Human Centered Design of a Pre-collision System

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Abstract. Human error such as distraction and inattention while driving is one of the major causes of the rear-end collisions. In order to help reduce those accidents, a pre-collision system (PCS) has been developed and spread. A PCS basically consists of the warning, the brake-assist, and the autonomous brake functions. The total effectiveness of the system depends on not only the autonomous brake performance but also the driver's reaction to the warning and the braking maneuver. Earlier activation timing can make the system more effective in terms of collision mitigation/avoidance; however, the drivers may feel nuisance if the timing is too early. Thus, human factors issue should be considered in designing and evaluating a PCS. This paper describesthe human-centered design of a PCS from object recognition to the effectiveness estimation method.

Keywords: Pre-Collision System, Perceptual Risk Estimate, Safety Impact Methodology.

1 Introduction

Rear-end collision is one of the major accident types in many countries (Fig. 1). It was reported that more than 60% of the rear-end collisions were caused by such human errors as distraction and inattention [1]. In order to help reduce those accidents, a pre-collision system (PCS) has been developed and spread [2, 3].

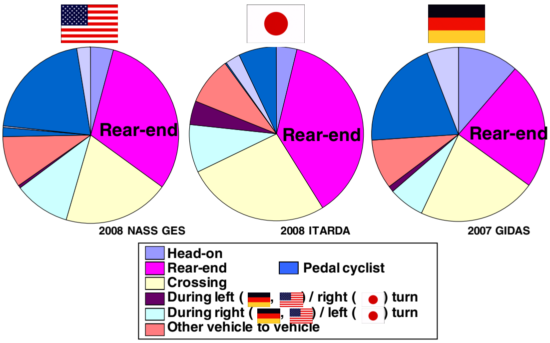

Fig. 1. Accident types in the US, Japan, and Germany

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A PCS basically consists of a forward sensing system, brake control system, and electronic control unit (ECU) to determine activation timing based on the information from the frontal sensor (Fig. 2).

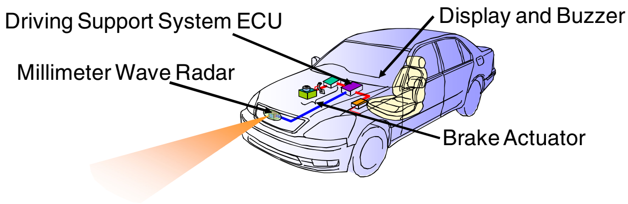

Fig. 2. A basic PCS configuration

A basic PCS is defined as having three functions: 1. warning, 2. brake assist, and 3. autonomous braking (Fig. 3).

1. Warning: The warning will be provided by using a display device and buzzers when the system determines the increase of collision risk to the obstacle in front of the vehicle. The warning is expected to trigger the driver's action for collision mitigation or avoidance.
2. Pre-collision Brake Assist (PBA): A conventional Brake Assist (BA) system boosts the braking force when the brake pedal is hit rapidly, whereas the PBA is immediately activated to supplement driver's braking force to reduce the collision speed or avoid collision once the PCS determines that a collision is probable.
3. Pre-collision Brake (PB): When the system determines collision is highly possible or unavoidable, autonomous braking (PB) is activated to decelerate the vehicle regardless of driver's operation. PB can work together with PBA.

Advanced PCSs have more features and functionalities such as pedestrian detection and driver monitoring functions.

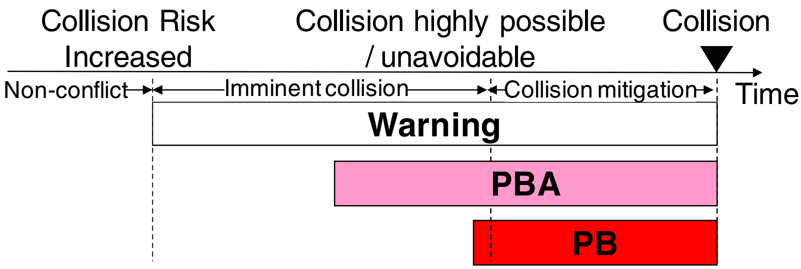

Fig. 3. Functions of a basic PCS

In the advanced driver assistance systems, one might imagine that the warning to the driver would be unnecessary if any rear-end collision was avoidable by the autonomous braking. However, due to the characteristic of the braking and steering avoidance maneuvers as described in the next chapter, the driver's steering avoidance maneuver could be intervened by the autonomous braking in a certain velocity area. Thus, human factors of the driving maneuvers should be considered in order to help mitigate/avoid rear-end collisions without intervention. The next chapter deals with the human-centered design of a PCS.

2 Human Centered Design of a PCS

2.1 The Relation between Braking and Steering Avoidance Maneuvers

The relation between braking and steering avoidance maneuver timing has been studied previously [4, 5, 6].It was found that the braking avoidance maneuver timing is later than the steering one in low relative velocity between the preceding and subject vehicles, therefore, the autonomous braking will not intervene in the driver's steering avoidance maneuver (Fig. 4). In fact, the autonomous braking system works in low velocity without any notice to the driver in advance is commercially available recently.

