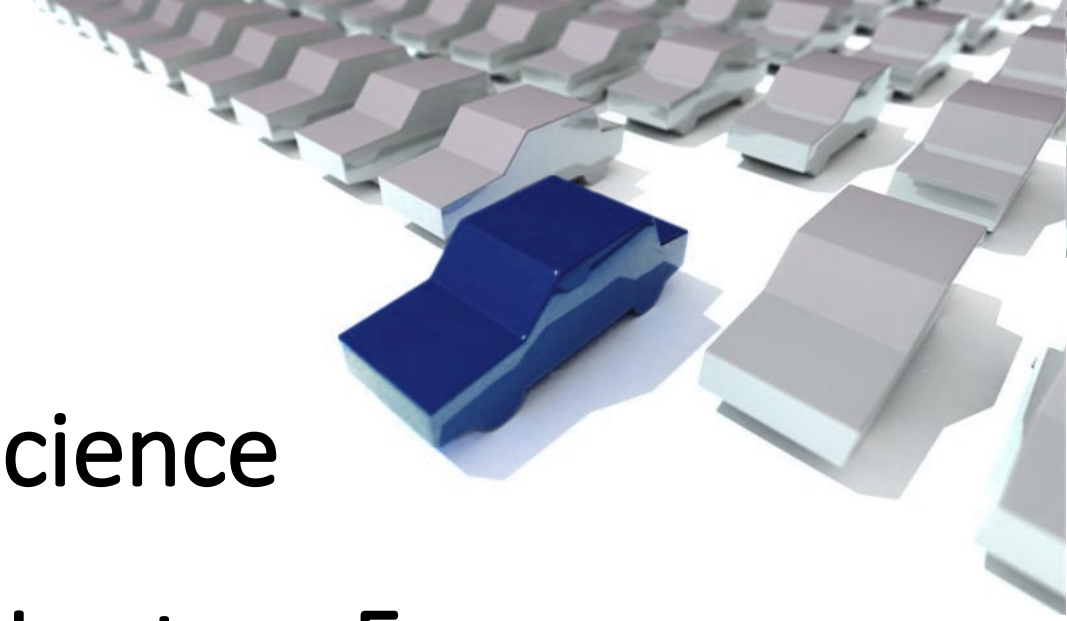


CEE 551 Traffic Science

Traffic Flow Theory Lecture 5

Implementation of CTM, vehicle trajectory data

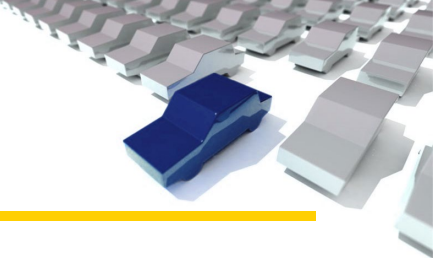
Dr. Xingmin Wang
Department of Civil and Environmental Engineering
University of Michigan
Email: xingminw@umich.edu

Tour to Macomb County Traffic Operation Center

- Thursday, September 26th (no class on that day), 3:00 – 4:30 PM
- Considering that you might have a conflict schedule, it is not mandatory. Email zjerome@umich.edu (Zachary Jerome) if you cannot make it
- Carpool amongst classmates recommended (email zjerome@umich.edu if you have trouble getting there)

- Link to Macomb County Department of Roads Traffic Operations Center

Content



- Implementation of the Cell Transmission Model (CTM)
- Introduction to connected vehicle trajectory data

Content

- ❑ Implementation of the Cell Transmission Model (CTM)
- ❑ Introduction to connected vehicle trajectory data

Cell transmission model

- CTM is a specific implementation of the Godunov scheme

  - Notations of CTM

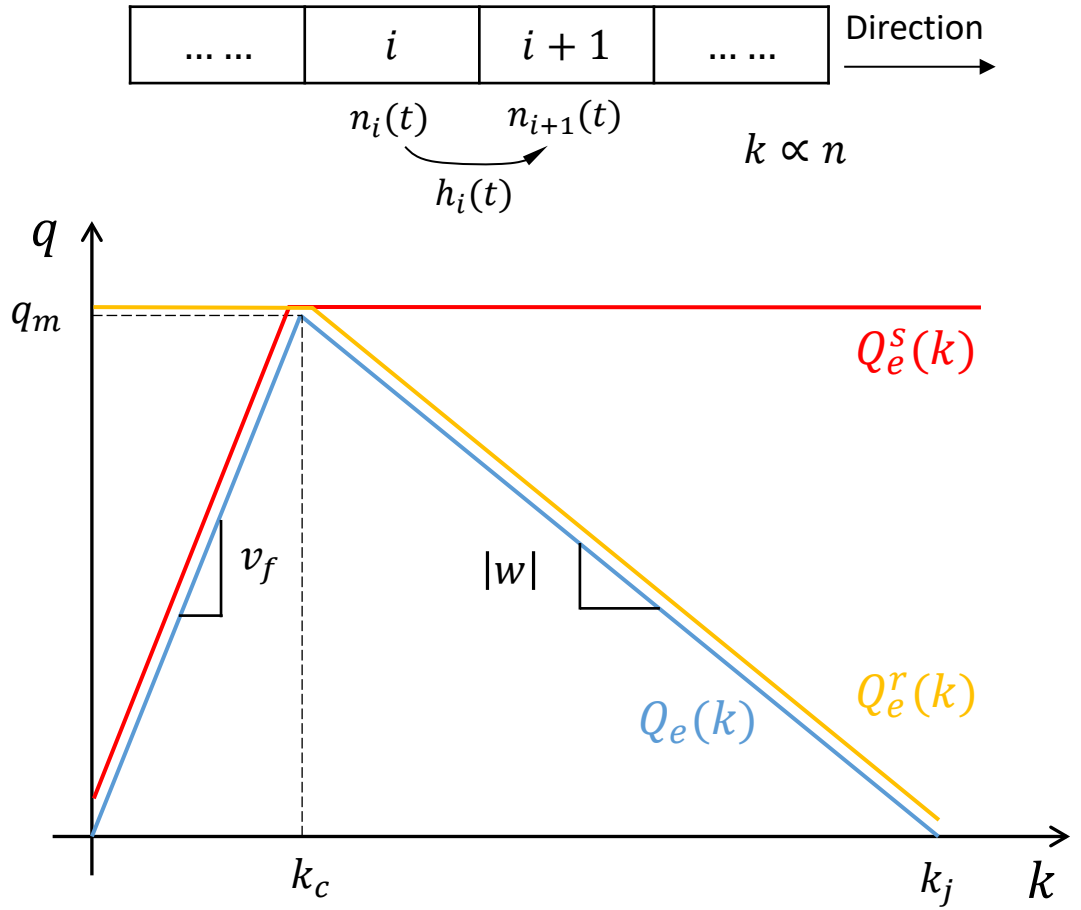
- $n_i(t)$: number of vehicles in cell i at time step t
- $h_i(t)$: boundary flow (# of vehicles) between cell i and cell $i+1$

