Journal of Safety Research 62 (2017) 143–153

Contents lists available at ScienceDirect

Journal of Safety Research

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

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

Giulio Bianchi Piccinini, [a,*] Johan Engström, [a,b] Jonas Bärgman, [a] Xuesong Wang [c]

[a] Department of Applied Mechanics, Chalmers University of Technology, Gothenburg, Sweden
[b] Volvo Group Trucks Technology Advanced Technology & Research, Gothenburg, Sweden
[c] School of Transportation Engineering, Tongji University, Shanghai, China

A R T I C L E I N F O

Article history:
Received 15 December 2016
Received in revised form 16 February 2017
Accepted 6 June 2017
Available online 24 June 2017

Keywords:
Naturalistic driving data
Truck drivers
Human factors
Traffic safety
Active safety systems

A B S T R A C T

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.

* Corresponding author at: Chalmers University of Technology, Department of Applied Mechanics Department, Division of Vehicle Safety, Accident Prevention Group, Lindholmspiren 3, Lindholmen Science Park, 41756 Gothenburg, Sweden.
E-mail address: giulio.piccinini@chalmers.se (G. Bianchi Piccinini).

http://dx.doi.org/10.1016/j.jsr.2017.06.004

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.

Table 2
Description of variables annotated.

Variable name	Variable description
Weather	Weather conditions at the start of the event
Light condition	General light conditions during the event
Road surface condition	Type of roadway condition that would affect the vehicle's coefficient of friction at the initiation of the precipitating event. For a description of *precipitating event*, please refer to SHRP2 (2016)
Number of crashes[a]	The number of crashes visible during the event
Number of near-crashes[b]	The number of near-crashes visible during the event
Crash/near-crash type	The type of crash/near-crash that the SV has with other objects of conflict for the most severe type of crash or near-crash
Visual obstructions	The visual factors that are likely to have contributed to the event
Evasive maneuver	The subject driver's reaction or avoidance maneuver in response to the event/incident
Secondary task	Observable driver engagement in secondary tasks at any point during the event
Driver drowsiness	Observer's rating of the drowsiness of the driver

[a] A crash is any contact that the subject vehicle has with another conflict partner, either moving or fixed, at any speed that is observable or in which kinetic energy is measurably transferred or dissipated. This excludes roadway features meant to be driven over, such as speed bumps.
[b] A near-crash is any circumstance that requires a rapid evasive maneuver by at least one conflict partner to avoid a crash.

The second part of the analysis (the upper part in Fig. 1) characterizes the nature of the corrective action (if any), such as steering and/or braking, performed by the SV driver in response to the conflict. This includes the corrective action's *effect* (e.g., controlled braking, steering or skidding) and how the effect is influenced by the *vehicle* or *road-surface conditions*. The vehicle conditions can have an influence when the vehicle's braking or steering systems are not functioning properly. The road-surface conditions can also impact the corrective action's effect when the road surface is slippery due to weather (e.g. rain, snow, ice), type of road surface (e.g. gravel) or residual material (e.g. oil).

Moreover, the *timing* of the corrective action (if any) is characterized as either normal, or delayed where the latter is defined as a corrective action initiated significantly later than a corrective action performed under normal conditions (attentive driver and no visibility problems). Finally, component causes of delayed or lacking actions are identified, such (lack of) *attention to driving*, *expectation* (mismatch) or (reduced) *visibility*. The coding of attention to driving identifies mismatches between the current allocation of attention and that demanded by activities critical for safe driving: examples of mismatches are sleep-related attentional impairment, internal or external distraction, and visual scanning mismatches. The coding of expectation aims to establish when the expectation of the SV driver does not match how the situation develops, resulting in a delayed or lacking reaction to the conflict. The coding of visibility aims to determine any possible reduction of SV driver's visibility which affected the delayed (or the lack of) action: this could be due to lighting conditions (e.g. darkness, glare), environmental factors (e.g. rain, fog), low CP conspicuity (CP headlights malfunctioning) or occluding objects (e.g. parked vehicle, tree, vehicle sunshield).

The 91 events were analyzed by the first three authors of the paper using the CANDE method and the results are described in the next section.

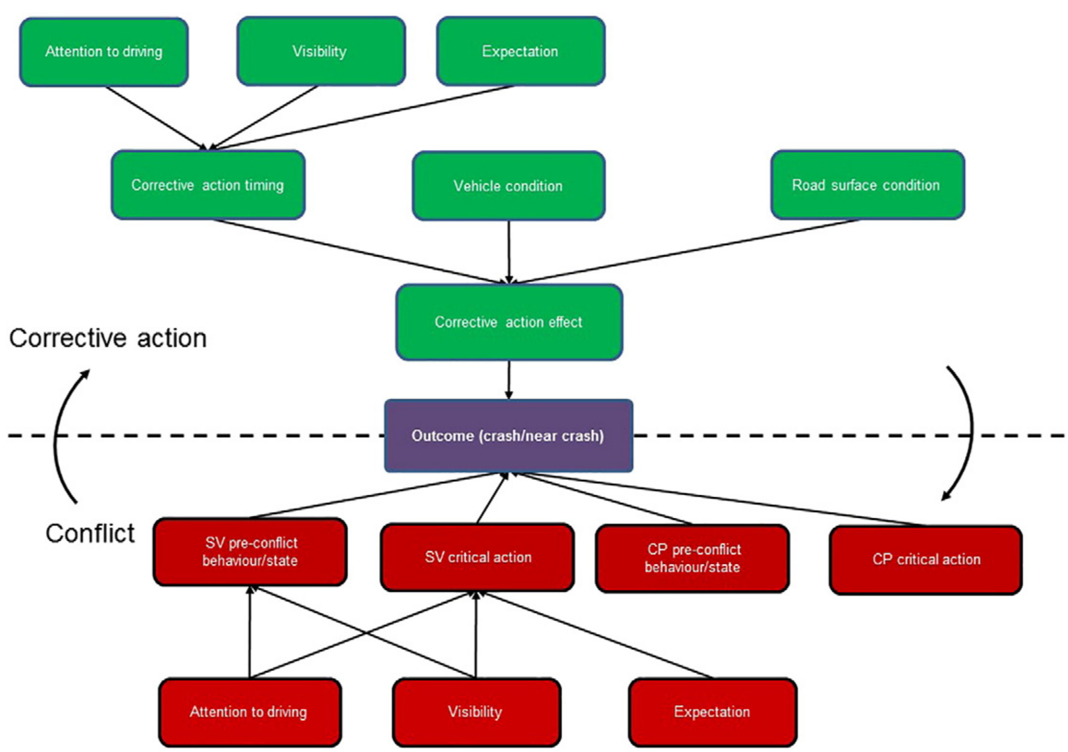

Fig. 1. Template for CANDE coding (SV refers to subject vehicle and CP to conflict partner).

Table 3
CNC and crashes triggered by each driver and corresponding vehicle.

