Scheduling of Heterogeneous Connected Automated Vehicles at a General Conflict Area

Xiaopeng Li, Saeid Soleimaniamiri, Yu Wang
Department of Civil and Environmental Engineering

Introduction

- 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)?

Objective

- To propose a centralized optimization framework that coordinate CAVs at a multi-conflict point.
- Minimize total delay with respect to vehicles priorities considering heterogeneous headways
- Propose an efficient algorithm to efficiently solve the proposed model to optimality that can be applicable in real world
- Accelerate the algorithm performance by decreasing the solution space

Model

\[
\begin{align*}
\min & \quad \sum_{j \in \mathcal{J}} \sum_{m \in \mathcal{M}} u_{jm}(t_{0m} - t_{jm}) \\
\text{Subject to} & \quad \Delta t_{jm} = t_{jm} - t_{0m} \\
& \quad \Delta t_{jm} \geq 0, \forall j, m \\
& \quad t_{0m} \geq jM + t_m, \forall j, m \\
& \quad t_{0m} \leq \min(t_{jm} + T, \tau_{jm}), \forall j, m \\
& \quad \tau_{jm} = \min(t_m + \tau_m, \tau_{jm}), \forall j, m \\
& \quad \tau_m = \min(3 \text{ minutes time horizon}, \tau_{jm}), \forall j, m \\
& \quad \tau_{jm} = \min(M, t_{jm} + \tau_{jm}), \forall j, m \\
& \quad \tau_{jm} = \min(3 \text{ minutes time horizon}, \tau_{jm}), \forall j, m \\
& \quad \Delta t_{jm} = \min(\Delta t_{jm} + \tau_{jm}, \tau_{jm}), \forall j, m \\
\end{align*}
\]

Parameters:
- \( t \): number of approaches
- \( m \): set of vehicles
- \( j \): number of vehicles
- \( M \): number of vehicles
- \( N \): number of vehicles
- \( R \): number of vehicles

Variables:
- \( \tau_{jm} \): actual departure time
- \( \tau_{jm} \): value of travel time
- \( \tau_{jm} \): minimum departure time
- \( \tau_{jm} \): minimum following time
- \( \tau_{jm} \): minimum crossing time

Algorithm

- Algorithm: Start: start with sub-solution \((10 \text{ min} < t < 0.01)\) and set \( t = 0 \)
  - Step 1: creating feasible departure sequence of \( t + 1 \) vehicles using a set of departure sequence at stage \( t \), update the created sub-solution information
  - Step 2: find the similar sub-sequence with the same \( t + 1 \) information, remove the one that is rated in both \( w_1 \) and \( w_2 \)
  - Termination: if \( t = N - 1 \)

Results

Numerical example setting:
- Two one-lane straight highway merging into one lane
- Considering heterogeneous time headways and priorities for CAVs
- Considering unsaturated traffic flow
- 3 minutes time horizon
- Use GUROBI as a benchmark for computational time
- Use the solution of first-in-first-out (FIFO) as a benchmark for delay cost
- Maximum speed = 30 \( \text{m/s} \)
- Maximum accelerations = 3 \( \text{m/s}^2 \)

Result:
- 94.67% reduction of the total delay cost
- 97.41% improvement in computational time compare with GUROBI

Conclusion and Future Approach

Conclusion
- A new and efficient model is proposed to solve the exact optimal solution to the vehicle scheduling problem at a multi-conflict point considering heterogeneous vehicle headways and values of time
- An efficient modified Dynamic programming algorithm is presented to efficiently solve the investigated problem to the optimality

Future research direction
- Scaled experiments using robot cars
- Decentralized & collaborative control
- Using fuel consumption as the objective function

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)
- Vehicle scheduling at a multi-conflict points (e.g., Wu, Jia, and Abdeljalil Abbas-Turki, 2009)
- No CAV-based centralized optimization problem that coordinate vehicles at a general-conflict point efficiently with using heterogeneous time values and headways

References