A real-time optimization algorithm to maximize intersection efficiency using connected and autonomous vehicles

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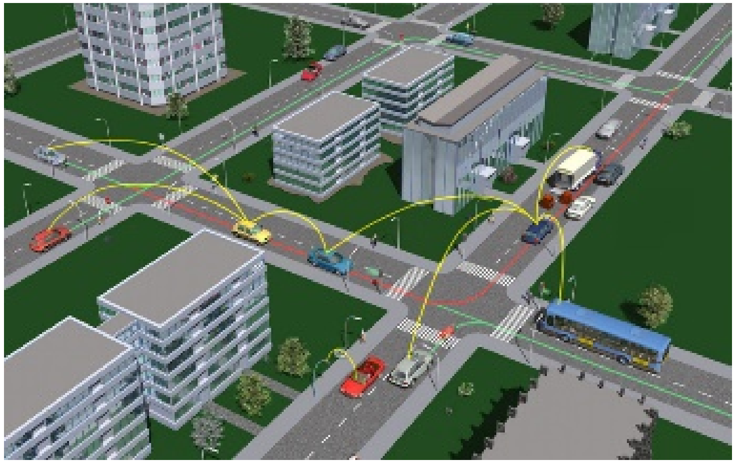
December 7, 2017

Introduction

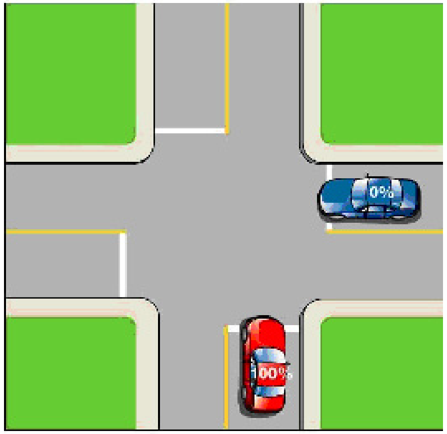
- Vehicular technology has rapidly improved over the last decade and is expected to improve even further in the near future.
- Advances in communications now allow vehicles to collect and share information about their surroundings with adjacent vehicles and infrastructure.
- These types of vehicles that can "speak" to the infrastructure are often referred to as Connected Vehicles.
- The next step is the proliferation of self-driving, or autonomous, vehicles.

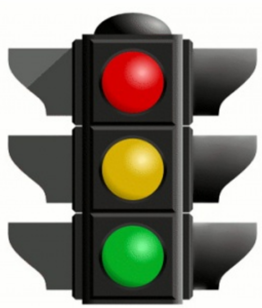
http://www.dot.state.fl.us/trafficoperations/ITS/Projects_Deploy/CV/Connected_Vehicles.shtm



http://www.automotiveworld.com/analysis/dot-suggests-us-standardisation-of-connected-vehicle-devices-and-roadway-systems/

Introduction





- These advancements offer exciting opportunities for the next-generation of traffic control.
- Can be used to design a more efficient signal control strategy
  - Even with actuated signals → still subject to restrictions such as minimum or maximum green times.
  - There could be a margin for improving the efficiency of traffic operations at intersections by better catering to the traffic demand.
- Moreover, it can be possible to control the trajectory of autonomous vehicles with a centralized controller

Goal

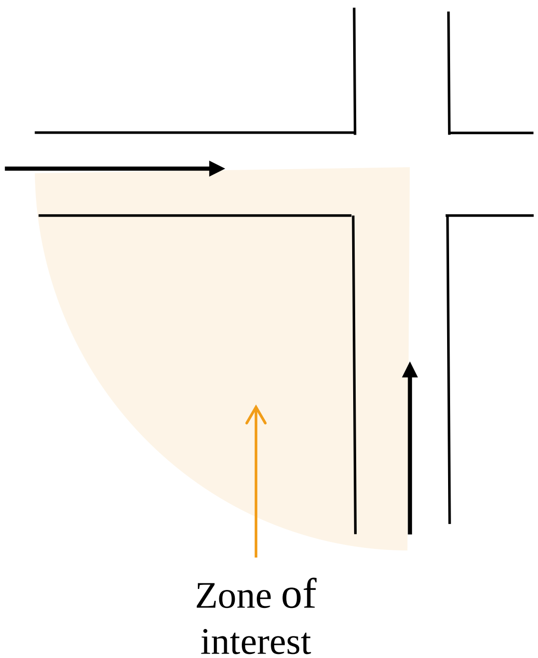
- To optimize traffic operations at an intersection by using information from connected vehicles such as the position and speed of individual vehicles.

- To achieve this goal:
  - A control algorithm for traffic operations while allowing for trajectory design of autonomous vehicles is developed.