Driver ID	Vehicle type	Number of CNC	Number of crashes
Driver_1	Van	19	2
Driver_2	Van	14	
Driver_3	Light truck	7	1
Driver_4	Van	7	
Driver_5	Van	4	
Driver_6	Van	4	
Driver_7	Light truck	4	1
Driver_8	Van	4	
Driver_9	Light truck	4	1
Driver_10	Light truck	3	1
Driver_11	Van	3	
Driver_12	Light truck	2	
Driver_13	Van	2	
Driver_14	Van	2	
Driver_15	Van	2	
Driver_16	Van	2	
Driver_17	Light truck	1	1
Driver_18	Light truck	1	
Driver_19	Van	1	
Driver_20	Van	1	
Driver_21	Van	1	
Driver_22	Van	1	
Driver_23	Van	1	
Driver_24	Van	1	
Total vans		69	2
Total light trucks		22	5
Total		91	7

3. Results

3.1. Participants of selected events

The 91 rear-end CNC used for the analysis involved 24 of the 37 drivers. 69 CNC (76%) involved participants driving vans, 22 CNC (24%) involved participants driving light trucks and no CNC involved participants driving heavy trucks. The number of CNC and the number of crashes triggered for each driver (and corresponding vehicle type) are reported in Table 3.

3.2. Aggregation of results for crashes and near-crashes

In the 91 rear-end CNC analyzed, there were overall 7 crashes and 84 near-crashes. Figs. 2 and 3 show the aggregation charts resulting from the coding with the CANDE methodology, respectively for only crashes and for crashes and near crashes altogether.

First, for both the 7 crashes and the 91 CNC, the most common pre-conflict behavior/state for the SV relative to the CP was that the SV followed the CP at a (relatively) constant short headway. The headway was coded as "short" if the estimated time gap was below 1.75 s, a criterion based on pre-conflict behaviors recorded in previous studies (Eiríksdóttir, 2016; Victor et al., 2015). However, it should be noted that even shorter headways (below 1 s) were very common. In all the crashes and in the CNC with short headway, the conflict originated with the CP braking, typically due to a stopped or braking vehicle ahead of it. In the other main pre-conflict situation, the SV and the CP were initially driving in different lanes and the conflict was usually induced by the CP suddenly braking or cutting in front of the SV.

Second, the corrective action typically involved controlled braking — in some CNC combined with swerving — at strong (>6 m/s^2) or medium (4–6 m/s^2) deceleration levels. Thus, skidding due to a slippery road surface, or weak deceleration due to malfunctioning brakes, was uncommon in CNC but occurred more often in crashes (notably, in 2 crashes). Moreover, the timing of the corrective action was coded as "normal" (i.e., not delayed or lacking) in 74.7% of the CNC but this percentage dropped to 57.1% for crashes. Finally, for the CNC involving a delayed reaction, the dominant reason was a visual scanning mismatch (e.g., related to mirror checking). Driver distraction did occur, but only to a limited extent and, in

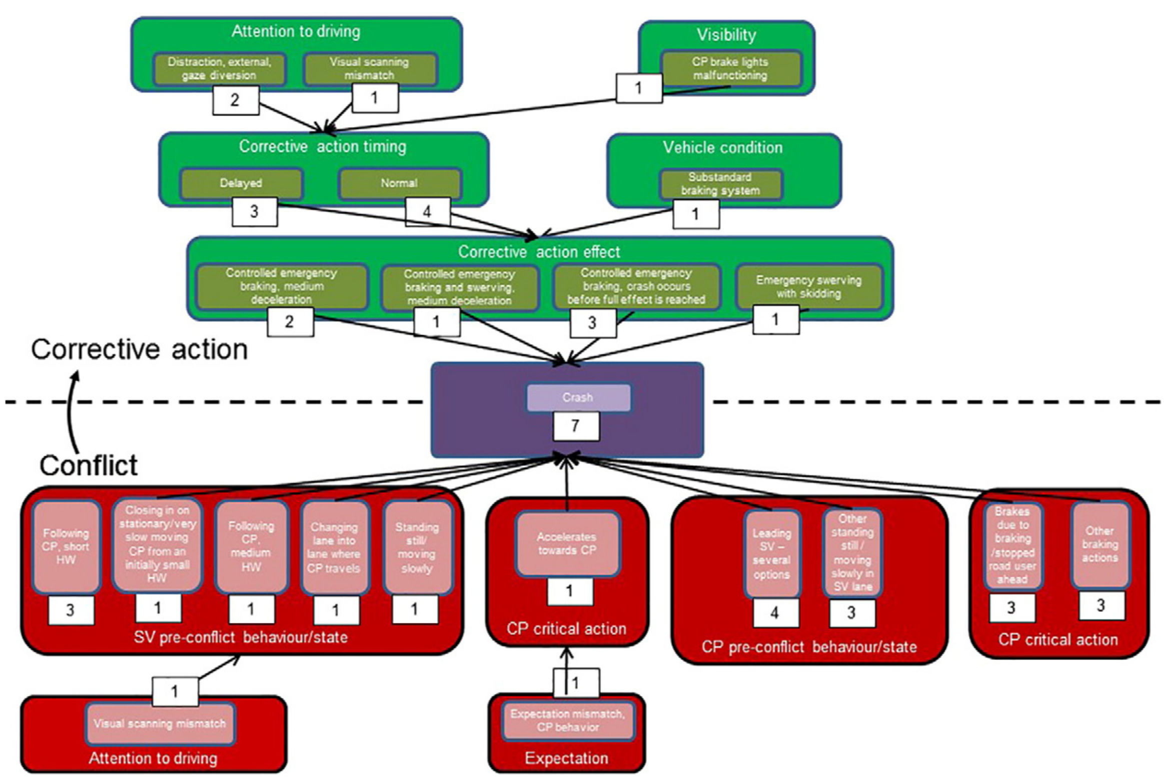

Fig. 2. Aggregation chart for crashes.

