

Method to Optimize Key Parameters and Effectiveness Evaluation of the AEB System Based on Rear-End Collision Accidents

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ABSTRACT

Rear-end accident is one of the most important collision modes in China, which often leads to severe accident consequences due to the high collision velocity. Autonomous Emergency Braking (AEB) system could perform emergency brake automatically in dangerous situation and mitigate the consequence. This study focused on the analysis of the rear-end accidents in China in order to discuss about the parameters of Time-to-Collision (TTC) and the comprehensive evaluation of typical AEB. A sample of 84 accidents was in-depth investigated and reconstructed, providing a comprehensive set of data describing the pre-crash matrix. Each accident in this sample is modeled numerically by the simulation tool PC-Crash. In parallel, a model representing the function of an AEB system has been established. This AEB system applies partial braking when the $TTC \leq TTC1$ and full braking when the $TTC \leq TTC2$. Lastly, the AEB system's model is coupled to the kinematic of the vehicle in simulation for virtual trajectories preceding the collision point to evaluate the potential effectiveness of different combinations of TTC according to the collision velocity reduction effectiveness and the excessive avoidance performance. After the simulations of 4284 run with 51 combination of the parameters based on 84 accidents, the results show that among the four desirable combinations, $TTC1 = 1.0$ s and $TTC2 = 0.6$ s is suitable for collision avoidance while $TTC1 = 0.9$ s and $TTC2 = 0.5$ s has satisfactory excessive collision avoidance.

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INTRODUCTION

In China, with the growth of economy and the improvement of people's living quantity, the automobile industry has been rapidly developed. However, the accompanying automobile safety problems cannot be ignored. Although automotive safety technology has achieved continuous development and evolution, and that the average annual death toll of road traffic accidents in China is gradually declining in recent years, there are still 58,523 people died of traffic accidents injuries in 2014. China has become one of the countries with the highest traffic fatality rate in the world [1]. Rear-end accident is one of the most frequent collisions between vehicles in the road traffic accidents right after side impact and head-on collision. Moreover, it is the most frequent collision form that happens on the expressway. The direct economic losses resulting from this kind of collision amounted to 30.6% in the inter-vehicle accidents [2]. Autonomous Emergency Braking (AEB) system can alert the driver and automatically brake to avoid accidents or mitigate

accidental injuries in rear-end situations for purpose of compensating the driver for slow or insufficient braking operations [3]. Euro-NCAP studies [4] show that 90% of traffic accidents are caused by driver's inattention or distraction and Automatic Emergency Braking (AEB) system can avoid about 27% of traffic accidents.

AEB system mainly consists of three modules [5]: sensors for detection, a unit for processing and actuators for triggering an emergency maneuver. In order to detect the vehicle ahead and predict the possible collision, different sensors such as radars and cameras are used. The decision to start braking and the control of braking are based on the relative velocity and relative distance between vehicles calculated by the processing element. AEB system uses the TTC measure to define an adequate criterion for activating AEB in order to avoid or mitigate an accident [6]. An important issue in developing AEB system is to define a criterion that only gets involved when the driver is really at danger and

immediate action is required. Misses should be at the greatest extent avoided, but too early false activation may lead to uncomfortable disturbances to the driver.

A variety of methods have been used to study the effectiveness and performance of the certain AEB system on the purpose of developing products suitable for different traffic conditions by means of simulation tests. Based on the NASS/CDS (National Automotive Sampling System / Crashworthiness Data System), American scholars [7,8] established typical rear-end accident scenarios by analyzing more than 1,400 independent accident cases in 2010, and proposed a method to evaluate AEB system in rear-end collision accidents, in which 14% of the accidents were completely avoided with the application of AEB, and the collision speed or severity were mitigated in more than 40% of the accidents. Australian researchers [9] reconstructed and simulated traffic accidents based on in-depth researches and analysis to estimate the potential benefit of AEB. German academics [10,11,12] researched the effectiveness and performance of AEB systems based on GIDAS (German In-Depth Accident Study), by setting TTC to 1 s, the collision avoidance simulations were carried out with different braking deceleration rates: 3 m/s², 6 m/s² and 8 m/s², the collision avoidance rate was 45%, 57% and 68%, respectively.