Background

- Traditionally, there are three general approaches to traffic signal control:
  - Fixed-time
  - Actuated
  - Adaptive
- Connected vehicle technology can be used to:
  - Modify trajectory of fully autonomous vehicles (safety application)
    Li and Wang, 2006; Zohdy and Rakha, 2012; Lee and Park, 2012
  - Optimize phases (cycle length and green splits) of a signal (operations application)
    Grandinescu et al., 2007; He et al., 2012; Lee et al., 2013; Goodall et al. 2013
  - Optimize vehicle discharge sequence (operations application)
    Dresner and Stone, 2004; Wu et al. 2007; Cai et al., 2012

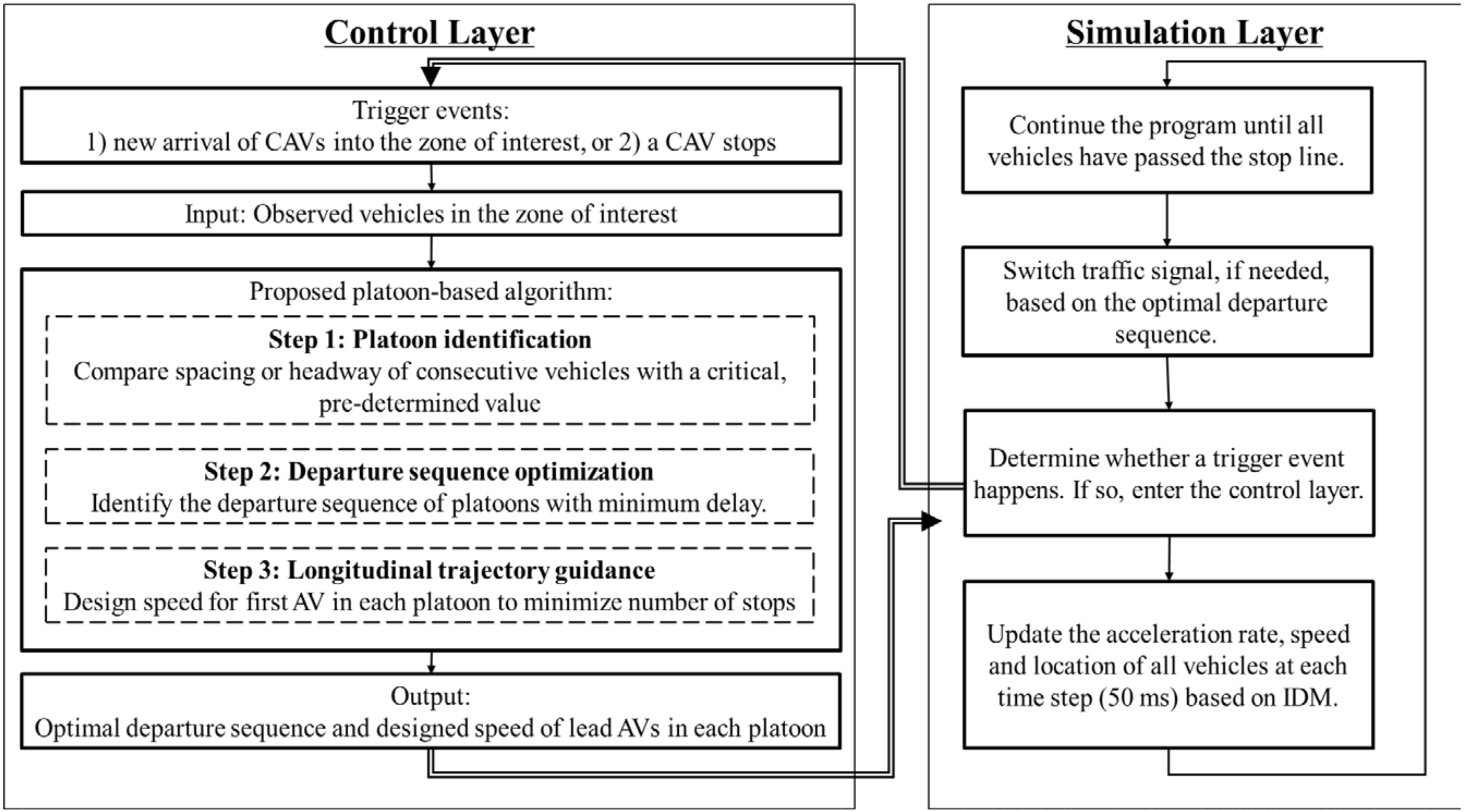
Signal Control Algorithm



- Three types of vehicles are considered:
    - Traditional vehicles,
    - Connected but non-autonomous vehicles (connected vehicles), and
    - Autonomous vehicles

