Project 0-6847: An Assessment of Autonomous Vehicles

Traffic Impacts and Infrastructure needs

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Research Team

Kara Kockelman:	Research supervisor, travel demand modeling
Stephen Boyles:	Network-level analysis and forecasting
Christian Claudel:	Sensing and control
Peter Stone:	Traffic simulation
Jia Li:	Identifying current technologies and opportunities
Duncan Stewart:	Project advisor

Research Team

The following graduate and undergraduate research assistants provided invaluable contributions:

- Michael Levin
- Prateek Bansal
- Rahul Patel

Project Outline

Objective: Understand the impacts (positive and negative) of CAV technologies in traffic flow, and the relationship with roadway infrastructure.

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Major outcomes:

- Identify key opportunities of CAV technology
- Develop forecasts of adoption rates and traffic simulation tools
- Provide cost-benefit and impact assessments of new technologies
- Develop recommendations and best practices

This talk focuses on dynamic traffic assignment modeling of CAVs.

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In particular, the key elements of dynamic traffic assignment are:

- Network-wide scale
- Model changes in congestion and queue dynamics over time
- Represent long-term behavior shifts (such as route diversion)

Problem statement

How do connected autonomous vehicle (CAV) technologies affect traffic flow?

CAV technologies:

- Reduced reaction times from adaptive cruise control
- More precise maneuverability
- Short-range wireless communications

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Potential effects on traffic:

- Reduced following headways — greater road capacity
- More efficient intersection control — greater intersection capacity

Outline

1. Flow model
2. Intersection model
3. Effects of AVs on traffic networks
4. Paradoxes of reservation-based intersection control

Flow model

How do reduced reaction times affect flow?

- Greater road capacity from reduced following headways
  - Kesting et al. (2010); Schladover et al. (2012)
- Greater flow stability
  - Li & Shrivastava (2002); Schakel et al. (2010)
- Greater backwards wave speed (rate of congestion wave propagation)

Flow model

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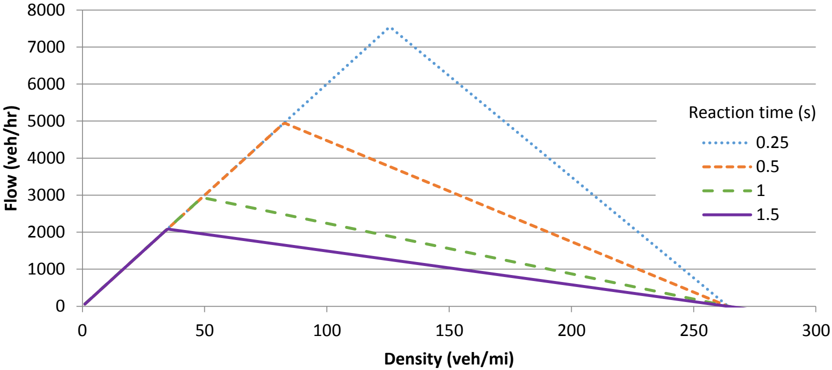
Car following model based on reaction time

- Based on safe following headway for a given speed
- Yields maximum safe speed for given density



$$q^{\max} = u^{\mathrm{f}} \frac{1}{u^{\mathrm{f}} \Delta t + \ell} \qquad w = \frac{\ell}{\Delta t}$$

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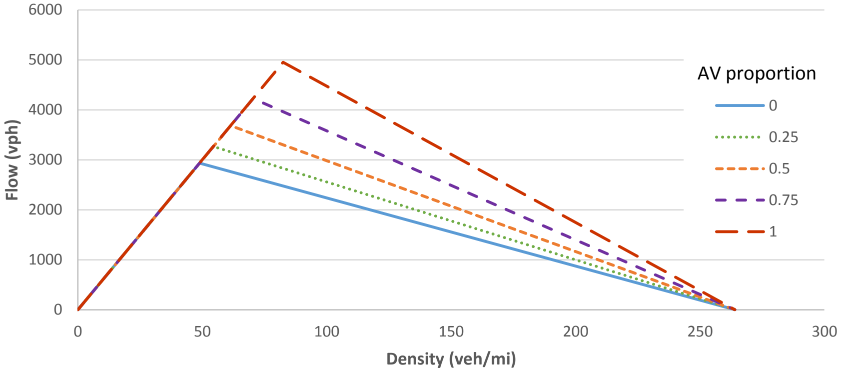
u^{f}	free flow speed	$q^{\max}$	capacity
ℓ	car length	w	backwards wave speed
Δt	reaction time		



