ARPA-E CHANGING WHAT'S POSSIBLE

Transportation Optimization Workshop

Overview and Objectives

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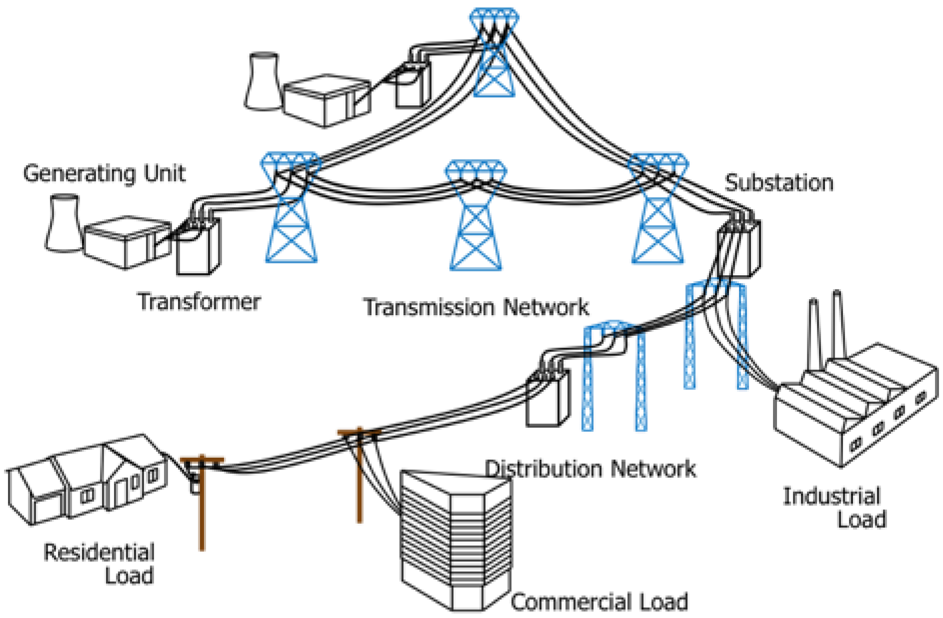
Outline

- 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.



