Efficient Control of Automated Vehicles on Freeway Merge Segments

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Introduction

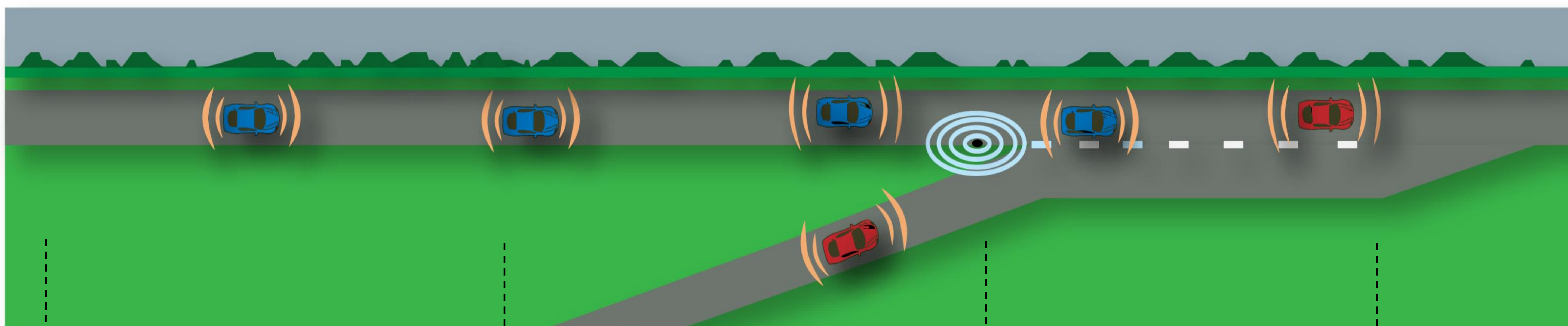
The growing interest in automated and connected vehicle technology has created many opportunities for traffic control innovation. The ability to communicate from vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) provides a huge platform for real-time data transfer. This data transfer capability along with vehicle enhancements such as adaptive cruise control, lane-centering, and fully automated vehicles have made it possible to optimize traffic streams and intersections based on a wide range of performance measures.

Objectives

- Develop a merging algorithm to provide a smooth and safe merging operation for autonomous vehicles, while minimizing the total delay experienced by motorists
- Create a hypothetical merging segment in the CORSIM microsimulator to evaluate the impacts of the merging algorithm
- Run simulations using CORSIM's default car following and lane changing algorithms considering different traffic demand levels to test the flexibility of the algorithm
- Evaluate the impacts of the merging algorithm by comparing throughput, delay, travel time, average travel speed, time to breakdown, and duration of congestion

Merging Algorithm

The developed merging algorithm divides the merging segment into three zones. Communication occurs 10 times per second between the vehicles and the controller located in the gore area. Trajectories of the vehicles entering the communication zone are optimized by minimizing the total travel time.



Zone I

Incoming mainline vehicles communicate with the controller and are assigned speeds to harmonize the mainline traffic prior to the merging area. This allows gaps to be created easily in Zone II where conflicts occur.

Zone II

Gaps are created in the mainline traffic stream to allow ramp vehicles to merge. At the same time ramp vehicles are given trajectory information to perform the merge as efficiently as possible. The objective of the optimization is to minimize total travel time.

Zone III

Mainline vehicles maintain acceptable gaps while the ramp vehicles complete the merging maneuver. Once the vehicles leave Zone II, they are no longer under any influence from the controller.

Zone II Problem Formulation

$$\text{minimize} \sum_{i=0}^{m} \sum_{j=0}^{n} tm_i + tr_j$$

$$\text{s.t.} \quad tm_i = \frac{y}{\sqrt{v_i^2 - 2\alpha_i x}} + \frac{2(v_i - \sqrt{v_i^2 - 2\alpha_i x})}{\alpha_i}, \forall i$$

$$tr_j = \left(\frac{v_j - \mu_j}{\beta_j}\right) + \left(\frac{z}{v_j}\right) - \frac{\mu_j}{v_j}\left(\frac{v_j - \mu_j}{\beta_j}\right) - \frac{(v_j - \mu_j)}{2 v_j \beta_j}, \forall j$$

(constraints continued)

$$|\alpha_j| - \alpha_{max} \le 0, \forall i$$

$$|\beta_j| - \beta_{max} \le 0, \forall j$$

(maximum acceleration constraints)

$$|tr_j - tm_i| \ge h_m, \forall i, \forall j;$$

$$|tr_j - tr_{j-1}| \ge h_m, \forall j$$

$$|tm_i - tm_{i-1}| \ge h_m, \forall i$$

(minimum headway constraints)

Where:

tm_i = time for mainline vehicle i to reach merging point
tr_j = time for ramp vehicle j to reach merging point
v_i = merging speed of mainline vehicle i
α_i = acceleration of mainline vehicle i
x_i = distance traveled during acceleration of mainline vehicle i
y = coasting distance of mainline vehicle i
v_j = merging speed of ramp vehicle j
μ_j = initial speed of ramp vehicle j
β_j = acceleration of ramp vehicle j
z = distance traveled during acceleration of ramp vehicle j
β_{max} = maximum allowable acceleration
h_m = minimum time headway

Simulation and Testing

Simulation Tools

The microsimulator CORSIM is used in conjunction with the optimization modeling software LINGO to simulate the merging segment. Results can the be compared on the same merging segment with and without the merging algorithm in use.

Vehicle and Network Assumptions

- All vehicles in the network are assumed to be fully automated and equipped with Dedicated Short Range Communications (DSRC)
- DSRC communicates at a rate of 10 times per second
- Range of DSRC is assumed to be approximately 1000 ft
- Data packet sent by vehicles includes vehicle position, speed, acceleration, and vehicle size
- Before entering the DSRC controller range, automated vehicles are assumed to operate independently of external control
- A range of acceptable minimum time headway values will be tested ranging from 0.5 seconds to 3 seconds

Expected Results and Continued Research

Expected Results

- It is anticipated that the results will show an improvement in all identified performance measures including throughput, delay, travel time, average travel speed, time to breakdown, and duration of congestion
- Improvement is expected to be greatly influenced by the selection of the acceptable vehicle time headway and the selected merging speed

Continued Research

- Expand the merging algorithm to accommodate a varying number of mainline and ramp lanes
- Incorporate the error associated with data transmission accuracy and vehicle translation to guarantee the safety of the algorithm
- Evaluate the algorithm performance considering a percentage of non-equipped vehicles in the traffic stream
- Include heuristics to govern the merge during non-congested conditions to reduce computational demand