Traffic management challenges: traffic congestion, safety risks, environmental concerns, driver discomfort and frustration, etc.

One major cause to these issues are bottlenecks such as intersections and merging roadways

Connected and automated vehicles (CAVs) technologies enable shorter gaps between vehicles, faster responses and precise control.

Heterogeneous CAVs

• Different priorities (or time values)
• Heterogeneous headways

How to coordinate heterogeneous CAVs to minimize delays at a bottleneck (e.g., a merge)?

Objectives

• To propose a centralized optimization framework that coordinate CAVs at a merging zone.
• Minimize total delay with respect to vehicles priorities considering heterogeneous headways

Literature Review

• Automated and cooperative vehicles: cooperative merging control (e.g., Rios-Torres and Malikopoulos, 2017)
• Capacity analysis (e.g., A. Ghiasi et al., 2017), Stochastic and heterogeneous headways (e.g., Nowakowski et al., 2010)
• No CAV-based centralized optimization problem that coordinate vehicles at a merging zone with using heterogeneous time values and headways

Model

Min $\sum_{i=1}^{N_R} \left[ (t_{ij} - t_{ij})_{i}^{M} + (t_{ij} - t_{ij})_{j}^{M} \right]$

Subject to:

Minimum exit time constraints:

- $t_{ij}^{M} \geq t_{ij} \quad \forall i \in N^{R}$
- $t_{ij}^{M} \geq t_{ij} \quad \forall i \in N^{R}$

Rear-end collisions avoidance constraints:

- $t_{ij}^{M} \geq t_{ij} \quad \forall i \in N^{R}\{1\}$
- $t_{ij}^{M} \geq t_{ij} \quad \forall i \in N^{R}\{1\}$

Side collisions avoidance constraints:

- $t_{ij}^{M} - t_{ij}^{M} \geq t_{ij}^{M} \quad \forall i \in N^{R} \& \forall j \in N^{R}$
- $t_{ij}^{M} - t_{ij}^{M} \geq t_{ij}^{M} \quad \forall i \in N^{R} \& \forall j \in N^{R}$

Valid inequalities:

- $y_{ij} = 1 \quad \forall i \in N^{R} \& \forall j \in N^{R}$
- $y_{ij} = 0 \quad \forall i \in N^{R} \& \forall j \in N^{R}$

Parameters:

- $N^{R}$ & $N^{M}$: Number of vehicles in ramp road and main road
- $t_{ij}^{M}$ & $t_{ij}^{M}$: Minimum time required to exit the merging zone without having interaction for vehicle $i$ in ramp road and for vehicle $j$ in main road
- $t_{ij}^{M}$: Minimum headway between the vehicle $i$ in ramp road and vehicle $j$ in main road
- $t_{ij}^{M}$: Minimum headway between two consecutive vehicles in the same road
- $U_{ij}^{M}$: $U_{ij}^{M}$: The vehicles’ value of time
- $M_{ij}$: Big M

Variables:

- $t_{ij}$: Actual exit time for vehicle $i$ in ramp road
- $t_{ij}$: Actual exit time for vehicle $j$ in main road
- $y_{ij}$: It is integer. In case if vehicle $i$ from the ramp road passed the merging zone before vehicle $j$ from the Main Road and 0 otherwise.

Results

• One lane straight highway for each road
• We used Gurobi as a solver to find the optimal answer of the model

Theorem:

FIFO is the optimal sequence if all vehicles’ time values and headways are the same

Example 1:

• Consider an ambulance with time value 10 at different positions
• All other vehicles with time value 1

Results 1:

• 26.1% reduction of the total delay cost on average
• Improvement can be as up to 78% if the ambulance is the head of a platoon

Example 2:

• Random time value (from 1 to 10)
• Random minimum headway (from 0.6 to 1.1)
• Different instances with different numbers of vehicles

Results 2:

• 59.32% reduction of the total delay cost on average
• The delay reduction increases with the number of vehicles

Conclusion and Future Approach

Conclusion

• A new and efficient model is proposed to coordinate merge of heterogeneous CAVs to minimize total delay
• Theoretical properties (e.g., on the FIFO solution) and numerical exact solution approaches

Future research direction

• Extension to multi-lane highways
• Scaled experiments using robot cars
• Decentralized & collaborative control

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References