

Analysis and Modeling of Interactive Low-Speed Merging Behavior Using a Driving Simulator

Ren Kuroyanagi¹⁾ Tatsuya Ishiguro¹⁾ Hiroyuki Okuda¹⁾ Kenta Tominaga²⁾ Tatsuya Suzuki¹⁾

¹⁾ The University of Nagoya, Graduate School of Engineering
Furo-cho, Chikusa-ku, Nagoya, Aichi, 464-8603, Japan

²⁾ Mitsubishi Electric Corporation, Advanced Technology R&D Center

KEY WORDS: Electronics and control, Autonomous driving, Simulation, Decision-making model (E1)

This study focuses on low-speed right-angle merging from a parking area onto a main road and aims to model the interaction between a merging vehicle and mainline vehicles. In our previous study, a merging vehicle model including “inching,” which is a slight forward movement during the waiting state, was constructed from driving simulator experiments. However, the mainline vehicles were controlled by a simple ACC system, and their acceptance decisions and reactions to the merging vehicle were not considered. Therefore, this study constructs a mainline vehicle model by observing the acceptance decisions of human mainline drivers in experiments using the previously developed merging vehicle model. The constructed mainline vehicle model is then implemented into the experimental environment, and merging driver behavior is observed again. Through these experiments, we analyze how mainline vehicle reactions affect the merging driver’s decision-making and inching behavior. In this paper, the condition without mainline vehicle reactions is referred to as Step1, and the condition with mainline vehicle reactions is referred to as Step2.

The proposed mainline vehicle model consists of an acceptance decision estimation model and an ACC-based vehicle control model. The decision estimation model estimates the probabilities of the three decision states, namely Undecided, Accept, and Reject, using multinomial logistic regression. The state with the highest estimated probability is selected as the current decision of the mainline vehicle, and the target headway and target velocity of the ACC are modified according to the estimated decision state. The explanatory variables and the response variable are shown below. The definitions of these variables are illustrated in Fig.1.

Explanatory variables

- $x_M, x_M^2, \dot{x}_M^2, \ddot{x}_M^2$: position of the merging vehicle, its square, squared velocity, and squared acceleration
- $y_E, y_E^2, \dot{y}_E^2$: position of the ego mainline vehicle, its square, and squared velocity
- $y_L, \dot{y}_L$: position and velocity of the leading vehicle
- $y_F, \dot{y}_F$: position and velocity of the following vehicle
- $Dist_{L,E}^2, Dist_{E,F}^2$: squared distance between the leading vehicle and the ego vehicle, and squared distance between the ego vehicle and the following vehicle

Response variable

$D(t) \in \{\text{Undecided, Accept, Reject}\}$

- Accept : the decision to allow the merging vehicle to cut in front of the ego vehicle
- Reject : the decision not to allow the merging vehicle to cut in front of the ego vehicle
- Undecided : the state in which neither Accept nor Reject has been selected

Through this framework, the proposed model can reproduce human-like reactions such as yielding and not yielding based on the observed data. Fig.2 shows an example of the observed data for the mainline vehicle acceptance decision. Each trajectory corresponds to one experimental condition, and the color represents the driver’s decision. The figure shows that the decision of the mainline driver changes depending on the relative position between the merging vehicle and the ego mainline vehicle. Therefore, variables that clearly represent the separation among the decision states were selected as candidate explanatory variables. The final variables were selected through a top-down procedure by sequentially removing variables whose p-values were greater than 0.05.

The estimation accuracy of the mainline vehicle model was evaluated, and the average accuracy for the three subjects was 87.38%. In addition, the Step2 merging vehicle model, which was constructed from the data observed again in the environment incorporating the mainline vehicle model, estimated the merging driver’s decision with an average accuracy of 82.82%. Next, to compare the behavior of the Step1 and Step2 merging vehicle models, merging simulations were conducted under the same condition in which the mainline side was represented by the same mainline vehicle model. As shown in Table1, no collisions occurred in either model. In the Step2 model, the average completion time decreased from 2.99 s to 2.36 s, and the minimum inter-vehicle distance increased from 12.93 m to 13.58 m. These results indicate that considering the reactions of mainline vehicles enables smoother merging behavior while maintaining safety.

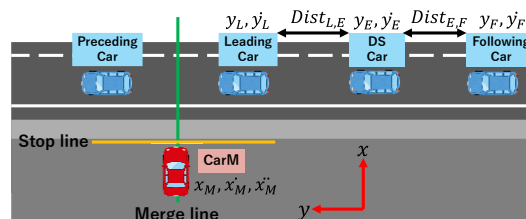


Fig.1 Definition of each explanatory variable

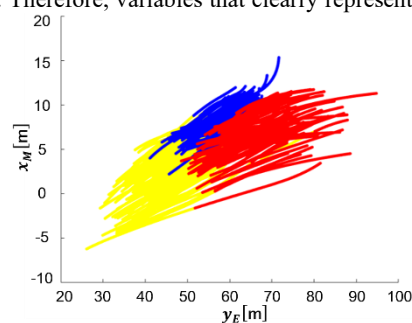


Fig.2 Data distribution for each decision

Table1 Comparison Results

	Completion Time[s]	Minimum Distance[m]	Collision Count[-]
Step1 model	2.99	12.93	0
Step2 model	2.36	13.58	0