CEE 551 - Traffic Science

Topic: Traffic Signal Control (6)

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Outline

- Adaptive traffic signal control (ATSC)
- Traffic signal control with connected and automated vehicles (CAVs)
  - Performance evaluation based on trajectories
  - Offset optimization based on vehicle trajectories
  - Traffic signal control & automated vehicles

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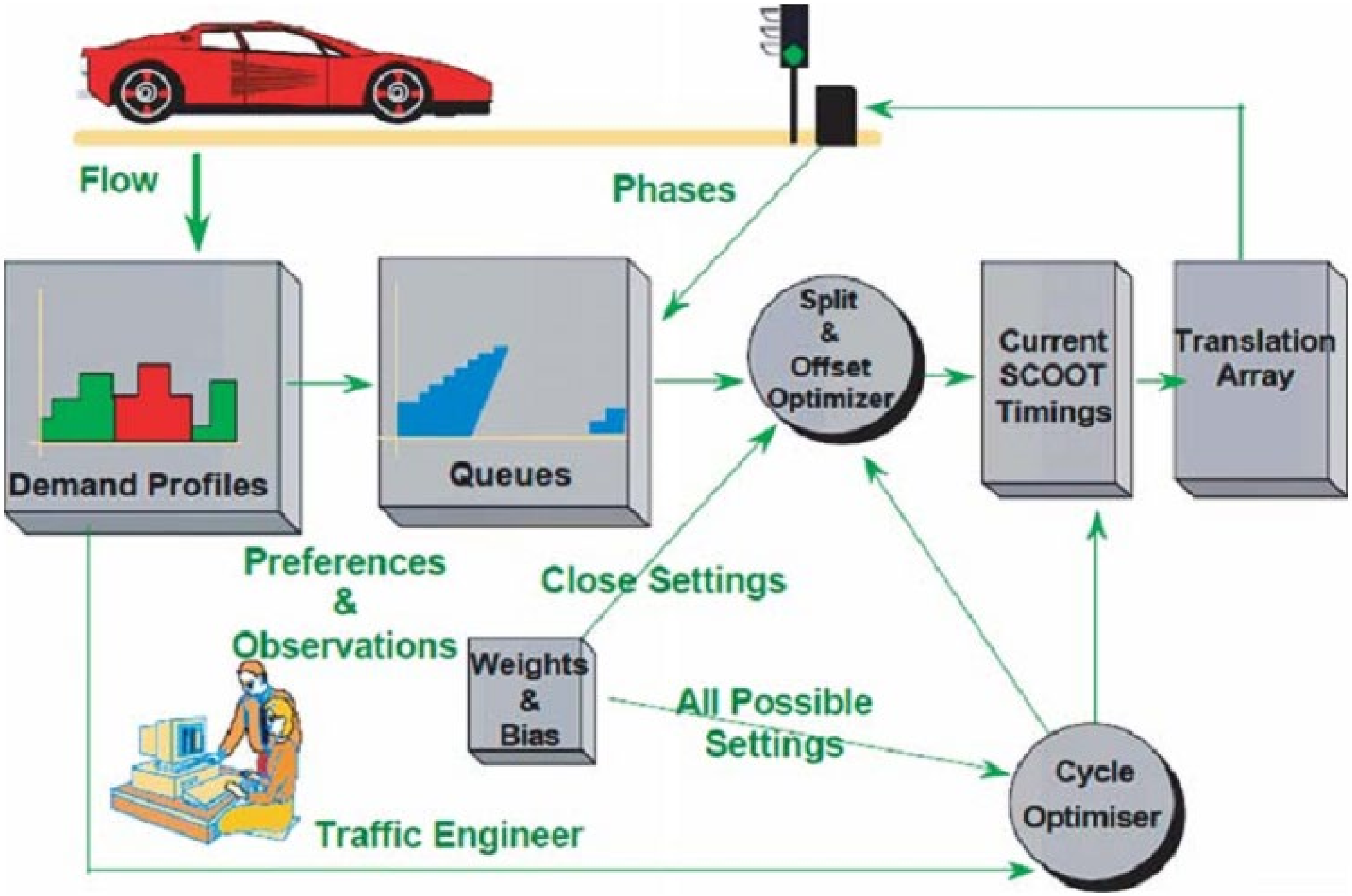
Signal Control Types

- Fixed-time control: fixed parameter, fixed duration
- Actuated control: fixed parameter, flexible duration
  - Semi-actuated: detectors on minor approach
  - Fully actuated: detectors on each approach
  - (Rule-based: max out/gap out/force off)
- **Adaptive control**: flexible parameters, flexible duration
  - Usually based on certain traffic flow model and traffic signal optimization techniques

Major Adaptive Control Systems

- SCOOT (Split, Cycle, and Offset Optimization Technique)
- SCATS (Sydney Coordinated Adaptive Traffic System)
- OPAC (Optimization Policies for Adaptive Control)
- RHODES (Real-time Hierarchical Optimized Distributed Effective System)
- ACS-Lite (Adaptive Control System – Lite)

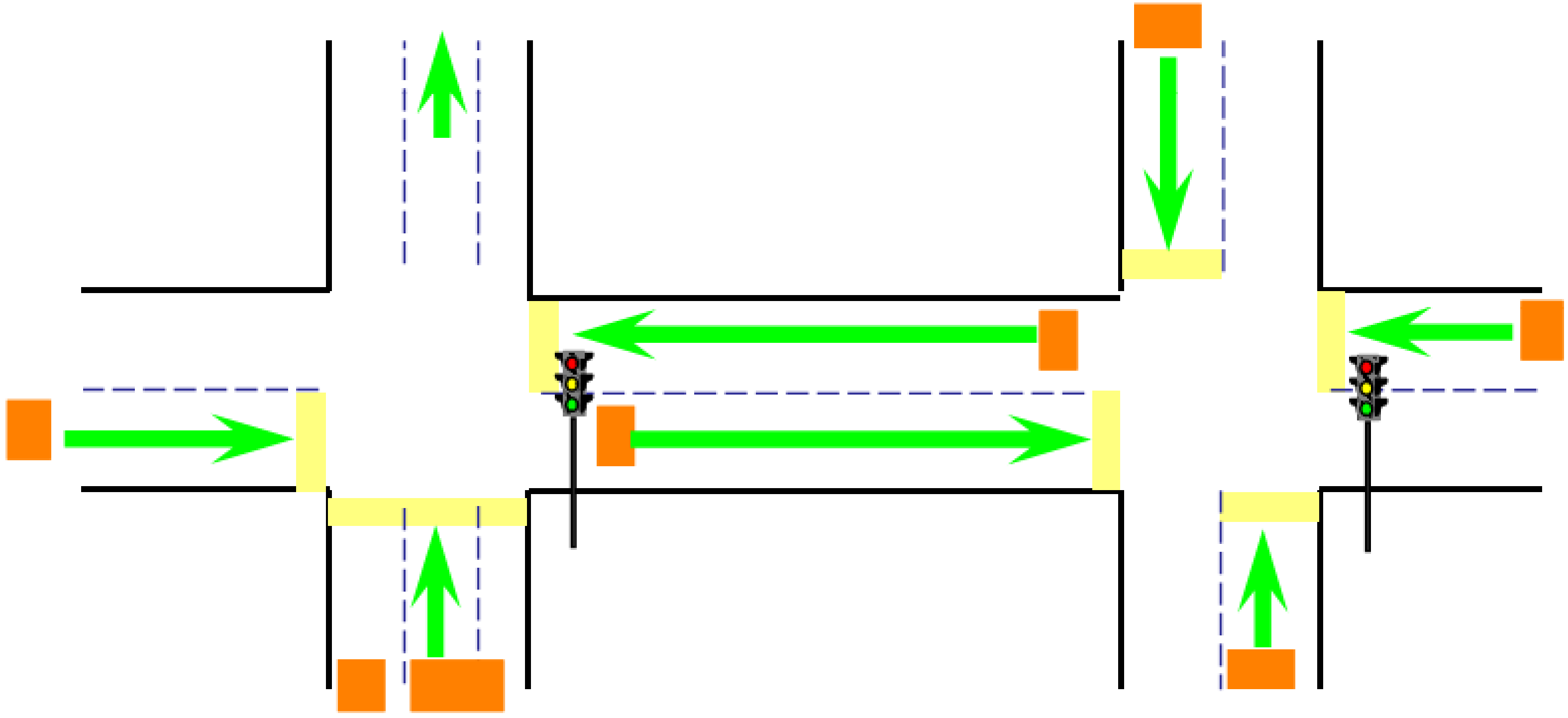
SCOOT - Overview



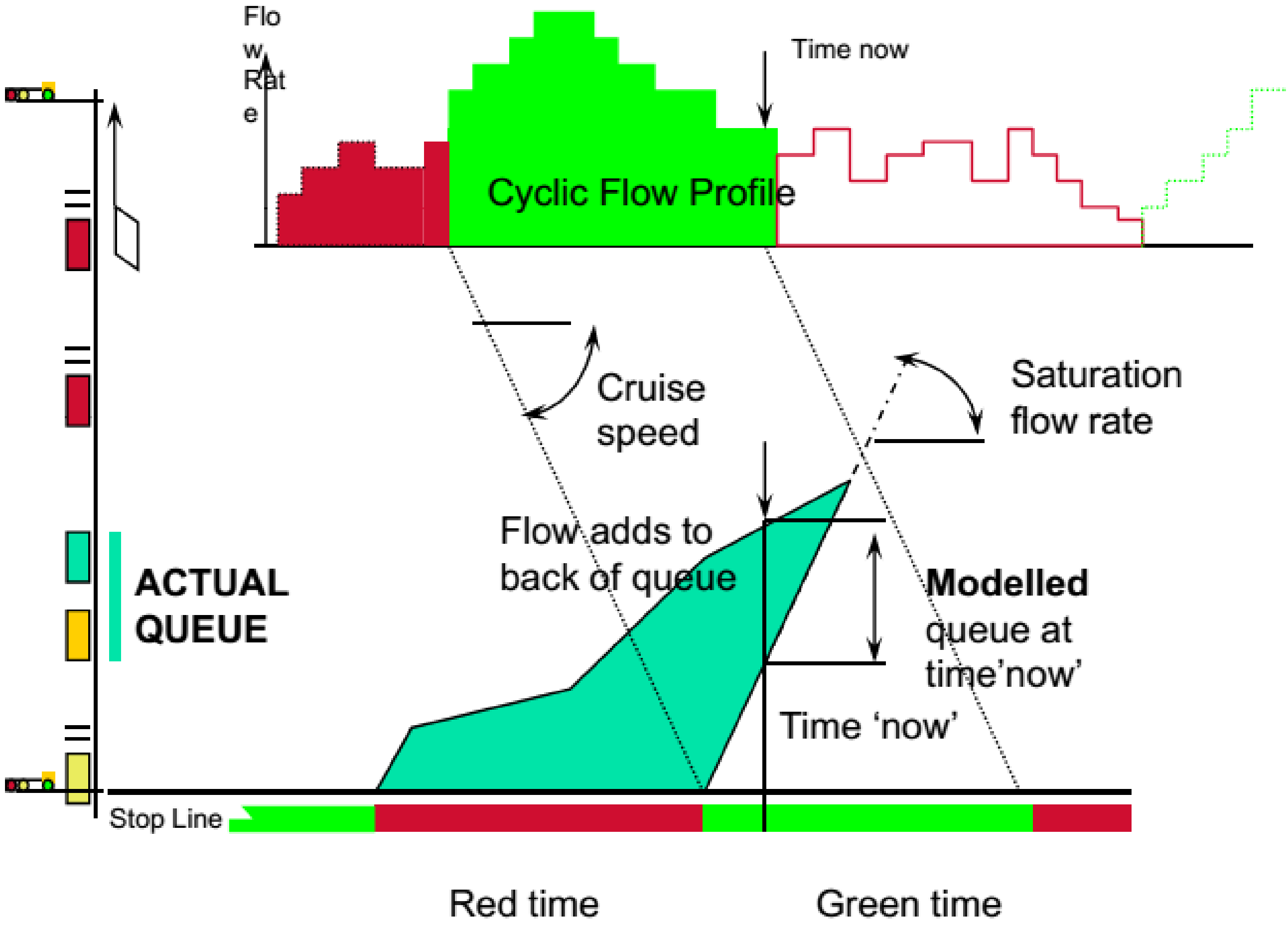
SCOOT – Data Requirements

- Detectors generally located at upstream end of link
- Detectors are connection to central computer
- Links with no detection run fixed length or can have data derived from upstream links
  - Fixed length phases can be varied by time of day