Many AEB systems have already been introduced to the market, such as the Mercedes-Benz's PRE-SAFE® Brake System [13], which uses radar sensors to help identify critical situations. At speeds between 30 km/h and 200 km/h, a detection distance as far as 200 m ahead of the car can be reached. At 2 s before impact, the driver is warned of a potential danger. If the critical situation continues to develop and the driver does not react, the car applies partial braking around 1.5 s before the collision and tensions seat belts in preparation for the impact. Finally, if PRE-SAFE® Brake determines that a collision cannot be avoided, the car applies maximum braking force to reduce the speed of the impact as much as possible. Ford Active City Stop [14] is a system which helps to avoid or to mitigate accidents at low speeds (0-30km/h). If the vehicle detects a braking, slower-moving or stationary vehicle in front and it determines that a collision is likely, the pressure of brakes is pre-charged. If the driver remains inactive, the system applies full braking automatically. It is estimated that Active City Stop could provide a useful benefit (i.e. avert or mitigate the accident) in around five to nine percent of all car to car collisions. In this paper, the control strategy using the TTC approach for a typical AEB system will be theoretically researched in terms of the following two aspects:

- Identify the value of TTC1 when AEB applies partial braking and the value of TTC2 when AEB applies full braking.
- Evaluate the collision velocity reduction effectiveness and the excessive avoidance performance of AEB systems with different TTC combinations.

Actually, these two critical parameters as control conditions directly affect the collision avoidance performance of AEB system and its effect on the collision speed reduction before impact. It is important to note that the bigger the TTC, the higher possibility of false activation AEB system may have. In this study, the combinations of

TTC and the comprehensive effect of AEB system are analyzed through the simulation of rear-end accidents happened in China based on in-depth investigation.

MATERIALS AND METHODS

This paper uses rear-end traffic crashes from in-depth traffic accidents as a sample, which were reconstructed by means of PC-Crash [15]. Meanwhile, the required algorithm for the necessary functional modules of AEB system was written. Finally, the AEB system is connected with the reconstruction of accident data. The study utilized this modular and tightly coupled platform to simulate the effectiveness of AEB system.

Accident Data

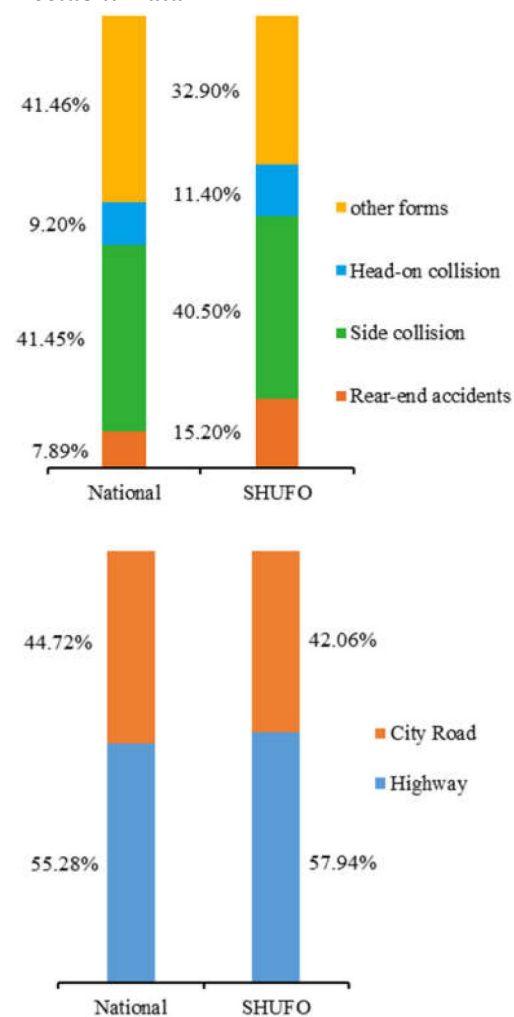


Figure 1. The representativeness of traffic accident data from SHUFO

SHUFO (Shanghai United Road Traffic Safety Scientific Research Center) is the first non-profit research institute engaged in road traffic accident research in China, which aims to explore the safety of vehicles and to improve road traffic safety through long-term accident investigation and research. From 2005 to 2014, SHUFO has investigated 1336 serious traffic accidents in Shanghai. In contrast, the whole China has recorded 196,812 cases in 2014. As shown in

Figure 1, the distribution of various conflict forms and the road types of accident site show the representativeness of the overall situation of the national traffic accidents.

A sample of 84 rear-end cases was extracted from the investigation databases of SHUFO through the following filter criteria:

1. SV (Subject Vehicle): only passenger cars are included, for they are the main object carrying AEB system currently.
2. TV (Target Vehicle): non-motor vehicles and motorcycles are excluded from the sample. The small cars are mainly composed of passenger cars, and the large cars including trucks, trailers, and other heavy vehicles.
3. For multi-vehicle serial rear-end collisions, this study took the first rear-end crash as the case to be studied, where the car in front was seen as TV and the other as SV.
4. The first collision point of an accident must be explicit or can be inferred from the existing data, what's more, the collision speed should be available by using accident reconstruction techniques.
5. Details of the braking and turning countermeasures before the collision taken by the two drivers should be obtained from the return visits or the police transcripts.