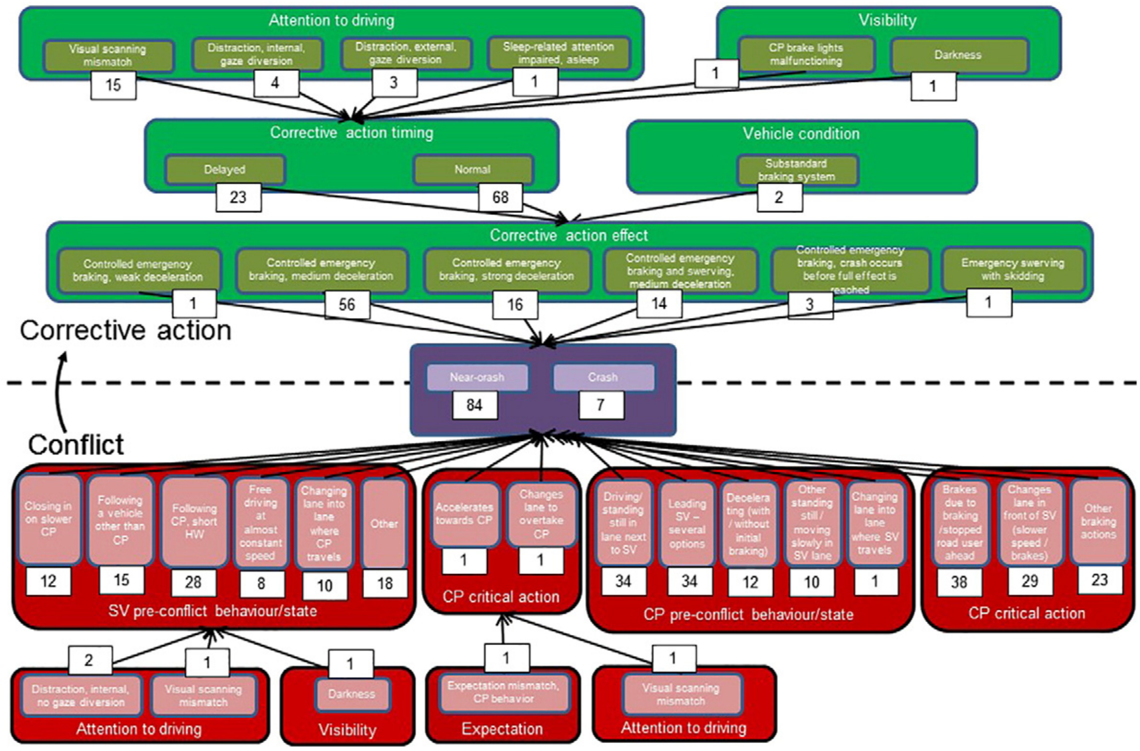

Fig. 3. Aggregation chart for crashes and near-crashes.

particular, in crashes where external distraction with gaze diversion was the main reason for delayed reaction (66.7%). Finally, sleep-related attentional impairment and visibility-related factors were very uncommon.

3.3. Analysis of specific conflict scenarios

Separate analyses were conducted for four common conflict scenarios defined by the kinematic situation and the behavior of the

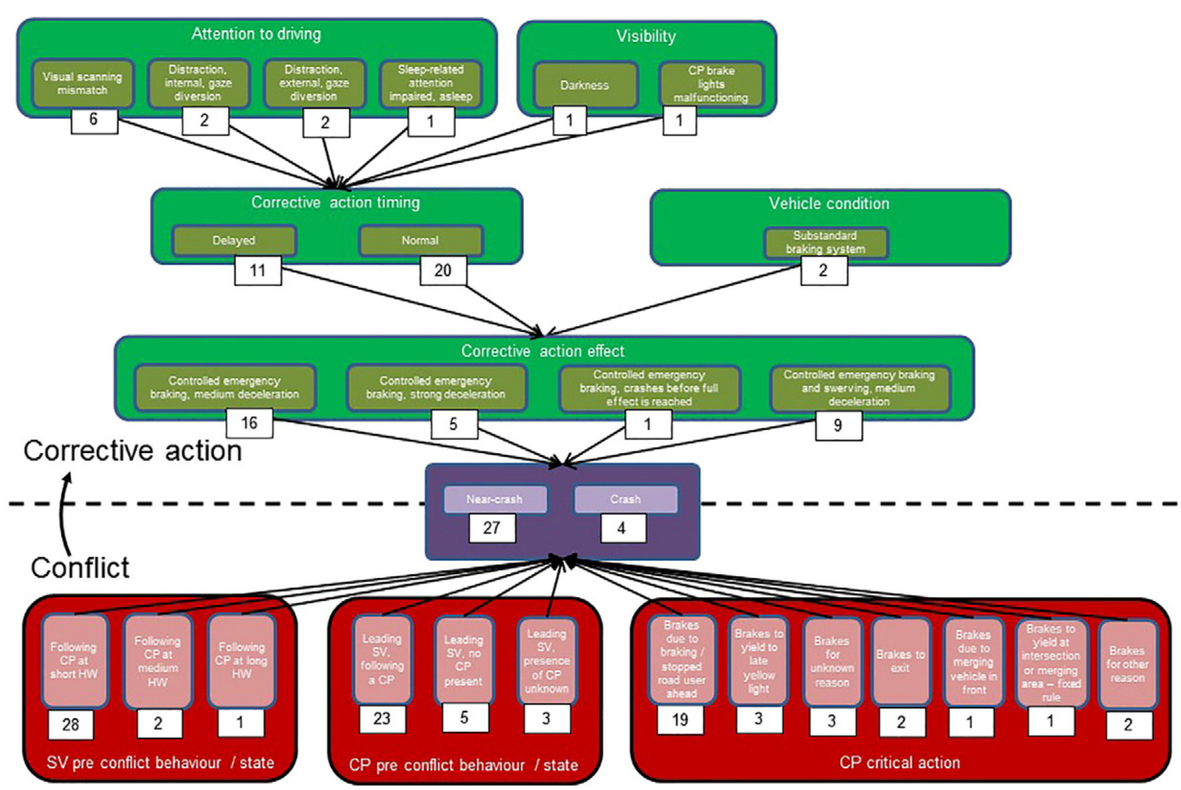

Fig. 4. Aggregation chart for conflict scenario 1 (SV following CP).

