Paper Review: Evaluation of ACC Vehicles in Mixed Traffic: Lane Change Effects and Sensitivity Analysis

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Overview

• Adaptive Cruise Control (ACC) vehicles tend to leave larger gaps in front when leading vehicles perform high acceleration maneuvers, leading to more cut-ins and other traffic disturbances.

• Objective: Evaluate the effect of lane changes on the benefits of ACC vehicles to the environment and traffic flow characteristics and the sensitivity of these benefits with respect to penetration of the ACC vehicles, level of traffic disturbances, and ACC vehicle position.
Results

• Disturbances that occur due to the larger gaps created during high-acceleration maneuvers by vehicles leading the ACC vehicle will not annul the benefits obtained in the absence of such cut-ins.

• Greatest benefit is seen when ACC vehicle is as close to the disturbance as possible, but increasing the number of ACC vehicles has relatively little impact.

• ACC vehicles provide an improvement in environmental benefits when the scenario is repeated for 100% manually driven vehicles.
Introduction

• New vehicular technologies are introduced to increase highway throughput and human safety while alleviating traffic congestion and reducing air pollution and energy consumption.

• ACC vehicles are designed to maximize driver comfort, resulting in a smooth response of the ACC vehicle to traffic disturbances. It is suspected that this smooth response will have beneficial effects on overall traffic flow characteristics and the environment.

• ACC vehicles are tested in mixed traffic with manually driven vehicles to measure environment and traffic flow characteristics.
ACC Vehicle Behavior in Mixed Traffic

- Emission model developed in prior work is used to calculate the benefits of ACC in terms of pollution and fuel economy based on speed data.
- Experiments performed using virtual simulations and actual vehicles
- High-Acceleration Maneuver: lead vehicle quickly accelerates, decelerates then accelerates once more.
- Sensitivity analyses performed based on position of ACC in group, acceleration of lead vehicle, penetration of ACC vehicles
High-Acceleration Maneuver

Interconnected system of vehicles following each other in a single lane.

All Manual

1 ACC Car
High-Acceleration Maneuver Results

- Significant environmental benefits observed when an ACC vehicle is present in the group
- Similar improvements seen when experiment repeated using real vehicles

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SUMMARY OF BENEFITS</th>
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<tbody>
<tr>
<td></td>
<td>Percent benefits of mixed over manual traffic in high acceleration vehicle following</td>
</tr>
<tr>
<td>HC emission</td>
<td>38 %</td>
</tr>
<tr>
<td>CO emission</td>
<td>52 %</td>
</tr>
<tr>
<td>NO\textsubscript{x} emission</td>
<td>30 %</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>8 %</td>
</tr>
<tr>
<td>CO\textsubscript{2} emission</td>
<td>Negligible</td>
</tr>
</tbody>
</table>
Sensitivity Analysis

- Position and Lead vehicle characteristics have the most significant impact on the calculated environmental benefits.
- Percent penetration has little impact on improvement.
Focus: Lane Change Effects

• When a leading car exhibits large acceleration, the ACC creates an increase in vehicle spacing.
• Increased spacing invites vehicles in other lanes to cut in, creating a disturbance to the traffic flow.
• Similar disturbance created when a car exits lane, creating a larger vehicle spacing in front of the ACC car.
• Compared to if the ACC car were driven manually, the disturbances introduced are dampened by the ACC.
Lane Cut-Ins: Simulation

- Ten vehicles follow each other in a single lane
- Lead vehicle accelerates, creating a large gap in front of the ACC vehicle
- Vehicle enters into the newly formed gap while ACC vehicles tries to close the gap
- The ACC allows the car to cut-in with minimum disturbance due to the large spacing created
- The simulation showed that even under lane cut-in the ACC provides environmental benefits

