

Autonomous Merging System in Traffic Congestion with Dynamic Adjustment of Decision Thresholds

Takumi Iwasa¹⁾ Hanwool Woo¹⁾

¹⁾Kogakuin University, 2665-1, Nakano-cho, Hachioji-si, Tokyo, Japan 192-0015

KEY WORDS: Electronics and control, control system/autonomous land system/autonomous driving system [E1]

In an environment where manual and automated vehicles coexist, driving operations that consider the decision-making of human drivers are essential. An example of this is a merging section during traffic congestion. If an automated vehicle merges forcefully without considering interactions with main lane vehicles, the collision risk increases, whereas continuing to yield excessively will worsen congestion in the merging lane. Therefore, it is necessary to construct a system that considers the decision-making of human drivers on the main lane to achieve both safety and improved traffic flow efficiency. Nishimura et al. constructed an autonomous merging system that mimics the driving operations of human drivers using a machine learning method. Automated vehicles controlled by this model were introduced into a simulation environment to conduct autonomous merging experiments onto the main lane. However, in this study, the threshold for determining whether merging is possible was a fixed value; thus, even if the main lane driver intends to yield, the merging maneuver is not executed if the threshold conditions are not met. Therefore, it is necessary to construct a system capable of statistically analyzing the driving data of surrounding vehicles and dynamically determining the feasibility of merging. In this study, we propose a method that statistically grasps the driving conditions of surrounding vehicles and dynamically adjusts the threshold for merging decisions. This approach achieves safe and efficient merging.

We assume a scenario where an ego vehicle merges into a congested single main lane. Our approach dynamically adjusts the merging threshold based on a cumulative probability density function of the time headway (THW) and inter-vehicular distances to the preceding and following vehicles on the main lane. THW is calculated inline in equation (1). Where x_r is the distance to the following vehicle on the main lane and v_e is the ego speed. If the current vehicle state falls within the bottom 25% of the cumulative distribution, merging is suspended. In a simulation reproducing empirical behaviors (where main lane vehicles yield 92.6% of the time), the ego vehicle evaluates these criteria for 6 s after activating the turn signal. If unfeasible, the target gap shifts backwards.

$$THW = \frac{x_r}{v_e} \quad (1)$$

The system was evaluated over 100 trials at average main-lane speeds of 5 m/s and 10 m/s. Performance was measured by trial duration and margin-to-collision (MTC). MTC is calculated inline in equation (2).

$$MTC = \frac{x_r - \frac{v_e^2}{2A_e}}{-\frac{v_r^2}{2A_r}} \quad (2)$$

Where v_r is the following vehicle speed and $A_e = A_r = -6.9 \text{ m/s}^2$. An MTC value of 1 or less indicates a high probability of collision if the following vehicle also brakes sharply when the subject vehicle decelerates rapidly.

The results for the merging duration are shown in Fig.1, and the results for MTC are shown in Fig.2. These results showed that compared to a baseline fixed-threshold method, the proposed dynamic adjustment significantly reduced the time required to complete the merge. Also, all MTC values are 1 or higher, confirming that merging is being performed safely. A possible reason for the outliers in the merging time observed with the proposed method is that the number of seconds used to determine whether to adjust the target following distance by one car length after the turn signal is activated is a fixed value; at low speeds, if the vehicle behind is slow to move out of the way, the system may judge that merging is not possible.

Dynamic adjustment of merging thresholds successfully reduced merging time without compromising safety. Future work will explore dynamic thresholding for give up merge attempts and evaluate the psychological impact on human drivers using driving simulators.

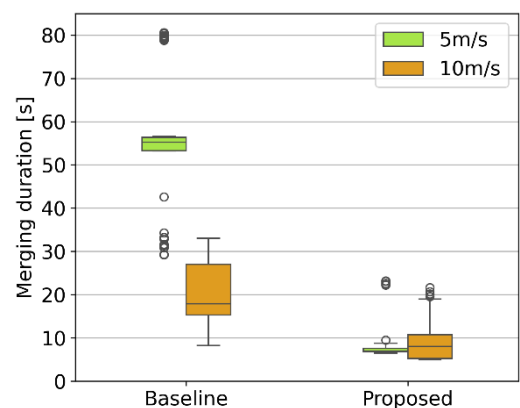


Fig.1 Comparison of merging duration

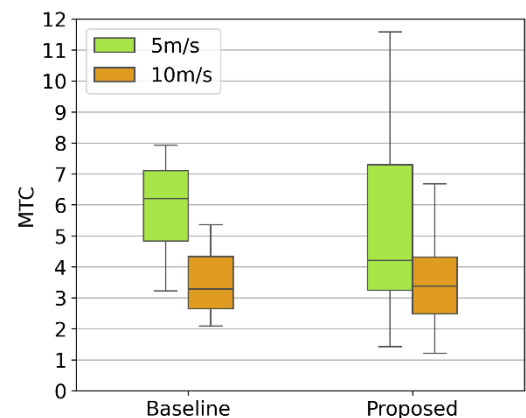


Fig.2 Comparison of collision risk