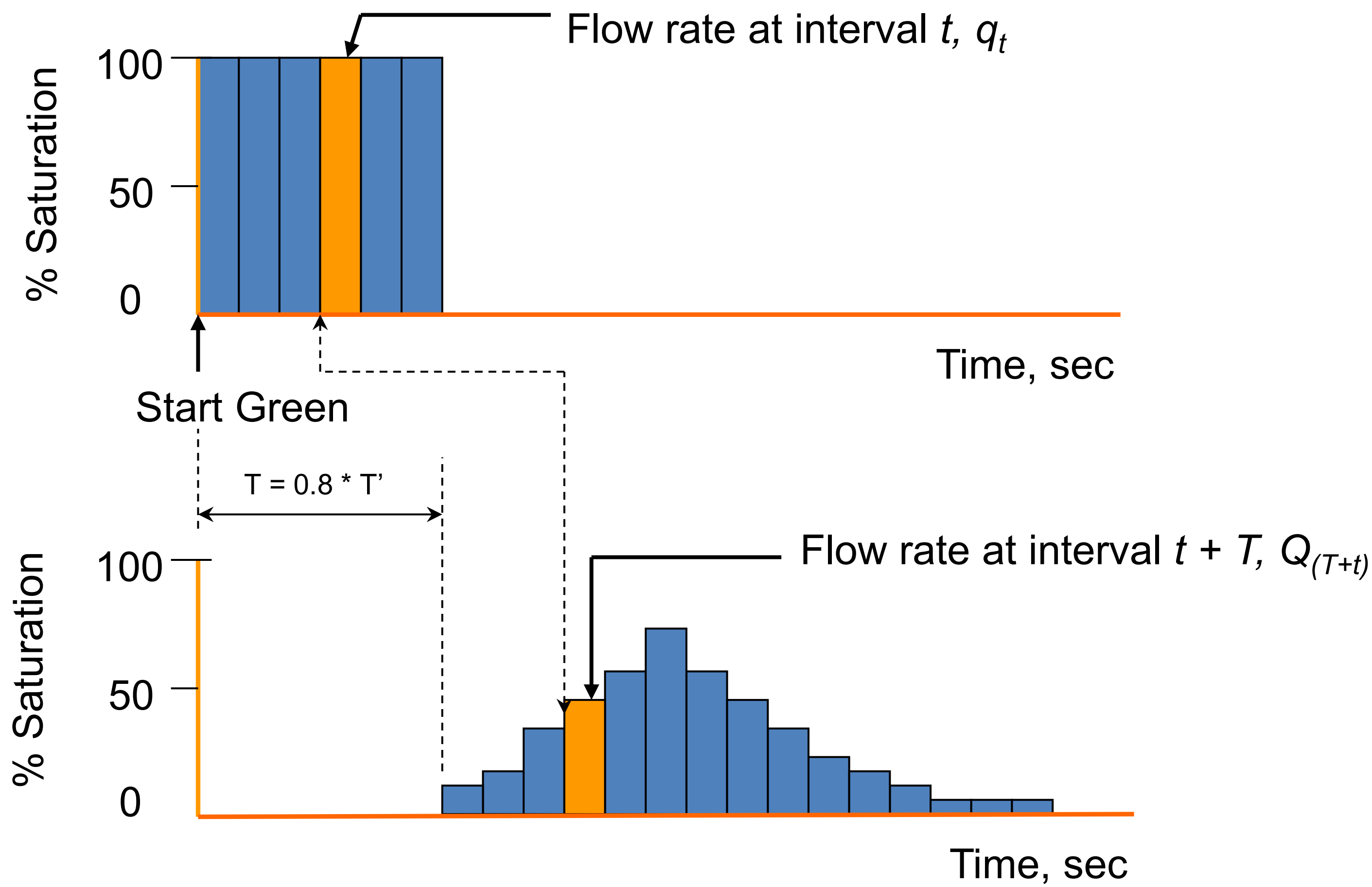
SCOOT – Detector Location



SCOOT – Queueing Model



Platoon Dispersion Model (Robertson, 1969)



Platoon Dispersion Model

- For each time interval (step) t, the arrival flow at the downstream stop line (assuming vertical queue), is calculated by solving the recursive equation:

$$Q_{T+t} = F \times q_t + [(1 - F) \times Q_{T+t-1}]$$

$$T = \beta \times T', F = \frac{1}{1 + T\alpha}$$

  - where, F is the dispersion factor; q_t is the arrival flow at upstream detector at time t; T' is the free flow travel time; and α and β are model parameters
  - Usually, $\beta = 0.8$ and $\alpha = 0.5, 0.35, 0.25$ for heavy, moderate and light traffic conditions

SCOOT – Optimizers

- Split Optimizer
  - Change split every phase to balance degree of saturation
  - Change increments are typically around a few seconds
- Offset Optimizer
  - Change offset once per cycle for each intersection to minimize delay and number of stops
- Cycle Optimizer
  - Operate on a region basis once every 5 (2.5) minutes
  - Identify “critical intersection” within the region
  - Adjust cycle time to maintain the intersection with 90% saturation on each phase

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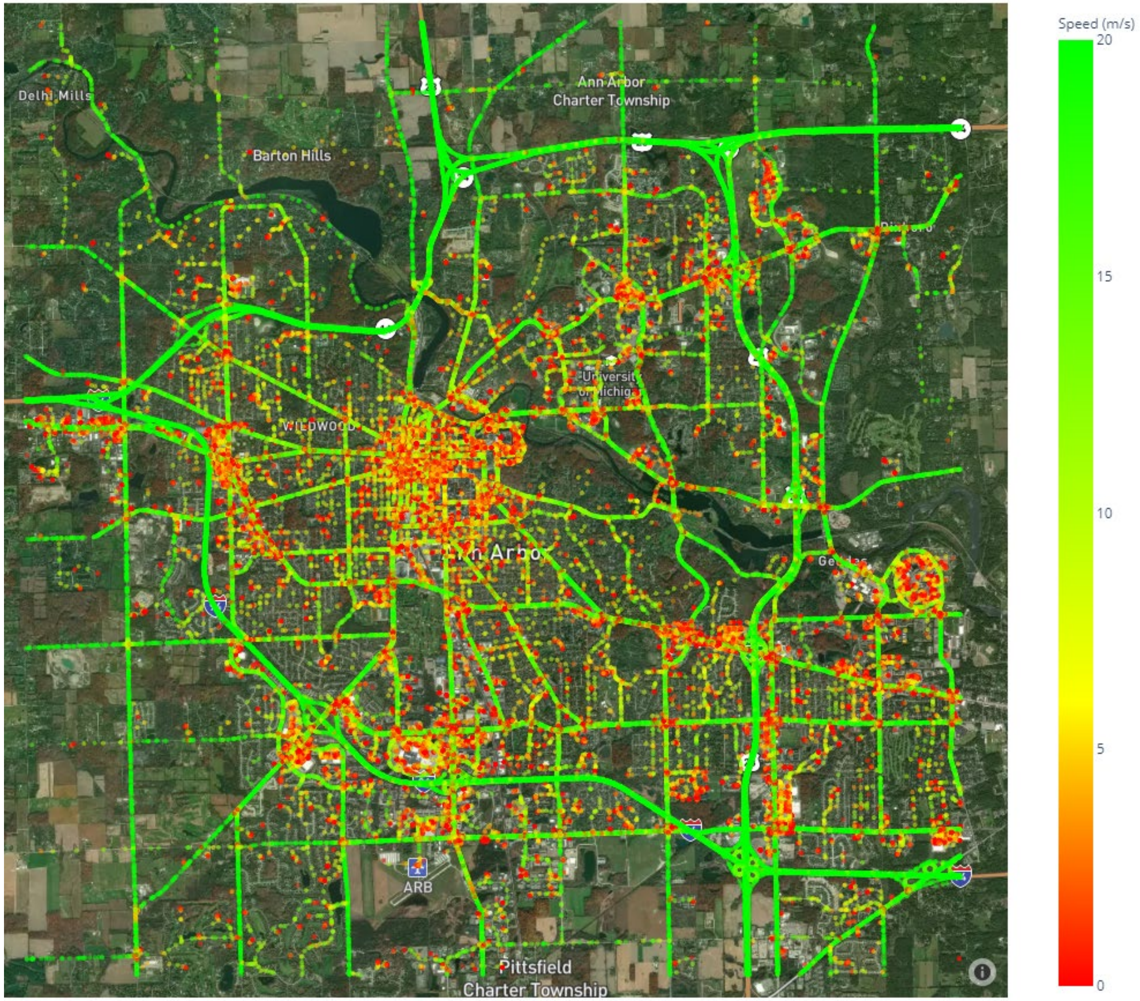
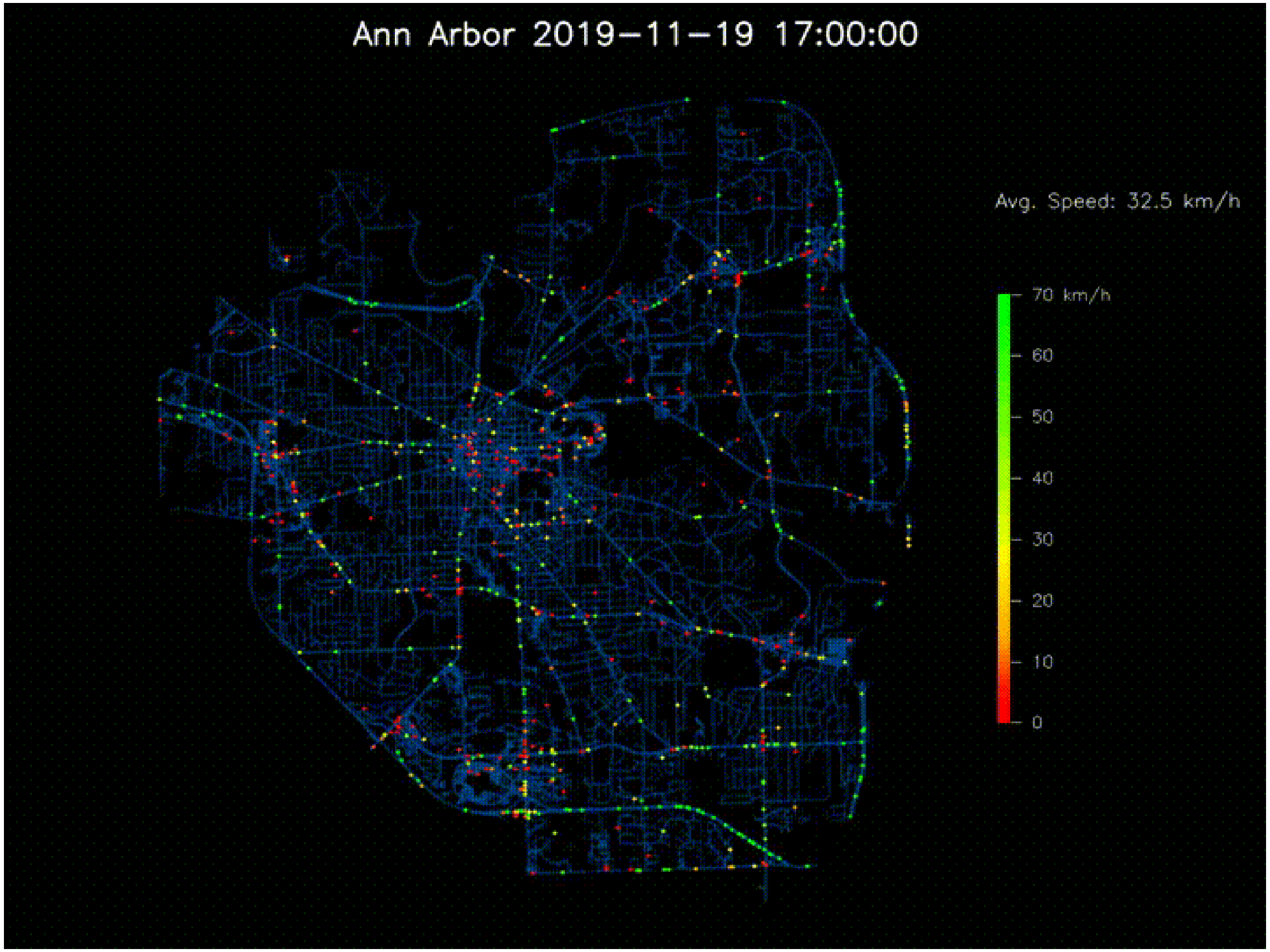
Vehicle Trajectory Data

