

Simulation-Based Evaluation of One-to-Many Remote Support for Automated Driving Services

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Level 4 automated mobility services require remote operators to monitor and support multiple vehicles while maintaining both safety and operational efficiency. However, methods for quantitatively determining an appropriate one-to-many (1:N) supervision ratio have not yet been sufficiently established. This study examined an automated bus service in a rural area and identified three routine tasks for driverless Level 4 operation: door-closing confirmation and decision, pre-departure safety confirmation, and passing/stopping decision at bus stops. A remote supervision simulator reproducing the road environment and bus routes in Kamishihoro, Hokkaido, was developed to evaluate these tasks under multi-vehicle supervision. The experimental scenario covered 15 bus stops on two routes, and the number of boarding/alighting passengers at each stop varied from zero to three to reproduce changes in task demand during routine operation.

Ten participants involved in the local automated bus demonstration monitored two, three, four, or five vehicles. Each condition lasted approximately 25 min, and condition order was randomized. Participants were instructed to prioritize correct judgments and then respond as quickly as possible without sacrificing accuracy. Task performance was evaluated using response/processing time, accuracy or completion rate, subjective workload, sleepiness, and fatigue. Door-closing confirmation and decisions maintained 96.0-98.6% accuracy, and pre-departure safety confirmation maintained at least 98.8% accuracy. In contrast, the completion rate for stop-passing decisions was 53.0-71.1%, while that for stopping decisions was 85.8-92.7%. Passing decisions required 10.6-18.0 s on average, longer than door-closing decisions (6.0-7.2 s) and pre-departure safety confirmation (3.2-4.2 s). Subjective workload also tended to increase as the number of monitored vehicles increased, indicating that the passing/stopping task can become a major constraint in 1:N operation.

Using the measured task-processing times, a 1:N operational simulation was then conducted for 1 to 30 vehicles. For each task, a measured processing time was randomly sampled from the experimental data corresponding to the passenger count at the stop. The two modeled routes required 25 min per trip, with the next trip beginning 1 min after return to the origin. Passenger occurrence probability was set to 0.5 at each stop, remote tasks were processed in first-in-first-out order, and 100 simulation runs were performed for each fleet-size condition. Two operating schemes were compared: Operation 1, in which all vehicles stop at every bus stop and the supervisor performs only door-closing and pre-departure safety tasks; and Operation 2, in which vehicles may skip stops when no boarding or alighting passengers are present, and the supervisor additionally performs passing/stopping decisions. Remote operator utilization was defined as the cumulative remote-task processing time divided by the total simulation time. Mean departure delay and remote operator utilization were used as output measures. A 10-min mean-delay level was used as an operational reference based on examples of delay-certificate practices in public transport. Because previous supervisory-control research has reported performance degradation around 70% operator utilization, a provisional 60% utilization benchmark was adopted to retain operational margin for unexpected events and task switching.

In Operation 2, both delay and supervisor utilization increased rapidly with fleet size. Utilization reached 60.9% at nine vehicles, while mean delay increased from 5.8 min at 11 vehicles to 12.7 min at 12 vehicles. Thus, around nine vehicles was considered to be near the practical upper boundary under the 60% utilization benchmark. In Operation 1, mean delay remained only about 0.1 min even with 30 vehicles, whereas utilization increased almost proportionally with fleet size and reached 59.6% at 25 vehicles. These results indicate that 1:N capacity depends strongly on which tasks are assigned to the remote operator, rather than on fleet size alone. The results suggest that the passing/stopping decision is a dominant bottleneck because it requires longer processing time and can occur frequently during routine service. Transferring this decision to reservation systems, passenger intention interfaces at bus stops, or demand-responsive operation may substantially increase the number of vehicles that can be supervised by one operator. The estimated capacities are extrapolations from processing-time data collected under two- to five-vehicle conditions and do not constitute direct validation of human performance at nine or 25 vehicles.

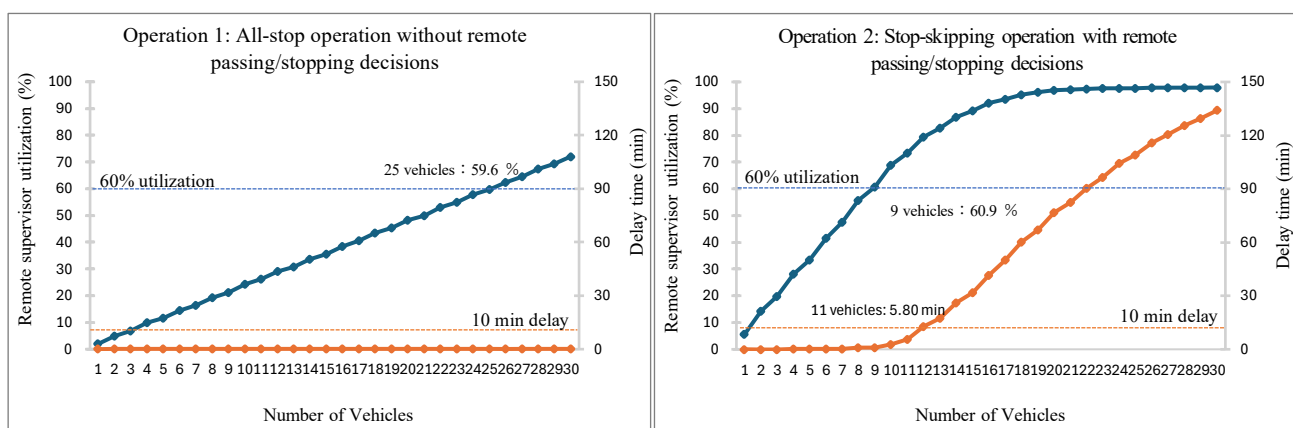


Fig.1. Results of the 1: N remote operation simulation. LEFT: operation 1 when all-stop operation was adopted and the remote operator did not perform the passing/stopping decision tasks. RIGHT: operation 2 when stop-skipping was allowed and the remote operator performed the passing/stopping decision tasks.