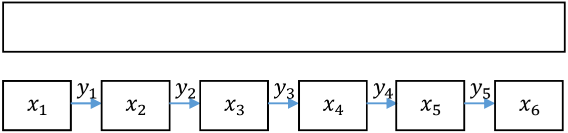
$$q^{\max} = u^{\mathrm{f}} \frac{1}{u^{\mathrm{f}} \sum_{m \in M} \frac{k_m}{k} \Delta t_m + \ell} \qquad w = \frac{\ell}{\sum_{m \in M} \frac{k_m}{k} \Delta t_m}$$

u^{f}	free flow speed	$q^{\max}$	capacity
ℓ	car length	w	backwards wave speed
Δt	reaction time	$\frac{k_m}{k}$	proportion of class m

Multiclass cell transmission model

- Based on the CTM of Daganzo (1994, 1995)
- Separates flow into AV and human vehicles
- Consistent with hydrodynamic theory of traffic flow

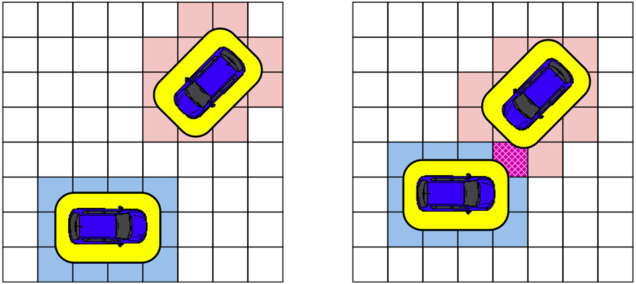
$$y_i^m(t) = \min\left\{ n_{i-1}^m(t), \frac{n_{i-1}^m(t)}{n_{i-1}(t)} Q_i(t), \frac{n_{i-1}^m(t)}{n_{i-1}(t)} \frac{w_i(t)}{u^{\mathrm{f}}} \left(N - \sum_{m \in M} n_i^m(t) \right) \right\}$$



Reservation-based intersection control

- Proposed by Dresner & Stone (2004, 2006)

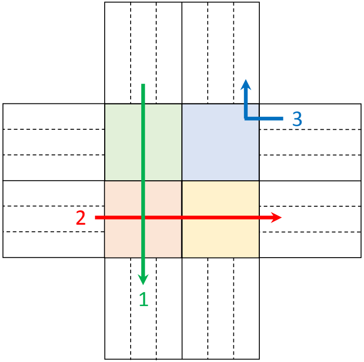
1. Vehicles communicate with the *intersection manager* to request a reservation
2. Intersection manager simulates request on a grid of space-time tiles
3. Requests can be accepted only if they do not conflict



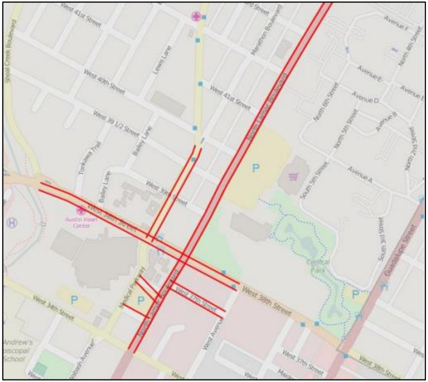
(a) Accepted (b) Rejected

Conflict region model

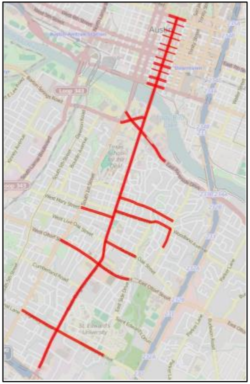
- Major limitation of reservations: microsimulation definition — not tractable for larger networks
- Conflict region simplification: aggregate tiles into capacity-restricted *conflict regions*
- Tractable for dynamic traffic assignment