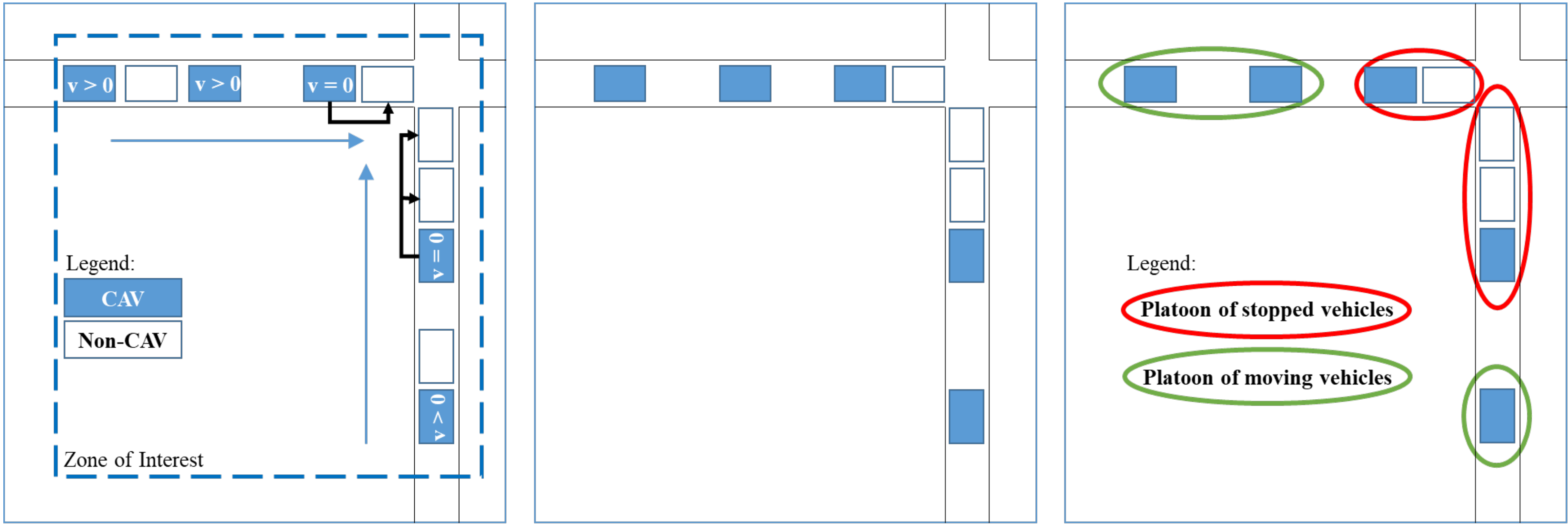
- Inputs:
    - Information obtained from connected vehicles:
        1. The time it enters the “zone of interest”
        2. The distance from the intersection at which it comes to a stop (if a queue exists)

Signal Control Algorithm



Platoon Identification

- Non-CAV vehicles are identified if a CAV stops behind it.
- Cars are platooned based on minimum spacing or headway



Vehicles on the road | Input to the algorithm | Group vehicles into platoons

Platoon Identification

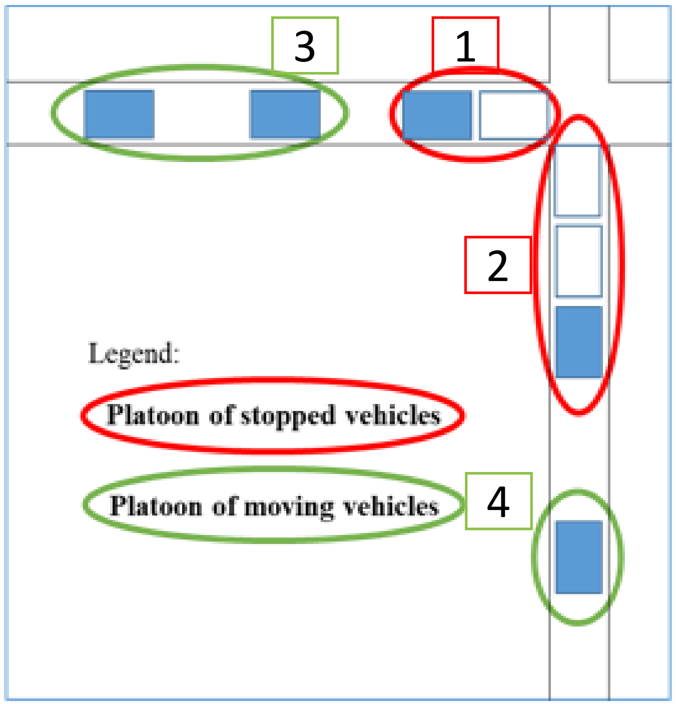
us vehicles.
but not autonomous
vehicles.

n

Solution method

- Estimate delays of departure sequences to identify the optimal departure sequence that will result in minimum delay:
  - Enumeration method, which simply identifies all possible combinations of platoon departure sequences
  - Branch-and-bound method that uses an intelligent tree search strategy to identify the optimal platoon departure sequence.

Departure sequence optimization



- 6 possible departure combinations considered:

1,2,3,4

1,2,4,3

1,3,2,4

2,1,3,4

2,1,4,3

2,4,1,3

Longitudinal Trajectory Guidance

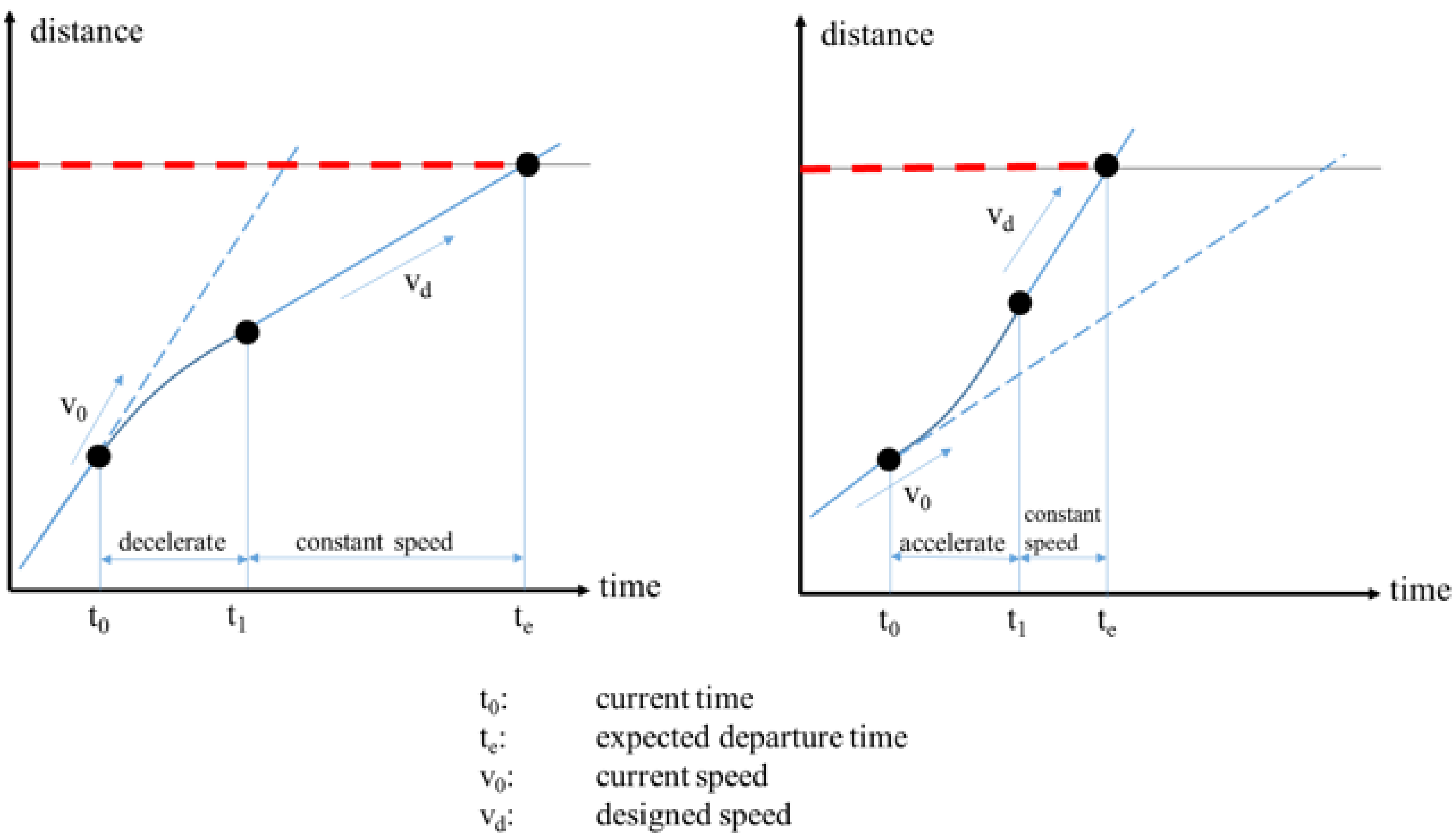
- Input:
  - Departure sequence from upper-level algorithm

- Modify car trajectories to:
  - Let vehicles pass the intersection at a specific time,
  - With the maximum possible speed and,
  - If possible, without stopping

- The trajectory design of each individual autonomous vehicle is done based on the real or estimated traffic information (departure time, speed, etc.) of the cars in front of it.

