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Driver behavior in car-to-pedestrian incidents: An application of the Driving Reliability and Error Analysis Method (DREAM)

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ABSTRACT

To develop relevant road safety countermeasures, it is necessary to first obtain an in-depth understanding of how and why safety-critical situations such as incidents, near-crashes, and crashes occur. Video-recordings from naturalistic driving studies provide detailed information on events and circumstances prior to such situations that is difficult to obtain from traditional crash investigations, at least when it comes to the observable driver behavior. This study analyzed causation in 90 video-recordings of car-to-pedestrian incidents captured by onboard cameras in a naturalistic driving study in Japan. The Driving Reliability and Error Analysis Method (DREAM) was modified and used to identify contributing factors and causation patterns in these incidents. Two main causation patterns were found. In intersections, drivers failed to recognize the presence of the conflict pedestrian due to visual obstructions and/or because their attention was allocated towards something other than the conflict pedestrian. In incidents away from intersections, this pattern reoccurred along with another pattern showing that pedestrians often behaved in unexpected ways. These patterns indicate that an interactive advanced driver assistance system (ADAS) able to redirect the driver's attention could have averted many of the intersection incidents, while autonomous systems may be needed away from intersections. Cooperative ADAS may be needed to address issues raised by visual obstructions.

1. Introduction

Road traffic crashes involving pedestrians are frequent and constitute a large fraction of all fatalities and injuries (WHO, 2009). In Sweden, pedestrians accounted for 16% of 319 fatalities that occurred in 2011 (Trafikanalys, 2012). In the United States (US), 12% of 33,808 road users who were killed in 2009 were pedestrians (NHTSA, 2011). The situation is often worse in low industrialized countries. For example, in Mozambique and El Salvador, pedestrians account for over 60% of all fatalities (WHO, 2009). However, the portion of pedestrian fatalities is also high in some industrialized countries. In Japan, pedestrians accounted for 32% of 6639 fatalities that were registered in 2007 (WHO, 2009), for example. Overall, these figures demonstrate an urgent need for countermeasures to enhance the safety of pedestrians.

To design safety countermeasures such as advanced driver assistance systems (ADAS) that support car drivers in avoiding safety-critical situations such as incidents, near-crashes and crashes, it is necessary to first obtain an throughout understanding of how and why these situations occur. Traditionally, data from retrospective crash investigations have been the only available source of information to accommodate this understanding. There are, however, well-recognized problems with quantity and quality of such data. Crash databases containing a large number of cases are usually representative for a specific population, but contain limited information on the sequence of events and circumstances leading up to the crash (Larsen, 2004; Shinar et al., 1983). Similarly, in-depth crash databases that provide rich information on crash causation normally contain a limited number of cases, making generalization of findings difficult (Fleury and Brenac, 2001; Ljung Aust, 2010). Also, such crash data are largely based on retrospective interviews of the involved road users and are thus vulnerable to recall errors and bias (Loftus, 1979).

In contrast, naturalistic driving studies (NDS) provide detailed and reliable information of observable driver behavior that cannot be obtained by using traditional crash data collection methods. In NDS, vehicles are driven in real-life traffic conditions and instrumented with cameras and other sensors that record information about the driver, vehicle, and environment (Dingus et al., 2006a). Usually, NDS capture few crashes and near-crashes but large numbers of incidents. NDS are, accordingly, a rich source of information to study incident causation.

In this study, we explore the use of NDS data to understand the causation of car-to-pedestrian incidents. This is, to our

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knowledge, a topic that has received limited attention in the literature. Authors such as Bromberg et al. (2012) and Werneke and Vollrath (2012) have used driving simulators to analyze causation mechanisms in safety-critical situations involving pedestrians. Habibovic and Davidsson (2011), Lenard and Hill (2004), and Molinero et al. (2008) used in-depth crash investigations to explore the topic of car-to-pedestrian crash causation, while Dingus et al. (2006a) identified a range of contributing factors in car-to-pedestrian incidents based on NDS data. However, the latter did not identify causal relationships between these factors, i.e. causation patterns. Since most critical traffic situations are caused by a combination of behavioral, technological, and environmental factors it is also necessary to understand how these factors relate to each other (Ljung, 2002).

This study analyzed 90 car-to-pedestrian incidents collected in an NDS in Japan. The incidents were collected by using an event-based trigger, and analyzed based on the video-recordings from onboard cameras. To identify and code causation patterns, we used the Driving Reliability and Error Analysis Method (DREAM) (Hollnagel, 1998; Ljung, 2002, 2007; Wallén Warner et al., 2008). Since DREAM was initially formulated for causation analysis based on in-depth crash investigations, some modifications to the method were made to suit the information available in video-recordings of incidents. The study discusses these modifications and the results of applying it to the 90 car-to-pedestrian incidents. The following research questions are addressed:

- What contributing factors and causation patterns can be identified when DREAM is applied to video-recorded incident data?
- Can the car-to-pedestrian incident causation patterns inform the design of ADAS?