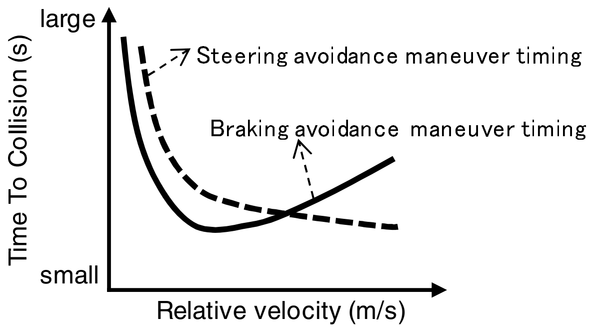

Fig. 4. Steering and braking avoidance maneuver timings

On the other hand, the avoidance maneuver timing of braking is earlier than that of steering in high relative velocity. Rear-end collisions cannot always be avoidable by the autonomous braking if you care about the intervention in the driver's steering maneuver when the relative lateral movement occurs between the preceding and subject vehicles; e.g., the faster subject vehicle overtakes the slower preceding vehicle or the subject vehicle turns whereas the preceding vehicle stops at the intersection [7]. Thus, the characteristics of steering and braking maneuvers should be considered for the object recognition, warning, PBA, and PB functions.

2.2 Object Recognition

A PCS has to determine a preceding vehicle or obstacles in front of the subject vehicle with a front-mounted sensor such as a millimeter-wave radar or a camera. As described in the previous section, it is necessary to consider the characteristic of the braking and steering avoidance maneuver for object recognition.

For a preceding vehicle, a driver usually keeps some distance; distance for reaction and deceleration, and headway offset. For obstacles outside the path (e.g., guardrails and poles), however, the driver only keeps distance to avoid them by steering maneuver. Object detection can be done by judging the subject vehicle's velocity, steering angle, yaw rate, and/or lane/object recognition.

Figure 5 shows an example of the object recognition based on the lateral acceleration (Gy). A PCS can be activate for the objects within the "keep out" zone during the normal driving.

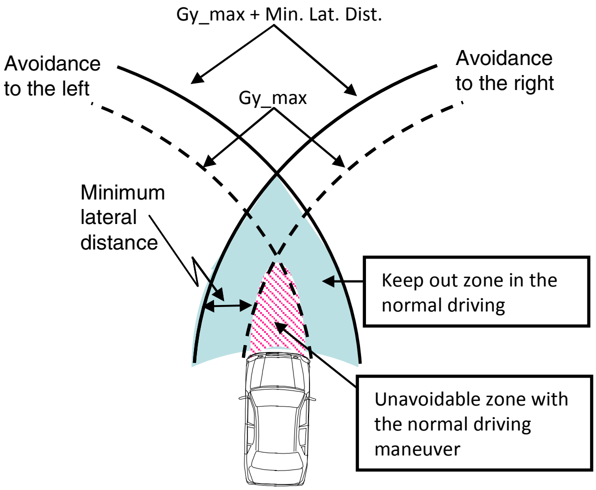

Fig. 5. Example of the object recognition by the lateral acceleration

2.3 Warning

Earlier the warning can be given, more effective the system can be. However, too early warning may cause a nuisance because the driver may not feel any avoidance maneuver is necessary at the timing. The system will be acceptable without nuisance if the system can estimate the driver's state/intention towards driving.

Hattori et al. [8] developed a warning system that utilizes driver's facial direction. The warning timing will become earlier when the system detects the driver looking aside for a certain period. Later, the system has evolved to detect the eyelid movement [9]. The system covers the situation when the driver closes their eyes due to drowsiness even though the facial direction is straight ahead.

It is assumed that drivers usually judge their braking avoidance maneuver timing based onthe perceptual proximity risk. Drivers' state can also be estimated by their braking avoidance maneuver timing if there is a useful index to show the perceptual proximity risk.

Aoki et al.[10] have developed an index of the driver's Perceptual Risk Estimate (PRE) of longitudinal direction (1).

$$\frac{Vr + \alpha Vs + \beta(Ap + Af)}{D^n} = \mathrm{P}RE \tag{1}$$

Where,

D: Relative distance(m)
n: Perceptual scaling of distance
Vs: Subject Vehicle speed (m/s)
Vr: Relative velocity (m/s)
Ap: Acceleration of lead vehicle (m/s2)
Af: Estimated deceleration (m/s2)
α: Sensitivity to subject vehicle speed
β: Sensitivity to deceleration (s)
PRE: Perception risk estimate

The index is formulated as "perceptual relative velocity" divided by "perceptual distance." Both elements are corrected from their physical value so as to reflect their perceptual magnitude. The model was evaluatedon the proving ground andalso on the public road. It was found that drivers' brake timings were well matched to the model; subjects braked when the proposed index reached a certain threshold. Thus, the PRE was tested asa PCS warning and found that it can distinguish nuisance alarm (false positive) and correct alarm (true positive) (Fig. 6).