- Essential attributes
  - Trip id
  - GPS coordinates
  - Timestamp

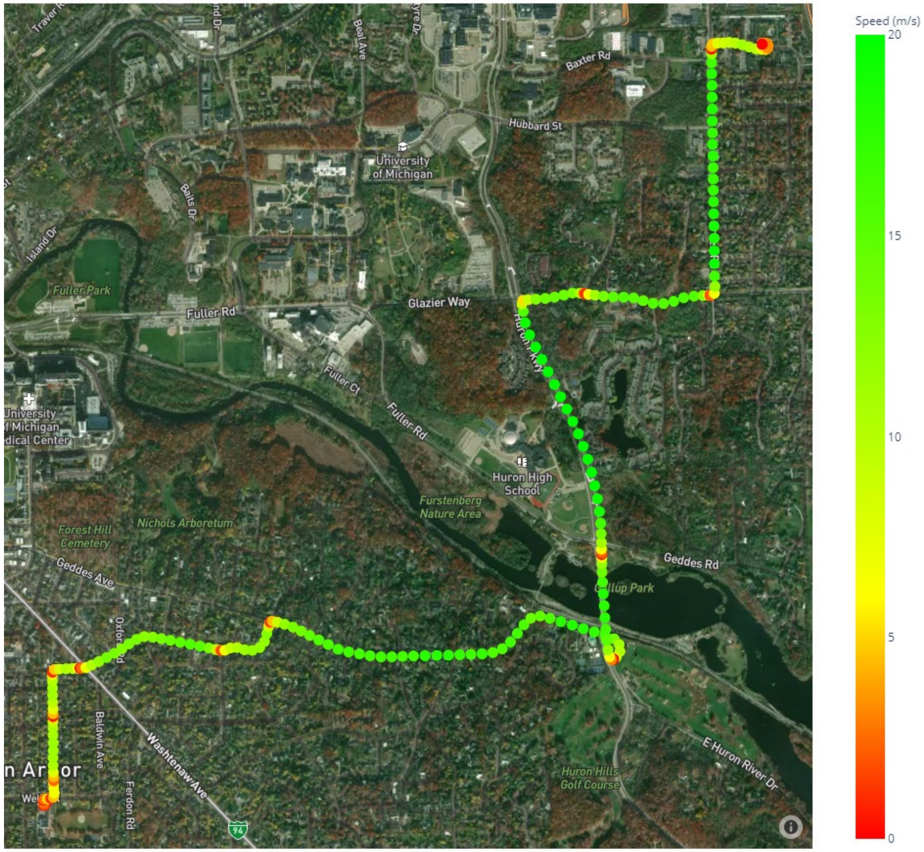


Vehicle Trajectory Data



Vehicle Trajectory Data

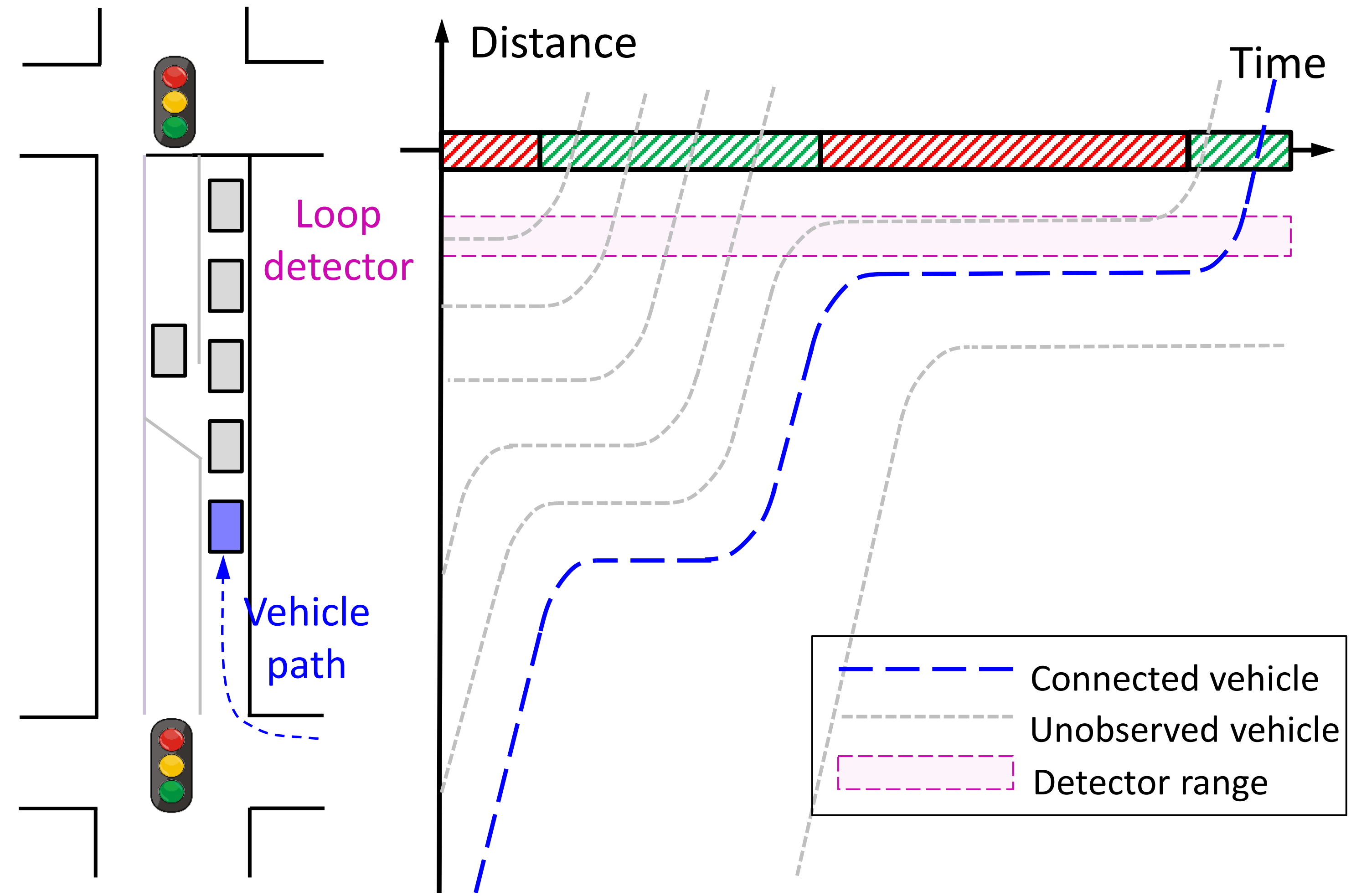
- Vehicle trajectory data: path information



