Dynamic Traffic Assignment
Practice and Frontiers

CE 392D

April 21, 2016

OUTLINE

- Schedule project presentations
- Finishing macroscopic models
- DTA models in practice
- Current frontiers in DTA

SCHEDULING PRESENTATIONS

DTA IN PRACTICE

When you hear about a DTA model or software, what questions you should ask?

CONNECTED AND AUTOMATED VEHICLES

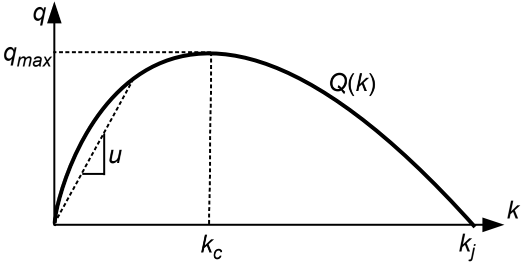
How might we model the effects of platooning on roadway capacity?

How might we model the effects of dynamic lane allocation?

How might we model the effects of reservation-based intersections?

In particular, can we find models simple enough to allow us to simulate large regions? Small corridor models can omit complex interactions (like elastic demand)

Fundamental diagram



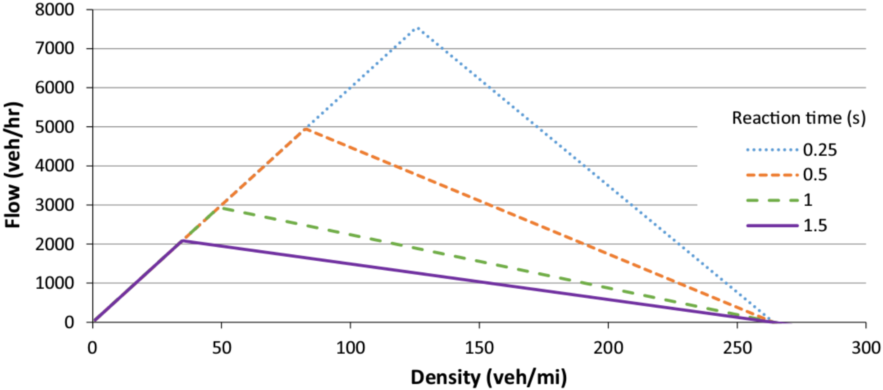
The fundamental traffic flow diagram relates vehicle **density** (veh/mi) to vehicle **flow** (veh/hr). The diagram can also produce vehicle speeds and shockwave speeds.

Car-following perspective Assume that in congested conditions, the time headway between vehicles is determined by the safe following distance (accounting for reaction time)

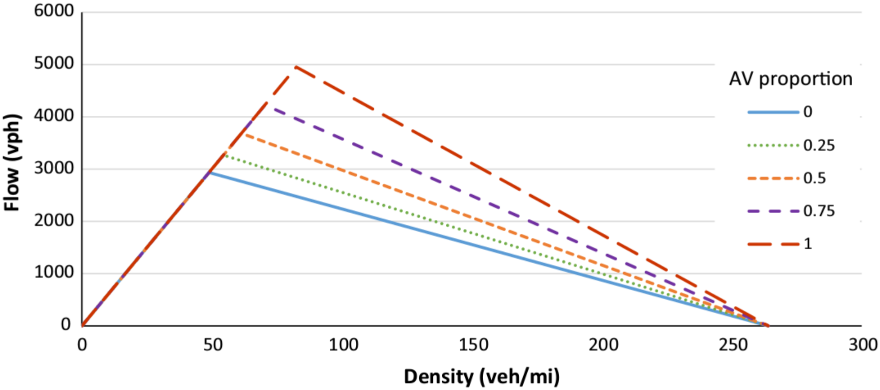
$$L \geqslant -\frac{u^2}{2a} + u\left(\frac{u}{a} + \Delta t\right) - \frac{1}{2}a\left(\frac{u}{a}\right)^2 + \ell = u\Delta t + \ell$$

$$u \leqslant \frac{L - \ell}{\Delta t}$$

Then we can derive a new speed-density relationship, and translate this to a new fundamental diagram.



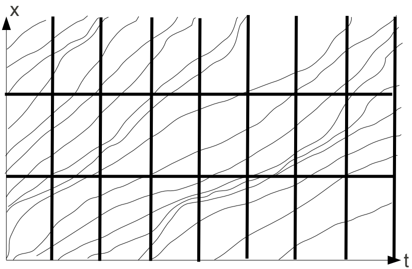
8000
7000
6000
5000
4000
3000
2000
1000
0
Flow (veh/hr)
0
50
100
150
200
250
300
Density (veh/mi)
Reaction time (s)
0.25
0.5
1
1.5



In these diagrams, we can directly see the capacity increase. Also, the congested portion of the diagram has a steeper slope. What does this mean?