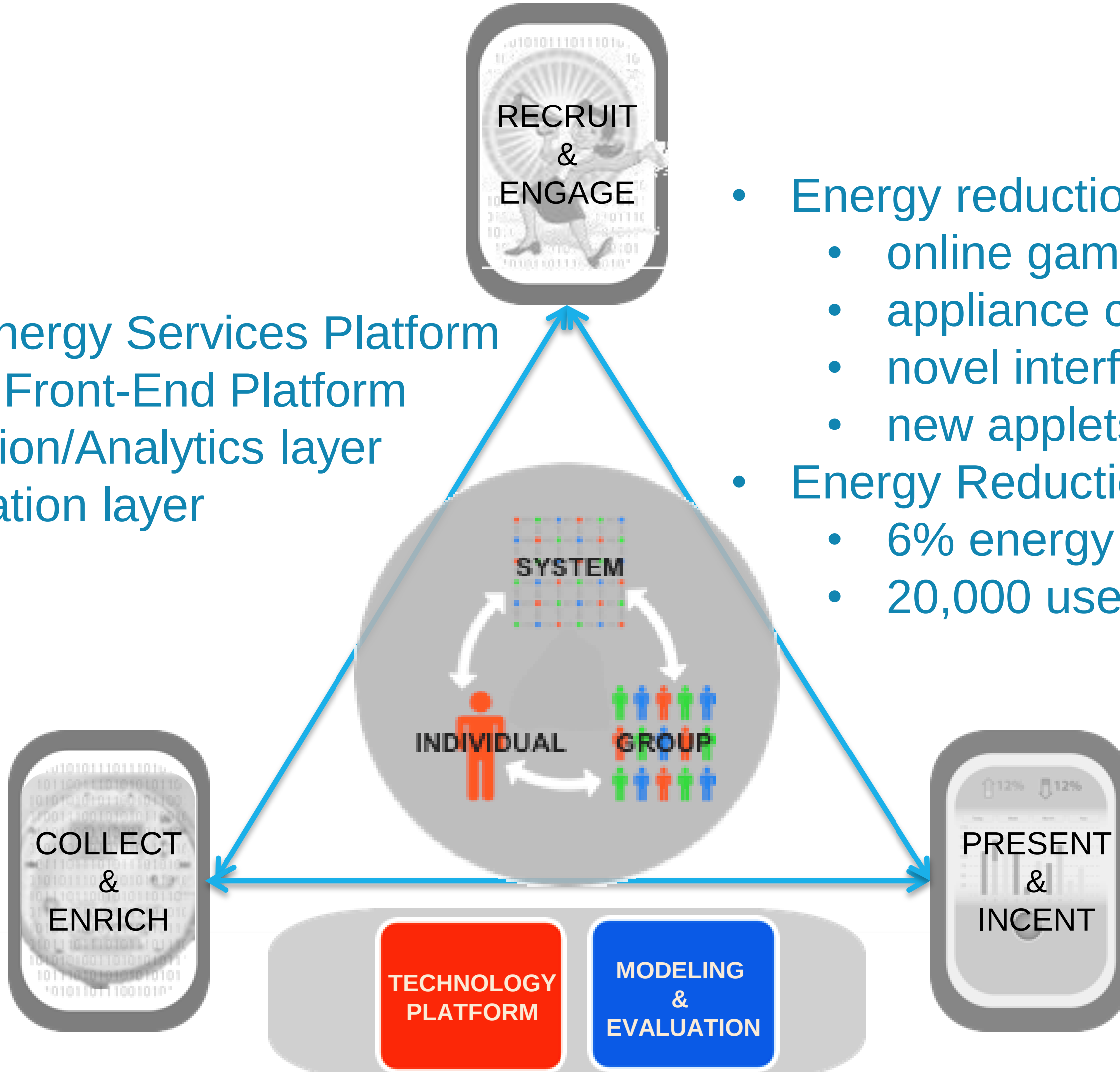
Primary Technical Targets (Metrics)
TEST BED: Minimum of 3 controllers/terminals connected on a small-scale mesh with a minimum of 5 nodes. Terminals configured for operation at > 10kV.
RESILIENCY: Protocol for testing the resiliency and stability of the interconnected controllers.
BI-DIRECTIONAL FLOW 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

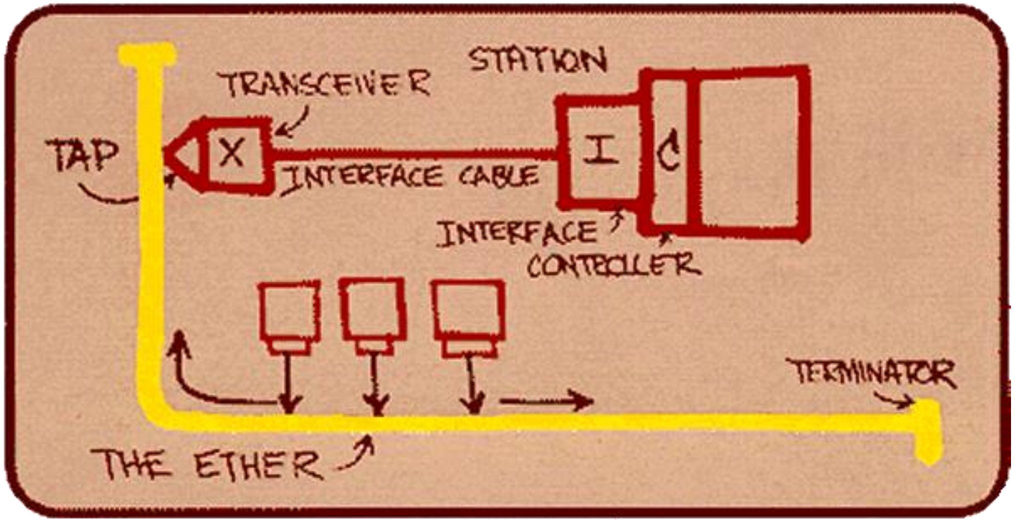
- Stanford Energy Services Platform
- Integrative Front-End Platform
- Segmentation/Analytics layer
- Disaggregation layer

- 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?"