Longitudinal Trajectory Guidance

- Accounts for realistic acceleration or deceleration of cars



Longitudinal Trajectory Guidance

Dark blue: autonomous vehicles.
ted but not autonomous
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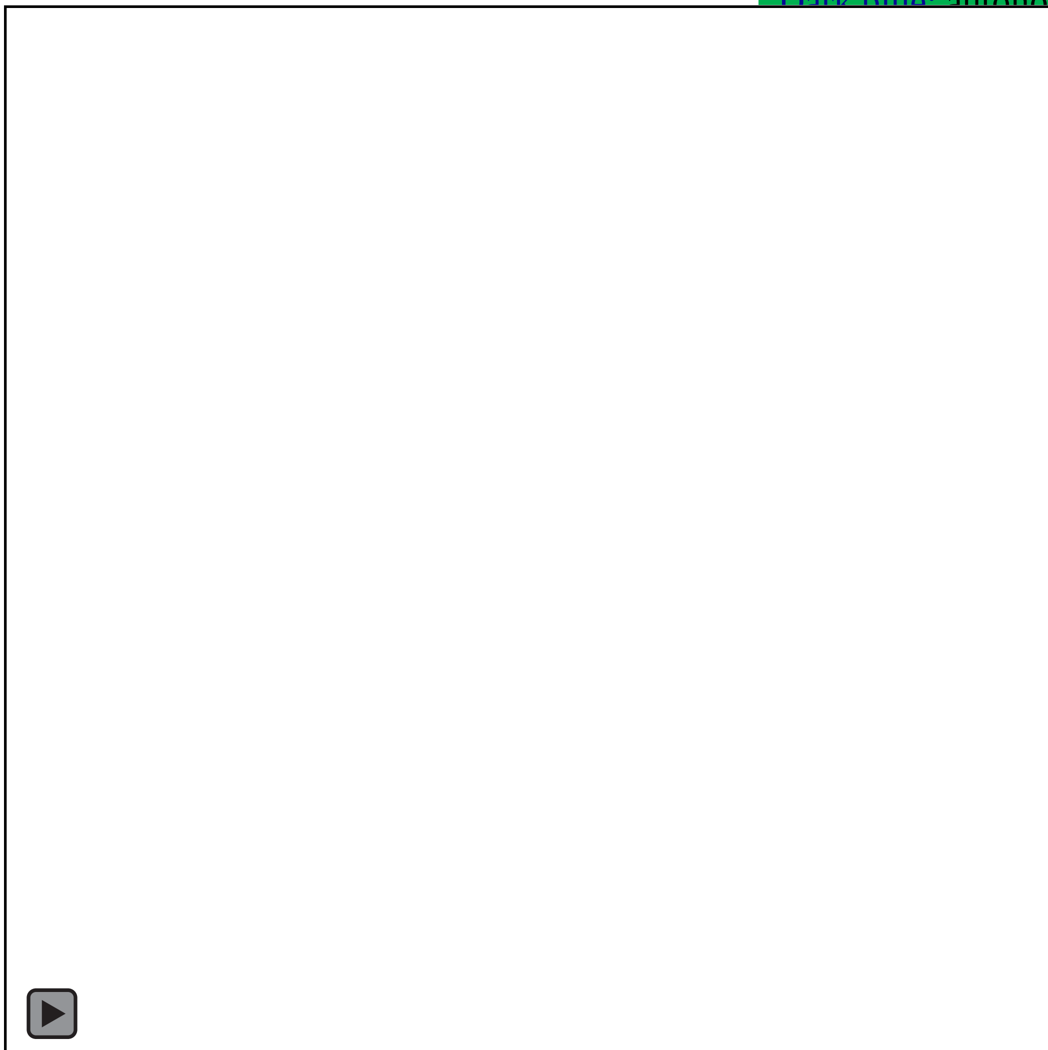
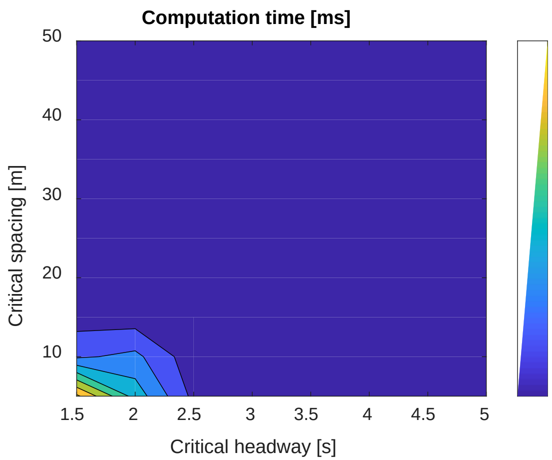
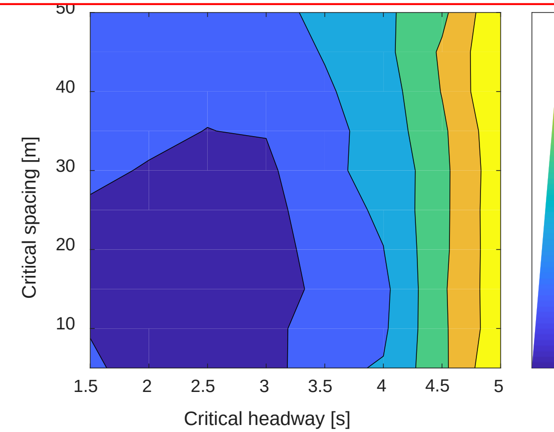


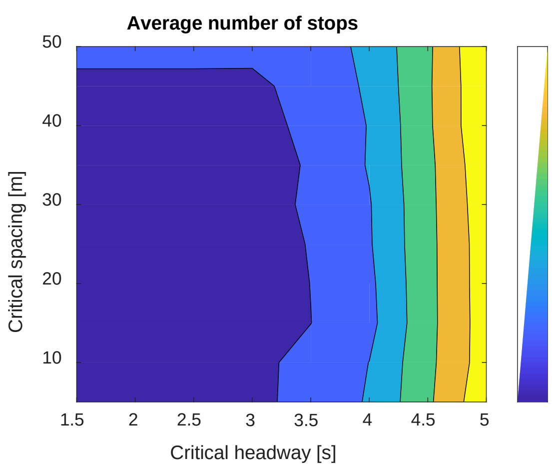
Benefits of Platooning



A critical headway of 2.5 seconds and critical spacing of 15 meters is chosen since it provides significant computational efficiency without much change to average delay or stop