It is indicated by the previous studies that the normal maneuver timing varies by the driver and the environment [11, 12].Such differences between/within the driver should also be considered for designing a receptive system. A method to predict the car-following tendency by such parameters as the throttle-pedal released timing and the braking timing is proposed to adjust the warning timing [13].

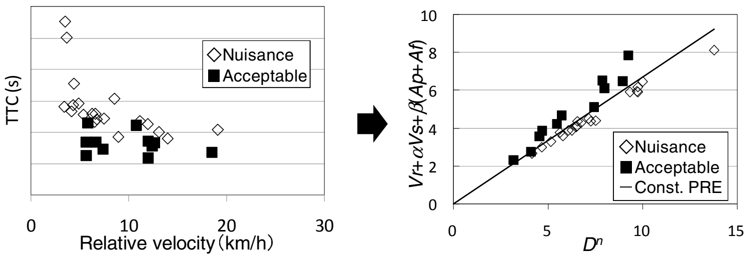

Fig. 6. Distinction between nuisance and acceptable warning by PRE

2.4 Brake Assist

Similar to the warning, the brake assist timing and the assist force should also be designed not to disturb or give incongruous brake feeling to the driver. The brake assist force can be determined by the timing after the warning is given, the speed when the brake pedal is depressed, and the time to collision (Fig. 7).

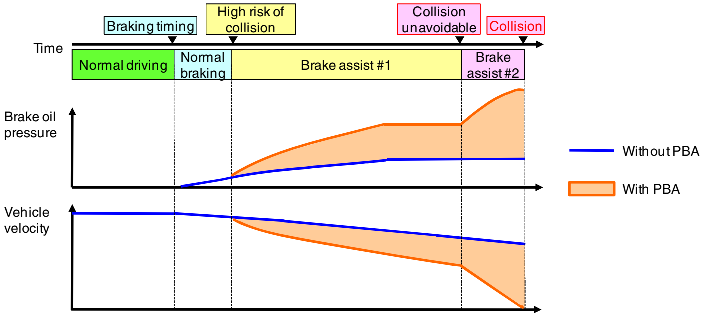

Fig. 7. Diagram of the Pre-collision Brake Assist (PBA) function

2.5 Autonomous Brake

Autonomous brake is like a double-edged sword: early correct brake will decrease much vehicle speed, i.e., collision impact or chance to avoid collision. However, the driver and even the driver in the following vehicle may be surprised if false brake is applied. Considering such a situation, autonomous brake is often initiated by the partial braking, followed by the full braking based on the proximity to the preceding vehicle. The partial braking also helps enhance the steering effort to avoid obstacles in front of the vehicle by the downward load on the front tires.

3 PCS Effectiveness Estimation

Since the benefit of each function is influenced by drivers' reaction before collision, it is difficult to estimate quantitative effectiveness of the PCS. Such drivers' reaction as the response time to the warning and the braking force by the drivers has been taken into account in the recent studies for the effectiveness estimation of a PCS [14, 15, 16].

Aoki et al. [14] proposed a safety impact methodology for the effectiveness estimation of a PCS by utilizing drivers' reaction obtained by the driving simulator (DS) test and Event Data Recorder (EDR) data.

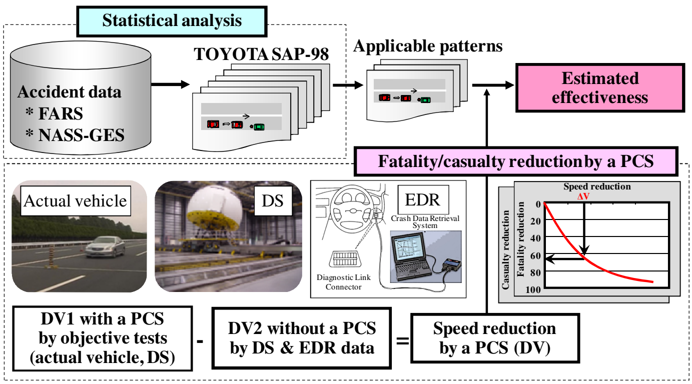

Fig. 8. Toyota-SIM for the PCS effectiveness estimation

The effectiveness can be estimated by comparing the speed reduction with and without a PCS. The speed reaction WITH a PCS was estimated by drivers' maneuvering data for rear-endcollision scenario of a DS test. A vehicle brake model measured on the proving ground and a PCS function model was numerically applied to the DS data. On the other hand, the speed reaction WITHOUT a PCS was estimated by the drivers' maneuver obtained by actual accident from EDR data. By changing the parameters of the PCS model, this method enables us to examine the influence of the system parameters on the effectiveness quantitatively.

4 Conclusion

In order to enhance the effectiveness of advanced driver assistance systems with drivers' acceptance, it is important to consider the system without disturbing their maneuvers. In this paper, we described human aspects for designing and evaluating a PCS as an example. Rear-end collision is one of the simplest form of traffic accidents. There are still a lot of human factors issues to be studied towards minimizing traffic accidents, injuries, and fatalities in the future.

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