Nash-Stackelberg games in transportation networks: leveraging the power of smartphones for traffic monitoring and management

Alexandre Bayen
Electrical Engineering and Computer Science
Civil and Environmental Engineering
UC Berkeley

http://traffic.berkeley.edu  http://float.berkeley.edu
"Classical" vs. "modern" source of traffic information

**Dedicated infrastructure:**
- Self inductive loops
- Pavement sensors
- FasTrak, EZ-pass RFID
- Cameras
- Radars
- License plate readers

**Mobile devices:**
- 1+B smartphones on earth

![Graph showing the number of mobile devices shipped per year (log scale).](image)
2007 (511.org) vs. 2010
**Mobile Millennium (2008-2011)**

**An early instantiation of participatory sensing**

- Funded by California DOT (DRI), US DOT, Nokia, NAVTEQ, NSF
- Initially, 5000 downloads of the FIRST Nokia traffic app worldwide
- Today: gathers about 60 million data points / day from dozen of sources (smartphones, taxis, fleets, static sensors, public feeds)
- Provides real-time nowcast (soon forecast) of highway and arterial traffic, provide routing and data fusion tools.
Example: 0.5% of Mobile Millennium data (one day)
Example: 0.5% of *Mobile Millennium* data (one day)
Data flow in traffic monitoring systems
Challenges of traffic estimation

Example: combined path-inference / map matching:
  - Naïve projection on map does not work.
  - Routing cannot be decoupled from map matching
  - Probabilistic model needs to be built (most probable travel time)
  - Learning (must be done from sparse data)
  - Time dynamics must be captured (streaming data)
  - Real-time computations (implementation architecture must reflect computational needs)
Granularity of the data (GPS data)

Physical model and data assimilation enable state estimation
- Works even with low penetration rate
- Interpolation will just not do the job
Flow reconstruction (inverse modeling)

Physical model and data assimilation enable state estimation
- Works even with low penetration rate
- Interpolation will just not do the job

10 measurement points
Flow reconstruction (inverse modeling)

Physical model and data assimilation enable state estimation
- Works even with low penetration rate
- Interpolation will just not do the job
Creation of a private – public marketplace

How can the government acquire private sector data
  – Aging infrastructure does not support data needs anymore
  – Procurement procedures are new to the government
  – Pricing of this new data is unknown too
  – Contract conformance is new as well
  – 2010-2011: first ever procurement of GPS data by the State of California, administered by UC Berkeley.
How to buy data: example of problems

How to build good quality metrics for procurement

Example problems

- Delay of the data
- Time variations in the data
- Spatial coverage of the data
Mission 2015: integrated corridor management

- BART Express Lanes
- HOT/HOV control
- Local Arterial Traffic Signals
- Parking
- Ramp Metering
- Smartphone enabled reroute
- CMS
- Express Lanes HOT/HOV control
- BART
- Local Arterial Traffic Signals
Can people collect data for good behavior?

Wherever public agencies would want traffic to be reduced:
– Can drivers be incentivized to leave the freeway?
– In which conditions does this make sense?
  – Recurring congestion vs. incident response
– Success stories and pitfalls: sustainability
An enormous potential for behavior change

Efficient use of social networks
- Frustration on congestion is enormous
- Lack of information prevents reroutes
- Lack of coordination makes reroutes dangerous for social optimality
Congestion Routing Games

Goal: to allocate flow optimally in a parallel network (i.e. a network in which alternative routes are possible)

- Parallel network, N edges

- Continuum of players, total flow demand \( r \) (jobs/s, cars/s)
- Individual latency \( \ell_n(q_n) \) on link \( n \) depends on total flow \( q_n \)
- Total cost:

\[
C(q) = \sum_{n=1}^{N} q_n \ell_n(q_n)
\]
Definition of the Stackelberg game

**Stackelberg game**

- First, leader routes **compliant** drivers $\alpha r$ : strategy $s \in \mathbb{R}^N_+$
- Second, followers (non-compliant drivers $(1 - \alpha)r$) choose their routes selfishly: strategy $t(s)$

Leader seeks to minimize system-wide cost: $\min_s C(s + t(s))$

Optimal Stackelberg strategies $\arg\min C(s + t(s))$ are NP-hard to compute (in the size N).
The emergence of the human as a sensor

**Best known sensor for earthquakes: accelerometer**
- USGS has dedicated array of embedded accelerometers
- Human is faster than USGS by posting on Twitter
- All smartphones have accelerometers, UCLA already succeeded in capturing a P-wave from a smartphone (CENS)
- Information could be enhanced by having additional accelerometer information available.

UC Berkeley iShake app and shake table testing procedure

USGS shakemap (from static USGS sensors)
Floating Sensor Network

**Floating sensor network**

- Summer 2012: deployment of 100 floating / submersible units in the San Francisco Bay / Sacramento Delta, DWR
- Stillwater, OK, rapid levee breech repair demo, DHS
Floating Sensor Network

Floating sensor network

- Summer 2012: deployment of 100 floating / submersible units in the San Francisco Bay / Sacramento Delta, DWR
- Stillwater, OK, rapid levee breech repair demo, DHS
Floating Sensor Network

Floating sensor network
- Summer 2012: deployment of 100 floating/submersible units in the San Francisco Bay/Sacramento Delta, DWR
- Stillwater, OK, rapid levee breech repair demo, DHS
"Surely You're Joking, Mr. Feynman!"
Adventures of a Curious Character

The outrageous exploits of the world's most outspoken Nobel Prize-winning scientist

Richard P. Feynman
Author of "What Do You Care What Other People Think?"