<table>
<thead>
<tr>
<th>Exhaust gases emission/ Fuel consumption</th>
<th>Comparison between manual and mixed traffic</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Both manual and mixed traffic with a cut-in (responses from Figures 12 and 13)</td>
</tr>
<tr>
<td></td>
<td>Benefits due to ACC</td>
</tr>
<tr>
<td>HC</td>
<td>24.4 %</td>
</tr>
<tr>
<td>CO</td>
<td>28 %</td>
</tr>
<tr>
<td>Fuel</td>
<td>5 %</td>
</tr>
<tr>
<td>NOx</td>
<td>16.7 %</td>
</tr>
<tr>
<td>CO₂</td>
<td>8 %</td>
</tr>
</tbody>
</table>
Lane Cut-Ins: Simulation

• ACC vehicle blocks rapid acceleration effects from reaching following vehicles
• ACC vehicles produces much smoother speed curves for itself and following cars

Fig. 12. (Manual case) Speed responses of the vehicles at positions 1, 3, 4, 6, and 10, as well as that of vehicle (C) from the adjacent lane and cuts in front of the fourth vehicle.

Fig. 13. Speed responses of the vehicles at position 1, 3, 4 (ACC), 6, and 10, as well as that of vehicle (C) from the adjacent lane that cuts in front of the ACC vehicle.
Lane Cut-Ins Simulations

- When an ACC vehicle is present, the following vehicles’ behaviors closely resemble scenario with all manual and no cut-in
- Vehicles after the ACC vehicle have a dampened acceleration, leading to improved environmental impact
- No oscillatory behavior

Fig. 11. (Manual case) Speed responses of the vehicles at positions 1, 3, 4, 6, and 10 (without a cut-in).

Fig. 13. Speed responses of the vehicles at position 1, 3, 4 (ACC), 6, and 10, as well as that of vehicle (C) from the adjacent lane that cuts in front of the ACC vehicle.
Lane Exit: Simulation

- Ten vehicles follow each other in a single lane
- Second vehicle leaves group, creating a large gap in front of the ACC vehicle
- Vehicles attempt to close the newly formed opening by accelerating to a higher speed.
- ACC vehicle limits acceleration to maintain environmental benefits over the all manual scenario

<table>
<thead>
<tr>
<th>TABLE IV</th>
<th>SUMMARY OF BENEFITS</th>
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<tbody>
<tr>
<td></td>
<td>Percent benefits of mixed over manual traffic in lane exit scenario described by Figures 21, 22</td>
</tr>
<tr>
<td>HC emission</td>
<td>27 %</td>
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<tr>
<td>CO emission</td>
<td>57 %</td>
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<tr>
<td>CO₂ emission</td>
<td>Negligible</td>
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<tr>
<td>NOₓ emission</td>
<td>25.4 %</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>5 %</td>
</tr>
</tbody>
</table>
Lane Exit: Simulation

- In the all-manual case, vehicles rapidly accelerate to close the gap
- The ACC vehicle limits the acceleration of itself and its following vehicles to produce a much smoother speed response
Experimental Results

- The ACC vehicle helps to smooth out the velocity fluctuations resulting from various disturbances.
- Smoother speed response results in improved environmental effects.

Fig. 6. Speed responses in the mixed traffic during the high-acceleration maneuver. The second vehicle is equipped with the ACC system: experimental results.

Fig. 19. Speed responses of two manually driven and one ACC vehicle during a scenario that includes both lane exiting and a cut-in maneuver.

Fig. 25. Speed responses of two manually driven and one ACC vehicle during the lane exit maneuver. At ~81 s, vehicle two exits the lane, and vehicle 3 (ACC) accelerates to catch up with the new predecessor.
Conclusion

• A disturbance generated by vehicle during a high-acceleration maneuver is attenuated when it reaches an ACC vehicle due to the fact that the ACC vehicle is designed to respond to such disturbances in a smooth way and with lower acceleration.
• ACC systems act as filters to traffic disturbance, and provide a smoother trajectory for the vehicles behind to follow than in the all-manual case
• Lane change experiments yielded positive results in line with simulation results
• Mixed manual/ACC traffic shows maintain environmental benefits even under the presence of disturbances
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