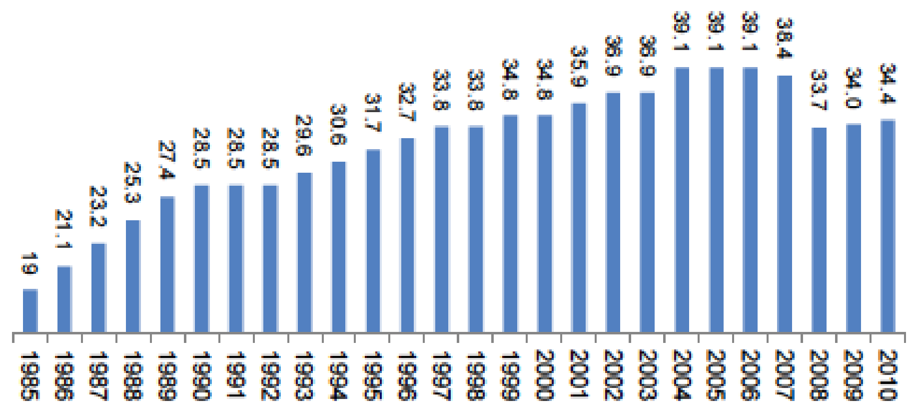
Macro Trends Driving Urban Mobility (cont'd)

FONTINALIS PARTNERS

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

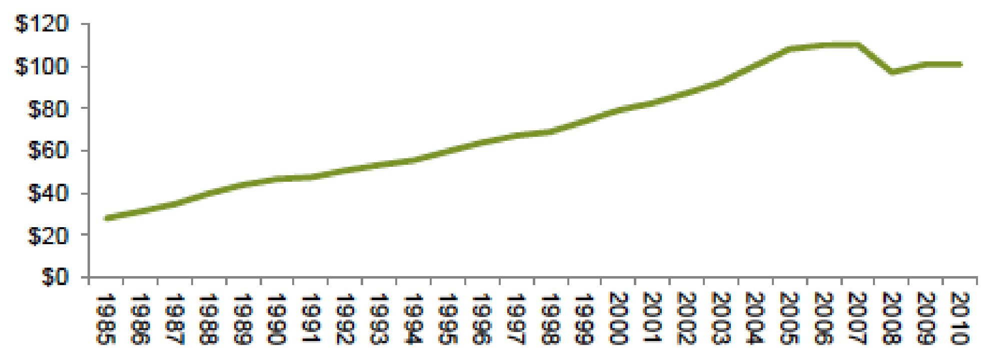
U.S. Annual Delay per Commuter (Hours)

- 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



Source: *2011 Urban Mobility Report.* Texas Transportation Institute.

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

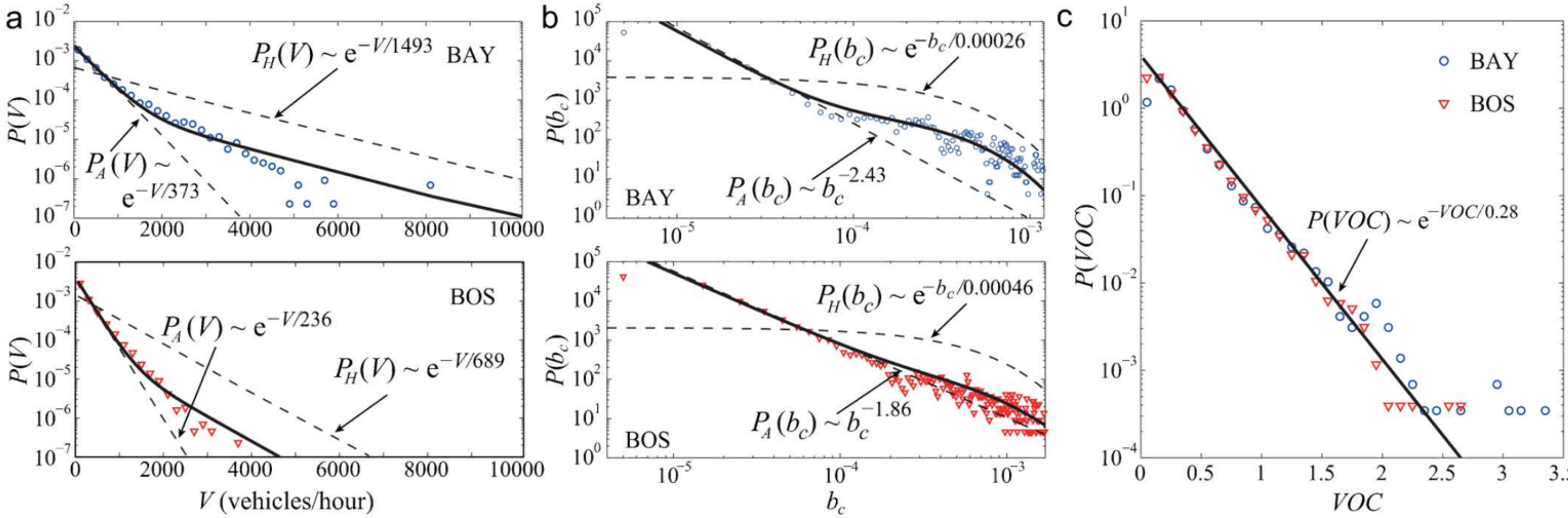
- Models quantitatively support roadway construction: Civil Engineering and Policy motives
- Now, ubiquitous portable sensors and low power wireless communications are game changers

