Effect of Size of Preceding Vehicle on Behavior of Following Vehicle

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***Abstract*— In this study, we demonstrated that the size of a preceding vehicle affects the behavior of the following driver. Intelligent assistance systems, including autonomous driving, have been considered in the prevention of traffic accidents. If forecasting future actions of surrounding vehicles is possible, driving safety can be significantly improved. Therefore, our research group developed a prediction system. Previous studies reported on the effect of the size of the preceding vehicle on the driving behaviors of the following vehicle. However, the effect on the lane changes of the following vehicle has not yet been discussed. This paper analyzes the effect of the size of the preceding vehicle, particularly focusing on lane changes. It is demonstrated that drivers frequently change lanes when a large vehicle is ahead compared with when a normal-sized vehicle is ahead. In addition, the model of lane-change detection considering the size of the preceding vehicle was constructed using actual traffic data. Based on a comparison with a conventional model, our approach proved to be capable of improving early detection performance.**

I. INTRODUCTION

As solutions to traffic accidents, advanced driver-assistance systems and autonomous driving have been developed to support or substitute human drivers. These intelligent systems can assist the recognition abilities of the host driver and provide a warning of dangers; this can ensure driving safety. If forecasting future actions of surrounding traffic participants is possible, the host driver can be provided with sufficient reaction time. In particular, the anticipation of lane changes is urgently required to improve driving safety since lane changes are the primary causes of traffic accidents [1].

The key factor in accidents during lane changes is late cognition. Almost 75% of lane-change crashes were reported to be caused by late cognition [2]. Many previous studies measured driver brake-reaction times from the first sighting of an obstacle until the driver applied the brake, and the time varied by driving conditions [3], [4]. In particular, Mehmood and Easa conducted experiments using a driving simulator, and the reaction time was between 0.92 and 1.94 s [4]. Based on these studies, we can conclude that for lane-change detection, the assistance system should provide a warning to the host driver at least 2 s before crossing the lane marking. However, no previous method satisfies the requirements of early detection. Because of a trade-off between early detection and accuracy [5], improving the performance of both simultaneously is quite difficult.

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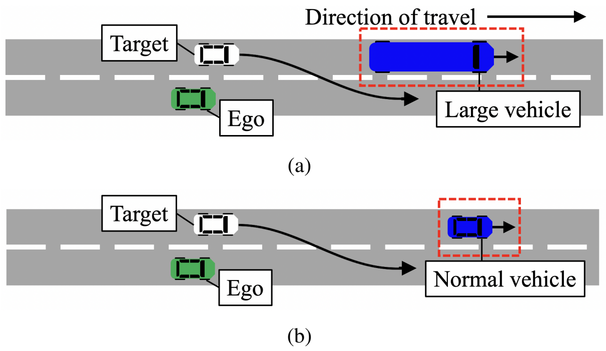

Fig. 1. Problem definition: two driving conditions are defined as follows. In Conditions A and B, a large vehicle and a normal vehicle precedes the *target* vehicle, respectively. Under these two conditions, the driving tendency of the *target* was investigated in this study.

To overcome these limitations, our research group developed a system to recognize the driving condition and apply useful information for lane-change detection [6], [7]. Among the many factors affecting lane-changing [8], this paper focuses on the size of the preceding vehicle. When a large vehicle is ahead, a driver is assumed to generally consider overtaking it to secure the field of view. However, no previous study explicitly investigated this tendency. Considering these scenarios, this study investigated the driving tendency of the driver following behind a large vehicle using an actual traffic dataset [9]. We investigated how the size of the preceding vehicle affects the behavior and the lane-changing rate of the following driver compared with the scenario in which a normal-sized vehicle is ahead. In addition, the model of lane-change detection considering the size of the preceding vehicle was constructed using machine learning techniques. Compared with a conventional model, our approach proved to be capable of improving early detection performance.

II. PROPOSED METHOD

A. Problem definition

To investigate the effect of the size of the preceding vehicle, we define two driving conditions as follows. In the first condition, the preceding vehicle is large (Fig. 1(a)). In this paper, the first condition is defined as Condition A. In contrast, in the second condition, a normal-sized vehicle is ahead (Fig. 1(b)), and it is described as Condition B. In addition, this paper focuses on the scenario in which the following vehicle is a normal-sized vehicle, which is defined as the *target*. In the experiments, the behaviors of the *target* were analyzed.

