A Comparison of Probabilistic and Deterministic Collision Risk Assessment Algorithms for Rear-end Collision Prevention

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I. INTRODUCTION

The inclusion of active safety systems, such as Autonomous Emergency Braking (AEB) and Forward Collision Warning System (FCWS), in modern vehicles is expected to reduce the number and severity of road collisions. [1] In order to avoid or mitigate the collision, active safety systems should be able to predict the collision before it happens, using environmental sensor information. Time-to-collision (TTC) and the Warning Index are commonly used to represent the risk of rear-end collision [2-3]. Modified versions of these deterministic approaches are also proposed [4-5]. Probabilistic risk assessment was proposed by Kim *et al.,* which is designed to assess the risk of collision in various scenarios, such as lane change (LC) or multi-vehicle crashes [6-8].

The probabilistic risk assessment was designed to present the risk of collision in general situations. Therefore, its performance should be evaluated in rear-end collision scenarios compared to the existing approaches, such as TTC. This paper proposes to compare probabilistic and deterministic risk assessment algorithms in rear-end collision scenarios, especially collision probability-based risk assessment strategy as compared with TTC-based risk assessment, which are the two most typical deterministic risk assessments. For this study, rear-end collision scenarios with the vehicle equipped with AEB is simulated using vehicle simulation software, CARSIM and MATLAB/Simulink.

II. METHODS

In this section, definitions and characteristics of deterministic and probabilistic risk assessment algorithms are explained briefly.

Deterministic risk assessment: time-to-collision (TTC)

TTC is the most common index for the collision risk assessment in rear-end collision scenarios. It can be defined as follows:

$$TTC = \frac{c}{v_{rel}}, \tag{1}$$

where c and v_{rel} are clearance and relative velocity between subject and preceding vehicle. Although there are modified risk indices, such as perceptual risk estimate, modified TTC or several other indices, TTC is used as the reference because of its representability [4-5], [7-8].

Probabilistic risk assessment: collision probability-based risk assessment

Kim *et al.* present the probabilistic risk assessment algorithm based on the collision probability [6]. They estimated the state of subject and preceding vehicle using Extended Kalman Filter (EKF) and interacting multiple model (IMM) approach, and predicted the vehicle's possible behaviour, including its uncertainties. Using these state and uncertainty data, they generated the particles that represent the probabilistic states of subject and preceding vehicle. Using these particles, they checked the existence of intersection between each particle of subject and preceding vehicle. Using this information, they then calculated the collision probability and used it as an index of the risk of collision [6].

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III. INITIAL FINDINGS

Deterministic risk assessments have the advantage of being easy to understand and calculate. However, they were designed only for rear-end collision scenarios, without uncertainty consideration. On the other hand, the probabilistic risk assessment of Kim *et al.* is designed to assess the risk of collision in various scenarios, which is not possible for TTC. In order to use the probabilistic risk assessment instead of the deterministic approaches, its performance in rear-end collisions should be evaluated by comparison with the deterministic approaches.

To evaluate the performance of these risk assessment algorithms, simulation of AEB algorithm based on TTC was conducted in rear-end collision scenarios using vehicle simulation software, CARSIM and MATLAB/Simulink.

The simulation result is presented in Fig. 1. As shown in Fig. 1(a), collision probability can be represented as a risk map on predicted time versus time plane. The lower boundary of the risky region shows similar tendency with the time history of TTC. However, TTC remains in the dangerous region longer than the lower boundary of risky region on the risk map. At this moment, the risk of collision is already decreasing due to the deceleration of the subject vehicle. This shows that the collision probability-based approach assesses the risk of collision as well as TTC, taking into consideration the acceleration of the vehicles.

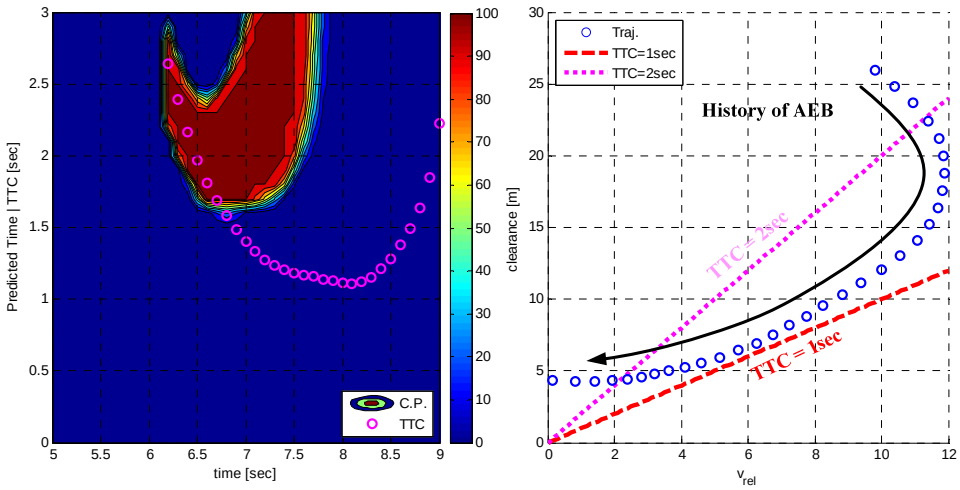

Fig. 1. Schematic view of collision probability-based risk assessment: (a) Collision Probability and TTC for rear-end collision; (b) history of AEB in relative velocity-clearance plane.

IV. DISCUSSION

As mentioned above, in order to use the probabilistic risk assessment instead of the deterministic approaches, its performance should be evaluated in rear-end collision scenarios by comparison with the deterministic approaches. In this paper, collision probability-based risk assessment is compared with TTC. This probabilistic risk assessment shows better performance due to the prediction model, which takes into account acceleration of the vehicle. Since probabilistic risk assessment can also assess the risk of collision in complex scenarios, it is expected to be used for general active safety systems. In this paper, collision probability-based risk assessment is only compared with TTC, but for general comparison of the characteristics of probabilistic and deterministic risk assessment, several assessment algorithms and additional scenarios should be added for more reliable comparison.

V. REFERENCES

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