Understanding Road Usage Patterns in Urban Areas

SCIENTIFIC REPORTS

Pu Wang[1,2], Timothy Hunter[4], Alexandre M. Bayen[4,5], Katja Schechtner[6,7] & Marta C. González[2,3]

nature.com



Examples of Data

Prevalence ↑

Travelers	Vehicles	Routes
Cell tower reporting	License plate readers	Inductive Loop sensors
GPS reporting	On-board computers	Traffic cameras
Transit cards	GPS Reporting	Traffic helicopters
Face recognition?	Connected vehicles	
	Battery chargers	
	Automation	
	Fully autonomous?	

Anonymity →

A physics/engineering view of traffic flow

Fundamental Relationships

- Vehicles observed in *t* hours:

$$q = \frac{\text{no. of vehicles}}{\text{total elapsed time}} = {}^{n}\!/_{t}\ \text{vph}$$

- Concentration/density of traffic over *v* km road within 1h:

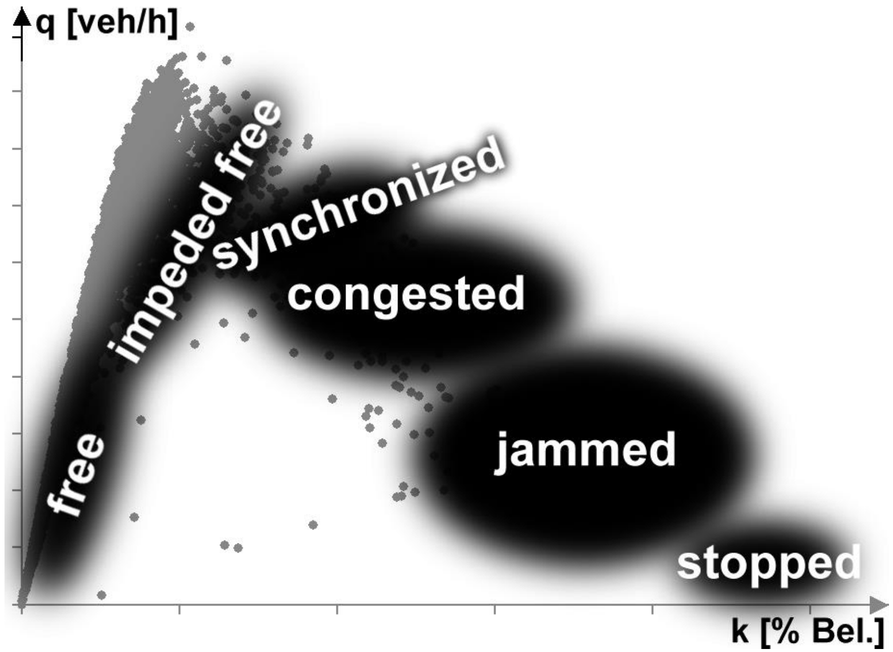
$$k = \frac{\text{no. of vehicles}}{\text{length of road}} = {}^{n}\!/_{l}\ \text{veh/km}$$

- Space mean speed of vehicles:

$$u = \frac{\left({}^{1}\!/_{n}\right)\sum_{i=1}^{n} d_i}{\bar{t}}\ \text{km/hr}$$