  - Conservation law

$$n_i(t+1) = n_i(t) + h_{i-1}(t) - h_i(t)$$

  - Boundary flow calculation

$$h_i(t) = \min\left\{n_i(t), Q_m, \frac{|w|}{v_f}\left(N_{jam} - n_{i+1}(t)\right)\right\}$$



Implementation of CTM

- Building your CTM model (initialization)
  - Choose a proper time interval Δt and length of the road segment Δx such that:

$$\Delta x = v_f \Delta t$$

  - Establish your CTM model such as number of cells, cell connections
- CTM stepping (for each time t)
  - Step 1: get the boundary flow (in units of # of vehicles) for each cell connection

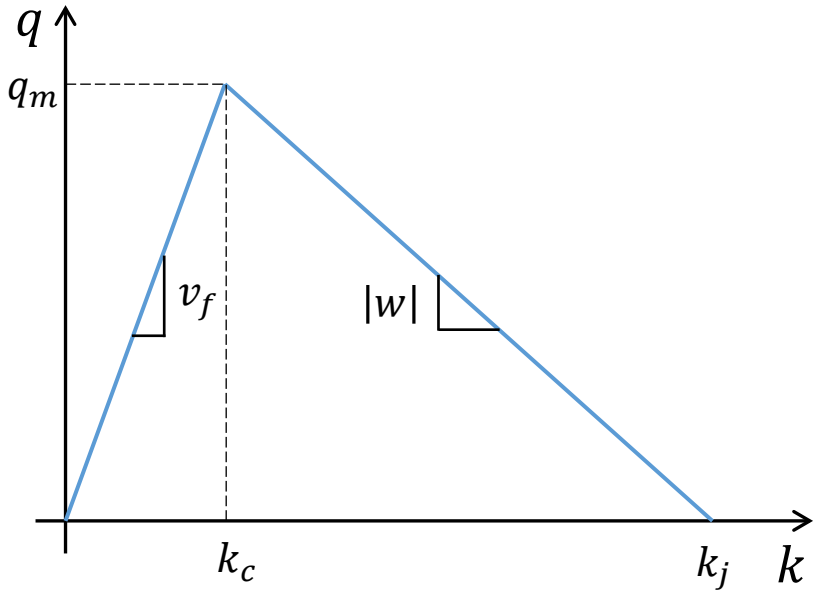
$$h_i(t) = \min\left\{n_i(t), Q_m, \frac{|w|}{v_f}\left(N_{jam} - n_{i+1}(t)\right)\right\}$$

  - Step 2: update the number of vehicles according to the conservation law

$$n_i(t+1) = n_i(t) + h_{i-1}(t) - h_i(t)$$

FD parameters and CTM parameters

- CTM parameters can be determined given FD parameters



v_f	Free-flow speed	m/s
w	Shockwave speed	m/s
k_c	Critical density	$veh/meter$
k_j	Jam density	$veh/meter$
q_m	Maximum flow	veh/sec

$$q_m = v_f \cdot k_c$$

$$|w| = \frac{q_m}{k_j - k_c}$$

$$h_i(t) = \min\left\{n_i(t), Q_m, \frac{|w|}{v_f}\left(N_{jam} - n_{i+1}(t)\right)\right\}$$

CTM parameters

Δt	Time interval	/	sec
Δx	Cell length	$= v_f \Delta t$	m
w, v_f	/	$= w, v_f$	m/s
Q_m	Maximum flow per time step	$= q_m \Delta t$	$veh/step$
N_{jam}	Maximum # of vehicles per cell	$= k_j \Delta x$	$veh/cell$

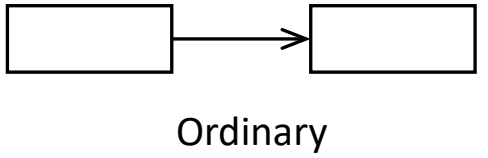
CTM example

- A road with a single lane controlled by a fixed-time traffic signals

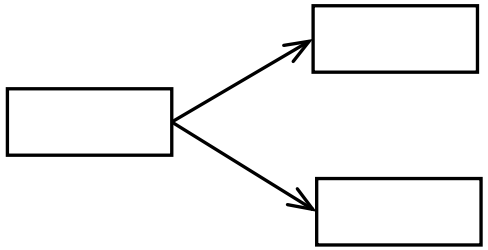
(Implemented by Excel)

CTM – general connections

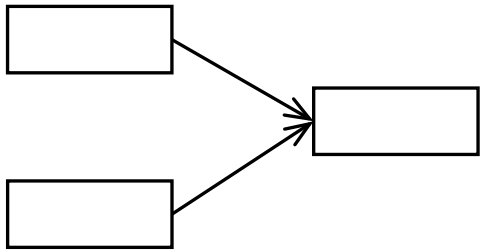
- To model a general network, there are some other connection types:



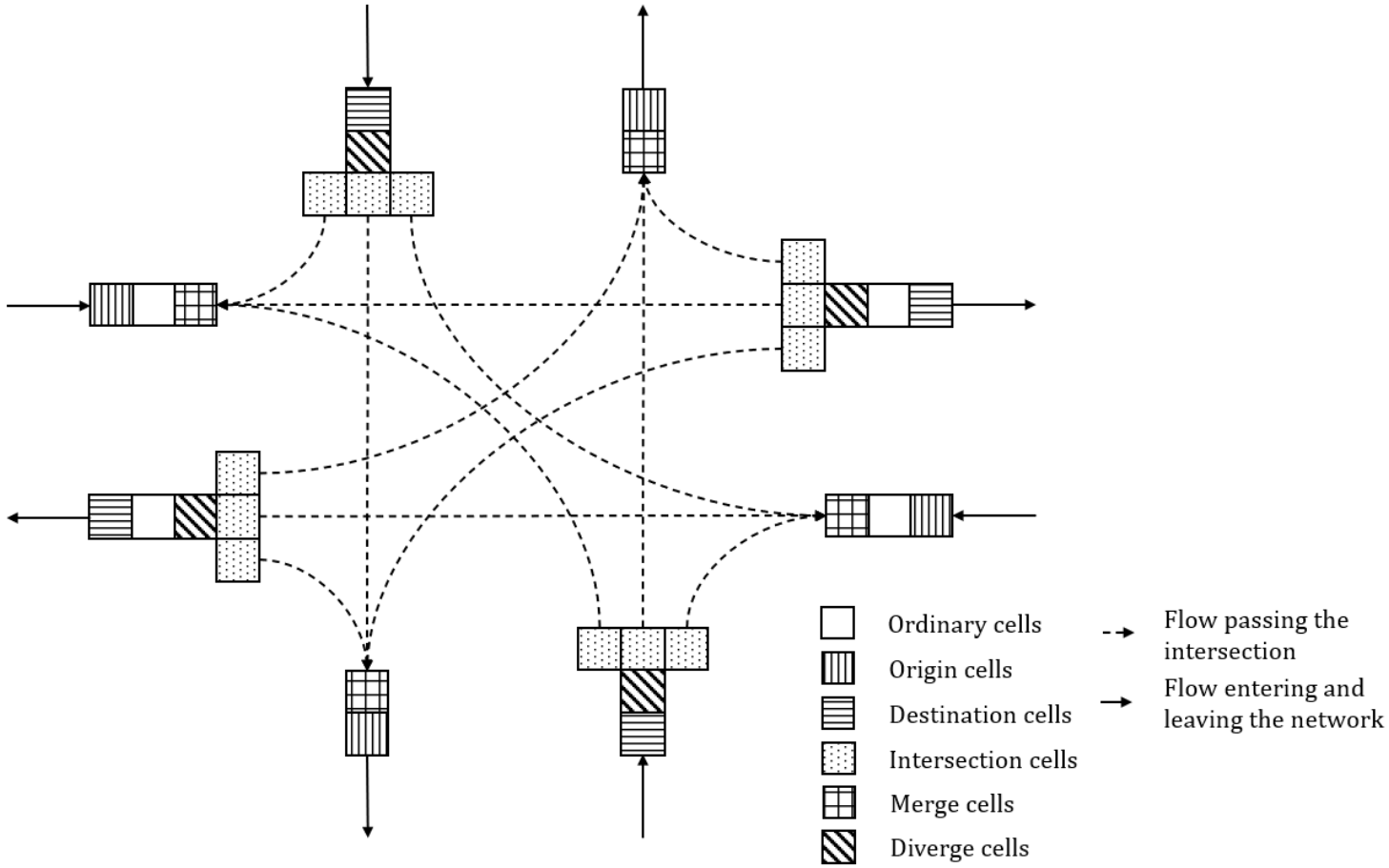
Ordinary



Diverge



Merge



Mini-project 1 – traffic flow theory

- Mini-project 1 is posted today and due on Oct. 2.
- This is a group work. Each group has up to two students (working alone is not suggested). You need to submit a report as well as your implementation (code, etc.)
- We will have some of you present on Oct. 3 (only those groups need to present need prepare slides). If you volunteer to present the mini-project 1, email me (xingminw@umich.edu) with the presenter's name and the group member before Sept. 18. I only accept volunteers until the time slots are filled. If not fulfilled in the end, I will assign randomly

- We will have three mini-projects throughout this semester, and each student needs to present at least once
- By principle, one student represents the whole group to give a complete presentation (we do not suggest two students split the presentation)

Grading policy

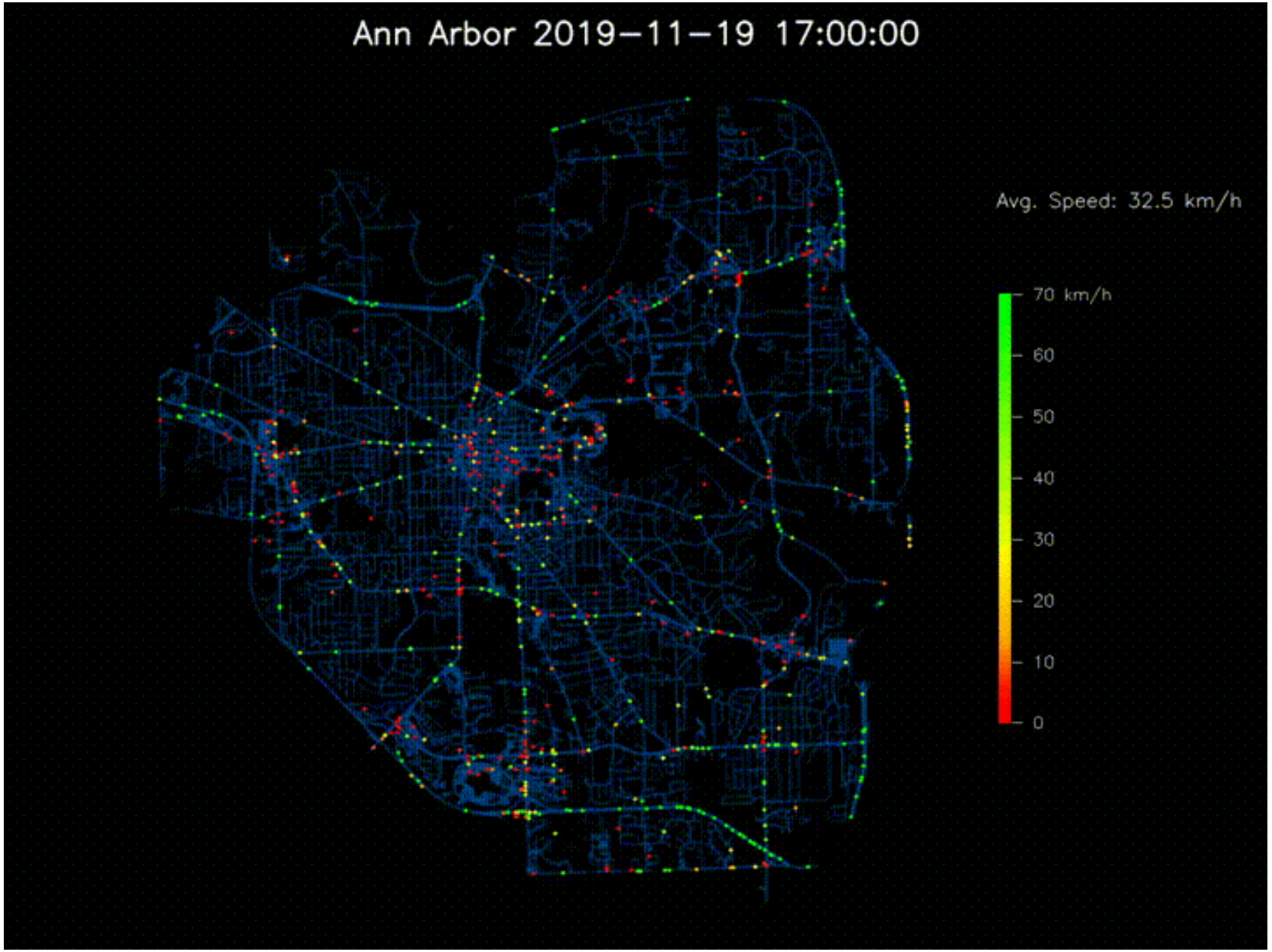
- Class participation 5%.
  - To get the full score, each of you is allowed to be absent for one lecture without informing the instructor (please email both Professor Henry Liu henryliu@umich.edu and Dr. Xingmin Wang, xingminw@umich.edu). If you have something else urgent, please do not worry; just email us in advance. In addition to that, you will get 1 point deducted (5 in total).
- Homework assignment 15% (5% each)
- Mini-project 40% (10% for each of the 3 projects, 10% for the presentation)
- Final exam 40%