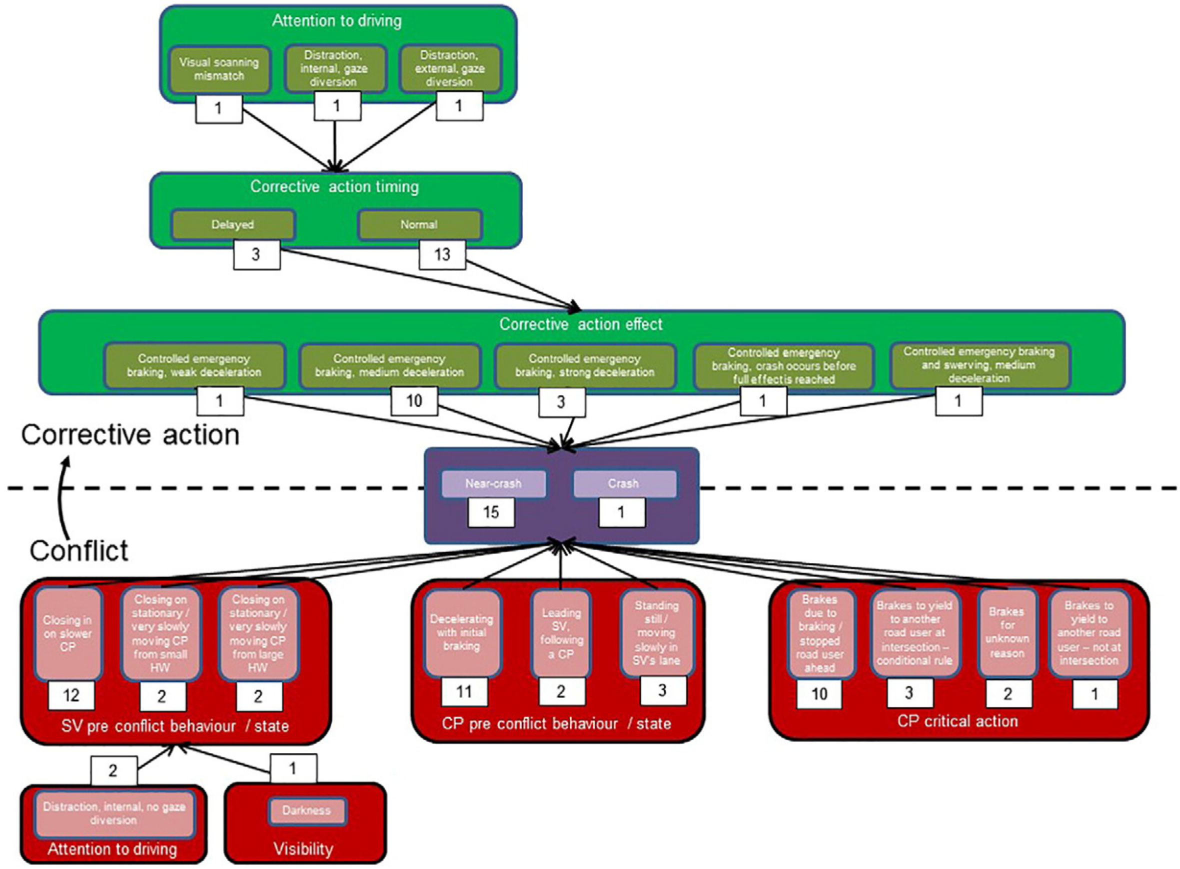

Fig. 5. Aggregation chart for conflict scenario 2 (SV closing in on CP).

SV and CP preceding the crash or near crash. These four scenarios together accounted for 94.5% of the 91 rear-end CNC in the study:

- CS1: SV following CP: 31 CNC (34%; 27 near-crashes and 4 crashes)
- CS2: SV closing in on CP: 16 CNC (18%; 15 near-crashes and 1 crashes)
- CS3: CP cutting in front of SV: 29 CNC (32%; 29 near-crashes and 0 crashes)
- CS4: SV changing lane behind CP: 10 CNC (11%; 9 near-crashes and 1 crash).

3.3.1. CS1: SV following CP

Fig. 4 shows the aggregation chart for conflict scenario 1 (CS1). As can be observed, a clear causation pattern emerges in which the SV follows the CP before the start of the conflict. In a prototypical scenario, the SV initially follows the CP at a short headway while the CP is also following another vehicle; the headway was coded as "short" (<1.75 s) in 87.1% of the CNC and the CP was following another vehicle in 74.2% of the CNC. The CP then typically braked suddenly due to a braking/stopped road user ahead (61.3% of the CNC). In most cases, the SV driver reacted relatively quickly by braking only (71.0% of the CNC) or braking and swerving (29.0%) in a controlled fashion. However, delayed reactions were also relatively common in this scenario (occurring in about one third of the CNC), typically caused by visual scanning mismatches or external/internal visual distraction. Overall, these conflicts typically occurred in dense traffic, with short headways, where the critical situation was induced by a sudden unexpected event ahead (e.g., a vehicle cutting in or a pedestrian entering the road), and the SV driver's reaction was sometimes (but most often not) delayed by the eyes being taken off the forward roadway.

3.3.2. CS2: SV closing in on CP

In this scenario, like CS1, the SV is initially behind the CP, in the same lane. However, here the SV initially closes in on the CP rather than following at a constant headway. In the prototypical case for this scenario, the SV is closing in on a decelerating CP, which then suddenly brakes due to a braking or stopped vehicle ahead. However, a few CNC involve a CP which is leading the SV without braking, or which is stopped/moving slowly before the start of the conflict.

As shown in Fig. 5, the SV driver's corrective reaction typically involves controlled braking (87.5% of the CNC) initiated without a marked delay (delayed reactions were observed in 18.8% of the CNC). Thus, the typical causation mechanism is similar to CS1, where the CP brakes unexpectedly in dense traffic when the SV is following closely. However, one key difference is the lower prevalence of delayed reactions and visual inattention in CS2 (18.8% in CS2 compared to 35.5% in CS1), which may be due to the fact that the driver is closing in on the CP, and thus less likely to take his eyes off the road. Another difference is the lower prevalence of combined braking and swerving (6.3% in CS2 compared to 29.0% in CS1), which may be explained by the fact that the driver generally has better control over the situation, since attention and gaze were initially allocated towards the CP, although the SV driver did not expect it to brake. This may also explain the lower proportion of crashes in this scenario (6.3% in CS2 compared to 12.9% in CS1).

3.3.3. CS3: SV changing lane behind braking SV

The aggregation chart shown in Fig. 6 describes the analysis for conflict scenario 3 (CS3). In the prototypical case, the SV is initially engaged in a lane change with the aim to merge behind the CP, traveling in the adjacent lane, and the CP then brakes suddenly, most often due to a