Potential application

- OD demand estimation
- Path choice model
- ……

Vehicle Trajectory Data and Loop Detector Data

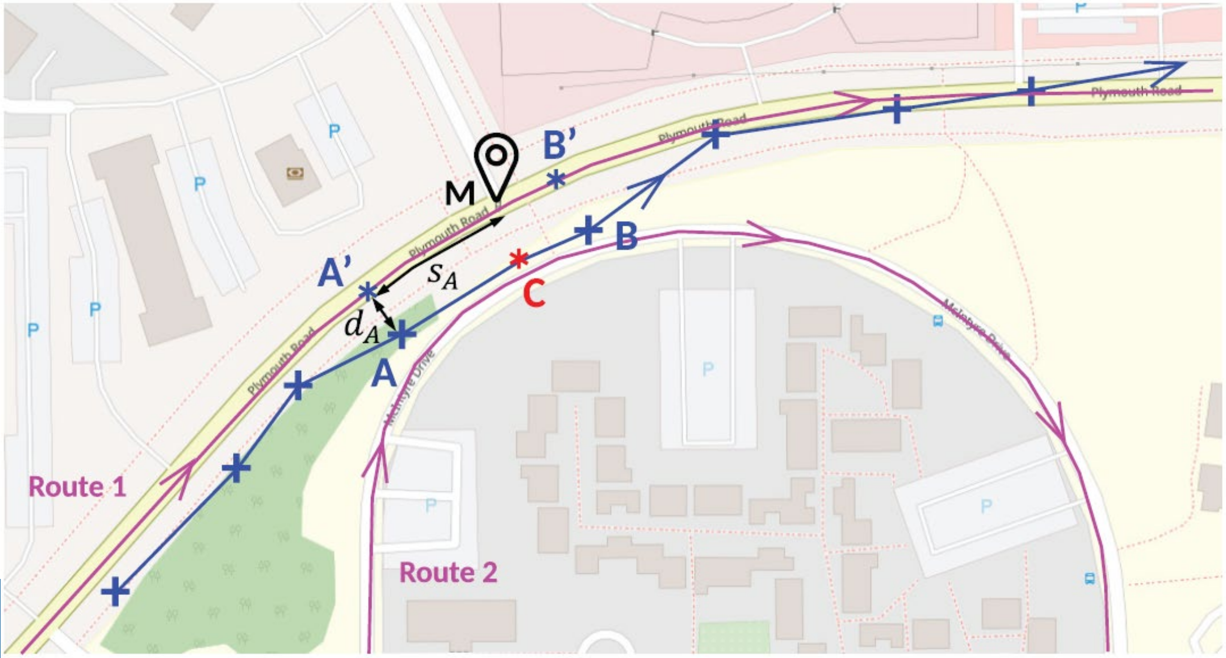


Different Types of Trajectories

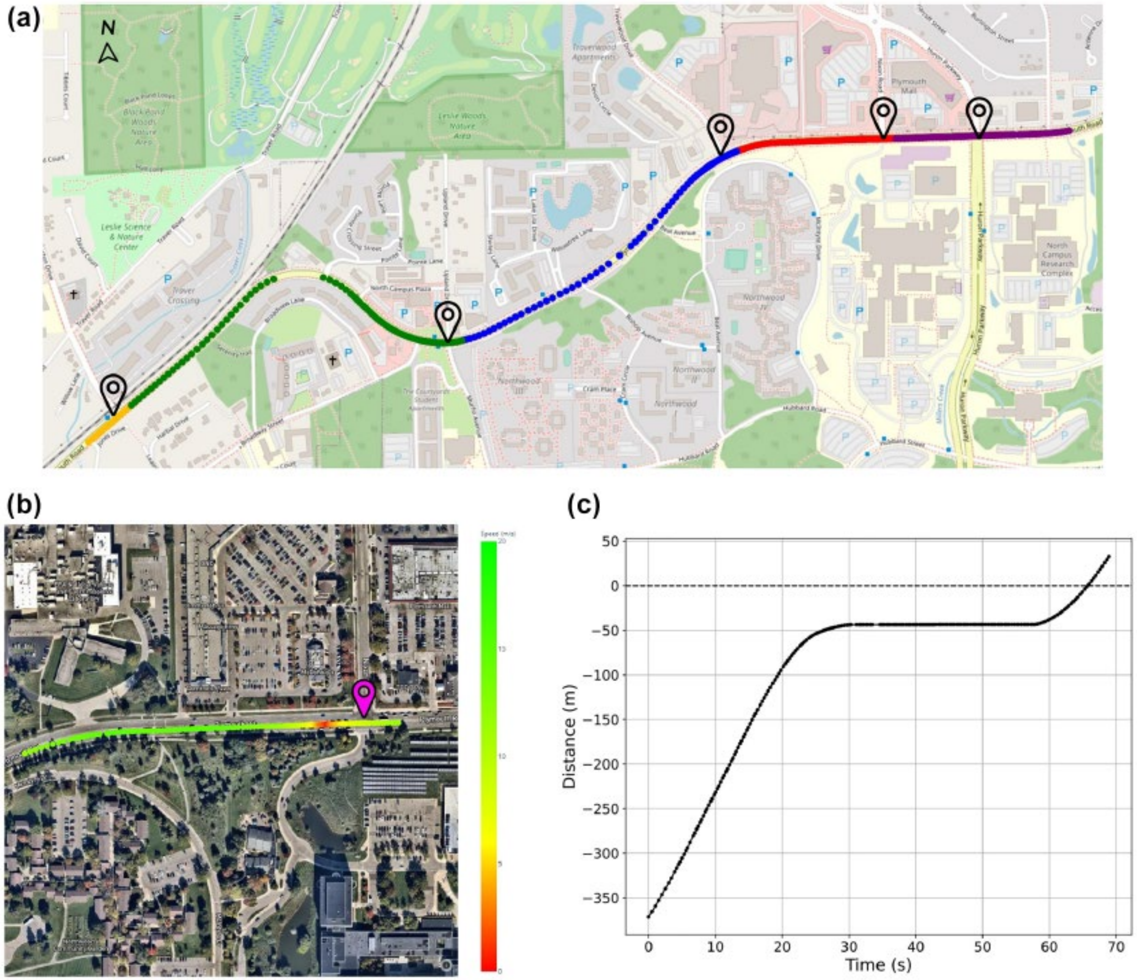
- Trajectories collected through DSRC (dedicated short-range communication)
  - BSM: basic safety message (SAE standard)
  - High frequency, require installation (OBU, on-board unit), only near the RSU (road-side unit)
- Road-side perception: camera, drones, etc.
  - Detection & tracking error
- Directly from the vehicle: cell phone, vehicle navigation system (GPS), etc.
  - Long continuous trip, unstable frequency

Trajectory Data Map Matching

- Map matching: match the vehicle trajectory data to the road network
- Map matching principles: two main factors
  - Distance between the GPS coordinates and the road network
  - Path feasibility (close roads,)

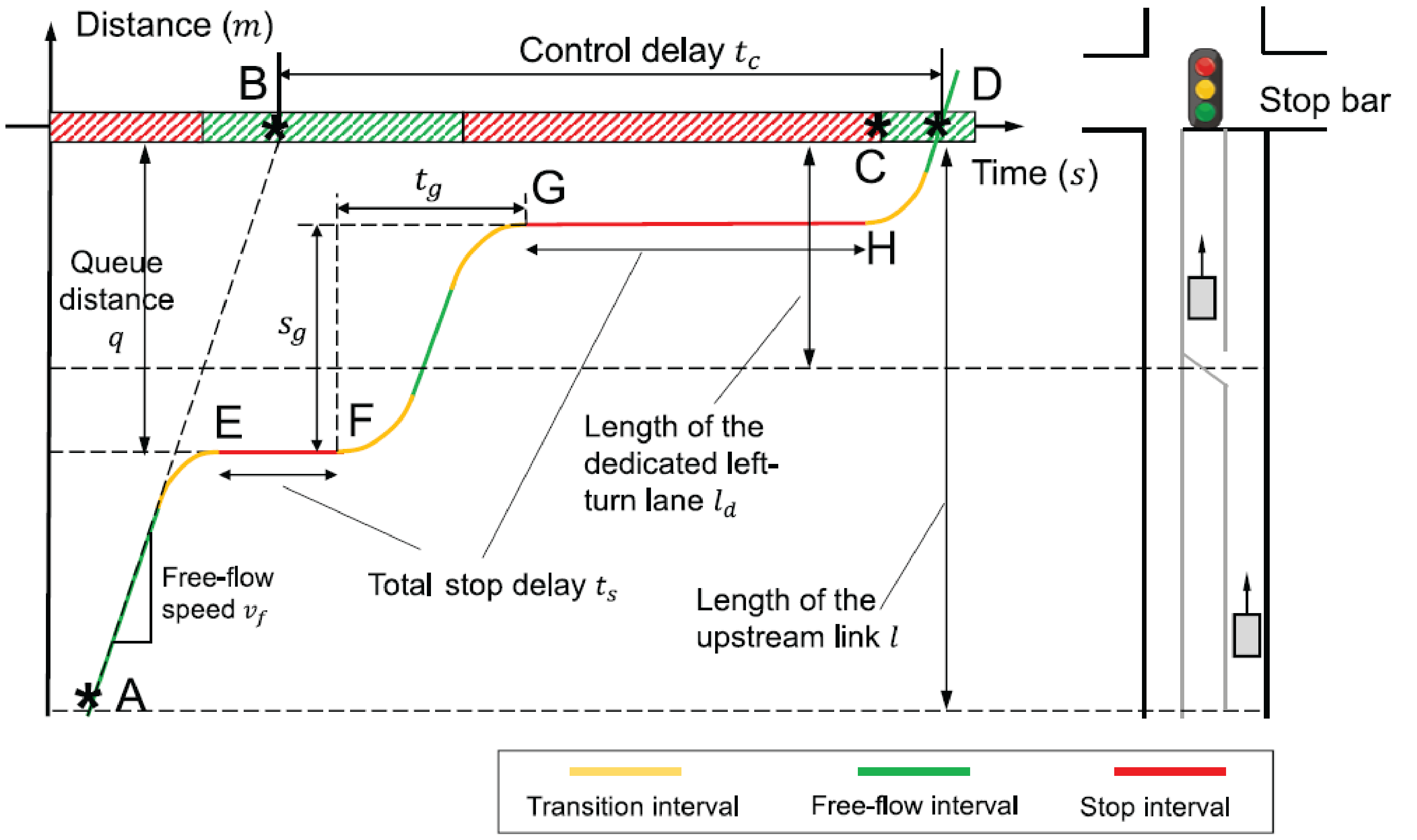


GPS Coordinates to Distance

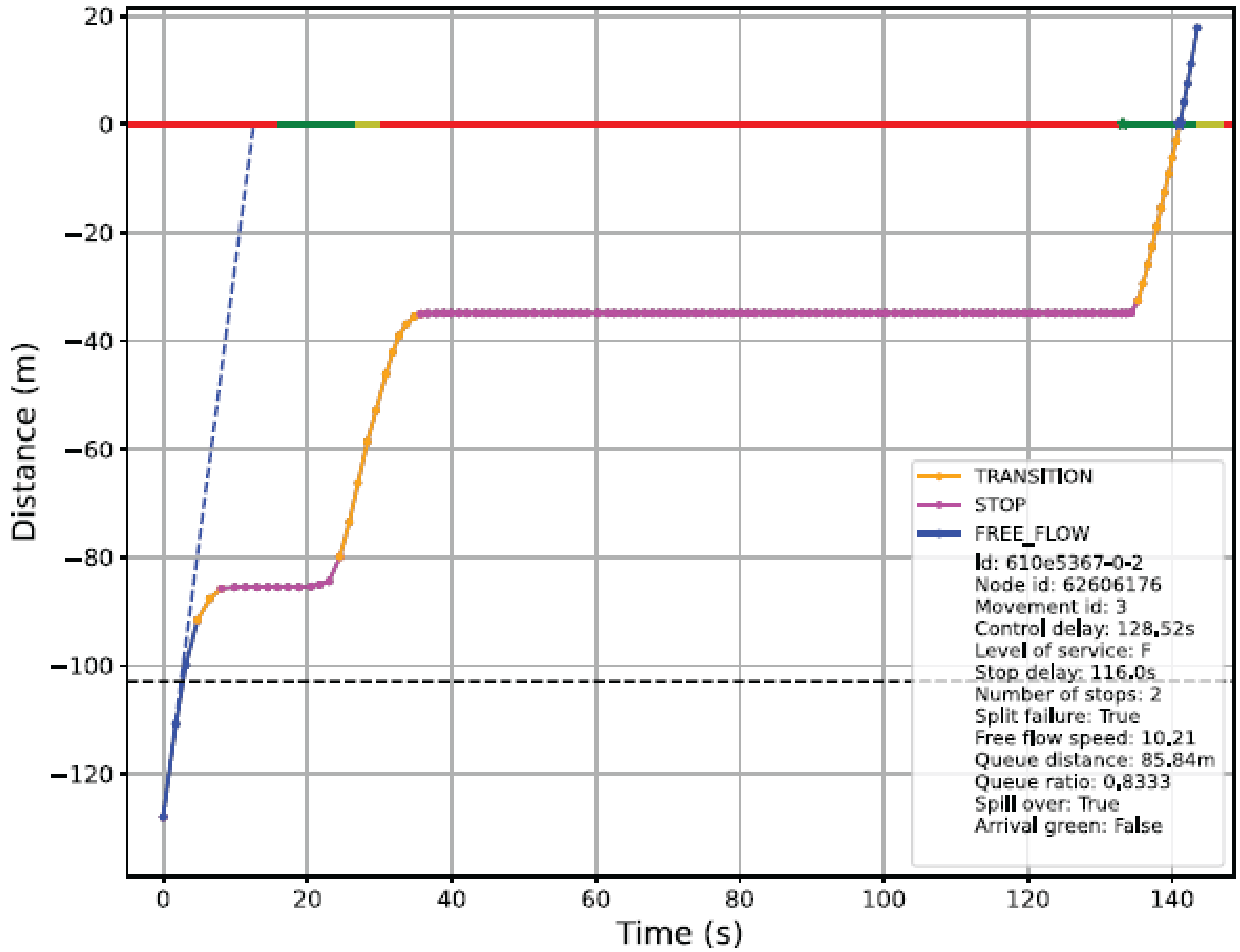


We need a reference (zero) point for the distance (center of the intersection as shown in the figure)