- **Seminar participation is not required anymore**
- **Late submission policy:** Homework submitted after the deadline without a valid reason will be accepted with a maximum possible score of 80%

Content

- ❑ Implementation of the Cell Transmission Model (CTM)
- ❑ Introduction to connected vehicle trajectory data

Demonstration of vehicle trajectory data



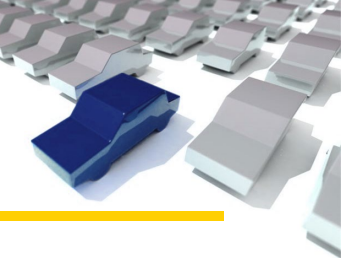
Essential attributes

- Time step
- Latitude
- Longitude

Optional attributes

- Speed
- Acceleration
- Altitude
- Maneuver information from CAN Bus (steering angle, brake status, etc.)

Collection of vehicle trajectory data



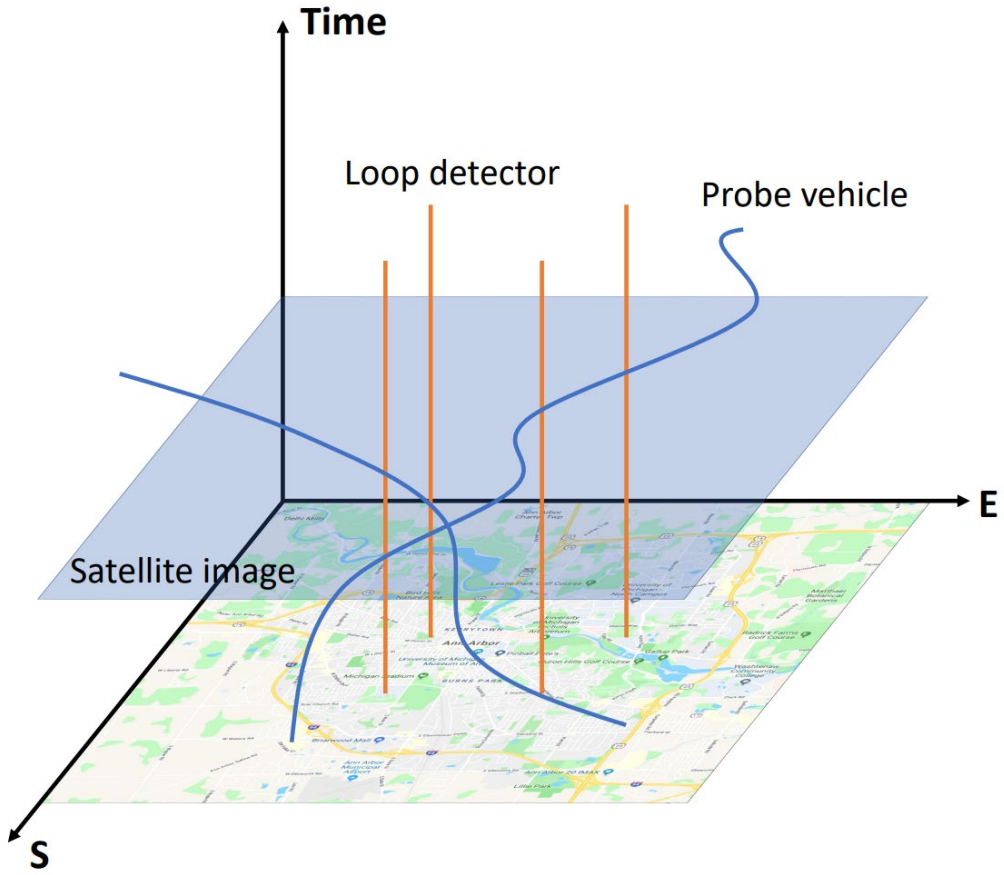
- Trajectories collected through V2X communication
  - BSM: basic safety message (SAE standard)
  - High frequency, require installation (OBU, on-board unit), only near the RSU (road-side unit)

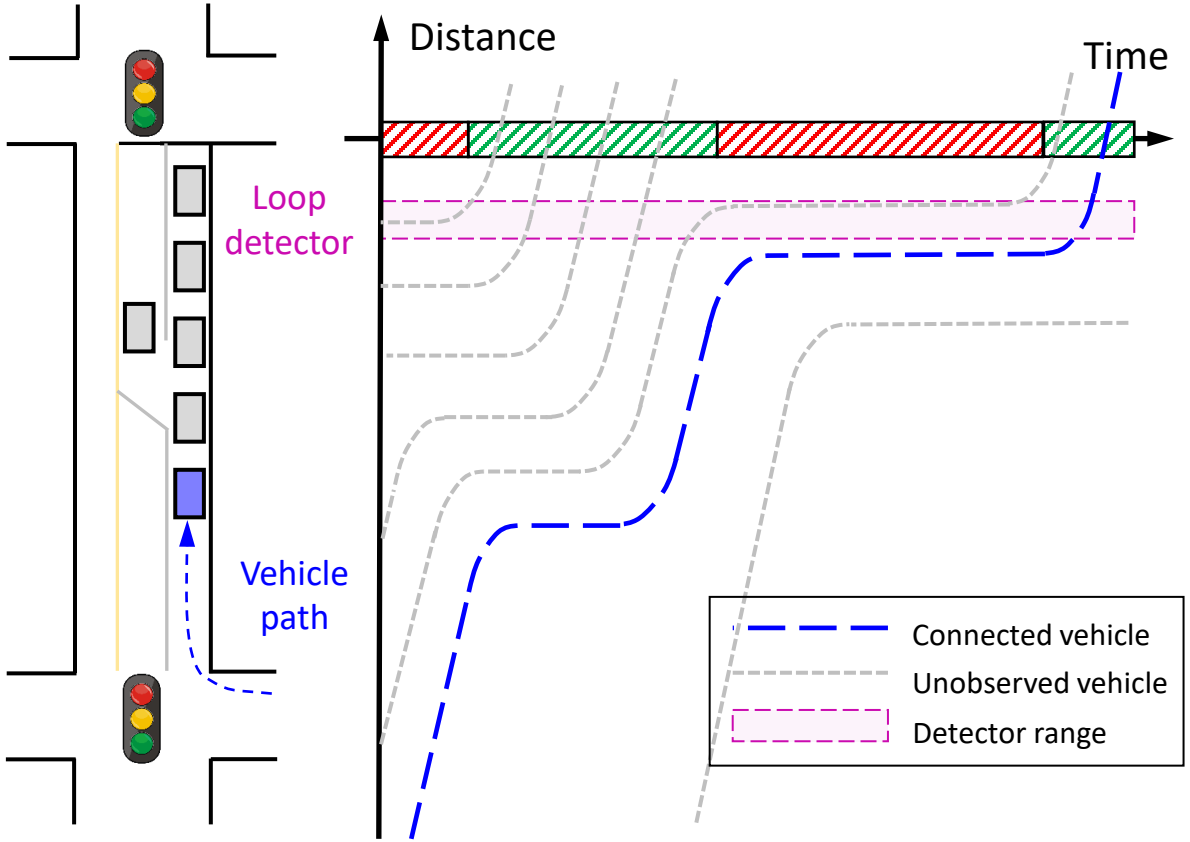
- Road-side perception: camera, drones, etc.
  - Similar to V2I communication but with detection & tracking error

