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
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Research Team

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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); Schladoover 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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- Greater road capacity from reduced following headways
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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
\[ q^{\text{max}} = u^f \frac{1}{u^f \Delta t + \ell} \]

\[ w = \frac{\ell}{\Delta t} \]

- \( u^f \) free flow speed
- \( \ell \) car length
- \( \Delta t \) reaction time
- \( q^{\text{max}} \) capacity
- \( w \) backwards wave speed
\[ q^{\text{max}} = u^f \frac{1}{u^f} \sum_{m \in M} \frac{k_m}{k} \Delta t_m + \ell \]

\[ w = \sum_{m \in M} \frac{\ell}{k_m/\Delta t_m} \]

- \( u^f \): free flow speed
- \( \ell \): car length
- \( \Delta t \): reaction time
- \( q^{\text{max}} \): capacity
- \( w \): backwards wave speed
- \( k_m/k \): 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

\[
y^m_i(t) = \min \left\{ n^m_{i-1}(t), \frac{n^m_{i-1}(t)}{n_{i-1}(t)} Q_i(t), \frac{n^m_{i-1}(t)}{n_{i-1}(t)} \frac{w_i(t)}{u^f} \left(N - \sum_{m \in M} n^m_i(t)\right) \right\}
\]
Reservation-based intersection control


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

![Diagram showing accepted and rejected reservations](image)
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

![Conflict region model diagram]
Arterial networks

- 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

- 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

Demand from A to D: 2400 vph
Traffic signal at C: 60 seconds 2 → 4, 10 seconds 3 → 4
Paradoxes of reservation controls

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Traffic signal at C: 60 seconds 2 → 4, 10 seconds 3 → 4

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