2. Method

The car-to-pedestrian incident data, the characteristics of DREAM, the modification of DREAM and its application to the data are described in the following sections.

2.1. Incident data collection and characteristics

The data used in this study were collected in a NDS in Japan, funded by the Japan Automobile Manufacturers Association (JAMA) (Uchida et al., 2010). The data were collected during business trips (e.g., visiting a customer) by a fleet of 60 passenger cars instrumented with data acquisition systems. The cars were owned by one company based in more than 16 urban areas in Japan. Data collection was initiated in September 2006 and completed in December 2008.

The data acquisition system synchronized five video views and data from several other sensors, including GPS position and acceleration. As Fig. 1 shows, the video views were: forward, right-side forward, left-side forward, driver's face and driver's feet. The recordings were stored in AVI file format (720×480 pixels, 30 Hz) with the five views merged in a split-screen image. The recordings also contain audio information collected by a microphone installed inside the car. When and only when a trigger was activated, 40 s of data were stored; 30 s pre-trigger and 10 s post-trigger. The trigger condition was a deceleration of at least 3.5 m/s^2 with an activated brake pedal. The recordings were then manually classified as either "safety relevant" or "safety irrelevant" incidents by an experienced analyst. A safety relevant incident was defined as "a situation in which two or more road users approach each other in space and time to such an extent that it appears likely that their trajectories would intersect if their movements remain unchanged".

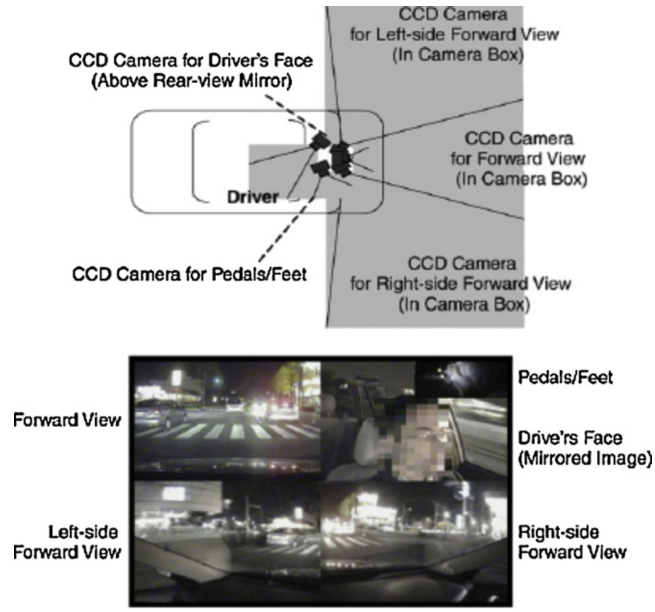

Fig. 1. Data acquisition system showing five video views (Uchida et al., 2010).

This study used a sample of 500 safety relevant incidents of which 95 involved a pedestrian. In 90 of the 95 incidents, the pedestrian was approaching or waiting to cross the roadway. In the remaining five incidents, the pedestrian was walking in the roadway and not intending to cross. These 5 incidents were excluded since they were considered as a unique group of incidents with too few cases to perform a meaningful analysis. The remaining 90 car-to-pedestrian incidents were selected for further analysis.

A total of 45 drivers were involved in the 90 incidents. The most frequent driver was involved in 10 incidents. The age of these drivers ranged from 25 to 55, and only one was female. More than 90% of the incidents occurred in daylight, in clear weather and on dry roads. The vast majority of the incidents also occurred on a city street. Fully 75% occurred at an intersection.

2.2. The DREAM analysis method

2.2.1. Background of DREAM

DREAM (Ljung, 2002) is an adaptation of Hollnagel's (1998) Cognitive Reliability and Error Analysis Method (CREAM) to the domain of traffic safety. The goal of DREAM is to enable identification of contributing patterns in single- and multi-vehicle crashes that can be addressed through interactive ADAS. Accordingly, DREAM posits a set of formally defined contributing factors that provides a structured way of sorting information that explains why an event occurred (Habibovic and Davidsson, 2011; Ljung, 2002, 2007; Ljung Aust, 2010; Ljung et al., 2007; Sandin, 2009; Wallén Warner et al., 2008). DREAM has been revised several times to include new empirical and theoretical findings (Ljung, 2007; Wallén Warner et al., 2008). It was for the first time applied to in-depth investigation of vehicle-to-pedestrian crashes in the European project SafetyNet (Björkman et al., 2008; Habibovic and Davidsson, 2011).

2.2.2. The main characteristics of DREAM

DREAM contains two basic elements: critical events and contributing factors. The critical events capture the observable consequences of the traffic adaptation failure(s) that immediately precede a crash or incident. The critical events are expressed in the physical dimensions of time, space, and energy. Only one critical event is assigned to each road user involved. A critical event can be