- Directly from the vehicle: cell phone, vehicle navigation system, ride-hailing services, taxi, etc.
  - Long continuous trip, unstable frequency

Detector vs. vehicle trajectories

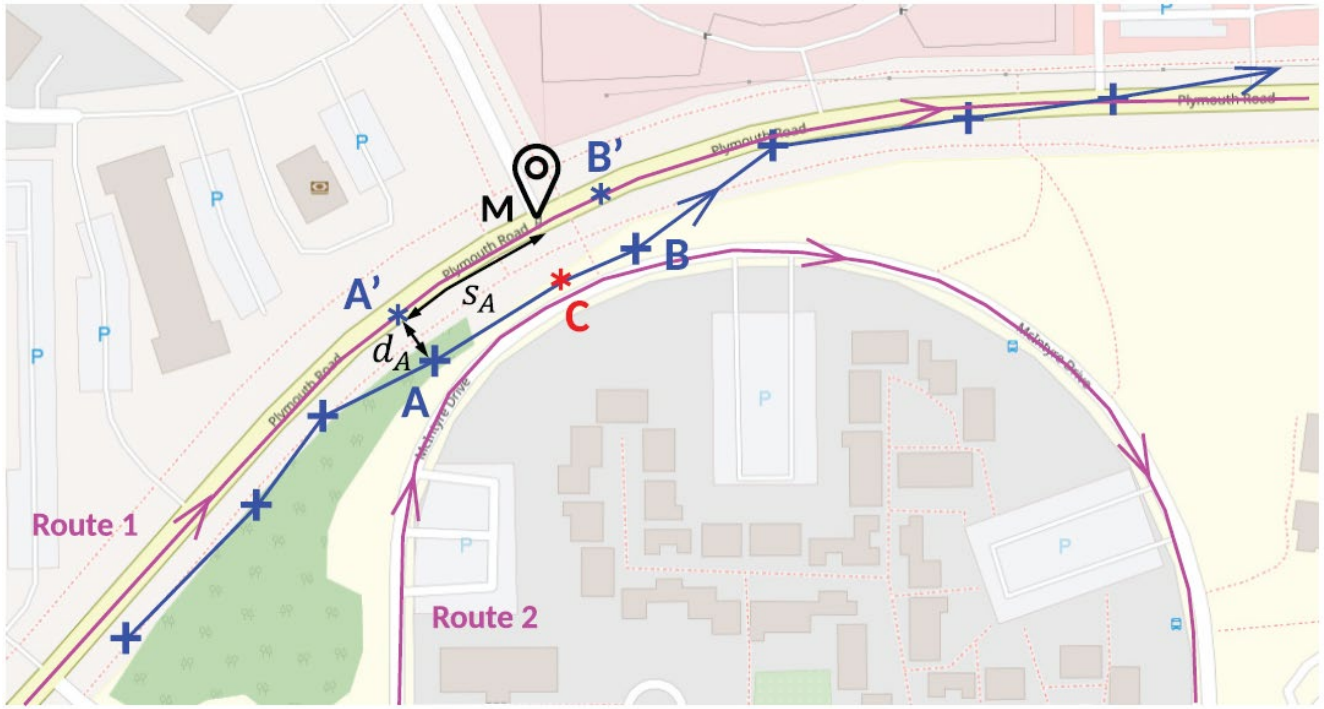
- Vehicle trajectory data has a larger spatial-temporal coverage but limited by **a low penetration rate**