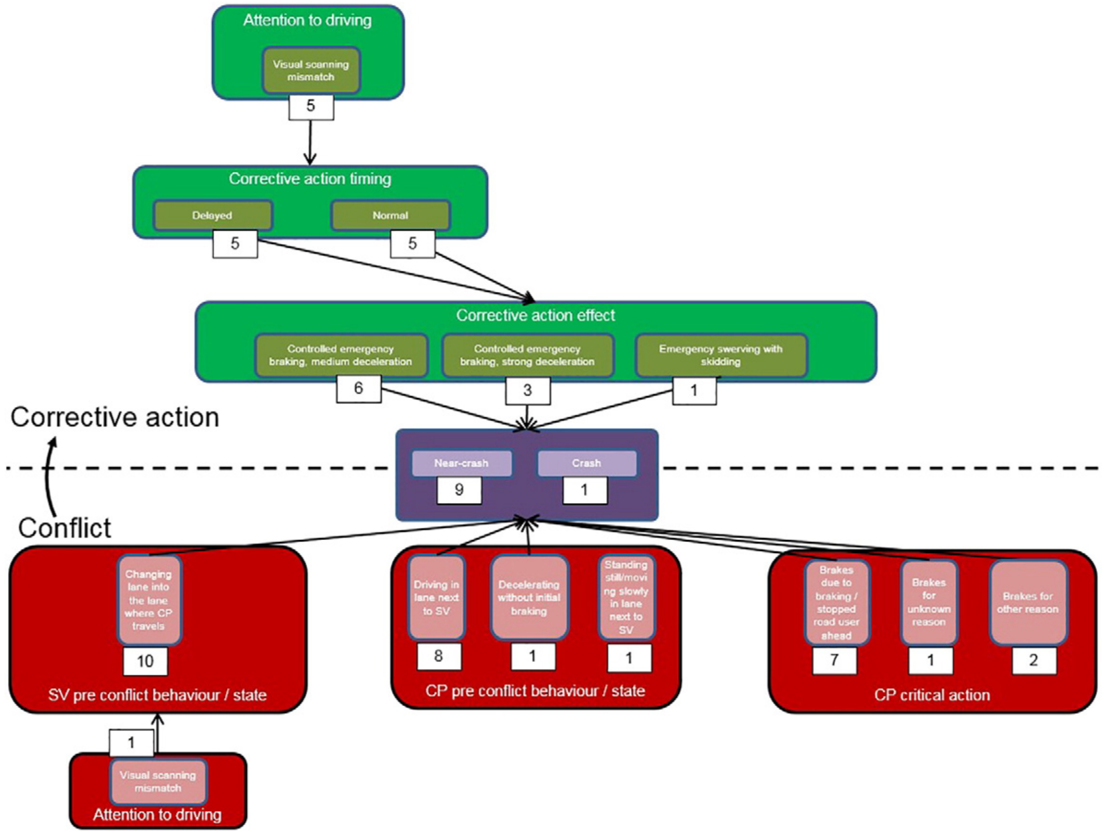

Fig. 6. Aggregation chart for conflict scenario 3 (SV changes lane behind braking CP).

braking or stopped road user ahead. The conflict initiation in CS3 is thus very similar to that in CS2, with the main difference that the SV is changing lanes behind the CP, rather than approaching the CP in the same lane. As in CS2, the corrective action mainly results in controlled braking (90% of the CNC); however, in CS3, delayed reactions occur relatively frequently (50% of the CNC). The delayed reactions were all attributed to visual scanning mismatches, mainly ascribed to the SV driver checking the mirror to perform the lane change.

3.3.4. CS4: CP cutting in front of SV

Fig. 7 displays the aggregation chart for conflict scenario 4 (CS4), in which the CP cuts in front of the SV. An analysis of the pre-conflict behavior indicates that the SV is usually following a vehicle other than the CP (48.3% of the CNC) or driving without a vehicle in front (24.1% of the CNC). The CP usually drives in the lane adjacent to the SV (75.9% of the CNC) before changing lanes in front of it. During the lane change, the CP is typically driving at a slower speed than the SV (75.9% of the CNC) but, in some CNC, the CP also brakes while or after cutting in (24.1% of the CNC).

In the great majority of CNC, the SV driver reacts quickly to the conflict (without a marked delay) by braking. Delayed reactions are uncommon (6.9% of the CNC) and exclusively induced by visual scanning mismatches. Moreover, combined braking and swerving is rare (6.9% of the CNC).

4. Discussion

Event-triggered naturalistic data was collected in Shanghai, using data acquisition units provided by Lytx as part of their behavior-based safety service. Forty-seven vehicles (trucks and vans) were instrumented, belonging to a local commercial fleet. After initial screening, 91 rear-end CNC (84 near-crashes and 7 crashes) were analyzed by 3 researchers, using the CANDE methodology for expert-based causation mechanism analysis based on videos and kinematic variables.

The preliminary descriptive analysis shows that the 91 rear-end CNC were triggered by 24 drivers and, more in detail, that roughly 80% of the CNC were triggered by about 30% of the drivers. Interestingly, this result roughly follows the 80/20 rule or Pareto Principle suggesting that "20% of something always are responsible for 80% of the results" (Reh, 2005). The principle was originally created to describe the unequal distribution of wealth but later applied to other phenomena, including road crashes (Koch, 2011).

The analyses conducted with the CANDE methodology yielded a fairly clear picture of the main causation patterns behind the collected rear-end CNC. In contrast to analyses of US rear-end crashes and near-crashes (Eiríksdóttir, 2016; Engström et al., 2013; Victor et al., 2015), the "perfect mismatch" between an off-road glance and the lead vehicle braking was relatively rare in the current Chinese dataset. As a matter of fact, in the majority of the CNC, the SV driver had his eyes on the road and reacted fast in response to the evolving conflict. When delayed reactions occurred, this was mainly due to driving-related visual scanning mismatches (e.g., mirror checks prior to changing lanes) rather than visual distraction associated to secondary tasks (which was the dominating cause of inattention in both Engström et al., 2013; Victor et al., 2015). It is worth to notice though that delayed reactions were mostly due to external distraction with gaze diversion in the very limited number of crashes available.

The most common factor behind most of the CNC was, then, the adoption of very small safety margins (in terms of short headways or tight cut-ins) combined with the erratic, unpredictable behaviors of other road users. These results confirm the findings of a previous

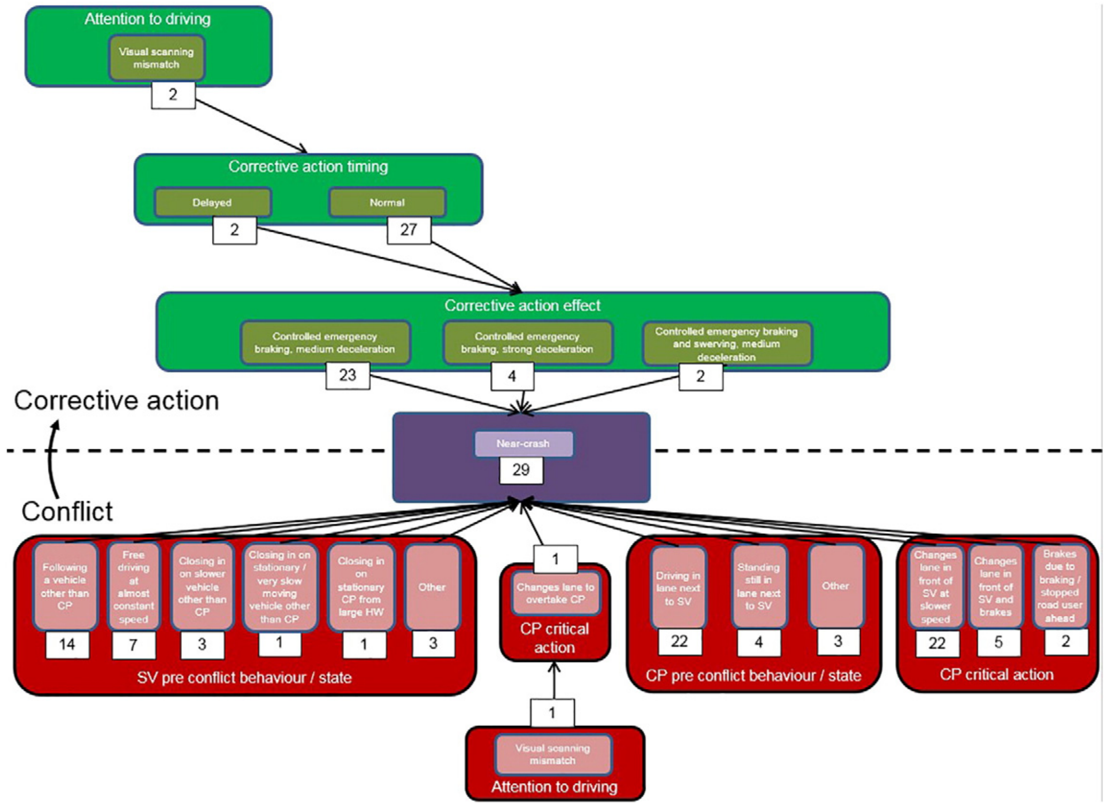

Fig. 7. Aggregation chart for conflict scenario 4 (CP cuts in front of SV).