Accident Reconstruction

PC-Crash can provide scientific calculation method for accident analysis and is capable of realizing the numerical output of reconstruction data. It has been one of the leading tools for traffic accident reconstruction. The specific procedure includes:

1. Input the necessary parameters, including road environment which is used to graphically reconstruct the scenario), weather conditions which limit driver's vision and affect the coefficient of friction, vehicle attributes which determine the vehicle's property and the passenger information.
2. Input the collision and post-collision kinetic sequences of the vehicles. The dynamic model is used to make the vehicle arrive at the final location, which approximates that in the real accident case when the collision contact position is in accordance with reality.
3. Validate the simulation results through the use of other speed-[16,17] and EES (Equivalent Energy Speed) -calculation methods [18]
4. Set up the vehicle kinematics model including the braking and steering avoidance measures taken by the driver to retrieve the motion process before the crash.

When finished, the reconstruction includes the trajectories of the two vehicles and the location of the SV relative to the TV in several seconds prior to the collision.

Accident Characteristics

The collision speed is a significant factor influencing the severity of the crash and has a very important effect on the consequences of the accident. In this sample, the collision speeds of SV and TV are shown in Figure 2. The velocity distribution of TV in rear-end crashes shows that about 33% of the cars are at standstill ($v=0$ km/h) at the moment

of impact and 49% at speeds less than 30km/h. the average speed of TV is 28 km/h. In terms of SV, the collision speeds in about 56% of the cases are more than 60 km/h and in 20% of the cases more than 90 km/h. Furthermore, the maximum of the collision speed of SV is 160 km/h, and the average value is 71 km/h.

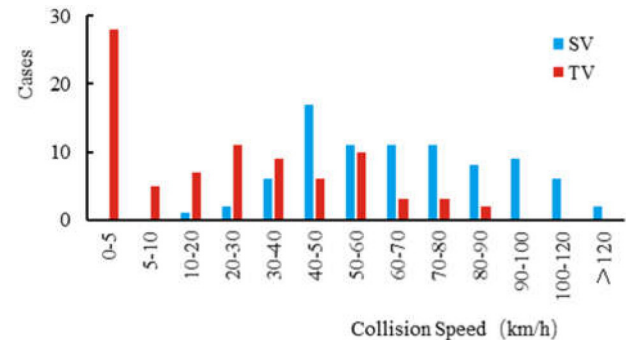


Figure 2. Distribution of collision speed (N=84)

The ΔV , which means the relative velocity difference between TV and SV, can more intuitively reflect the severity of the collision compared to the collision speed in rear-end crashes. As described in Figure 3, a majority of ΔV is generally within the range of 0-30km/h and 30-60km/h accounting for 44% and 38%, respectively.

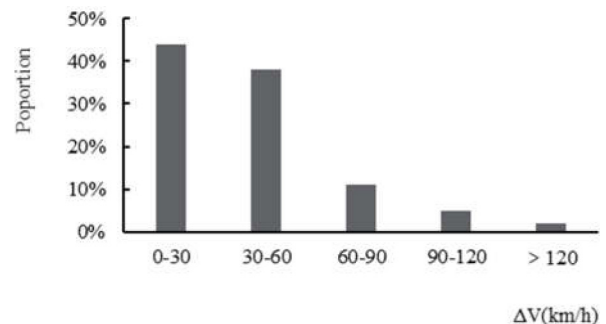


Figure 3. Distribution of ΔV (N=84)

In rear-end collision, the overlap rate equals to dividing the head width of SV by contact width. Figure 4 shows that the rear-end collision with overlap rate less than 50% takes up a considerable proportion of the sample, which is because some SV drivers may have taken steering measures before impact to avoid accident.

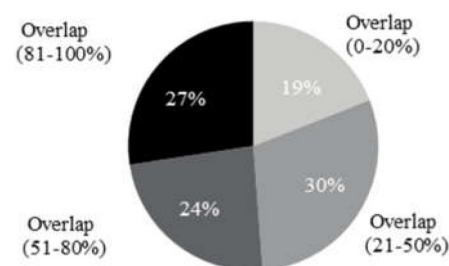


Figure 4. Distribution of Overlap (N=84)

Considering the driving status of SV and TV before the collision, 4 typical scenarios were extracted and established from the sample as illustrated in Table 1.