Cell transmission model

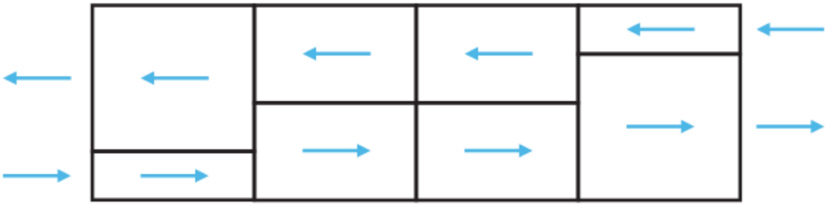
Daganzo's cell transmission model is a practical way of modeling traffic flow on large networks, given the shape of the fundamental diagram.



3	3	3	2	2	1	2	3
3	4	4	4	2	2	4	5
4	4	4	4	5	4	3	1

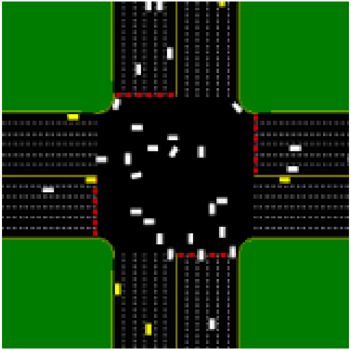
Roadway segments are divided into cells, and vehicles propagate from one cell to the next.

By defining a **per-lane** capacity for each link (using the modified fundamental diagrams), we can represent dynamic lane allocation by using different capacities for cells within the same link.



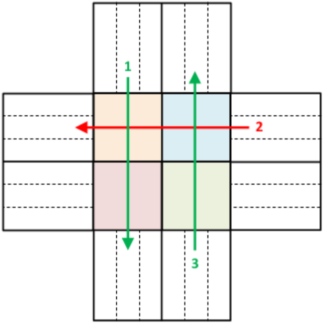
Reservation-based intersections

The first simulation model for reservation-based control was AIM (Autonomous Intersection Management)



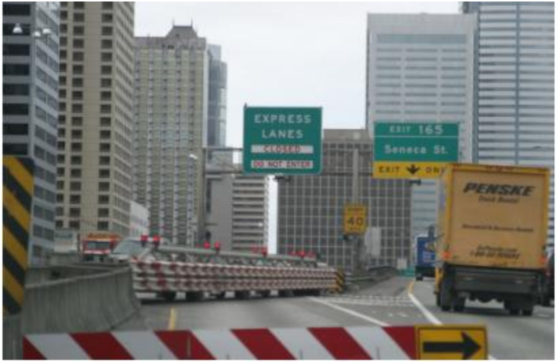
This microsimulator is very detailed, but is too complex to efficiently model large networks.

The conflict region model provides a simpler way to approximate this type of roadway control.



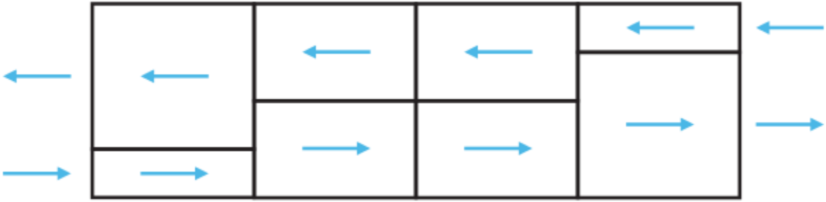
Each region permits a certain maximum flow rate. Vehicles from each approach are assigned trajectories as long as all of these limits are satisfied. Any remaining vehicles are queued.

Reversible lanes are nothing new in the transportation world.



For safety reasons, and to avoid confusion, these are typically operated under predetermined schedules.

In principle, AV technology can allow lane reversing to be done as an *agile* response to real-time traffic conditions.



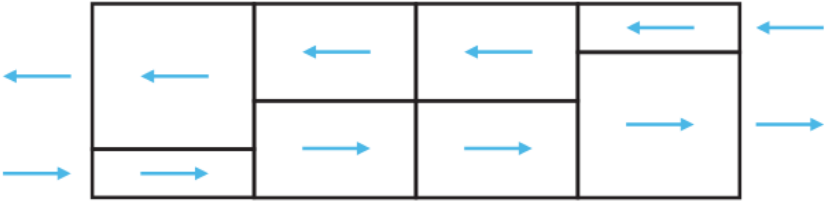
Lane configurations can change nearly continuously, and can even vary within a roadway segment.

How can we make such a system safe?

The following assumptions are meant to ensure safe operation (assuming a fully autonomous traffic stream):

1. Vehicles can change lanes at most once every six seconds (roughly 250 feet when traveling at 30 mph).
2. Lane directions can be switched at the same frequency as vehicles change lanes (at most once per 6 seconds).
3. Any changes in lane directions must be compatible with current jam densities, and vehicles' ability to switch lanes.
4. All lanes traveling in the same direction are contiguous.
5. The system operates on two-way roads where both directions have the same free-flow speed.

In the cell transmission model, we can change the capacity of each cell based on the number of lanes in each direction



This suggests an optimization model in which *the lane allocations are the decision variables.*

Integer programming formulation

Objective: Maximize total outflows over a future time horizon.

