Transportation Optimization Workshop

Overview and Objectives
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Outline

• What has ARPA-E done in this area, and why are we holding a workshop?
• What is the problem we’re looking to you to help solve, and why do we think it’s hard?
• How is the problem approached today, and what do we perceive as the limits of current practice?
GENI (Green Energy Network Integration)

- Combines power transmission controllers + optimization, incorporation of uncertainty, distributed control & increased customer control.

### Primary Technical Targets (Metrics)

| TEST BED: Minimum of 3 controllers/terminals connected on a small-scale mesh with a minimum of 5 nodes. Terminals configured for operation at > 10kV. |
| RESILIENCY: Protocol for testing the resiliency and stability of the interconnected controllers. |
| BI-DIRECTIONAL FLOW CONTROL: Software controls with simulated latency used to demonstrate full bi-directional control of real and reactive power flows. |
| HIGH EFFICIENCY: Conversion efficiency of controllers/terminals must be > 99%. |
| COMMERCIAL FEASIBILITY: A cost-benefit analysis for a single controlled link using the proposed technology on the transmission grid is required. |
| AC MESH CONTROLLERS: >10x reductions in cost (target cost < $0.04/W). |
| MULTI-TERMINAL HVDC CONTROLLERS: >4x reductions in terminal and line cost. |
Stanford ARPA-E Project (Phase II)

- Online platform to incentivize consumers to use electricity more efficiently to increase the impact of smart meter data

- Stanford Energy Services Platform
- Integrative Front-End Platform
- Segmentation/Analytics layer
- Disaggregation layer

- Energy reduction content
  - online games
  - appliance calculators
  - novel interface designs
  - new applets

- Energy Reduction Trial
  - 6% energy reduction
  - 20,000 users
Can these ideas extend to transportation?

- Distributed/user control + optimization with uncertainty
- Should be the **smartest** grid! But (relatively speaking)
  - Heterogeneous
  - Path constrained
  - Regularly further from optimal
- “If it works, will it matter?”
Macro Trends Driving Urban Mobility (cont’d)

Drivers are Feeling the Pain and Increased Cost of Lengthening Driving Times

U.S. Annual Delay per Commuter (Hours)
- Commuters average of 34.4 hours in traffic per year, up 85% in 25 years
- Decline in 2007-2010 driven only by higher fuel costs and economic slowdown

U.S. Total Cost of Commuter Delays (2010 $Billion)
- The cost of commuter delays has risen 260% over the past 25 years
- Decline in 2007-2010 driven only by higher fuel costs and economic slowdown

The core problem

- Reduce congestion by redirecting travelers

- 28% of US Primary Energy is used in transportation, more than half of that is used for “light duty vehicles” (automobiles)

- In many regions, however, traffic does not flow freely at certain times of the day: Estimates of the energy cost of congestion range from 15-25% of fuel in major urban areas, yet…
  ...roadways & alternative modes are below capacity.
  ...incentives are required (i.e., energy/time saved not enough).
  ...adding peak capacity makes things worse before better.

- Even if an optimum were known (vs. what parameters?), there are few knobs or levers to adjust the network.
Traffic & Congestion

- “Traffic” dates from 1827, and an ARPA-E program (if run) will celebrate the 100th anniversary of “Traffic Jam” (b. 1917): It is a modern problem that needs modern solutions
- Primarily private, single-occupancy vehicles on government supported roadways
- The transportation “network” is a broader concept
  - Includes transit, bicycles, sidewalks, etc., any way a traveler travels
  - Easily observed, difficult to measure?
  - Very heterogeneous elements
Network “control”

- Largely a negative psychological mechanism
  - Law enforcement: Signals, speed limits, etc.
  - Congestion avoidance
  - Tolls (economics): At what price convenience?

- Shifting to public transportation (including air travel) increases network control but decreases personal control (disincentive)

- Commercial fleets or military transport may be an easier problem to solve because of higher degree of control, but is that sufficient?
Data Collection and Transportation Models

- Models quantitatively support roadway construction: Civil Engineering and Policy motives
- Now, ubiquitous portable sensors and low power wireless communications are game changers
# Examples of Data