Arterial networks



Lamar & 38th Street



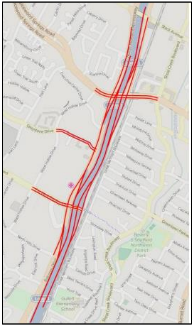
Congress Avenue

- Greater capacity reduced travel times on all networks
- Reservations *increased* travel time on Lamar & 38th St.
  - Reservations disrupted signal progression and allocated more capacity to local roads, causing queue spillback on the arterial

Freeway networks

Interstate 35

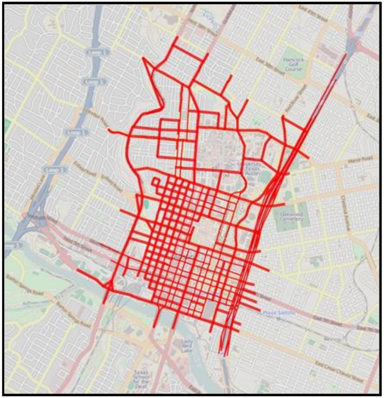
US-290



Mopac

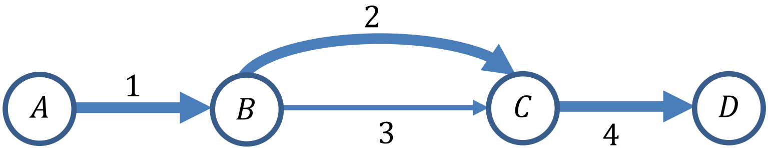
- Greater capacity reduced travel times on all networks
  - Improved travel time by 72% on I-35
- Reservations improved right-turn movements on signalized freeway access intersections

Downtown Austin network



- Greater capacity resulted in 51% reduction in travel time
- With reservations and AV reaction times, travel time reduction was 78%

Paradoxes of reservation controls



Link	Free flow travel time (s)	Capacity (vph)
1, 4	30	2400
2	80	2400
3	60	1200

Demand from A to D: 2400 vph
Traffic signal at C: 60 seconds $2 \rightarrow 4$, 10 seconds $3 \rightarrow 4$

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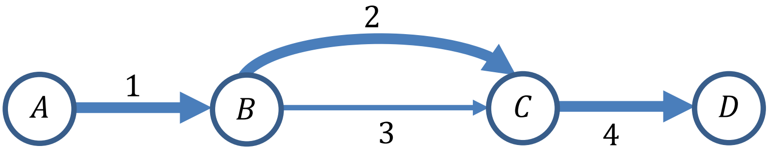

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Dynamic user equilibrium

- Traffic signals: 2400 vph on [1,2,4]
- Reservations: 2400 vph on [1,3,4]

Arbitrarily large queues due to route choice

- Variation on Daganzo's paradox
- 2400 vph on [1,3,4] is an equilibrium with *any* reservation policy: there are no vehicles on [1,2,4]

Arbitrarily large queues due to route choice

- Variation on Daganzo's paradox
- 2400 vph on [1,3,4] is an equilibrium with *any* reservation policy: there are no vehicles on [1,2,4]
- Avoiding this requires *artificial* cost at C with reservations: waiting time or toll

Conclusions

- Developed reaction time-based car following model and multiclass cell transmission model
- Developed conflict region simplification of reservation-based intersection control
- These were used to create a DTA simulator of arterial, freeway, and downtown networks
- Reduced reaction times improved travel times on all networks
- Reservations were effective in some scenarios but not in others
    - With user equilibrium route choice, reservations could lead to arbitrary large queues in the worst case scenario

Future work

- Calibrate car following model for CAVs
- Determine where to use reservation controls
- Priority policies for reservations for greater system efficiency
- Incorporate travel demand analyses into DTA simulator