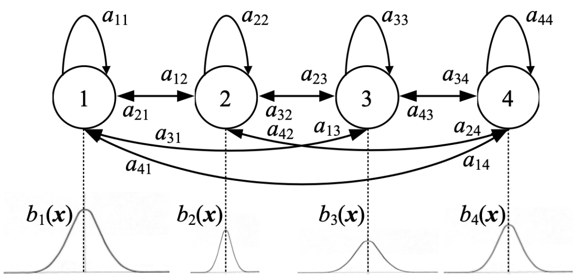

Fig. 2. Detection model of lane changes using HMM: the HMM is designed to have four internal states, and each internal state is assigned to a driving intention. Through the HMM, the current driving intention is estimated at each time step.

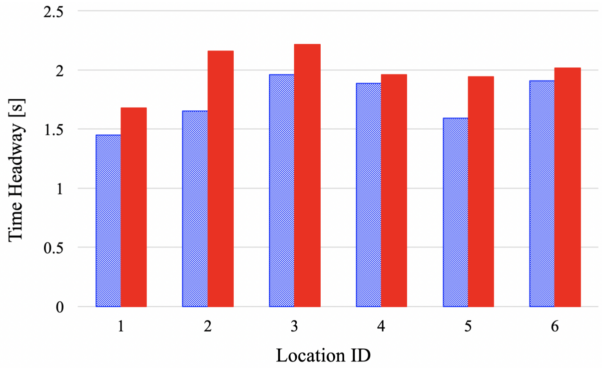

Fig. 3. Comparison of time headways: red depicts the result when the preceding vehicle is a truck while blue depicts the result when a normal-sized vehicle is ahead. Although the differences at some locations are small, the results indicate that the following driver tends to maintain a longer distance when a truck is preceding compared with the condition when a normal-sized vehicle is ahead.

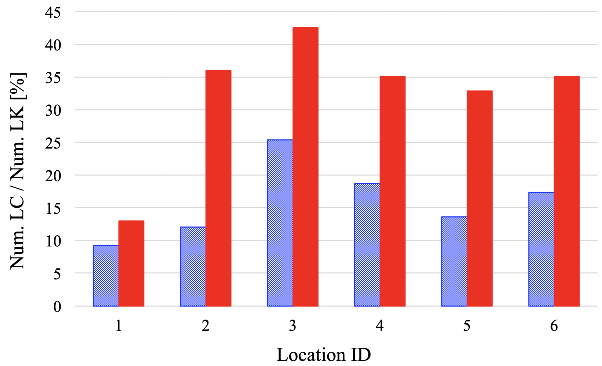

Fig. 4. Comparison of lane-changing ratio: red depicts the result when the preceding vehicle is a truck while blue depicts the result when a normal-sized vehicle is ahead. LK refers to lane-keeping while LC represents lane-changing. It is clearly shown that drivers frequently change lanes when a large vehicle is ahead compared to the moment when the preceding vehicle is normal-sized.

B. Model to detect lane changes

The proposed method uses a machine learning technique to estimate driving intentions. Generally, the hidden Markov model (HMM) is widely used to estimate driving intentions and detect lane changes [10], [11]. This paper assumes that the following intentions constitute the lane-changing process: *keeping*, *changing*, *arrival*, and *adjustment*. Subsequently, the HMM is designed to have four internal states as shown in Fig. 2, and each internal state is assigned to the driving intention. The output of the HMM at each step is the current driving intention. Based on the output, the lane-changing is detected at the moment when the output is *changing*.

The following information is used as the input of the HMM: the relative speed and relative distance from the *target* to the preceding vehicle, the distance from the *target* vehicle to the lane markings, and the lateral speed of the *target* vehicle.

III. Experiments

A. Dataset

Actual traffic data were applied to train and test the proposed method [9]. A drone was used to record the time series data of each vehicle on a highway in Germany. The data describe the records of 110 and 500 vehicles at six locations. Normal vehicles, trucks, and buses were present on the road. The data described the position, size, speed, and other information on each vehicle. The measurement rate was 25 Hz with an accuracy of approximately 10 cm.