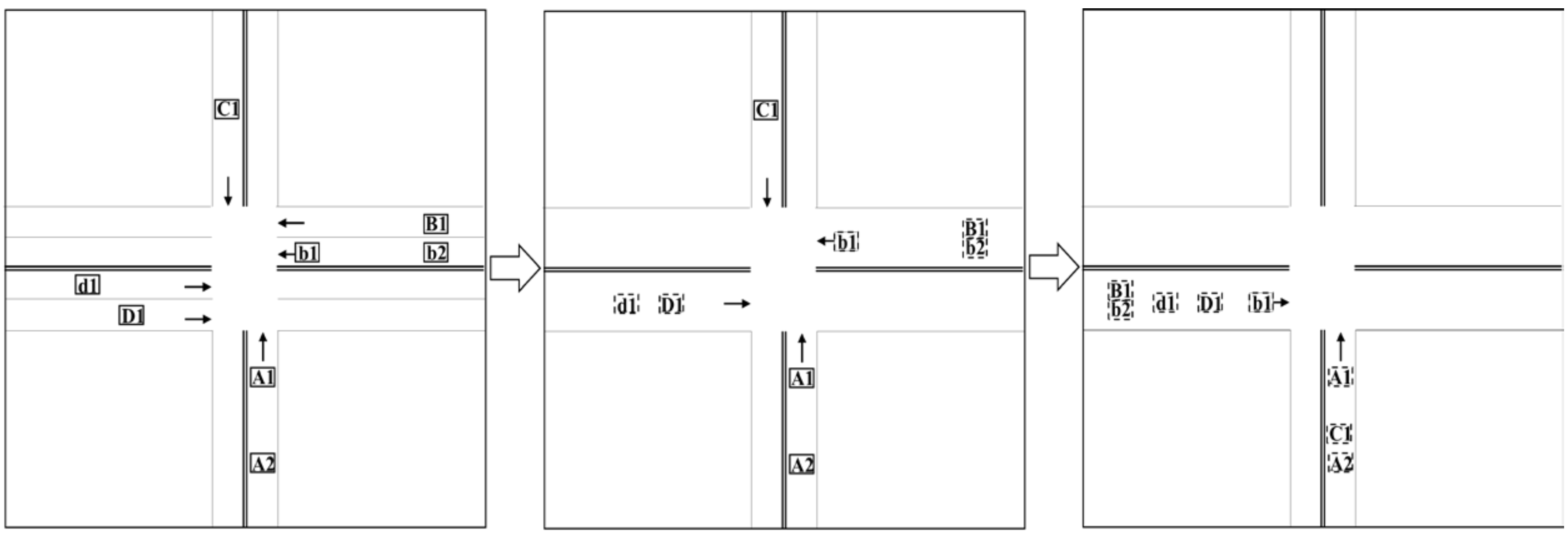
Average delay increases slightly as more cars are platooned together



Average number of stops increase as more cars are platooned together but the magnitude of increase is small.

Modeling 4 multi-lane approaches

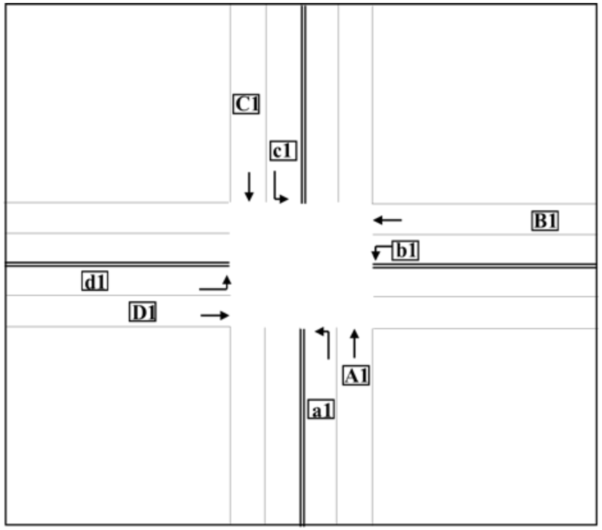
- Hypothetical approaches for vehicles that will discharge during the same phase are formed
  - Multiple lanes are collapsed onto one
  - Opposite directions are collapsed onto one



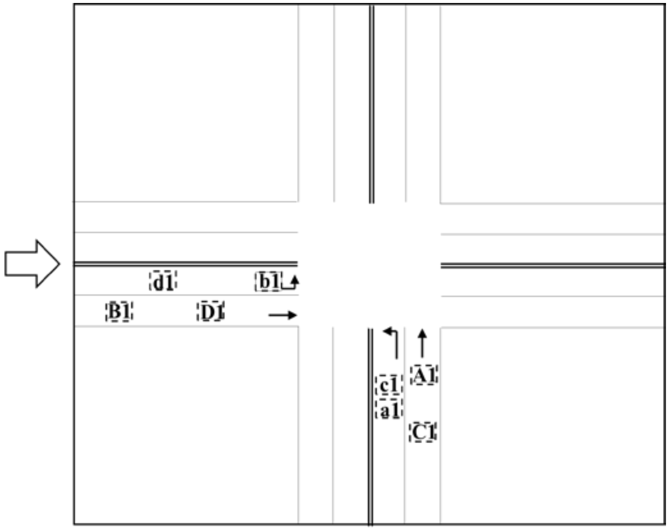
Four-multi-lane-approach intersections   Multiple lanes collapsed into one   Four approaches folded into two

Modeling 4 multi-lane approaches with conflicting left turns

- Hypothetical approaches for vehicles that will discharge during the same phase are formed
  - 4 hypothetical lanes are formed corresponding to the 4 phases:
    - NBT+SBT, NBL+SBL, EBT+WBT, EBL+WBL