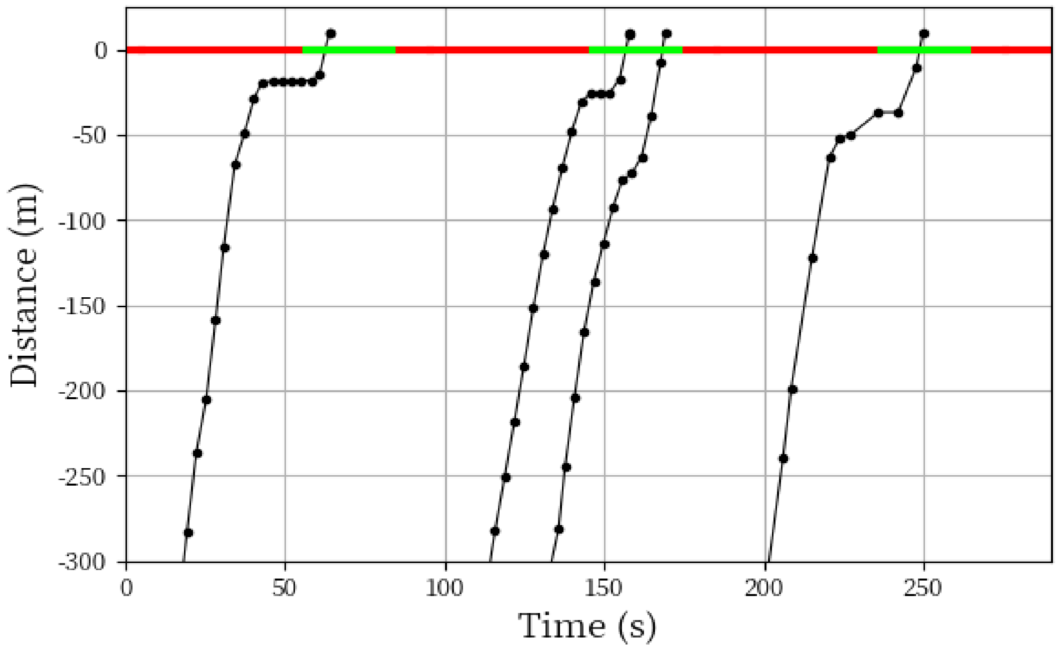
Performance Index Calculation

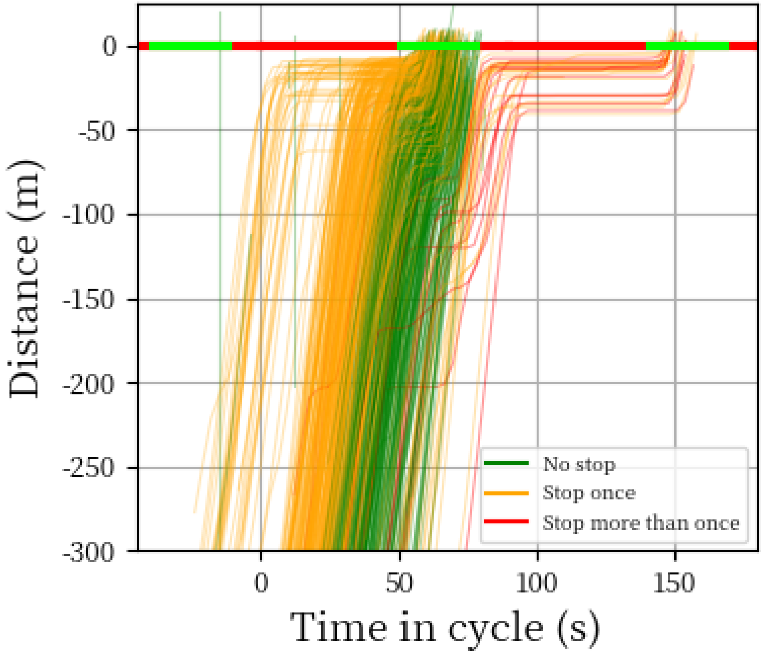


Over Saturation



Aggregated Time-Space Diagram





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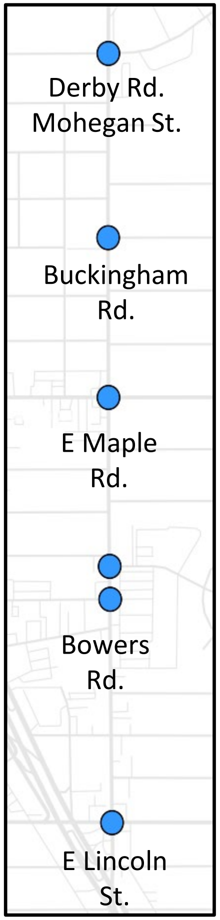
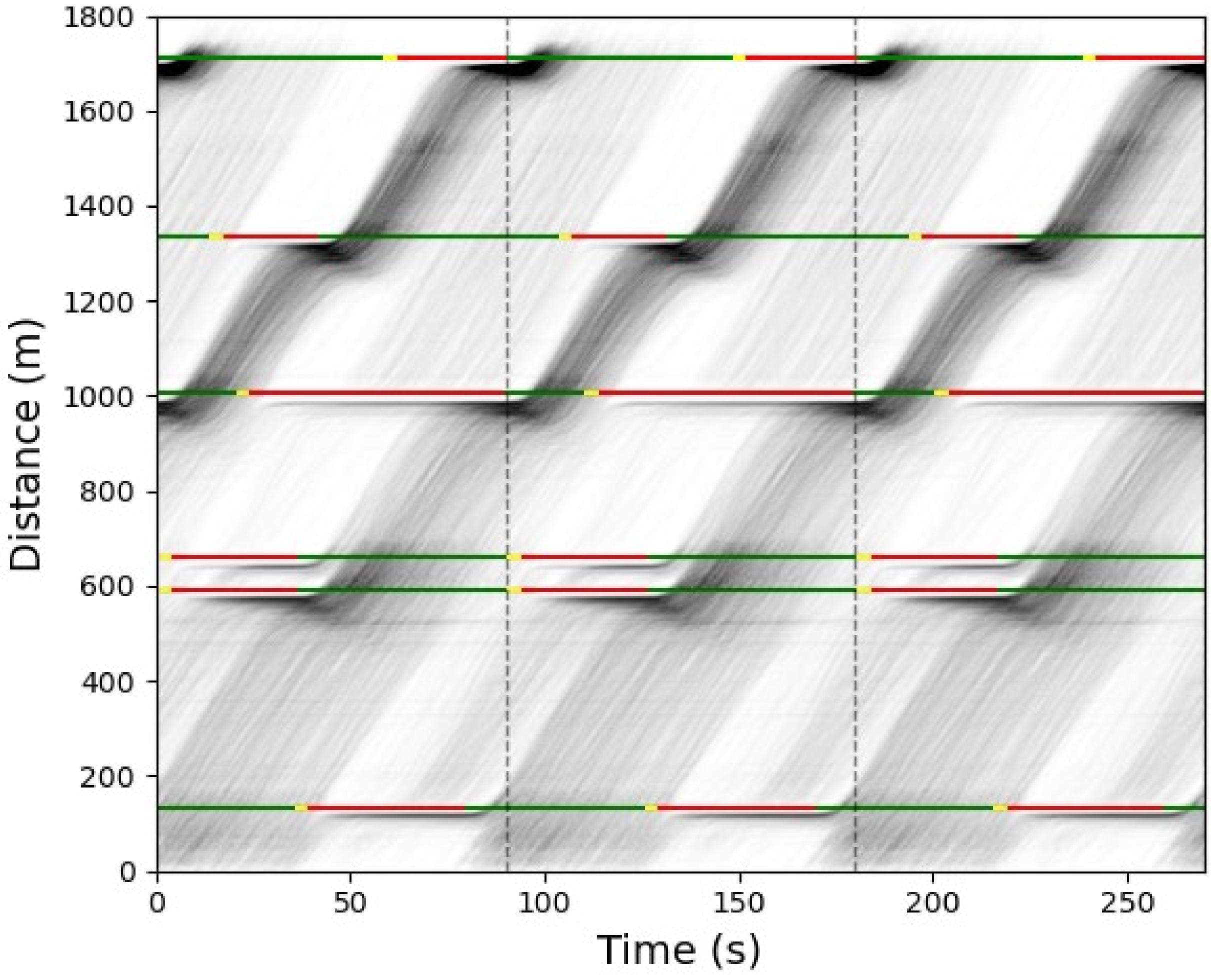