- Time mean speed of vehicles:

$$u = \left({}^{1}\!/_{n}\right)\sum_{i=1}^{n} \frac{d_i}{t_i}\ \text{km/hr}$$



Kim, Y. and H. Keller (2001): Zur Dynamik zwischen Verkehrszuständen im Fundamentaldiagramm (Dynamics between Traffic States in the Fundamental Diagram). Strassenverkehrstechnik, Issue 9/2001, pp. 433-442

An economists view of traffic flow

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

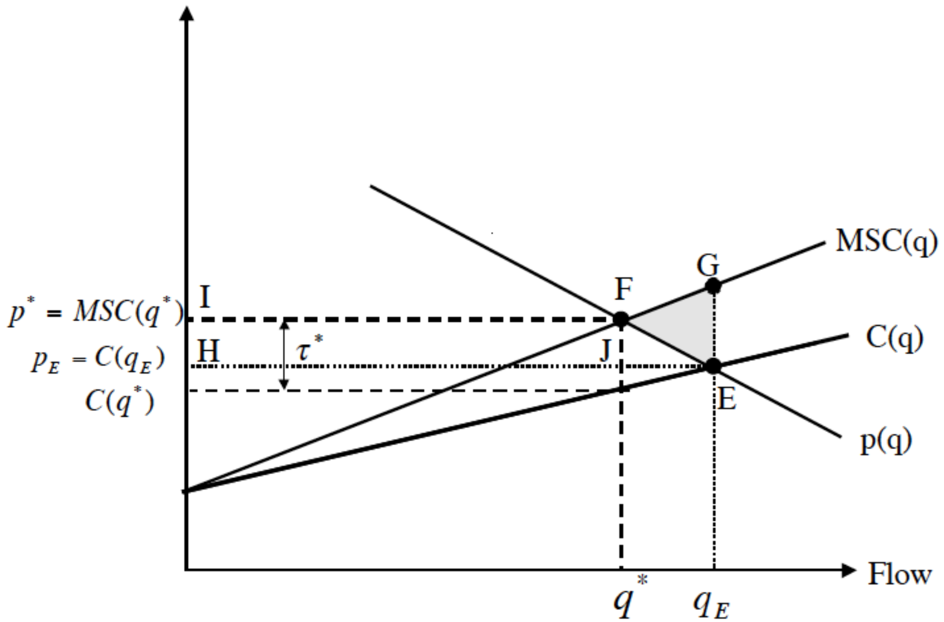


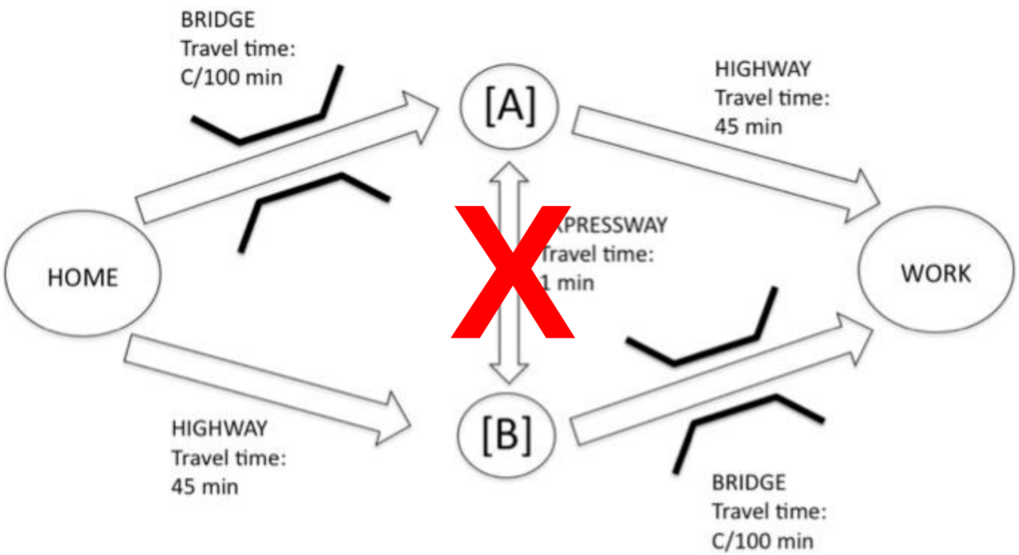
Figure 3. Equilibrium road usage, q_E, optimal road usage, q^*, and optimal congestion toll, τ^*