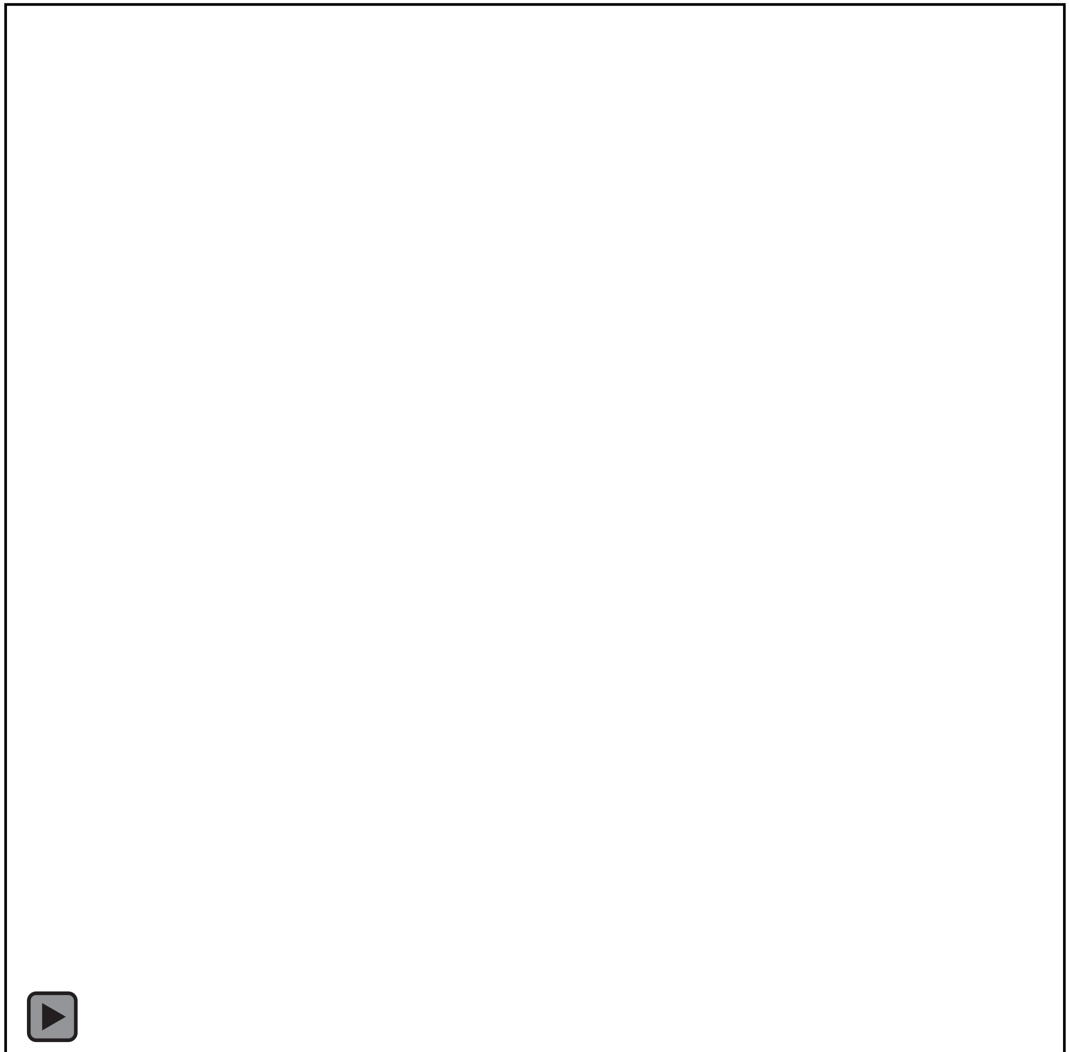


Four-approach intersections with conflicting left turns

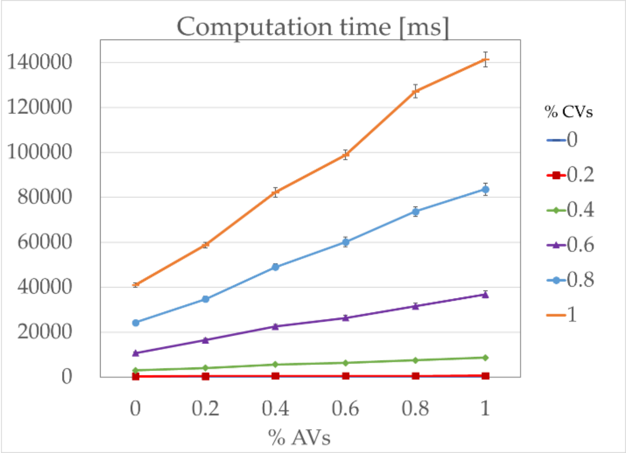


Equivalent intersection with four single-lane approaches

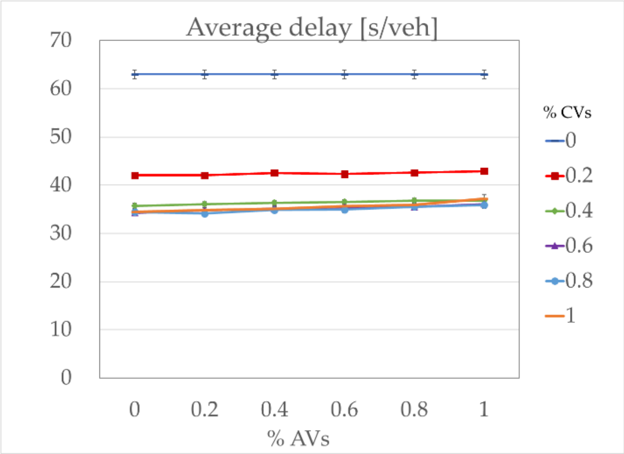
Modeling 4 multi-lane approaches with conflicting left turns



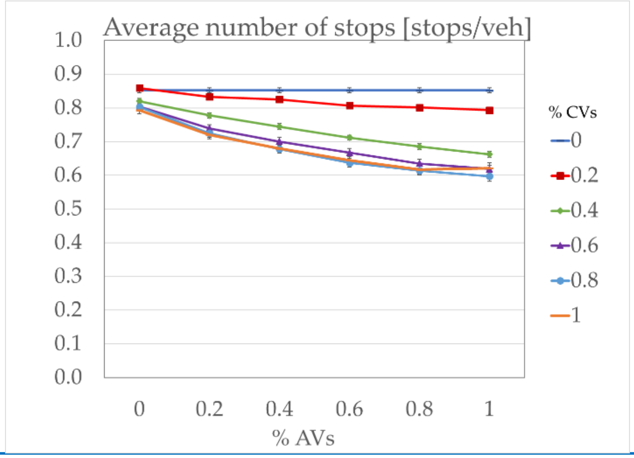
Sensitivity of algorithm to PR



Computation time significantly increases as more cars are connected, and also as more are autonomous



Average delay reduces with more information, but marginal benefits after 40% connected ratio are very small



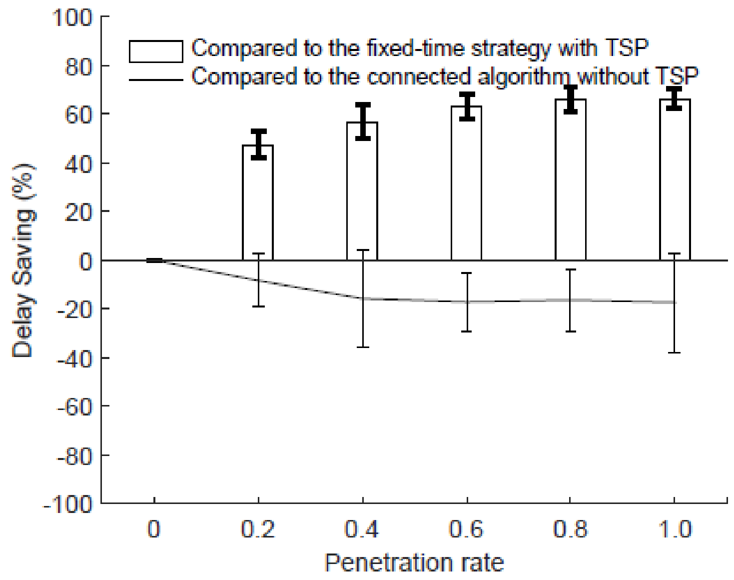
