

Evaluation of merging support system using assumed automated driving vehicles on main lane of Highway

- (First Report) Effective penetration rate of automated driving vehicles in the system at early penetration stage -

Hisashi Imanaga ¹⁾ Kenta Shintoku ²⁾ Nobuhiro Araki ²⁾ Tushar Shirotriya ²⁾

Ryota Okazaki ²⁾ Hideo Nakamura ¹⁾ Hiroshi Fujimoto ³⁾

1) Japan Automobile Research Institute
2530 Karima, Tsukuba, Ibaraki, 205-0822, Japan (E-mail: hima@jari.or.jp)

2) Kozo Keikaku Engineering, Inc.
4-5-3 Chuo, Nakano, Tokyo, 164-0011, Japan

3) Japan Automobile Manufacturers Association
1-1-30 Shibadaimon, Minato, Tokyo, 105-0012, Japan

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Automated driving (AD) technologies are expected to improve highway traffic operations, particularly at merging sections where insufficient gaps in the mainline traffic stream often create delays and inefficiencies. While highly cooperative merging control may become feasible when AD vehicles are widely deployed, such solutions are difficult to implement during the initial deployment stage when AD vehicles coexist with a large number of human-driven (HD) vehicles. This study investigates a practical merging support system designed specifically for this transition period, focusing on AD vehicles traveling on the highway mainline.

The proposed system creates mergeable gaps by instructing selected AD vehicles on the mainline to temporarily increase their time headway from the normal operating level of approximately 2 seconds to 3 seconds near a merge area. To avoid unnecessary gap creation and minimize adverse effects on traffic flow, the system utilizes information obtained from roadside sensing devices installed on both the mainline and merging lanes. Support is activated only when traffic demand falls within a suitable range and when a merging vehicle is predicted to arrive at the merge point at an appropriate time. This infrastructure-supported approach is intended to provide immediate benefits without requiring a high penetration rate of connected or automated vehicles.

The effectiveness of the system was assessed using a detailed Vissim traffic simulation model representing the Higashi-Ikebukuro merge section of the Tokyo Metropolitan Expressway. The simulation reproduced observed traffic conditions and included a merging decision model based on real vehicle trajectory data. AD vehicle penetration rates of 10%, 20%, 30%, 40%, and 50% were evaluated and compared with a baseline scenario in which AD vehicles maintained longer headways but did not actively perform gap-creation support.

Several performance indicators were used to evaluate both benefits and potential side effects. Positive indicators included the Merging Evaluation Score (MES), the number of vehicles forced to postpone merging more than twice, and travel time on the merging lane. Potential negative impacts were assessed using the number of low time-to-collision (TTC) events, shockwave propagation, and travel time on the mainline.

The results demonstrate that the proposed system provides meaningful benefits at moderate AD vehicle penetration levels. Improvements increased as penetration rose to approximately 30%, where the MES improved by 3.3% and the number of vehicles postponing merging more than twice decreased by 8.4%. In addition, the system produced only limited impacts on overall mainline travel time. However, the simulations also revealed that adverse effects, such as increased shockwave propagation, became more pronounced at higher penetration levels. Beyond approximately 30% penetration, the benefits of the simple gap-creation strategy diminished, and some performance measures deteriorated relative to the baseline condition.

These findings indicate that a relatively simple merging support system based on roadside sensing and selective AD vehicle control can effectively improve merge operations during the early introduction stage of automated driving. The study suggests that the proposed approach is particularly suitable when AD vehicle penetration remains below approximately 30%, providing operational benefits while avoiding substantial negative impacts on highway traffic flow. As AD vehicle adoption expands further, more sophisticated cooperative control strategies may be required to achieve additional improvements in merging performance.

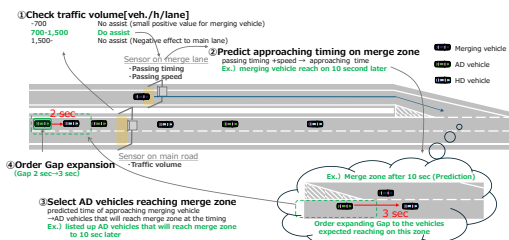


Fig.1 Merging support system using lane information

Table 1 Effect of merging support system

Evaluation index		Mixing rate of AD vehicles				
		10%	20%	30%	40%	50%
Merging evaluation score(MES)	+	0.1%	2.0%	3.3%	0.4%	-1.5%
More than twice postponement	-	0.0%	-6.2%	-8.4%	-1.4%	3.9%
Low TTC vehicles	±	0.0%	-11.7%	-4.9%	-5.0%	14.8%
Shockwave entering vehicles	-	1.2%	3.1%	4.6%	9.4%	6.0%
Passing time (main road)	-	0.0%	-0.4%	0.5%	0.8%	0.9%
Passing time (merging lane)	+	-0.2%	-0.6%	-0.6%	0.2%	0.2%