Data from 3,321 lane-changing vehicles were extracted for training and testing the proposed method. Among them, 3,000 vehicles were used for the training, and 321 vehicles were used for the test.

B. Results

Previous studies reported that the time headway between the preceding and *target* vehicles is affected by the size of the preceding vehicle [12], [13]. Otherwise, the opposite results have been reported. Sayer et al. reported that the distance when following a large vehicle is shorter than when following a normal-size vehicle [14]. In [15], the size of the preceding vehicle was reported to not affect the distance to the following vehicle. Considering these scenarios, the effect of the size of the preceding vehicle on the time headway from the *target* vehicle to the preceding vehicle was analyzed using an actual traffic dataset described in Section III. A.

Figure 3 shows the time headway between the preceding and following vehicles at six locations. Red indicates the results under Condition A while blue indicates the results under Condition B. Although the differences at some locations were small, it is observed that drivers in following vehicles tended to maintain a longer distance when a large vehicle was preceding. This result supports the claim of [13], and we can conclude that drivers exhibit different behaviors depending on the size of the preceding vehicle.

For clarifying the effect of the size of the preceding vehicle on lane changes, the analysis was conducted since no previous study investigated this. Figure 4 depicts the percentage of the number of lane-changing vehicles and lane-keeping vehicles under both conditions. Red represents the result under Condition A, while blue depicts the result under Condition B. The figure shows that drivers frequently change lanes when a large vehicle is ahead compared with

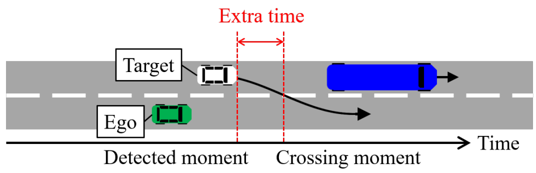

Fig. 5. Extra time: the time gap between the moment of crossing the lane marking and the moment at which the lane-changing was detected is used as the evaluation metric for early detection. A large value of the extra time indicates good early detection performance.

when a normal-sized vehicle is ahead. Except for the result at Location 1, over 30% of drivers performed a lane change under Condition A, and the value was over 40% at Location 3. The reason the difference at Location 1 was smaller than the other locations was that the densities of traffic flow were significantly different. In terms of the number of recorded vehicles, Location 1 had four times as many vehicles as the others. The average percentage at all locations was approximately 16% under Condition B, while the average was approximately 32% under Condition A. This result proved that the size of the preceding vehicle has an effect on the lane changes of the following vehicle, and it is considered as significant information for lane-change detection.

Two detection models were constructed according to the size of the preceding vehicle. Moreover, a conventional model without considering the size of the preceding vehicle was also constructed. Accuracy and extra time were used as the evaluation metrics. The extra time represented the time gap between the moment of crossing the lane marking and the moment at which the lane-changing was detected as shown in Fig. 5. A large value of the extra time indicated good early detection performance. For accuracy, the F_1 score was used.

Table I shows the performance comparison of the conventional and proposed models. It shows that the better performance of early detection was acquired with the proposed method compared with that of the conventional model although the accuracy was slightly decreased. As drivers tended to frequently change a lane under Condition A compared with Condition B, detecting a lane change at an early stage was possible. Consequently, the extra time was achieved approximately 2 s before the *target* vehicle arrived the center line. This performance satisfied the requirement for the warning system as described in Section I. This result proves that the proposed method considering the size of the preceding vehicle can improve early detection performance.

IV. Conclusions

In this study, we analyzed the effect of the size of the preceding vehicle on the behavior of the following driver using an actual traffic dataset. We observed that drivers frequently change lanes when a large vehicle is ahead than when a normal-sized vehicle is ahead. In addition, the detection model of lane changes was constructed according to the size of the preceding vehicle. Through a comparison with a conventional model, we proved that our approach can improve early detection performance.

In future research, the low accuracy should be solved. The proposed method can increase the extra time; however, the accuracy is slightly lower than that of the conventional model. A solution can be to apply additional information as the features for the detection model.

TABLE I
Comparison of detection performance.

	Conventional model	Proposed model
Extra time	1.8 s	2.3 s
Accuracy	95.6 %	95.4 %

Acknowledgement

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