naturalistic driving study conducted with passenger cars in Beijing (Lin et al., 2008) but differ from the outcome of US data described earlier, where the headway initially adopted by the SV driver before the conflict was typically relatively large. The propensity to adopt small safety margins can be related to the scrambling behaviors (Shi et al., 2011). Although such behaviors were not explicitly coded in the present analysis, it was frequently observed that Chinese drivers typically have to "create space" for themselves by cutting in front or plunging ahead at a T-junction with very small time gaps, thus knowingly creating a kinematic conflict. Such behaviors also appear common among vulnerable road users such as riders of powered two-wheelers, bicyclists, and pedestrians, leading to frequent critical encounters between multiple road users which develop rapidly and are hard to predict. In such a traffic environment, there is little leeway (or spare attentional capacity) for engaging in distracting activities, which is the likely reason for the difference from the US data in this respect. However, the need to scan the road and mirrors inevitably creates situations where drivers take their eyes away from the forward roadway to some extent, and thus become more vulnerable to a suddenly braking lead vehicle.

Thus, it appears that differences in traffic culture between China and US (Atchley et al., 2014) lead to different crash/near-crash causation patterns. In the US, the slower and more predictable traffic dynamics allow drivers to engage in distracting activities while driving, although it leaves them vulnerable to unexpected events occurring during glances away from the road. In contrast, in China drivers have to adopt a more aggressive driving style to create space for themselves in competition with other road users, leading to smaller safety margins and a greater degree of uncertainty in the traffic system as a whole. Chinese drivers (in particular professional drivers) could be expected to have adapted to this situation and thus generally attend to the driving task more than Western drivers. Hence, it seems that, because the Chinese traffic culture requires attentive and vigilant drivers, distracting activities are not the main cause of rear-end crashes and near-crashes. This has important implications for the development of countermeasures, as discussed below.

This study also identified four main conflict scenarios in the development of rear-end conflicts: SV following CP, SV closing in on CP, SV changing lanes behind CP, and CP cutting in front of SV. As reported in a previous study conducted in Beijing with passenger cars (Lin et al., 2008), the scenario in which the SV follows the CP is the most prevalent (34.0% of the CNC in the current study and 52.0% of those in Lin et al., 2008). However, the remaining conflict scenarios cannot easily be compared with those in Lin et al. (2008), due to differences in the methodology used to classify the scenarios: for example, they considered "Turning" to be a specific category for cases when the SV and/or the LV is/are turning left or right, while in this paper, those situations were coded according to the combination of SV and CP pre-conflict behaviors. Furthermore, the relevance of conflict scenarios in which the SV is following or closing in on the CP is shown by the naturalistic data collection conducted in Shanghai by Li, Zhu, and Ma (2014). In their research, the scenario "Following vehicle approaching a decelerating vehicle" was responsible for 20% of all types of near-crashes, not just rear-end near-crashes.

Overall, the results obtained from this research on rear-end crashes and near-crashes could be used to define specifications of in-vehicle safety measures (Kusano & Gabler, 2014; Ljung Aust, 2010) and automated driving (Rau, Yanagisawa, & Najm, 2015) and to design coaching/training procedures to improve driving habits (Sagberg, Selpi, Bianchi Piccinini, & Engström, 2015; Zhang, Yau, & Zhang, 2014). In particular, it is clear from this study that designers of in-vehicle safety measures, autonomous vehicles, and BBS services need to have a different mindset for deployment in China compared to other markets, such as the US. Some more specific suggestions follow.

- *Design of in-vehicle safety measures*: Although this study is focused on rear-end scenarios, several of the findings are probably generalizable to other conflict scenarios as well. In general, it seems unlikely that forward collision warning (FCW) systems will have more than a very minor effect on reducing the number or severity of crashes in China. The role of the warning is to alert drivers to the hazard when they are inattentive, speeding up the corrective action (Kusano & Gabler, 2014). However, in the majority of the present CNC, the driver was already attentive when the conflict started to develop. Moreover, the small safety margins adopted in Chinese traffic would make it difficult to avoid nuisance warnings. On the other hand, automatic emergency braking systems (AEBS) could have a strong benefit, at least for reducing impact speed if the collision cannot be avoided; the effect strongly depends on the initial safety margin. However, it should be taken into account that the small headways adopted in China may increase the risk of being hit harder from behind due to the AEBS' intervention. This also means that countermeasures addressing whiplash injuries (Linder et al., 2013; Svensson, Lövsund, Håland, & Larsson, 1996) may play a more significant role in Chinese traffic than in the US and even more so with AEBS systems on the market. In the near future, computer simulations of the operation of FCW and AEBS in typical Chinese rear-end scenarios could help estimate their potential effectiveness.
- *Design of automated driving*: The results of this study show that Chinese drivers adopt smaller headways compared to Western drivers and that scrambling behaviors are frequent during daily driving. A consequent challenge will be the design of automated vehicles that can guarantee both safety and comfort, given the dynamic Chinese driving environment. If automated vehicles reproduce the scrambling behavior, they might not meet safety requirements. On the other hand, if autonomous vehicles are designed to keep Western safety margins in China, it is unlikely that they would be accepted by Chinese drivers, in particular if automated vehicles are mixed with human-driven vehicles.
- *Education/coaching*: Education and/or regular coaching of drivers based on performance feedback could be very effective in inducing a safer driving style (see Sagberg et al., 2015 for a review). In our Chinese dataset, conflicts seem to be primarily caused by the interaction of small time headways, in some cases combined with short visual diversions from the forward roadway, which are usually related to driving rather than distraction (secondary tasks). A more cautious attitude with larger safety margins (in particular larger headways while following) could lead to a decrease in crashes. If such a behavioral change could be accomplished in a driver fleet, it must be further ensured that the drivers don't exploit this additional safety margin to engage in distracting activities. Nevertheless, for the implementation of BBS measures in China, it should be taken into account that a certain degree of aggressiveness is needed to be able to move forward at all in Chinese traffic.

As in all studies, the current research has some limitations. First of all, no information was available about drivers' skills and attitude towards driving: hence, further studies with Chinese professional drivers (as private drivers) should assess drivers' characteristics to draw broader conclusions.

It is also important to take into account the limited geographical area where the study was conducted: the vehicles included in this study delivered their goods in an area centered around the distribution hub in Shanghai. Caution should be taken in generalizing the results to the whole of China and in comparing the outcome with previous studies conducted in the US, which covered a broader geographical area, including both urban and rural environments. Future studies should be performed in other Chinese cities and in similar road environments in the US to provide a broader dataset for drawing conclusions.

