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Calibration and validation of a new time-based surrogate safety measure using fuzzy inference system

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ABSTRACT

Surrogate safety measures (SSM) are suitable tools to detect dangerous situations. These indicators can be applied as a warning strategy in collision avoidance systems (CAS). Time-to-collision (TTC) and post-encroachment time (PET) are two important time-based SSM that identify the probability of a rear-end collision. TTC refers to the imminent danger, and PET implies the potential danger. However, sometimes the results from each indicator are inconsistent. An appropriate warning strategy for CAS can be developed using a new index that combines the properties of both TTC and PET. For this purpose, a new mixed index (MI) is proposed. In order to develop this MI, three main microscopic parameters, clearance, speed and the relative speed, are simultaneously applied to the leading vehicle. To calibrate MI, based on a fuzzy inference system (FIS), a value would be determined by a combination of TTC and PET at each instant and then by regression analysis the model parameters would be determined. Finally, MI, TTC and PET values for real car-following scenarios on the I-80 freeway are determined and compared. The results show that MI may be more suitable in detecting the rear-end collision risk within the proper time and with less errors.

1. Introduction

Traffic accidents are undesirable events which lead to death, injury, or property damage. Each year, a great amount of a country's wealth is wasted due to road crashes. Accidents occur when a series of unfavorable factors occur. Therefore, if just one of these factors did not exist, then a collision may be avoided (Chin and Quek, 1997). Human error, influence and behavior are main contributing factors in crash occurrences. So reducing drivers' dominance during driving task, then it can be expected that many accidents can be avoided.

According to the National Highway Traffic Safety Administration, approximately 30,000 people each year are killed in

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the USA motor vehicle crashes, among which about 30 percent of accidents are due to rear-end collisions (Lee et al., 2007). Rear-end collisions occur in car-following situations when the following vehicle's speed is greater than that of the leading vehicle and when the clearance between vehicles is small (Behbahani et al., 2014, 2015). Driver inattention in maintaining proper distance behind the leading vehicle is the main cause of such accidents (Ben-Yaakov et al., 2002). Previous research indicates that usually drivers tend to overestimate safety during car-following situations (Taieb-Maimon and Shinar, 2001). Applying new technologies to reduce human errors and their influence on adverse mental or physical conditions can be a great step to decrease rear-end collisions on freeways.

Nowadays, car-manufacturers aim to develop intelligent vehicles with advanced driver assistance systems (ADAS), which help reduce driver errors. One of the main categories of ADAS is related to collision avoidance systems (CAS). CAS are built to collisions with enough time to alert the driver for an immediate reaction to avoid the collision. Also, the system errors must be as least as possible, since it might be disturbing for drivers during an interval. Thus, a proper warning strategy must be defined for an effective CAS (Ben Yaakov et al., 2002; Van Der Horst and Hogema, 1993).

Surrogate safety measures (SSM) are suitable criteria for defining CAS. SSM are indicators of evasive maneuvers, and, if properly defined, are suitable tools in detecting dangerous situations. (Archer, 2005; Barcelo et al., 2003; Cunto, 2008; Garber and Gousios, 2009; Gettman and Head, 2003; Sobhani et al., 2013; Young et al., 2014). SSM have been developed based on the motion characteristics of vehicles. Until now, different safety indicators have been developed, and examples are time-to-collision (TTC), post-encroachment time (PET), unsafe density (UD), deceleration rate to avoid collision (DRAC), proportion of stopping distance (PSD), gap time (GT), comprehensive time-based measure (CTM), rear-end collision probability (RECP), etc. (Hayward, 1971; Allen et al., 1978; Archer 2005; Barcelo et al., 2003; Behbahani et al., 2014, 2015; Cooper, 1983; Cunto, 2008; Minderhoud and Bovy, 2001).

Most of the SSM above mentioned relate to rear-end collisions. For rear-end collisions, TTC and PET are two efficient indicators in discriminating between critical and normal occasions (Vogel, 2003; Ben-Yaakov et al., 2002; Van Der Horst and Hogema, 1993; Oh et al., 2009). TTC and PET can convert distance between vehicles into time. However, the results obtained from these measures are sometimes inconsistent, hence making a decision would be difficult (Vogel, 2003). Applying PET and TTC simultaneously in CAS as a warning strategy may help to increase the system's reliability and efficiency. This paper develops a new model which includes both characteristics of TTC and PET. The model is also calibrated based on fuzzy inference system (FIS).

2. Literature review

In this section, the most important surrogate safety measures (SSM) are reviewed. Then two time-based measures are selected as the target indicators for analysis.

2.1. Time-to-collision (TTC)

TTC can be applied to different types of conflicts such as rear-end, head-on and right-angle collisions (Minderhoud and Bovy, 2001).

For read-end conflicts TTC can be computed as Eq. (1) (Minderhoud and Bovy, 2001).

$$TTC = \frac{X_L - X_F - l_L}{v_F - v_L} \quad (1)$$

where X_L is the leading vehicle position, X_F is the following vehicle position, v_L is leading vehicle speed, v_F is the following vehicle speed, l_L is the vehicle length.

Various improvements have been proposed for TTC, among which are the introductions of modified TTC (MTTC) (Ozbay et al., 2008), generalized formulations of TTC (Saffarzadeh et al., 2013), developments of an inverse time-to-collision (Kiefer et al., 2005), and TTC with respect to a moving line section and a point (Laureshyn et al., 2010).

For simplicity, this paper deals with the conventional definition presented in Eq. (1) (Minderhoud and Bovy, 2001).

2.2. Post-encroachment time (PET)

PET is the difference between the time a vehicle enters a conflict point (t_2) until the time another vehicle arrives to this

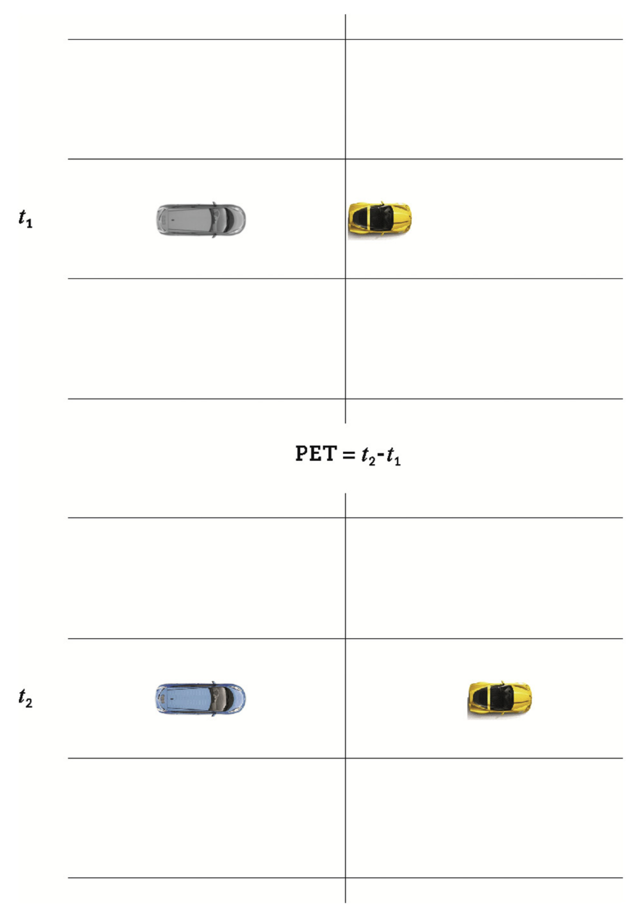

Fig. 1 – Schematic outline of post-encroachment time on a highway.