- Predicts incentives of traffic flow

Complications: Braess' Paradox

4000 commuters

4000 commuters



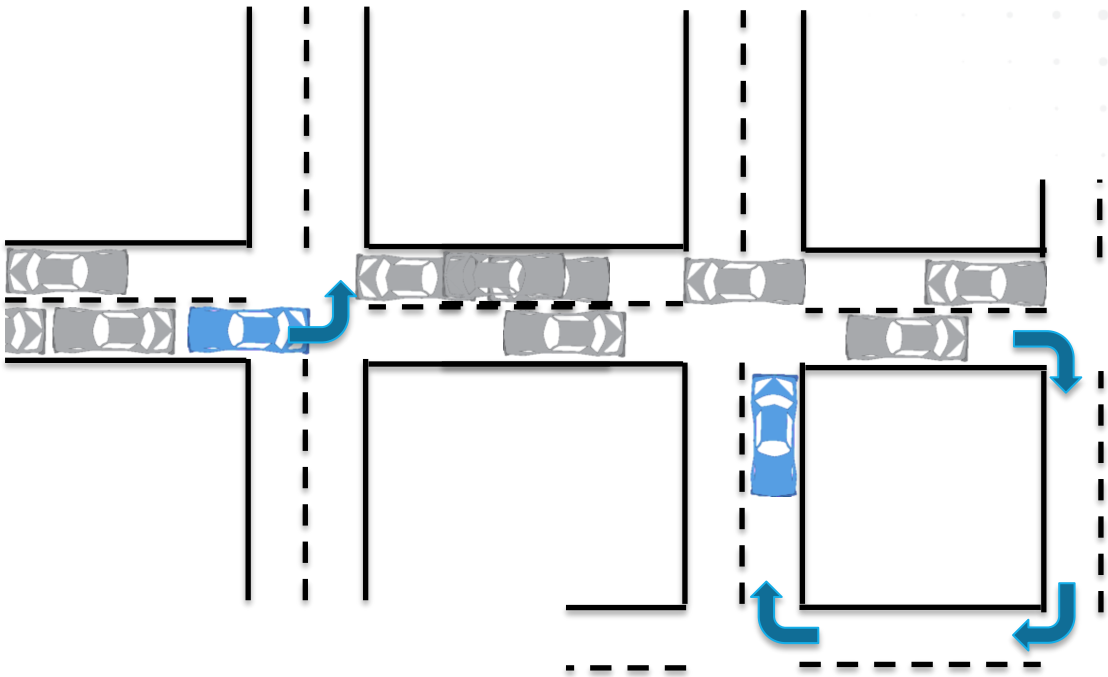
81' optimum Commute (2 bridges)

65' commute

Paradox arises from Nash equilibrium (Prisoner's Dilemma)
Drivers lack information about <u>other</u> 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.

**more on this from Yves-Alexandre de Montjoye*

…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.