Furthermore, this analysis is primarily based on near-crashes, and the included crashes are of relatively low severity. Although Eiríksdóttir (2016) and Victor et al. (2015) report that the prevalence of eyes-off road is similar for near-crashes and crashes, the overall mechanisms behind near-crashes and crashes are not necessarily the same. In this regard, Knipling (2015) recently challenged the validity of safety-critical events such as near-crashes to draw conclusions about serious crashes. Therefore caution is warranted when comparing the present results with previous ones obtained from US data (Eiríksdóttir, 2016; Engström et al., 2013). For example, it is possible that delayed reactions due to driver inattention would be more prevalent for crashes, as a delayed reaction may be precisely what distinguishes a crash from a near-crash in many situations (Victor et al., 2015). Indeed, delayed reactions due to visual diversion appear relatively more common in the present crashes (compared to the near-crashes), although the sample of crash events is too small to safely draw any conclusions. In any case, extending the present analysis to a larger number of rear-end crashes is clearly necessary to be able to draw firmer conclusions about crash-causation mechanisms. It would also be preferable to have not only low severity crashes, but also the full spectrum of crash severity.

Finally, the present analysis only included rear-end conflicts. Analyzing other event types will give a more comprehensive picture of the causation mechanisms behind Chinese crashes and how they may relate to Chinese traffic culture. In particular, the analysis of conflicts involving pedestrians, bicyclists and motorcyclists will be extremely relevant, considering that they represent the majority of fatalities on Chinese roads.

Acknowledgments

The authors are grateful to Vinnova and the China Sweden Research Centre for Traffic Safety (CTS) for providing funding for the project, to the colleagues at Chalmers for the interesting discussions, to Mia Cheng for the assistance during the management of the project, and to Rusty Weiss and Patrick Huang for their support in collection. The authors would also like to thank Kristina Mayberry for language revision. This work has been carried out at SAFER - Vehicle and Traffic Safety Centre at Chalmers, Sweden.

References

Atchley, P., Shi, J., & Yamamoto, T. (2014). Cultural foundations of safety culture: A comparison of traffic safety culture in China, Japan and the United States. *Transportation Research Part F*, *26*, 317–325.

Avery, M., & Weekes, A. (2009). *Autonomous braking systems and their potential effect on whiplash injury reduction*Proceedings of the21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany (June 15–18, 2009).

Blower, D., & Woodrooffe, J. (2013). *Survey of the status of truck safety: Brazil, China, Australia, and the United States.* (UMTRI-2012-13).

Deng, B., Wang, H., Chen, J., Wang, X., & Chen, X. (2013). *Traffic accidents in Shanghai-general statistics and in-depth analysis*Proceedings of the23rd International Technical Conference on the Enhanced Safety of Vehicles, Seoul, Republic of Korea (May 27–30, 2013).

Eiríksdóttir, H. (2016). *Quantitative analysis of rear-end crash causation mechanisms based on naturalistic crash data.* Master's thesis Göteborg, Sweden: Chalmers University of Technology.

Engström, J., Werneke, J., Bärgman, J., Nguyen, N., & Cook, B. (2013). *Analysis of the role of inattention in road crashes based on naturalistic on-board safety monitoring data*Proceedings of the 3rd International Conference on Driver Distraction and Inattention, Gothenburg, Sweden (September 4–6, 2013).

Habibovic, A., Tivesten, E., Uchida, N., Bärgman, J., & Aust, M. L. (2013). Driver behavior in car-to-pedestrian incidents: An application of the Driving Reliability and Error Analysis Method (DREAM). *Accident Analysis & Prevention*, *50*, 554–565.

Hickman, J. S., & Hanowski, R. J. (2011). Use of a video monitoring approach to reduce at-risk driving behaviors in commercial vehicle operations. *Transportation Research Part F*, *14*(3), 189–198.

Knipling, R. R. (2015). *Naturalistic driving events: No harm, no foul, no validity*Proceedings of 8th International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, Salt Lake City, USA (June 22–25, 2015).

Koch, R. (2011). *The 80/20 principle: The secret to achieving more with less.* Crown Business.

Kusano, K. D., & Gabler, H. C. (2014). Comprehensive target populations for current active safety systems using national crash databases. *Traffic Injury Prevention*, *15*(7), 753–761.

Li, L., Zhu, X., & Ma, Z. (2014). Driver braking behaviour under near-crash scenarios. *International Journal of Vehicle Safety*, *7*(3–4), 374–389.
Lin, Q., Feng, R., Cheng, B., Lai, J., Zhang, H., & Mei, B. (2008). Analysis of causes of rear-end conflicts using naturalistic driving data collected by video drive recorders. *SAE Technical Paper No. 2008-01-0522*.
Linder, A., Schick, S., Hell, W., Svensson, M., Carlsson, A., Lemmen, P., ... Tomasch, E. (2013). ADSEAT—Adaptive seat to reduce neck injuries for female and male occupants. *Accident Analysis & Prevention*, *60*, 334–343.
Ljung Aust, M. (2010). Generalization of case studies in road traffic when defining pre-crash scenarios for active safety function evaluation. *Accident Analysis & Prevention*, *42*(4), 1172–1183.
Ljung Aust, M., Habibovic, A., Tivesten, E., Sander, U., Bärgman, J., & Engström, J. (2012). Manual for DREAM version 3.2. Retrieved from http://publications.lib.chalmers.se/records/fulltext/204828/204828.pdf.
Lytx (2016). DriveCam program. Retrieved from http://www.lytx.com/our-solutions/drivecam-programs.
McGehee, D. V., Raby, M., Carney, C., Lee, J. D., & Reyes, M. L. (2007). Extending parental mentoring using an event-triggered video intervention in rural teen drivers. *Journal of Safety Research*, *38*(2), 215–227.
National Bureau of Statistics of China (2016). Possession of private vehicles. Retrieved from http://www.stats.gov.cn/tjsj/ndsj/2014/zk/html/Z1826E.htm.
Rau, P., Yanagisawa, M., & Najm, W. G. (2015). *Target crash population of automated vehicles*Proceedings of the 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Gothenburg, Sweden (June 8–11, 2015).
Reh, F. J. (2005). Pareto's principle—The 80-20 rule. *Business Credit*, *107*(7), 76.
Sagberg, F., Selpi, Bianchi Piccinini, G. F., & Engström, J. (2015). A review of research on driving styles and road safety. *Human Factors*, *57*(7), 1248–1275.
Shi, J., Bai, Y., Tao, L., & Atchley, P. (2011). A model of Beijing drivers' scrambling behaviors. *Accident Analysis & Prevention*, *43*(4), 1540–1546.
SHRP2 (2016). SHRP2 researcher dictionary for video reduction data. Version 3.4. Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/56719/V4.1_ResearcherDictionary_for_VideoReductionData_COMPLETE_Oct2015_10-5-15.pdf?sequence=1&isAllowed=y.
Siegmund, G. P., Winkelstein, B. A., Ivancic, P. C., Svensson, M. Y., & Vasavada, A. (2009). The anatomy and biomechanics of acute and chronic whiplash injury. *Traffic Injury Prevention*, *10*(2), 101–112.
Simons-Morton, B. G., Bingham, C. R., Ouimet, M. C., Pradhan, A. K., Chen, R., Barretto, A., & Shope, J. T. (2013). The effect on teenage risky driving of feedback from a safety monitoring system: A randomized controlled trial. *Journal of Adolescent Health*, *53*(1), 21–26.
Svensson, Å., & Hydén, C. (2006). Estimating the severity of safety related behaviour. *Accident Analysis & Prevention*, *38*(2), 379–385.
Svensson, M. Y., Lövsund, P., Håland, Y., & Larsson, S. (1996). The influence of seat-back and head-restraint properties on the head-neck motion during rear-impact. *Accident Analysis & Prevention*, *28*(2), 221–227.
Victor, T., Dozza, M., Bärgman, J., Boda, C. N., Engström, J., Flannagan, C., ... Markkula, G. (2015). *Analysis of naturalistic driving study data: SAFER glances, driver inattention, and crash risk SHRP 2 safety project S08.* Washington, DC: Transportation Research Board of the National Academy of Sciences (doi: ISBN: 978-0-309-27423-4. SHRP 2 S08A, from http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-S08A-RW-1.pdf).
Woodrooffe, J., Blower, D., Bao, S., Bogard, S., Flannagan, C., Green, P. E., & LeBlanc, D. (2012). *Performance characterization and safety effectiveness estimates of forward collision avoidance and mitigation systems for medium/heavy commercial vehicles.* (US DOT. UMTRI-2011-36).
Zhang, G., Yau, K. K., & Chen, G. (2013). Risk factors associated with traffic violations and accident severity in China. *Accident Analysis & Prevention*, *59*, 18–25.
Zhang, G., Yau, K. K., & Zhang, X. (2014). Analyzing fault and severity in pedestrian–motor vehicle accidents in China. *Accident Analysis & Prevention*, *73*, 141–150.
Zhang, G., Yau, K. K., Zhang, X., & Li, Y. (2016). Traffic accidents involving fatigue driving and their extent of casualties. *Accident Analysis & Prevention*, *87*, 34–42.

