ML applications in transportation system analysis and decision making

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Decisions

• Smart decision making
  • How to reduce crash frequency on streets?
  • When, how and where to retrofit a road segment?
  • Traffic impact of “complete streets”?
  • How to reduce bus bunching?
  • What are the optimal parking prices?
  • How to regulate Uber?
  • Design first/last mile mobility services?
  • ....
What to sense?

• Supply – Infrastructure
  • E.g., infrastructure performance using structural health monitoring, incidents, signage inventory

• Demand – Travelers’ behavior
  • E.g., Traffic flow using traffic cameras
How to sense?

• Supply
• Demand
Infrastructure monitoring using smartphones

- Mertz Navlab CMU
Infrastructure monitoring using smartphones
How to sense?

• Supply
• Demand
Network flow

- Road segment
  - Highways/Arterial roads
    - FLOW (veh/hour)
    - DENSITY (veh/mile)
    - SPEED (miles/hour)
    - Travel time (min)
  - Intersections
    - Turning flow (veh/sec)
    - Pedestrians
    - Bicyclists
- Others?
  - Parking
  - Vehicle class
  - Vehicle occupancy
  - Transit ridership by stops
  - ...
- Spatio-temporal flow
Fundamental diagrams

- Flow rate $Q$ – density $D$ – speed $U$
  - Two regimes

$$Q = U \times K$$

http://publish.illinois.edu/shimao-fan/research/generic-second-order-models/
How do we measure traffic flow?

• Inductive loop detectors
• Video image processing
• Magnetometers
• Pneumatic tubes
• Acoustic/Ultrasonic sensors
• Cell tower
• GPS
• ...
Smart sensing

• Traditional sensors used in a smarter way
• New sensors: traditional measurements are made more reliable and accurate
• New sensors: new measurements
Inductive loop detectors

- Intersections with traffic-actuated signals
- Freeway entrance with ramp metering
- Freeway and arterials segment
- Gated parking facilities
Inductive loop detectors

• A coil of wire embedded in concrete
• When a vehicle enters the loop, the metal body provide a conductive path for the magnetic field.
• Loading effect causes the loop inductance to decrease
• Resonant frequency exceeds a threshold, switch to ‘ON’
Inductive loop detectors

- Time-varying 0-1 indicating ‘non-occupied or occupied’.
- (Classified) traffic counts, instantaneous speed, headway (~density)
- Speed measurement is very rough, but can be enhanced by coupled loop detectors
- Reliable under all weather and lighting conditions
- Moderately expensive to maintain, fixed cost~ $800
- A lifetime of 5-10 years
- Can fail due to snow and ice
Inductive loop detectors

• 38,000 loops in California freeways/highways
• In California PeMS system, on average 40% are unhealthy
PeMS
Vehicle classification

- Data used for traffic and pavement management
Vehicle classification

- Intrusive
- Non-intrusive

Imaging based

Weigh-in-motion
Video image processing

• Traffic camera
• Monitoring camera
Video image processing

• Traffic camera
  • Mounted overhead above the roadway
  • A cable to transmit streams to the image processing system
  • Process frames of a video clip to extract traffic data

• Low resolution, still, requires calibrations
Video image processing

• Monitoring camera
  • One for each intersection or freeway segment
  • Surveillance footage can be transmitted to TMC
• High resolution, can remotely control the extent/scope
• Detect incidents/accidents
Video image processing

- (Classified) traffic counts, instantaneous speed, headway (~density)
- Speed measurement could be accurate under labor-intensive calibration
- Data + monitoring
- Flexible in setting up detection zones
- Very expensive to install and to maintain, fixed cost ~ $5,000
- Vulnerable to visual obstruction, e.g., weather, shadows, poor-lighting conditions, strong winds, etc.
Pneumatic tubes

- A rubber tube with a diameter of about 1 cm
- When a vehicle passes, the wheel presses the tube, and the air inside is pushed away.
- The air pressure moves the membrane and engages the switch
Pneumatic tubes

- (Classified) counts, instantaneous speed, flow direction
- Very portable, ideal for short-term studies
- System can be reused at other locations
- Fast installation
- Moderately expensive
- Limited lane coverage, not intended for long-term
New inventions: Magnetometers

- Developed by Sensysnetworks
- 5 min installation
- 10 years battery life
- Reliable measurements
- Water proof
- Under test
Magnetometers
Magnetometers

Earth’s magnetic field

Ferrous object

Distorted field

Magnetic sensor
Magnetometers

- One sensor measures flow, density, counts
- Two sensors separated by fixed distance can measure speed and travel time

\[ v = \frac{\Delta x}{\Delta t} \]
GPS/Cell tower

• Trajectories of individuals
• New measurements
  • Origin, destination, spatial info by time of day
• Translating GPS data into activities remains a big challenge
GPS/Cell tower

- AirSage

**As long as a mobile phone is active** on the cellular network, AirSage receives wireless signals and uses them to anonymously determine location. With AirSage’s carrier and partner relationships, we have nationwide coverage – more than any other location-based services (LBS) provider.

AirSage anonymously collects and analyzes wireless signaling data – processing more than 15 billion phone locations every day – and turns it into meaningful and actionable information, conveniently time- and date-stamped. Businesses, government agencies and other organizations can use this aggregated information to **model, evaluate and analyze the movement and flow** of commuters and consumers.
Google map / INRIX / Uber
Now what? Some use cases
Travel time prediction and reliability analysis

• What causes/relates to day-to-day and within-day travel time variation?
  • INRIX/HERE
  • Counts
  • Weather
  • Incidents
  • Events
  • All in high spatial and temporal resolutions (5-min, lat/log)
Bottlenecks
Bikability score
Pittsburgh Public Parking
Pittsburgh transit system
Surge pricing prediction
Issues of ML applications in transportation

Unexplored space
A possible solution: data + physics

Final goals: evaluation and intervention

- $x$: link flow (flux, density, speed...)
- $f$: path flow (flux, density, speed...)
- $c$: system states (cost, time, emissions...)

Given $x^o, f^o, c^o$ and supply, learn $(x, f, c) = G(\text{supply, demand})$
A machine of $G$

- Use OD demand $q$ to approximate demand
- Define user behavior $G$
  
  $G : (\text{supply}; q) \mapsto (x, f, c)$

- Given $x^o, f^o, c^o$ and supply, estimate $q$
- Calibrate $G$, estimate/predict $(x, f, c)$
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MAC data sets

• GIS, demographics, economics, weather
• Traffic counts
  • Highways, major arterials
• Travel time/speed
  • INRIX, HERE, TomTom, AVI, BT
• Transit
  • APC-AVL, Park-n-ride, incidents
• Parking
  • Transactions of on-street meters and occupancy of garage
• Incidents
  • RCRS/PD/911/311/PTC/PennDOT Crash/Road closures
• Social media (Twitter)
Ultimate goal