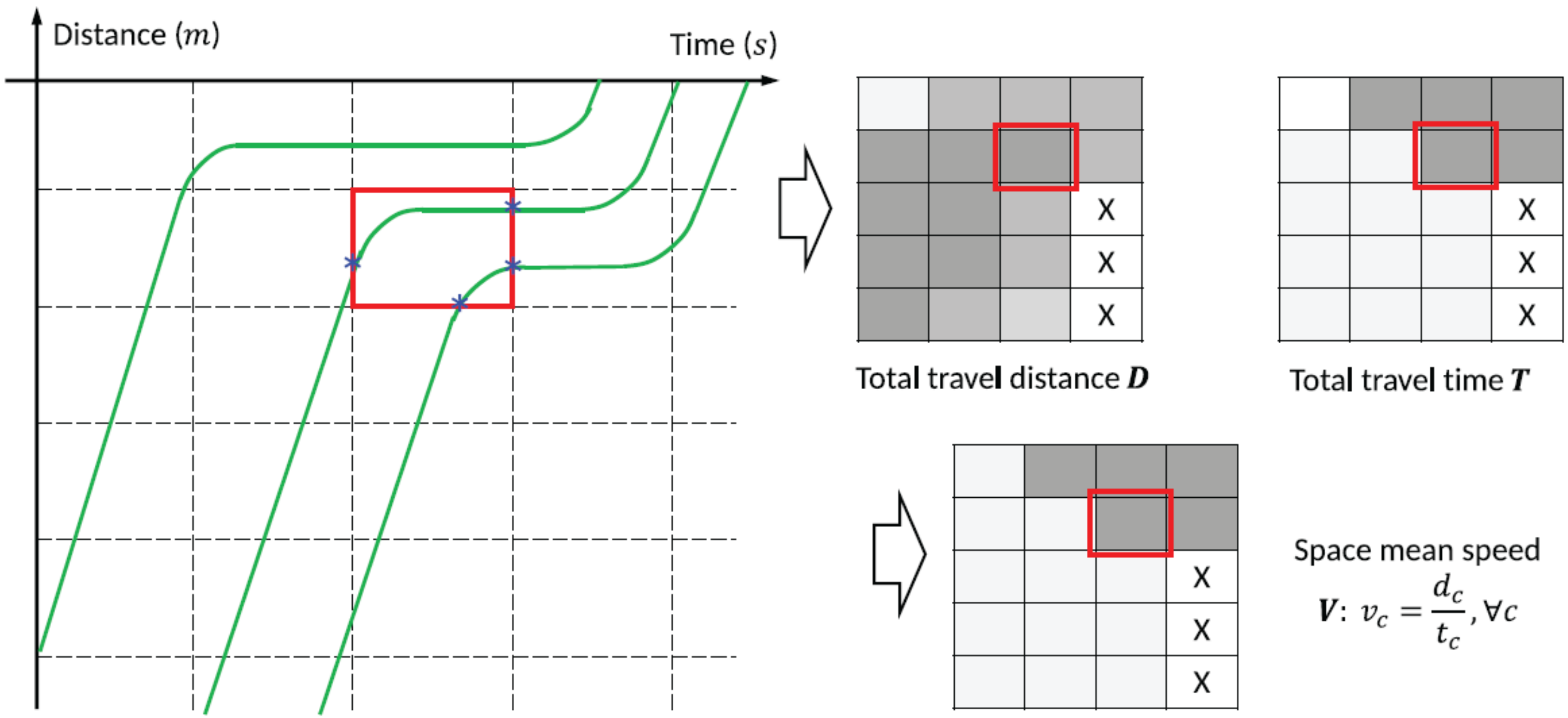
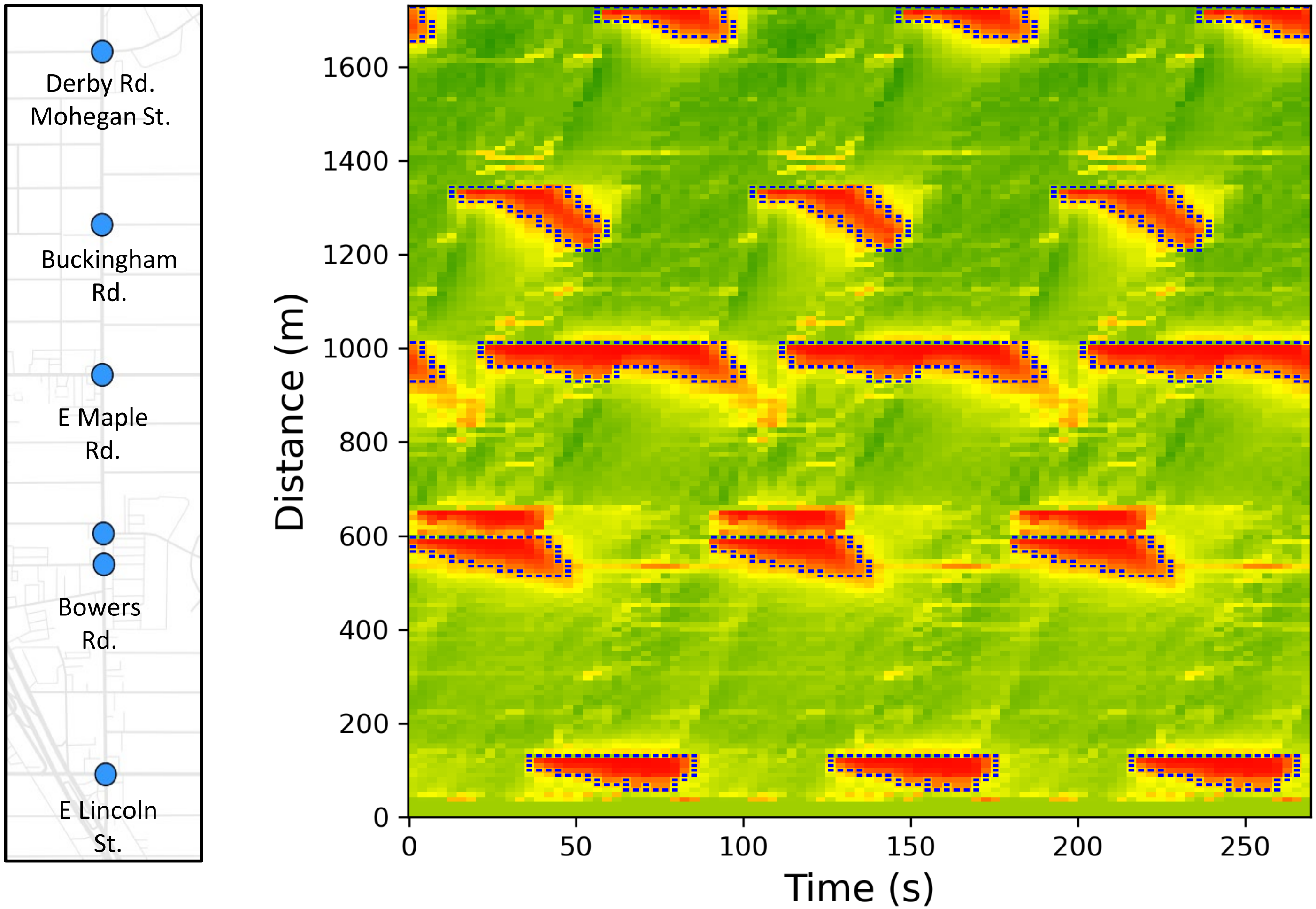




Space-Mean Speed Calculation

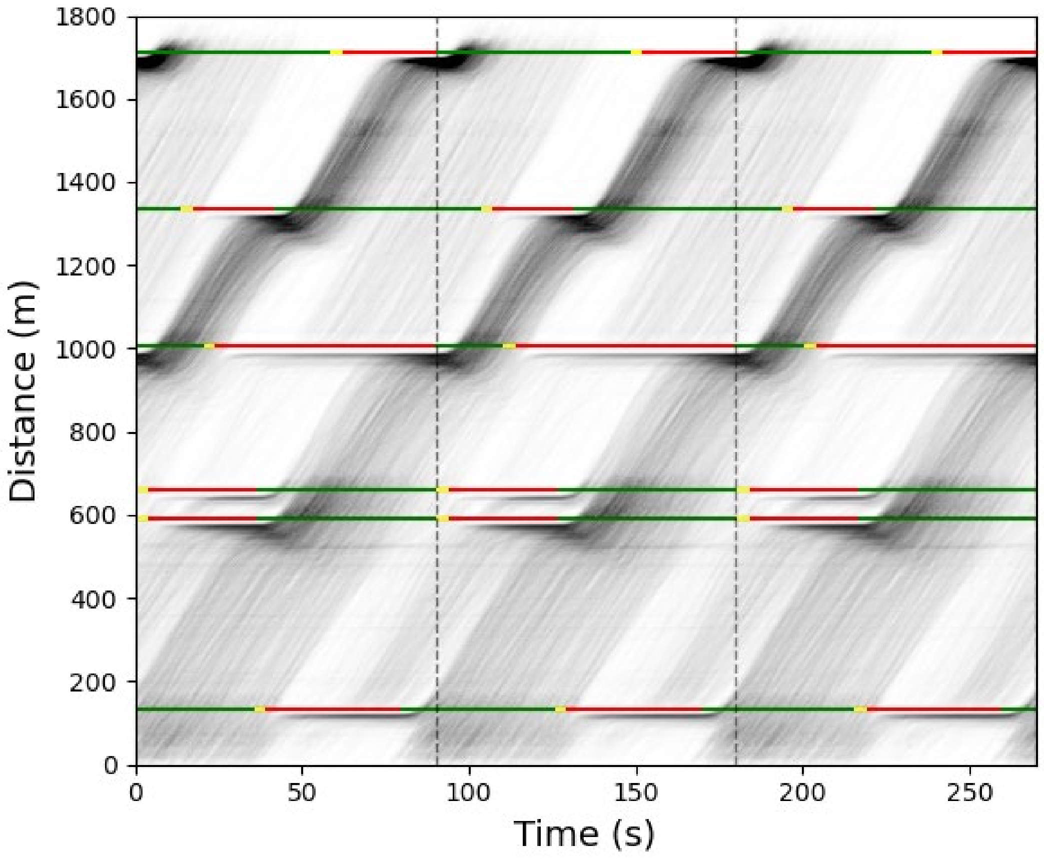


Space-Mean Speed



Traffic Signal Optimization using Vehicle Trajectory Data

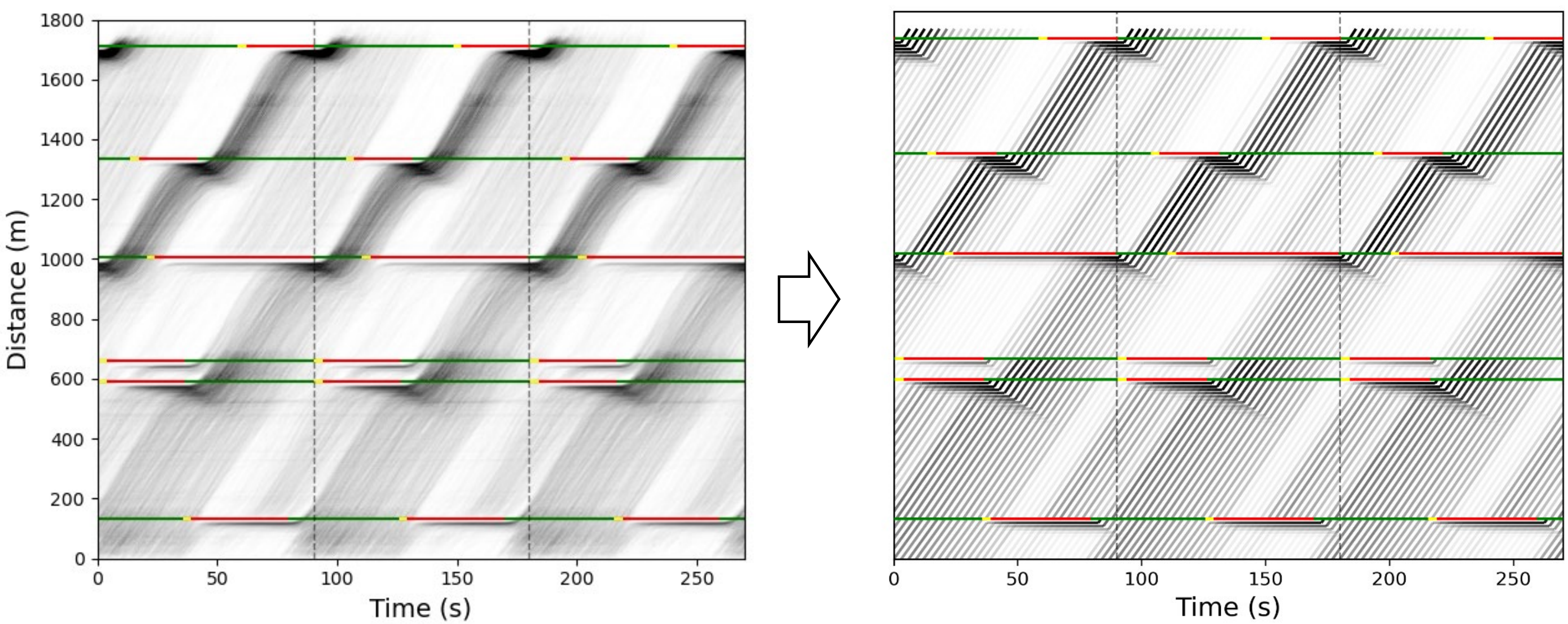
- Cycle, splits, and **offsets**.