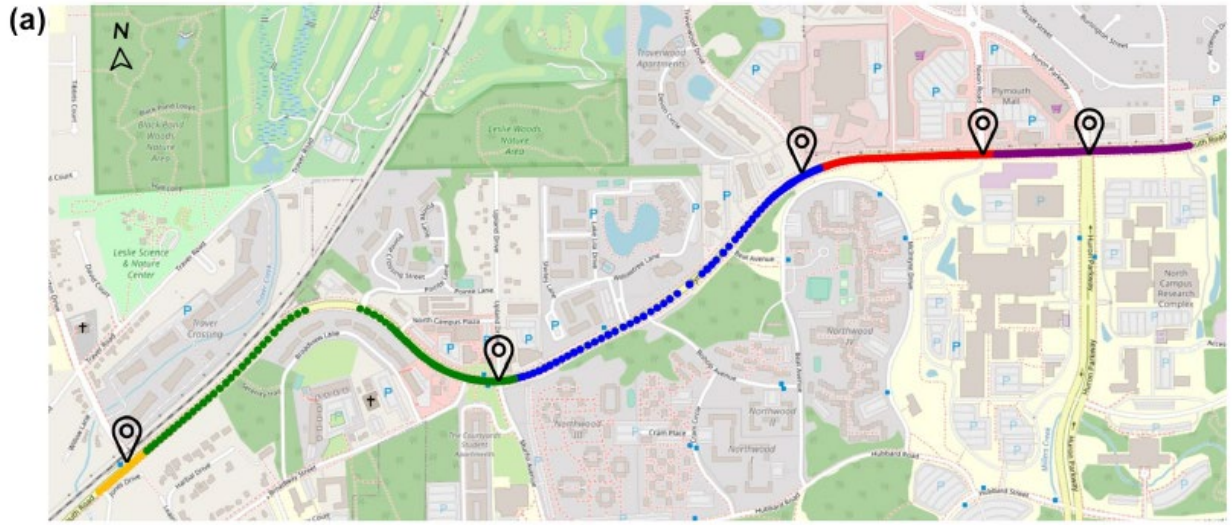


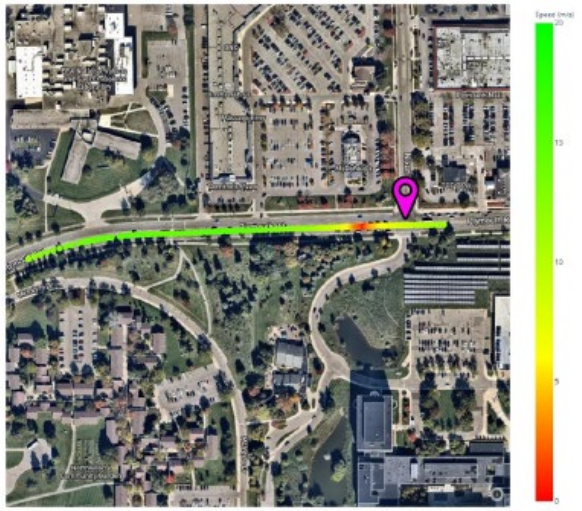
Trajectory data map matching

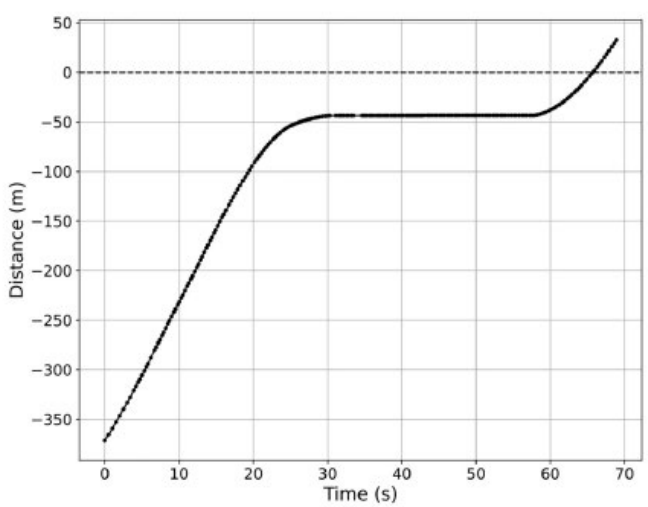
- Map matching: match the vehicle trajectory data to the road network
- Map matching principles: two main factors
  - Distance between the GPS coordinates and the road network
  - Path feasibility