Decision variables: Lane directions for each cell, over the time horizon. (Also affects flow variables.)

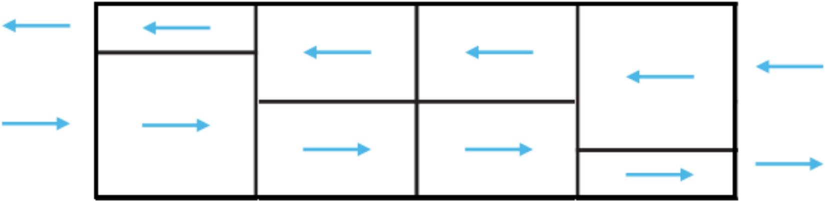
Constraints:

- Flows are consistent with the cell transmission model (fundamental diagram)
- Physical constraints (number of lanes allocated to both directions cannot exceed total number of lanes)
- Safety constraints (lanes must accommodate flow already on link; no more than one lane can reverse directions between consecutive cells)

We have to make some assumptions about future demand — this can be a bit tricky. Our objective discounts future flows, as one way to reflect this uncertainty.

Bottlenecks

An unwise allocation of lanes can create bottlenecks in the future:



(We must consider future demand and flows in some way... a “myopic” maximization of current outflows can cause problems.)

If we assume demand is deterministic, we can show the following properties:

- There is at least one feasible solution. (Assuming we start in a "reasonable" initial state.)
- It is never advantageous to let in more than the full roadway capacity at any one time step.
- (Stability). If there is no discounting, any lane allocation policy which can stabilize inflows (over an infinite time horizon), the solutions to the integer program will do so as well as $T \to \infty$.

Integer programming is NP-hard. We developed a custom heuristic, based on estimating future flows and favoring additional lanes for exiting flow.

If we model demand as stochastic, we can reformulate the model as a Markov decision process (MDP).

State space: Current cell occupancies and lane configurations

Controls: New lane configurations

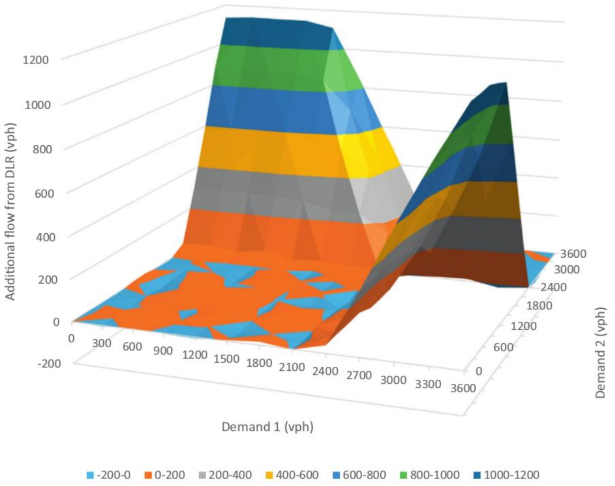
Reward function: Current outflows

Transitions: Based on controls and random demand at this time step, determine new occupancies

Objective: Find a control policy which maximizes expected long-term rewards.

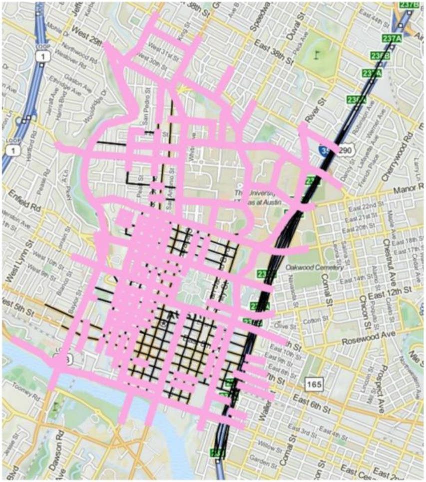
Heuristics are needed here as well. This MDP suffers from the "curse of dimensionality", and has a state space size of 10^{27} for a half-mile segment!

Testing on a single link...



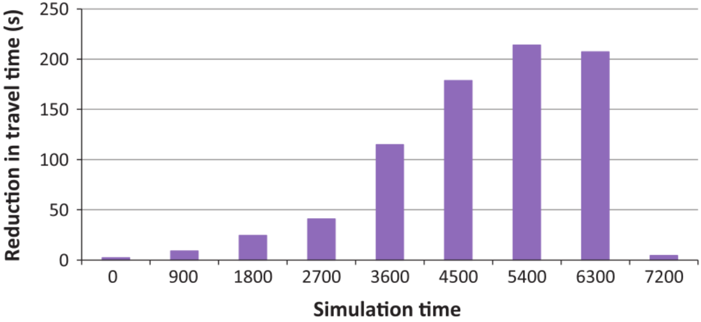
Benefits are particularly high when demand is unbalanced.

Testing on a network...



Here, we also assume drivers choose routes to minimize travel times (dynamic user equilibrium).

Travel time reductions for vehicles departing at selected times.



In all, VHT was reduced by almost 25%.

At any given time, relatively few links had nonstandard lane configurations.