- Traffic state estimation (model calibration)
- Offset optimization

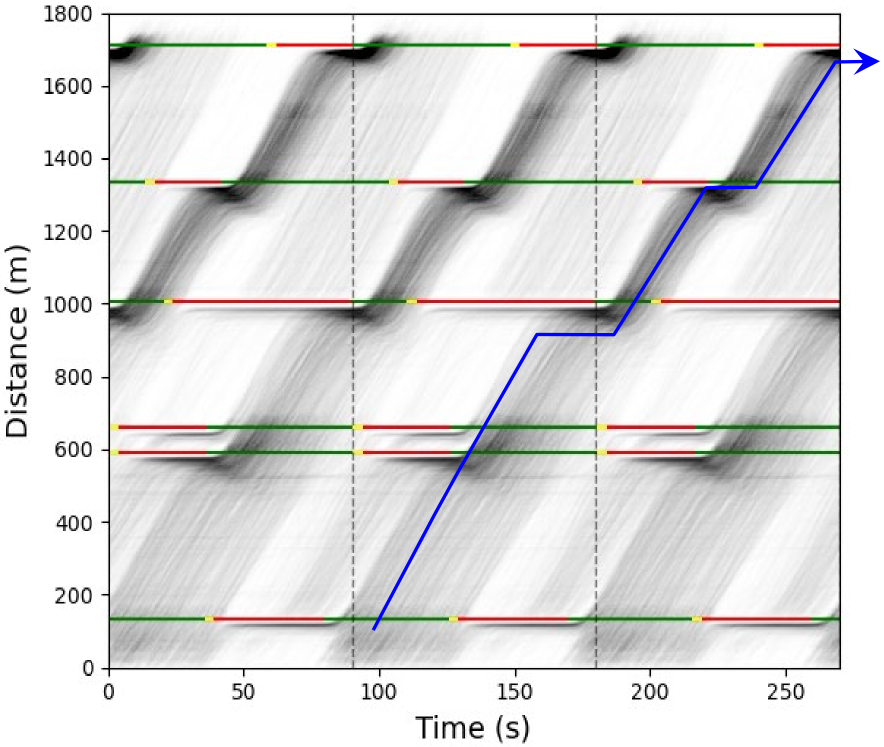
Model Calibration

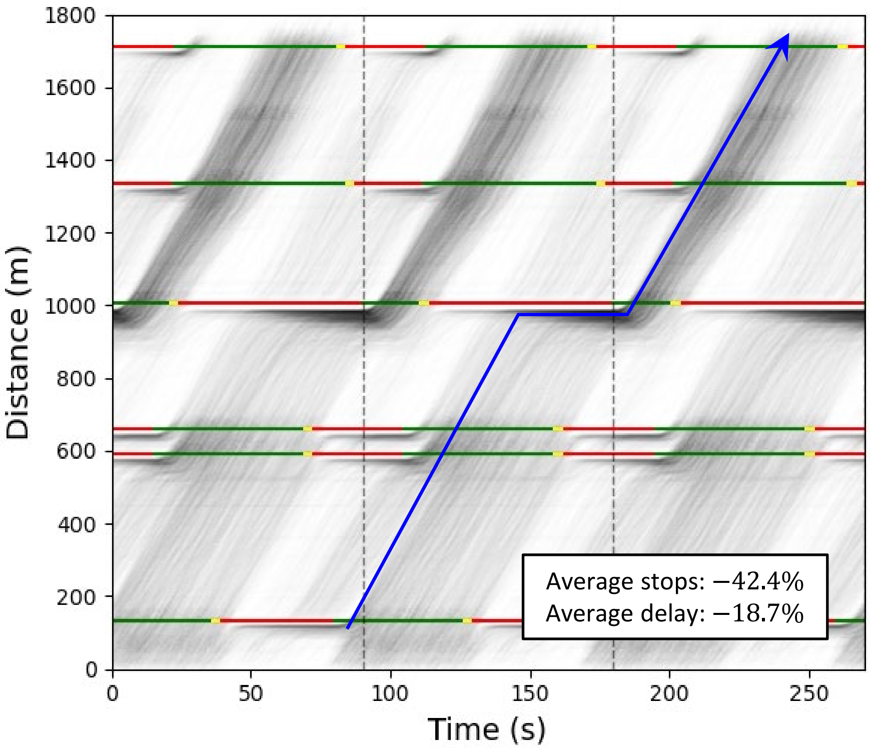
- Calibration of queueing model



We call it “probabilistic time-space diagram”, the transparency of each line segment shows the probability that there is a vehicle traveling along it

Offset Optimization





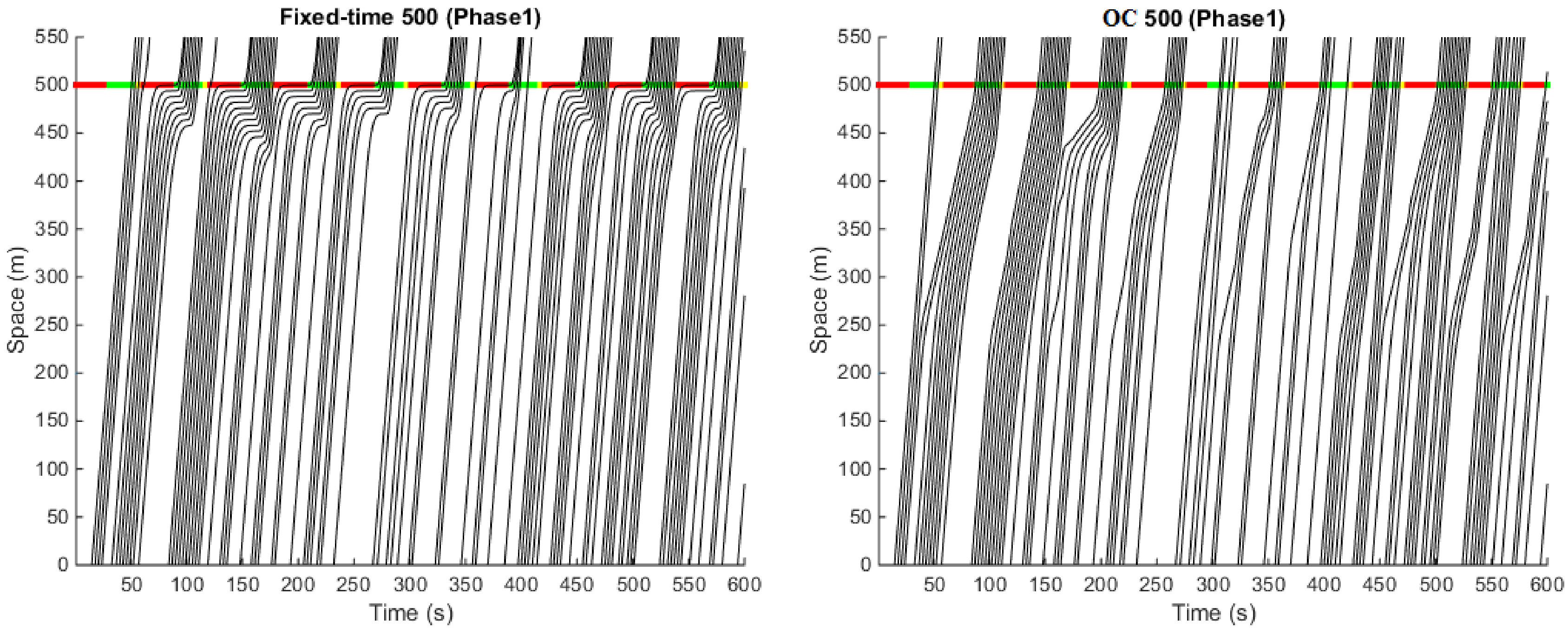
Field implementation by our lab. City of Birmingham, MI. April 2022.

Traffic Signal Control & Automated Vehicles

- Automated vehicles not only provide the vehicle trajectory, but they can also be used as “moving controller” or “moving regulator” to smooth the overall traffic

- This can be realized by controlling or sending driving guidance to the automated vehicle from the infrastructure

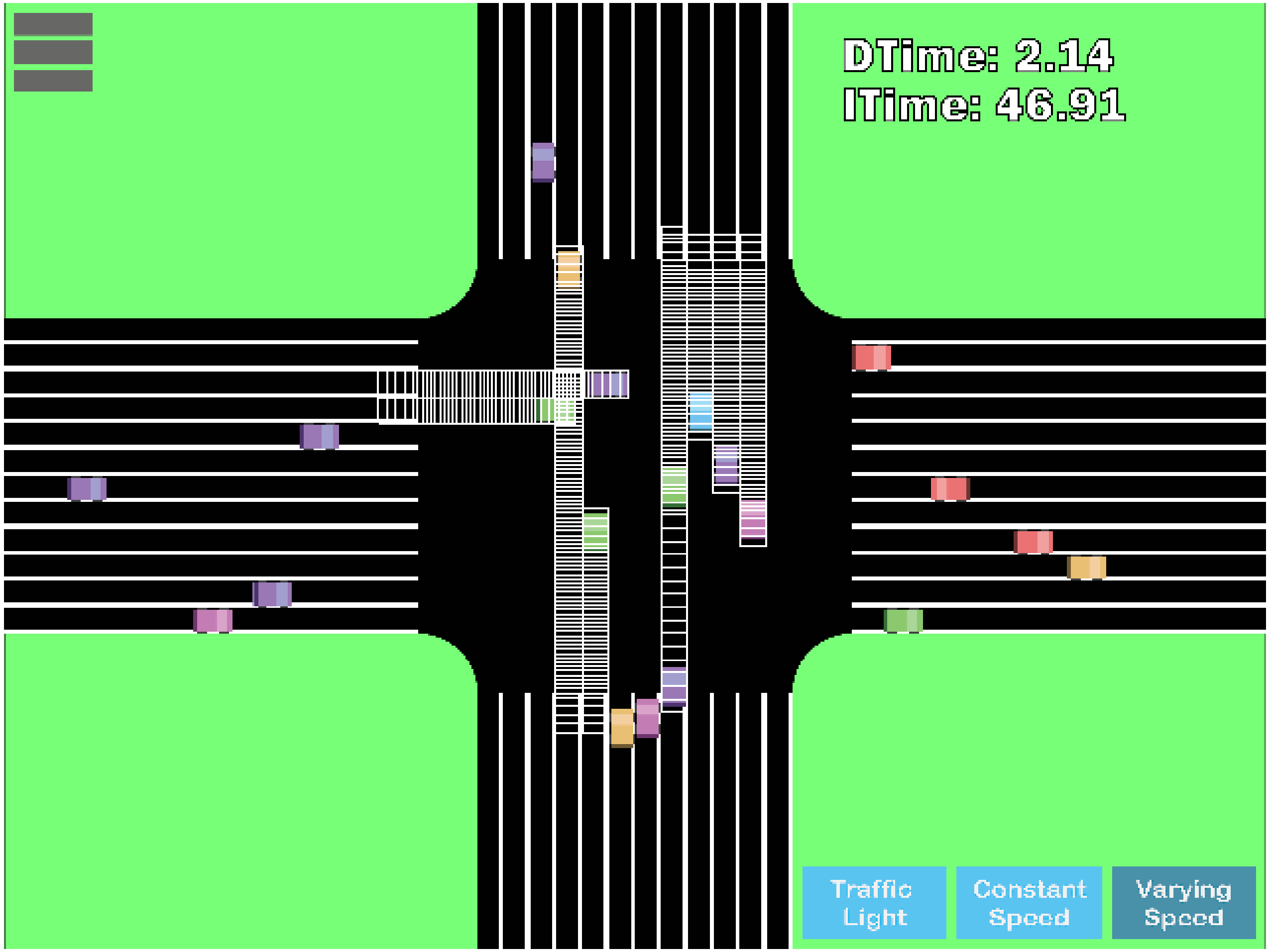
Signal Control + Trajectory Optimization