<table>
<thead>
<tr>
<th>Travelers</th>
<th>Vehicles</th>
<th>Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell tower reporting</td>
<td>License plate readers</td>
<td>Inductive Loop sensors</td>
</tr>
<tr>
<td>GPS reporting</td>
<td>On-board computers</td>
<td>Traffic cameras</td>
</tr>
<tr>
<td>Transit cards</td>
<td>GPS Reporting</td>
<td>Traffic helicopters</td>
</tr>
<tr>
<td>Face recognition?</td>
<td>Connected vehicles</td>
<td></td>
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<tr>
<td></td>
<td>Battery chargers</td>
<td></td>
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<tr>
<td></td>
<td>Automation</td>
<td></td>
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<tr>
<td></td>
<td>Fully autonomous?</td>
<td></td>
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</tbody>
</table>

**Prevalence**

**Anonymity**

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A physics/engineering view of traffic flow

Fundamental Relationships

• Vehicles observed in \( t \) hours:

\[
q = \frac{\text{no. of vehicles}}{\text{total elapsed time}} = \frac{n}{t} \text{ vph}
\]

• Concentration/density of traffic over \( v \) km road within 1h:

\[
k = \frac{\text{no. of vehicles}}{\text{length of road}} = \frac{n}{l} \text{ veh/km}
\]

• Space mean speed of vehicles:

\[
u = \frac{1}{n} \sum_{i=1}^{n} d_i \text{ km/hr}
\]

• Time mean speed of vehicles:

\[
u = \frac{1}{n} \sum_{i=1}^{n} \frac{d_i}{t_i} \text{ km/hr}
\]

An economist's view of traffic flow

- Supply and demand-based: Effect of “tolls”

![Diagram showing supply and demand-based traffic flow]

- Predicts incentives of traffic flow

Figure 3. Equilibrium road usage, $q_E$, optimal road usage, $q^*$, and optimal congestion toll, $\tau^*$
Complications: Braess’ Paradox

Paradox arises from Nash equilibrium (Prisoner’s Dilemma)
Drivers lack information about other drivers, so they make bad choices.
An Intuitive/Emotion-driven Example

- Left Turn Example

- Rational and emotional control mechanisms of traffic are user optimized, not network optimized
Privacy versus Security

To opt in may be risky…

▸ Traveler must trust service provider
▸ Service provider must secure personally identifiable information
▸ Even low resolution, low frequency data can compromise identity*
  A public database can be used maliciously.

…but a mandatory service may be on the horizon

Connected Vehicle 5.9 GHz radio service mandate considered by USDOT

▸ Privacy is relinquished, but trip trackability (O-D) pairs is not.
  (NHTSA on Federal Information Protection Standards = FIPS)
▸ Public Key Infrastructure (PKI) at scale and complexity (2.5 x 10^8 vehicles)
  – Primary purpose: vehicle safety
  – Secondary benefit: collection of vehicle location data.

*more on this from Yves-Alexandre de Montjoye
It’s about the traveler, not the vehicle

- Travelers want information in order to control outcome
  - They can be selfish, and don’t care about network optimum
  - They turn to technology to find a “shortcut”, to “win” the escalating war
  - They do not want to share with strangers, unless they see a personal benefit

- But this is a *Homo economicus* view. *Homo sapiens* are more complex, e.g., creatures of habit: Don’t want to think about alternatives and constantly reoptimize
Waze Mission

Save Everyone 10 Minutes, Every Day

Mission: impossible?
Discussion starters: Data

- Gaps?
- Trajectory?
- Security?
- Integration?

Business Must Address Big Data Knowledge Gaps

Biggest Problems With Big Data

- Turning it into useful information: 58%
- Access/database management: 16%
- Security: 10%
- Privacy issues: 9%
- Legal issues: 4%

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Discussion starters: Models

- Macro, meso, and/or micro?
- Implementation challenges?
- Optimization challenges?
Discussion starters: Incentives

- What to change? Departure time, mode, route?
- How to change? Effectiveness, presentation?
- Who to change? Individuals (segments), professionals?
Is there a solution?

- Information, *per se*, is not the whole solution
- Can we combine *existing* data streams, modern cloud-based computational models, and primarily non-monetary incentives to relieve congestion?
- A view of a possible future.

- Police action ahead, you’ll be late regardless. 5 points if you take the next right.
- Excellent choice. A Facebook friend is in town and made the same choice…
- How about joining him for coffee?
- Here’s a coupon for a coffee shop 2 blocks from you.
ARPA-E’S Funding Choices

▸ ARPA-E:
  – funds the development of disruptive new technologies rather than new scientific knowledge
  – focuses on high-risk, high-reward projects with significant commercial potential
  – chooses projects that are generally unable to attract private sector financing because of the significant risks involved

▸ **break-through** [brey-k-throo] – noun. 1. A military movement or advance all the way through and beyond an enemy’s front-line defense