Average number of stops decreases as more cars are autonomous

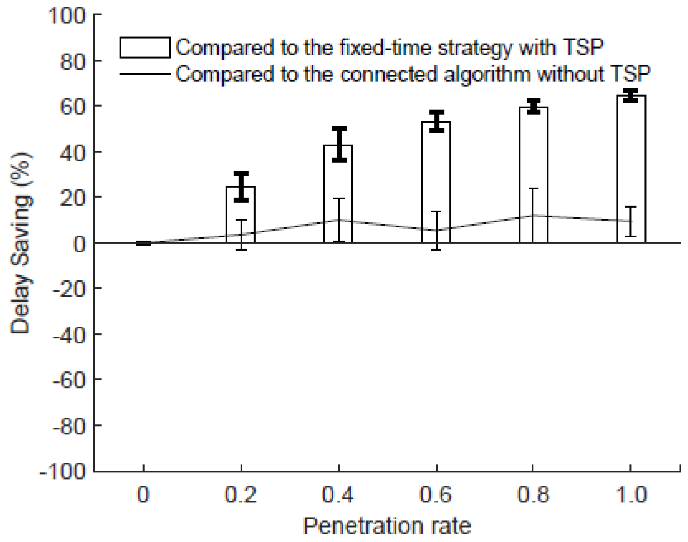
Other applications

- A demand responsive control strategy can be used to adapt to different traffic situations.
- This strategy dynamically switches between the two (or three) algorithms based on demand and information level:
  - Connected vehicle algorithm with trajectory design
  - Connected vehicle without trajectory design
  - Actuated algorithm (if the necessary infrastructure is available).

Other applications

- Multimodal traffic control
  - Account for buses, and bus stops to minimize total passenger delay
  - An alternative to providing Transit Signal Priority





Conclusions