Appendix A. Attribute levels for categorical variables reported in Table 2.

Variable name	Attribute levels
Weather	No adverse conditions
	Fog
	Mist/light rain
	Raining
	Snowing
	Sleeting
	Rain and fog
	Snow/sleet and fog
	Other
	Unknown
Light condition	Dawn
	Daylight
	Dusk
	Darkness, lighted
	Darkness, not lighted
	Unknown
Road surface condition	Dry
	Wet
	Snowy
	Icy
	Muddy
	Sand, oil, dirt
	Gravel
	Other
	Unknown
Number of crashes	0
	1
	2
	3
	4+
Number of near-crashes	0
	1
	2
	3
	4+
Crash/near-crash type	Rear-end, striking
	Rear-end, struck
	Road departure (left or right)
	Road departure (end)
	Sideswipe, same direction (left or right)
	Opposite direction (head-on or sideswipe)
	Straight crossing path
	Turn across path
	Turn into path (same direction)
	Turn into path (opposite direction)
	Backing, fixed object
	Backing into traffic
	Pedestrian-related
	Pedal cyclist-related
	Animal-related
	Other
	Unknown
	None
Visual obstructions	No obstruction
	Rain, snow, fog, smoke, sand, dust
	Reflected glare
	Sunlight
	Headlights
	Curve or hill
	Building, billboard, or other roadway infrastructure design features
	Trees, crops, vegetation
	Moving or stopped vehicle (with or without load)
	Parked vehicle
	Splash or spray of passing vehicle
	Inadequate defrost or defog system
	Inadequate roadway lighting system
	Inadequate vehicle headlamps
	Obstruction interior to vehicle
	Mirrors
	Broken or improperly cleaned windshield
	Other obstruction
	Vision obscured - no details
	Unknown whether vision was obstructed
Evasive maneuver	No driver present
	No reaction
	Braked
	Released brakes
	Steered to left
	Steered to right
	Braked and steered left
	Braked and steered right
	Accelerated
	Accelerated and steered left
	Accelerated and steered right
	Other actions
	Unknown if action was attempted

Appendix A (*continued*)

Variable name	Attribute levels
	Not Applicable
Secondary task	No secondary tasks (or no additional secondary tasks)
	Talking/singing, audience unknown
	Dancing
	Reading
	Writing
	Passenger in adjacent seat - interaction
	Passenger in rear seat - interaction
	Child in adjacent seat - interaction
	Child in rear seat - interaction
	Moving object in vehicle
	Insect in vehicle
	Pet in vehicle
	Object dropped by driver
	Reaching for object, other
	Object in vehicle, other
	Cell phone, holding
	Cell phone, talking/listening, hand-held
	Cell Phone, texting
	Cell Phone, browsing
	Cell Phone, dialing hand-held
	Cell Phone, dialing hand-held using quick keys
	Cell Phone, dialing hands-free using voice-activated software
	Cell Phone, locating/reaching/answering
	Cell phone, other
	Tablet device, locating/reaching
	Tablet device, operating
	Tablet device, viewing
	Tablet device, other
	Adjusting/monitoring climate control
	Adjusting/monitoring radio
	Inserting/retrieving CD (or similar)
	Adjusting/monitoring other devices integral to vehicle
	Looking at previous crash or incident
	Looking at pedestrian
	Looking at animal
	Looking at an object external to the vehicle
	Distracted by construction
	Other external distraction
	Reaching for food-related or drink-related item
	Eating with utensils
	Eating without utensils
	Drinking with lid and straw
	Drinking with lid, no straw
	Drinking with straw, no lid
	Drinking from open container
	Reaching for cigar/cigarette
	Lighting cigar/cigarette
	Smoking cigar/cigarette
	Extinguishing cigar/cigarette
	Reaching for personal body-related item
	Combing/brushing/fixing hair
	Applying make-up
	Shaving
	Brushing/flossing teeth
	Biting nails/cuticles
	Removing/adjusting clothing
	Removing/adjusting jewelry
	Removing/inserting/adjusting contact lenses or glasses
	Other personal hygiene
	Other non-specific internal eye glance
	Other known secondary task
	Unknown type (secondary task present)
	Unknown
Driver drowsiness	Alert
	Slight sleepiness
	Severe sleepiness
	Unknown

Giulio Bianchi Piccinini is appointed as Assistant Professor at Chalmers University of Technology. He obtained his PhD from the Faculty of Engineering of the University of Porto in 2014.

Johan Engström is appointed as Group Leader, Human Factors and Advanced System Testing Group at Virginia Tech Transportation Institute. He obtained his PhD from Chalmers University in 2011.

Jonas Bärgman is appointed as Group Leader, Accident Prevention Group at Chalmers University of Technology. He obtained his PhD from Chalmers University in 2016.

Xuesong Wang is appointed as Professor at Tongji University. He obtained his PhD from the University of Central Florida in 2003.