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

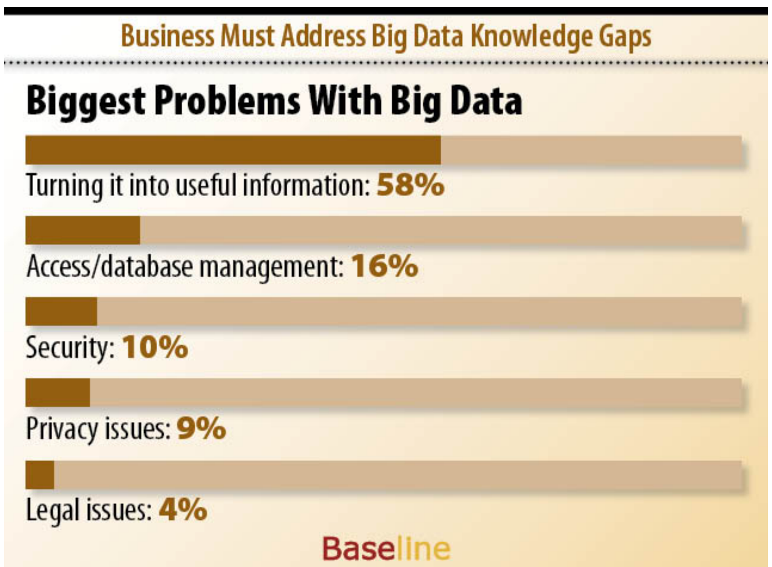
Waze Mission

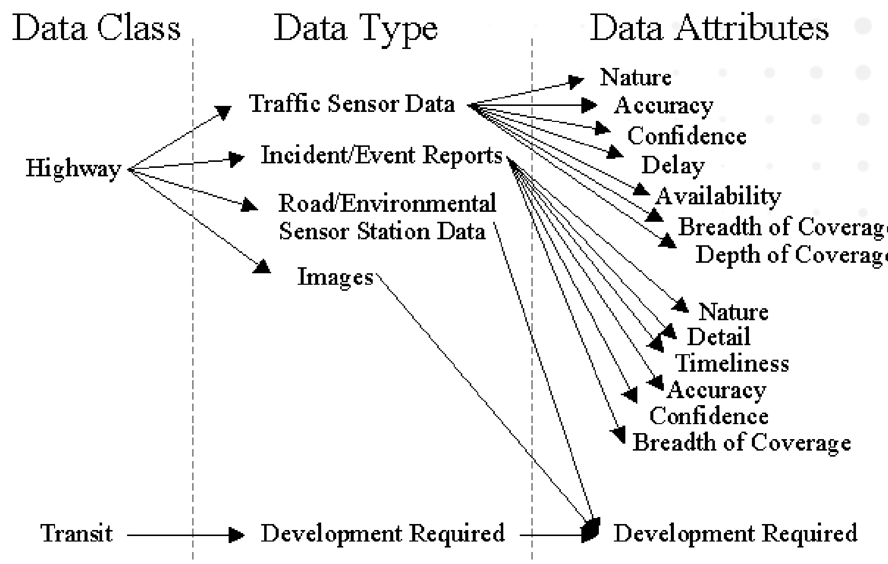
Save Everyone 10 Minutes, Every Day

Mission: impossible?

Discussion starters: Data

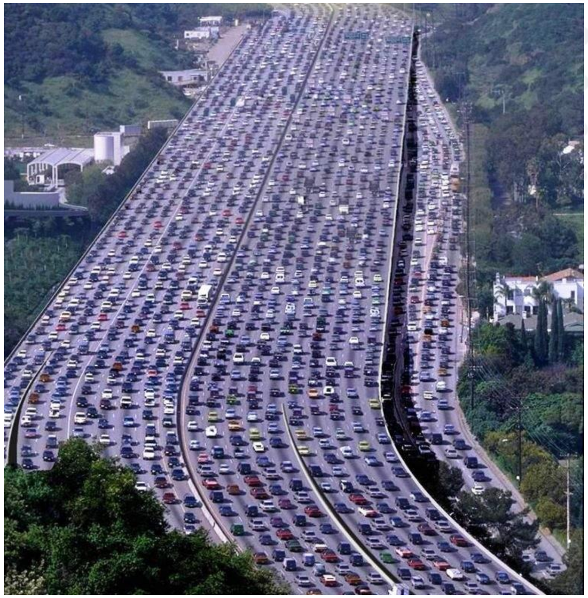
- Gaps?
- Trajectory?
- Security?
- Integration?