GPS coordinates to distance

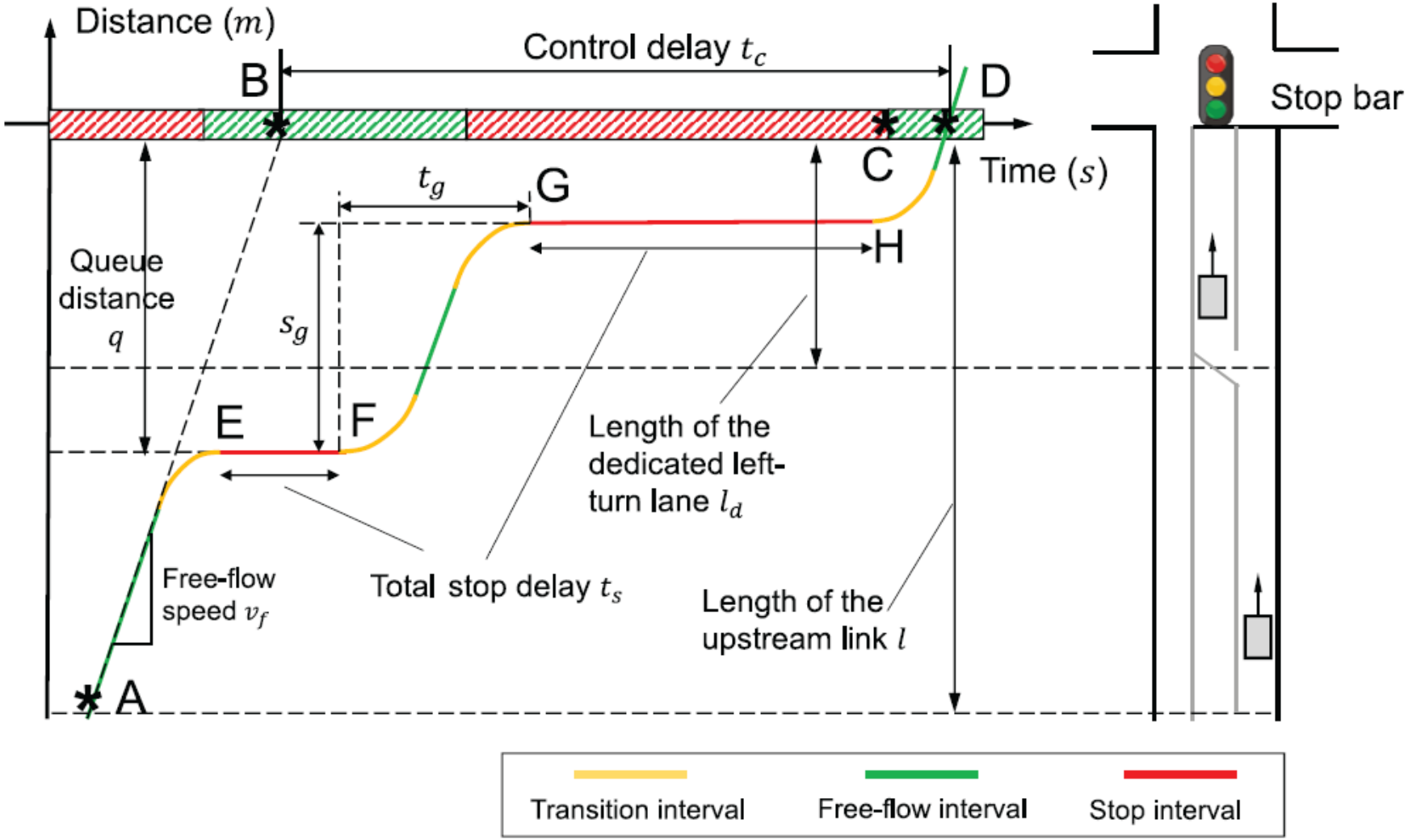






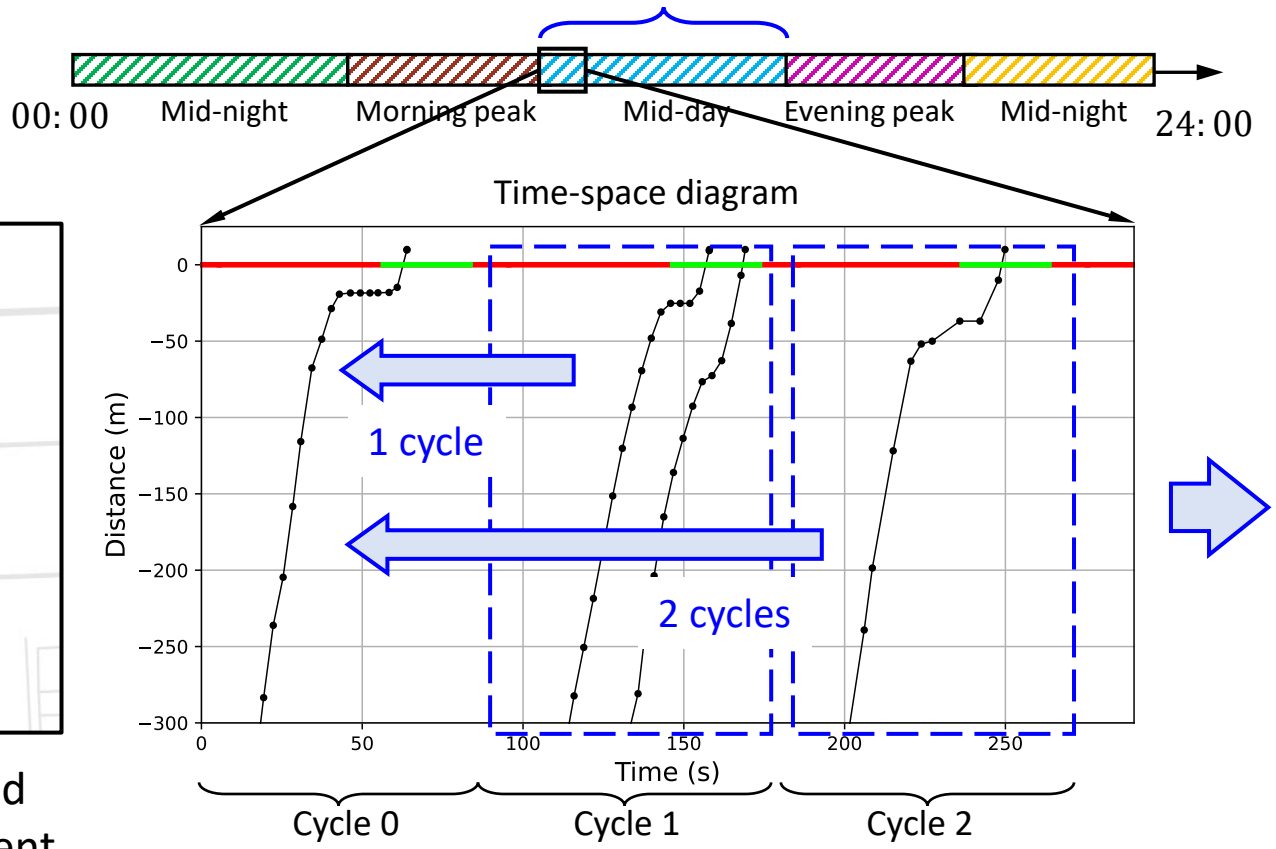
- Step 1: split long continuous trips to each intersection
- Step 2: convert GPS coordinates to distance by setting a reference (zero) point for the distance (center of the intersection as shown in the figure)

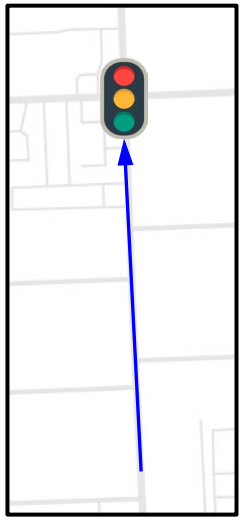
Performance index calculation



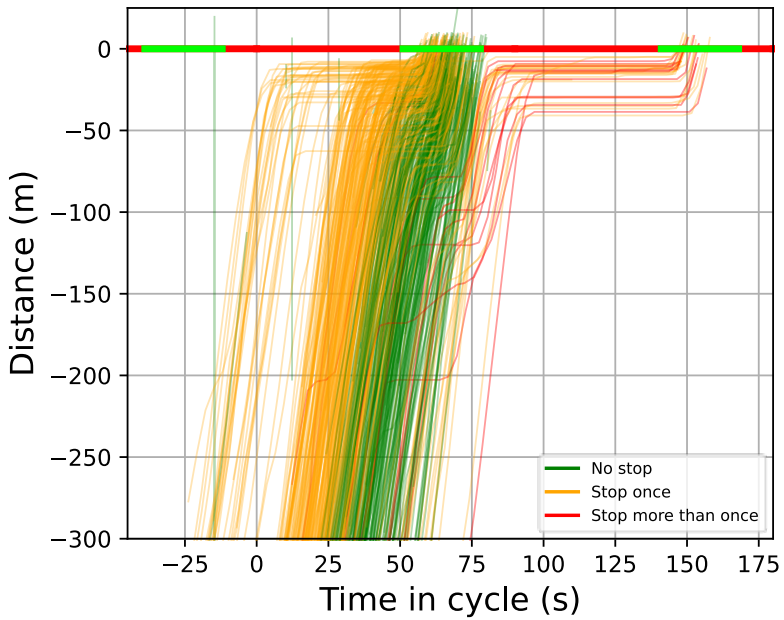
Trajectory aggregation: Aggregated Time-Space Diagram

Traffic signal parameters & traffic demand are **stationary** within the same time of day



