Siegmund, Winkelstein, Ivancic, Svensson, & Vasavada, 2009) — and cause significant costs to fleets (Avery & Weekes, 2009).

Previous studies in Western countries (primarily in the United States) have indicated that driver inattention (e.g., visual distraction and driver fatigue) and driving-related visual scanning (e.g. looking at the mirror) are the key factors behind rear-end crashes involving commercial vehicles (Engström, Werneke, Bärgman, Nguyen, & Cook, 2013; Woodrooffe et al., 2012). In particular, further quantitative analyses showed that rear-end crashes in commercial vehicle fleets (trucks and buses as well as passenger cars) typically occurred due to a "perfect" timing mismatch between an off-road glance and the lead vehicle braking unexpectedly (Eiríksdóttir, 2016; Victor et al., 2015). Notably, these datasets also included rear-end crashes where the key causation mechanisms were unrelated to inattention, being the subject vehicle following too closely behind a lead vehicle, which braked unexpectedly when drivers were looking at the road.

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Naturalistic driving studies previously conducted in China identified short time headways, rather than eyes off road, as the main contributing factor in rear-end crashes (Lin et al., 2008). However, none of those studies focused on commercial vehicles; as a result, there is little insight into the role played by the drivers of commercial vehicles in the development of traffic conflicts. While crash data is available for these vehicles, it is clear that they do not always provide information about contributing factors such as distraction (Blower & Woodrooffe, 2013); hence the need for a naturalistic study including commercial drivers as participants.

To prevent rear-end crashes, in-vehicle safety systems such as forward collision warning (FCW) and automatic emergency brake systems (AEBS), as well as different levels of vehicle automation, are being introduced into the Chinese market. Other safety measures, such as behavior-based safety (BBS) services, are also likely to get increased deployment in the Chinese market. Since differences exist between China and other countries with regard to the safety culture (Atchley, Shi, & Yamamoto, 2014), it is necessary to target local problems to ensure the effectiveness of those measures. *Scrambling behaviors* — defined as "the behaviors of drivers, pedestrians, or cyclists that challenge for right of way in violation of traffic codes" (Shi, Bai, Tao, & Atchley, 2011, p. 1540) — are a typical feature of Chinese traffic which could impact the development and success of safety measures.

The main objective of the present study was to conduct a detailed naturalistic investigation of causal mechanisms behind commercial vehicle rear-end crashes and near-crashes in China. The target population addressed by the study was represented by professional drivers in China. A further aim was to compare the obtained results to the ones available on rear-end crash/near-crash causation from Western countries (in particular the US), for use in the development of different safety measures. To this end, an event-triggered naturalistic data collection was conducted in Shanghai.

2. Method

2.1. Apparatus

Overall, 47 vehicles belonging to a commercial fleet were equipped with a data acquisition unit provided by Lytx (2016) and hereafter referred to as a Video Event Recorder (VER): 14 light trucks, 30 vans, and three heavy trucks with trailers. The VER was installed on the vehicles during a 12-month naturalistic driving study as part of a behavior-based safety service evaluation, similar to previous ones conducted in the US (Hickman & Hanowski, 2011; McGehee, Raby, Carney, Lee, & Reyes, 2007; Simons-Morton et al., 2013).

The VER integrated a variety of sensors (e.g. cameras, 3-axis accelerometer and GPS) and stored 12 s of data about safety-critical events every time a strong longitudinal or lateral acceleration was recorded by the unit. Among the overall information collected by the VER, the data used in this study is reported in Table 1.

2.2. Participants

The study involved 37 truck and commercial vehicle drivers employed at a customer fleet in China. Before starting the study, the participants were requested to fill in a questionnaire including demographic information (gender, age, years holding driving license) and sign a consent form. The participants were all male, their mean age was 32.2 years (SD = 7.40) and, in average, they held a driving license for 5.54 years (SD = 3.62) and drove 91,400 km yearly (SD = 35,200).

Table 1
Data recorded by the VER and used in the study.

Data acquired	Sensor source	Sensor recording frequency
Video of forward view	Camera	4 Hz
Video of driver view	Camera	4 Hz
Longitudinal acceleration	3-axis accelerometer	20 Hz
Lateral acceleration	3-axis accelerometer	20 Hz
Vertical acceleration	3-axis accelerometer	20 Hz
Speed	GPS	1 Hz

2.3. Data selection process and analysis methodology

2.3.1. Event selection and annotation

The safety-critical events acquired through the VER were primarily screened to discard events in which the camera was obstructed, events which occurred in a context not authorized for further analysis (e.g. in company yards), and events for which the participants had not provided written consent. After that, a second filtering process was conducted to retain only rear-end events which could be classified as near-crashes or crashes, since the aim of the study was to understand causation mechanisms. The final sample comprised 91 rear-end events, which were annotated by two persons who had been previously trained and had already performed the same task in other projects. The aim of the annotation process was to extract significant information about the event (e.g. weather conditions, driver's involvement in secondary task), from the videos. The variables annotated were retrieved from the SHRP2 researcher dictionary for video reduction (SHRP2, 2016). For the sake of brevity, not all variables are listed in the paper but Table 2 reports an overview of the most relevant ones and, in the Appendix, the attribute levels are indicated for each variable.

2.3.2. Causation analysis

The annotated variables - described in Section 2.3.1 - and the forward and face videos were used for the Causation Analysis for Naturalistic Driving Events (CANDE). The CANDE method, based on the expert assessment of videos, kinematic variables, and narratives, builds on previous methodologies developed for crash causation analysis (Engström et al., 2013; Habibovic, Tivesten, Uchida, Bärgman, & Aust, 2013; Ljung Aust et al., 2012). The aim of the analysis is to determine the observable causal mechanisms behind crashes and near-crashes by identifying component causes, which constitute necessary but insufficient conditions for the crash or near-crash to occur.

The general crash model underlying the CANDE methodology is illustrated in Fig. 1. The first part of the analysis (the lower part in Fig. 1) characterizes how the conflict between the subject vehicle (SV) and the conflict partner (CP; here, the lead vehicle) developed. A conflict here is based on Svensson and Hydén (2006): "a situation where two or more collision partners approach each other in time and space to such an extent that a collision is imminent if their movements remain unchanged". A further conflict criterion adopted in CANDE is that the conflict should be unintended by at least one of the conflict partners.

The coding of conflict initiation involves characterizing the *pre-conflict behaviors* of the SV and CP as well as the *critical action*(s) that induced the conflict. The pre-conflict behavior represents the kinematic state of the SV or the CP relative to other road users and the infrastructure just before the conflict was initiated, that is, just prior to the conflict start. In rear-end conflicts, typical examples of pre-conflict behaviors are given by the SV following CP or the approaching stationary or slowly-moving CP. By contrast, the critical action(s) refers to an action by the SV or CP that instantly induces a conflict, such as establishing a collision course by turning into another vehicle's path, accelerating into an intersection or braking in front of a following vehicle. In rear-end conflicts, the critical action is most often performed by the CP (e.g., braking or cutting in) but may also involve SV actions such as accelerating towards CP. SV-initiated critical actions are more common for other crash types (e.g., the SV is pulling out at an intersection). It should be noted that in some scenarios, such as when the SV closes in on the CP, the conflict evolves gradually without a distinct critical action.