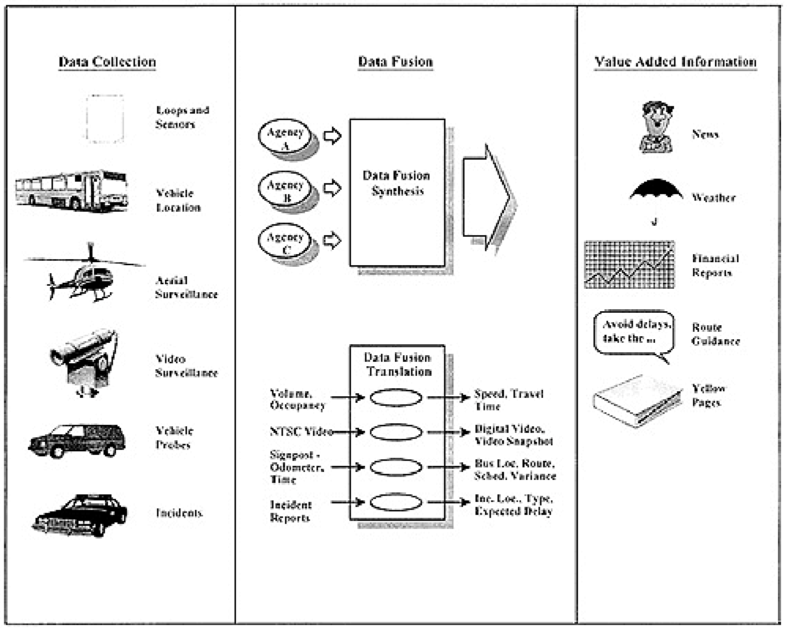


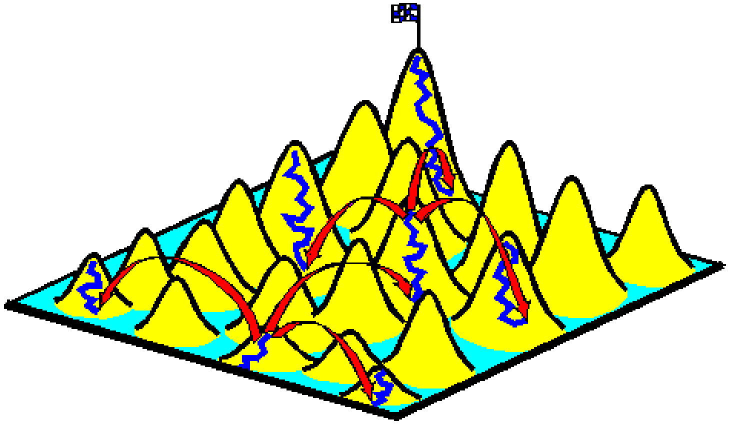


Discussion starters: Models

- Macro, meso, and/or micro?
- Implementation challenges?
- Optimization challenges?

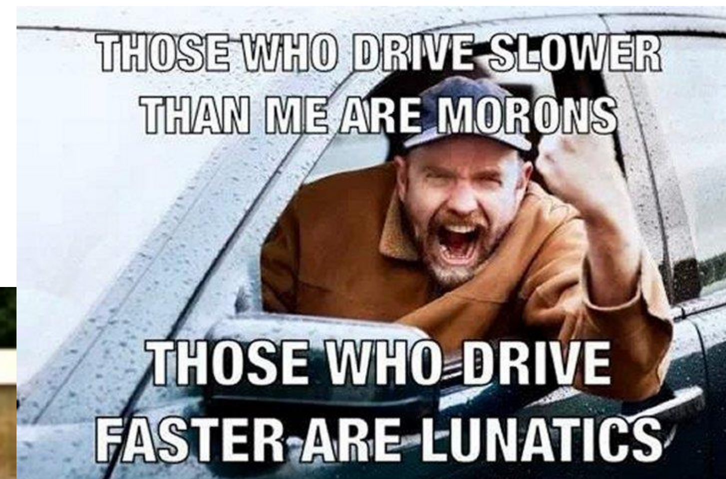






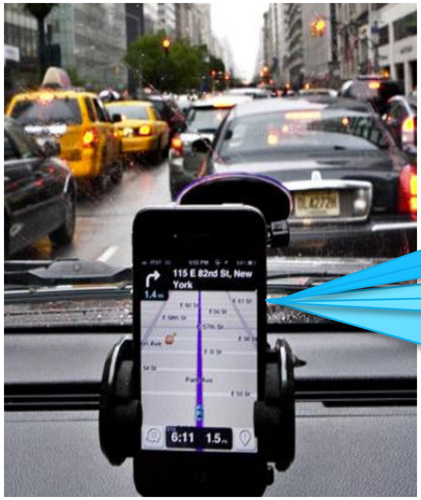
Discussion starters: Incentives

- 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 righ

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 that are generally unable to attract private sector financing because of the significant risks involved

- **break·through** [*breyk-throo*] *–noun*. **1.** A military movement or advance all the way through and beyond an enemy's front-line defense