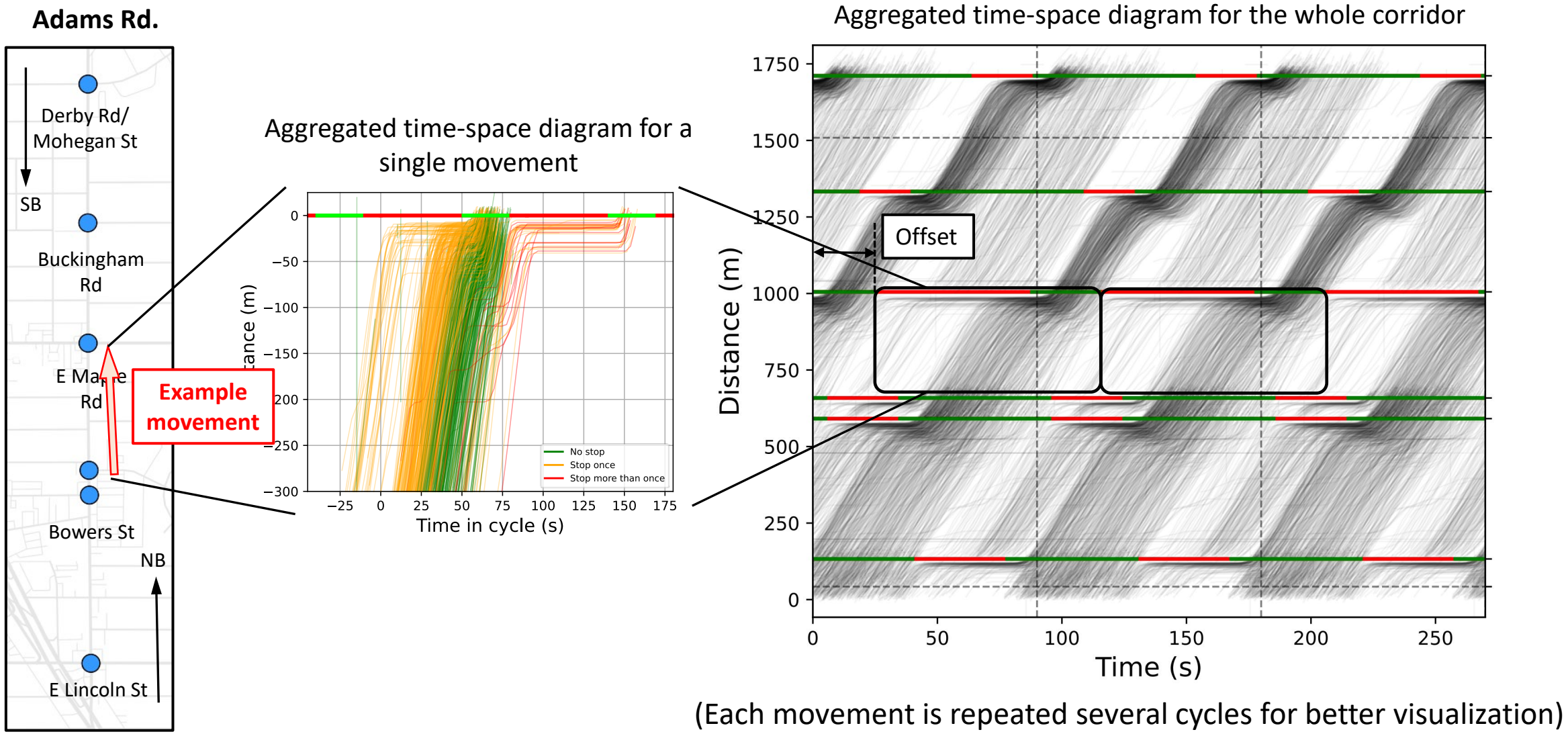


Isolated movement



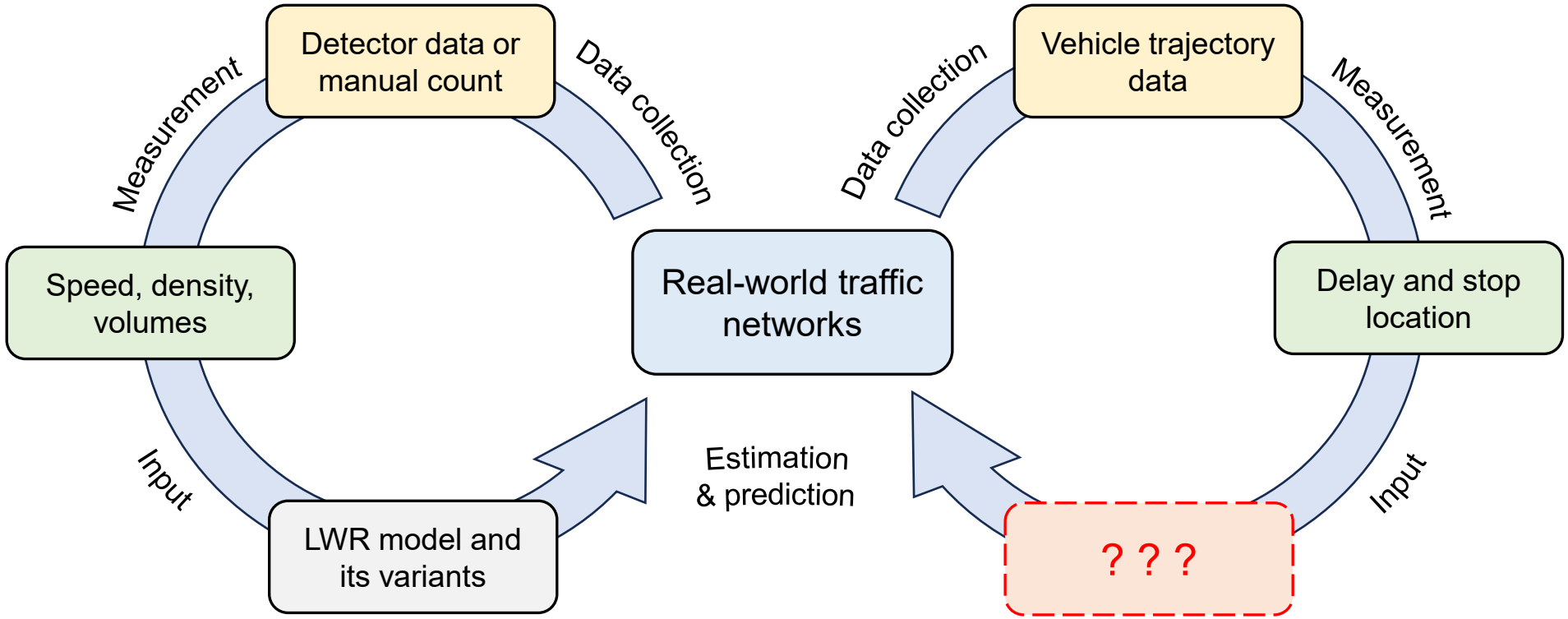
Trajectories can be shifted to the same cycle according their arrival time

Aggregated Time-Space Diagram for a Corridor



(Each movement is repeated several cycles for better visualization)

What traffic flow model should we use?



Reading

- Cell transmission model
  - TFT_Document.pdf Section 6
  - Daganzo, Carlos F. "The cell transmission model: A dynamic representation of highway traffic consistent with the hydrodynamic theory." Transportation research part B: methodological 28.4 (1994): 269-287.
  - Daganzo, Carlos F. "The cell transmission model, part II: network traffic." Transportation Research Part B: Methodological 29.2 (1995): 79-93.
- Vehicle trajectory data processing
  - Newson, Paul, and John Krumm. "Hidden Markov map matching through noise and sparseness." *Proceedings of the 17th ACM SIGSPATIAL international conference on advances in geographic information systems*. 2009.
  - Wang, Xingmin, et al. "Trajectory data processing and mobility performance evaluation for urban traffic networks." *Transportation Research Record* 2677.3 (2023): 355-370.