Stage 1: signal optimization to minimize delay
Stage 2: trajectory control to minimize energy consumption & emission

Ref: Feng, Yiheng, Chunhui Yu, and Henry X. Liu. "Spatiotemporal intersection control in a connected and automated vehicle environment." Transportation Research Part C: Emerging Technologies 89 (2018): 364-383

Reservation-Based Traffic Signal Control under Fully Automated Environment



"Signal-Free Intersection"

Signal-Free in Fully Automated Environment?

- Do we need traffic signal for intersection if all vehicles are automated vehicles?
- Intersection control formulation

Minimize Delay   Var: traffic signal state

s.t.   Traffic model (under normal driving behavior)

Traffic signal constraints

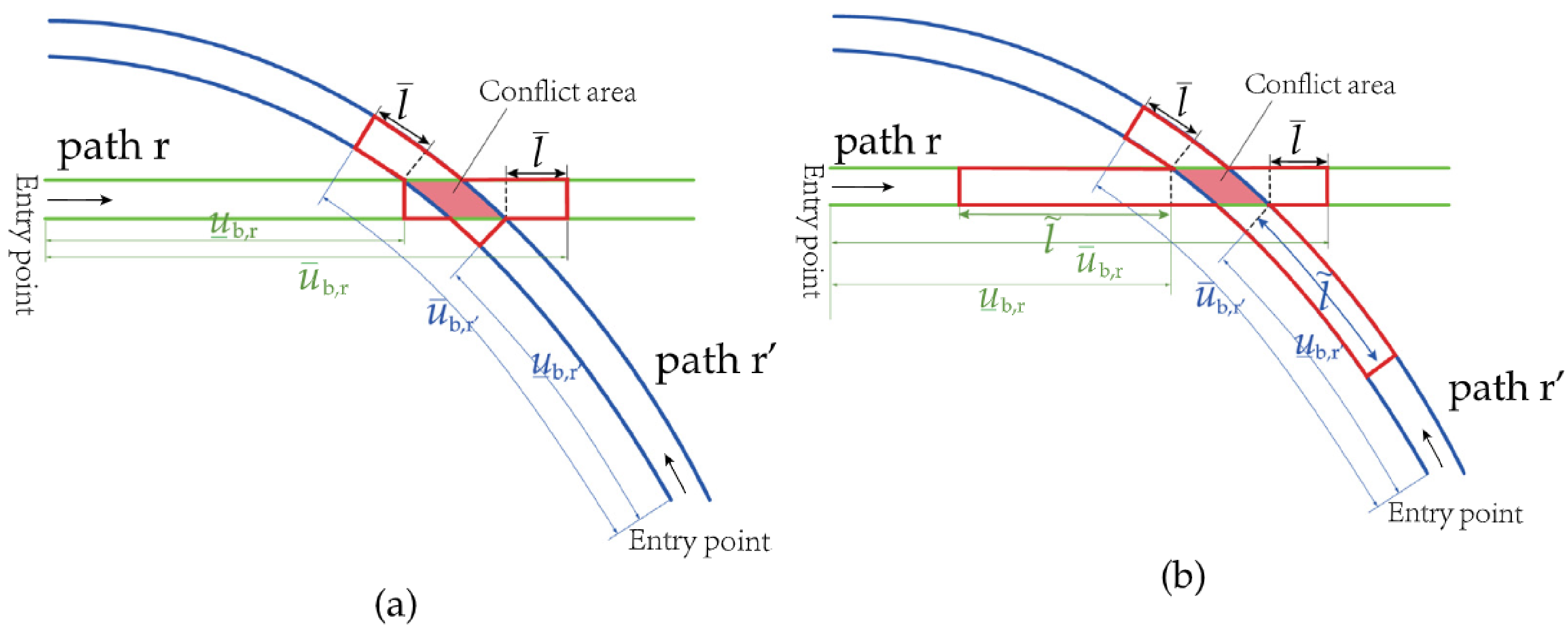
↓

Minimize Delay   Var: vehicle motions (acceleration, etc.)

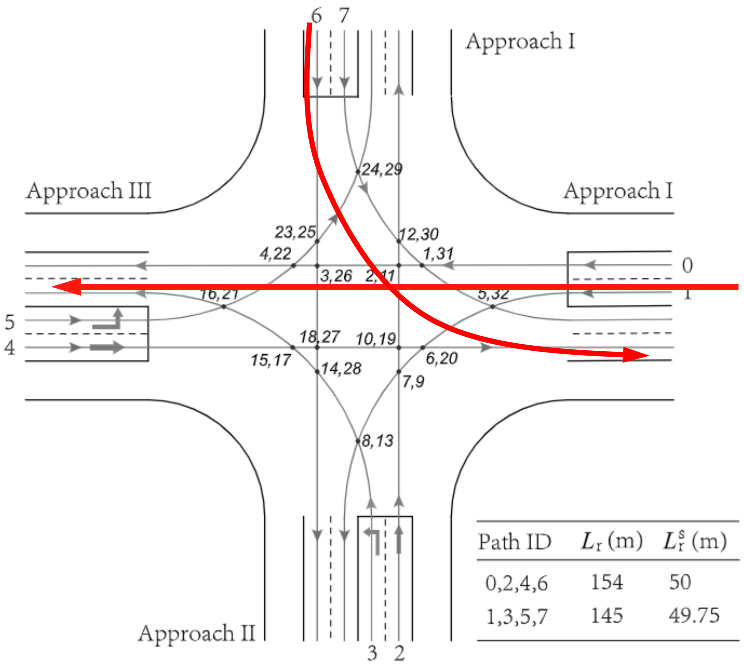
s.t.   Vehicle kinematics constraints

Constraints to avoid collision   (Much harder to solve)

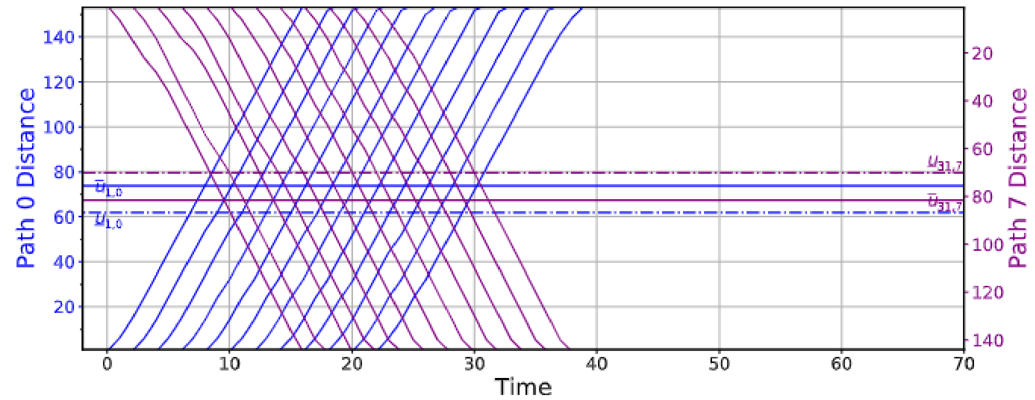
Conflict Point & Buffer



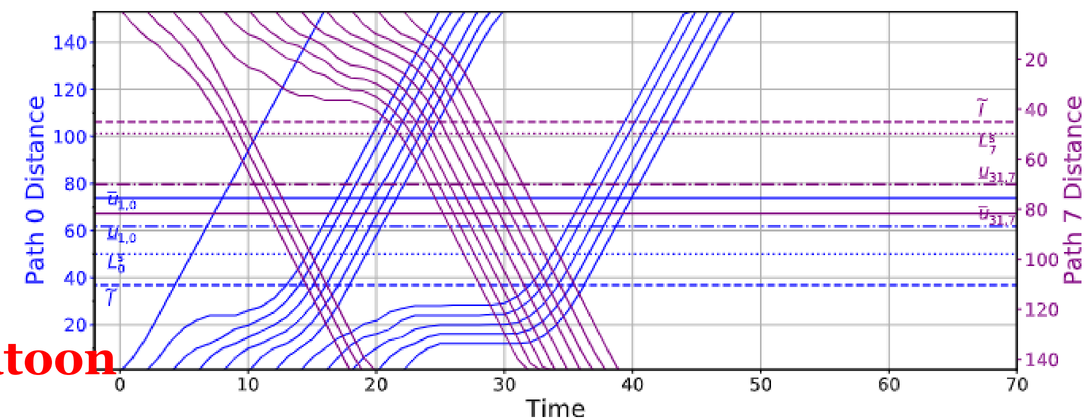
Computational Study



Path ID	L_r (m)	L_r^s (m)
0,2,4,6	154	50
1,3,5,7	145	49.75



Zero buffer



Add certain buffer

Vehicles will tend to form platoon to pass the intersection

Reference

- Wang, X., Jerome, Z., Zhang, C., Shen, S., Kumar, V.V. and Liu, H.X., 2022. Trajectory Data Processing and Mobility Performance Evaluation for Urban Traffic Networks. *Transportation Research Record*, p.03611981221115088.
- Lu, Gongyuan, et al. "Are autonomous vehicles better off without signals at intersections? A comparative computational study." Transportation research part B: methodological 155 (2022): 26-46.
- Feng, Yiheng, Chunhui Yu, and Henry X. Liu. "Spatiotemporal intersection control in a connected and automated vehicle environment." Transportation Research Part C: Emerging Technologies 89 (2018): 364-383.