ARTICLE IN PRESS

Transportation Research Part F xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part F

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

Curve safe speed model considering driving style based on driver behaviour questionnaire

Zejian Deng, Duanfeng Chu *, Chaozhong Wu, Yi He, Jian Cui

Intelligent Transportation Systems Research Center, Wuhan University of Technology, Wuhan, China
Engineering Research Center for Transportation Safety, Ministry of Education, Wuhan, China

A R T I C L E I N F O

Article history:
Received 31 December 2016
Received in revised form 5 November 2017
Accepted 3 February 2018
Available online xxxx

Keywords:
Vehicle lateral instability
Curve speed model
Driver behaviour questionnaire
Driving style

A B S T R A C T

Inappropriate curve speed influenced by the interactions of driver behaviours, vehicle dynamics and road environments is the dominant cause of vehicle lateral instability induced crashes, like sideslips and rollovers. The present study introduced a driver behaviour influence factor associated with drivers' driving styles comparing to a theoretical curve speed model that only considers the vehicle-road interaction. This factor is defined as the ratio of drivers' actual selected speed to the theoretical curve speed. Aiming at deriving the factor for different driving styles, it was utilized the 28-item Chinese version of Driver Behaviour Questionnaire (DBQ). A correlation analysis between DBQ subscales and the factor indicated that a driver with higher violations scores is prone to drive faster in curve negotiation. Based on this finding, 24 experienced professional drivers were classified into two types, i.e. the moderate and the aggressive, corresponding to their scores on DBQ violations scale. Through a simulation, it showed that the improved curve speed model could not only prevent the risks of rollover and sideslip, but also provided different appropriate curve safe speeds in accordance with drivers' driving styles.

1. Introduction

Road traffic safety is never beyond the range of research in the transportation field. Among various accidents, those happened on curves are companied by the high risk of fatality. According to a recent survey conducted by Chinese government, the fatality rate in curve crashes reached up to 0.8, which is a relative high level compared to 0.3, the average fatality rate among all crashes in 2014 (Chinese Ministry of Public Security, 2015).

Excessive speed is a significant cause of curve crashes (Aguil-Éra & Glaser, 2004). For a fixed curve, there should be a maximum critical speed to maintain the vehicle in a stable status and prevent it from lateral instable incidents like sideslip and rollover. Setting roadside speed limit signs along curves is a common and efficient measure to alert drivers because roadside signs are distinct to recognize, and drivers are familiar to those traffic regulations. However, as environmental conditions change, for example, when the road surface is frozen by ice, the sideslip risk would increase as the road friction coefficient drops considerably. Alternatively, the differences among vehicle types could also greatly influence the safety speed. Thus, the speed limit sign is limited to use by their nonadjustable properties, and may not provide accurate advisory speed for curve negotiation.

* Corresponding author at: Intelligent Transportation Systems Research Center, Wuhan University of Technology, Wuhan, China.
E-mail address: chudf@whut.edu.cn (D. Chu).

https://doi.org/10.1016/j.trf.2018.02.007
1369-8478/

Please cite this article in press as: Deng, Z., et al. Curve safe speed model considering driving style based on driver behaviour questionnaire. *Transportation Research Part F* (2018), https://doi.org/10.1016/j.trf.2018.02.007

Table 1
Cronbach's Alpha scores for DBQ subscales.

Measure	Cronbach's alpha
DBQ errors	0.886
DBQ lapses	0.703
DBQ violations	0.804

The development of Intelligent Transportation Systems (ITS) provides some new idea for solving the curve negotiation issue. One solution to improve the warning accuracy is the vehicle-mounted Curve Speed Warning (CSW) system. Various curve speed models are used in CSW to judge whether a vehicle approaches curves too fast. Generally, models used in CSW should be acceptable by drivers in case of uncooperative driving behaviours. Previous studies have made efforts to deduce the curve speed model focusing on different perspectives including road surface conditions, road geometry features, vehicle dynamics etc. Pratt and Geedipally (2016) designed a framework accounting for the influence of curve geometry and pavement friction. Glaser, Mammar, and Dakhlallah (2008) studied the effect of wind to the vehicle approaching curve roads and found that wind could panic the driver driving light vehicle and result in a lateral drift. For heavy trucks, lateral wind force could be an additional factor triggering rollovers. Vehicle dynamics characteristic is also a significant factor contributing to the lateral stability in a given curve road. Funk, Wirth, Bonugli, Watson, and Asay (2012) proposed a unified pseudo-cylindrical model to describe the translational and rotational vehicle dynamics throughout the rollover sequence. Similarly, Yang (2011) predicted the vehicle static and dynamic rollover threshold by establishing a three-axle vehicle model. Based on the road-vehicle interaction, Glaser et al. proposed an elaborate model that fully considered the road geometry and vehicle parameters for the calculation of the maximum safe speed when approaching an upcoming curve (Glaser, Mammar, & Sentouh, 2010; Lusetti, Nouveliere, Glaser, & Mammar, 2008; Sentouh, Glaser, & Mammar, 2006). The aforementioned studies focus on the impacts that road geometry, vehicle dynamics and environment conditions have on curve speed, which is necessary. However, it is also important to consider the influence of driver behaviour when discussing about the curve safe speed model because driving risks vary in great range when driving behaviours differ.

Inappropriate driver behaviour is also the cause of curve crashes (Jiménez, Liang, & Aparicio, 2012). Few previous researchers paid enough attention to considering human factors to the curve speed model in that the uncertainty and non-linearity of human behaviours are difficult to quantify. In the NextMAP framework, Pandazis (2006) developed a safe-speed profile that introduced the driver parameter corresponding to drivers' comfort lateral acceleration. In addition, a curve warning system designed in the NHTSA guidelines stated that the roadside friction factor should be associated with the driver's desired maximum side force (Pomerleau et al., 1999). Lee et al. integrated three gain factors corresponding to vehicles, roads and drivers into the curve speed model but it was not validated through field experiment (Lee, 2008; Lee & Deng, 2008). Driver factors are included in those models, but as drivers' driving styles vary in broad range, the model parameters corresponding to drivers are not likely to be identical. Even though quite a number of studies on Advanced Driver Assistance Systems (ADAS) have been conducted (Gámez Serna & Ruichek, 2017; Lee & Prabhuswamy, 2013; Park, Lee, & Han, 2015), the majority of them are not able to do further research towards the characteristics of drivers, let alone consider the driving style variations when designing their systems. That unavoidably leads to the underlying safety risks resulted from drivers' rejection and non-cooperation. Besides, the fixed algorithms without considering driver's driving styles do not conform to the concept of intelligent driving.

One important reason for this dissatisfactory actuality is the lack of efficient methods in evaluating drivers' performances and estimating their driving behaviours. Based on the studies of traffic psychology and human behaviour, it is widely accepted that self-report measures like Driver Aggression Indicator Scales (DAIS) (Özkan & Lajunen, 2005; Özkan, Lajunen, Parker, Sümer, & Summala, 2010) and Driver Skill Inventory (DSI) (Lajunen & Summala, 1997; Martinussen, Møller, & Prato, 2014) are effective and reliable to determine drivers' behaviours (Reason, Manstead, Stradling, Baxter, & Campbell, 1990), attitudes (Parker, Stradling, & Manstead, 1996) and traffic safety issues (Maycock, Lockwood, & Lester, 1991; Wells, Tong, Sexton, Grayson, & Jones, 2008). Such scales help to acquire the data on variables that are not easy to be collected through on-board devices.

Driver Behaviour Questionnaire (DBQ) is probably one of the most preferred self-report measures in the road safety research especially in measuring aberrant driving behaviours (Lawton, Parker, Manstead, & Stradling, 1997; Parker, Reason, Manstead, & Stradling, 1995; Parker, West, Stradling, & Manstead, 1995; Reason et al., 1990). Parker, West et al. (1995) established a basic 24-item version of the DBQ, with three subscales: errors, lapses and violations. The errors subscale tends to reflect misjudgments or failures of observation that may cause hazard to other transport users (e.g., on turning right, nearly hit a pedestrian who has come up on one's inside). The lapses subscale reflects absent-minded behaviours but normally do not threaten anyone's safety (e.g., forgetting where one left his/her car in a parking lot). The violations subscale reflects the deliberate contraventions of safe driving practice (e.g., racing away from traffic lights with the purpose of beating the driver next to one). This version of DBQ has been widely used and validated in massive literature (Parker, Mcdonald, Rabbitt, & Sutcliffe, 2000; Reimer et al., 2005; Stephens & Groeger, 2009; Wåhlberg, Barraclough, & Freeman, 2015).

One reason for the popularity of DBQ is the close relationships between DBQ scores and accidents involvement. In the studies concerning traffic safety, the violations subscale has attracted most researchers among these three factors mainly

Please cite this article in press as: Deng, Z., et al. Curve safe speed model considering driving style based on driver behaviour questionnaire. *Transportation Research Part F* (2018), https://doi.org/10.1016/j.trf.2018.02.007