ML applications in transportation system analysis and decision making

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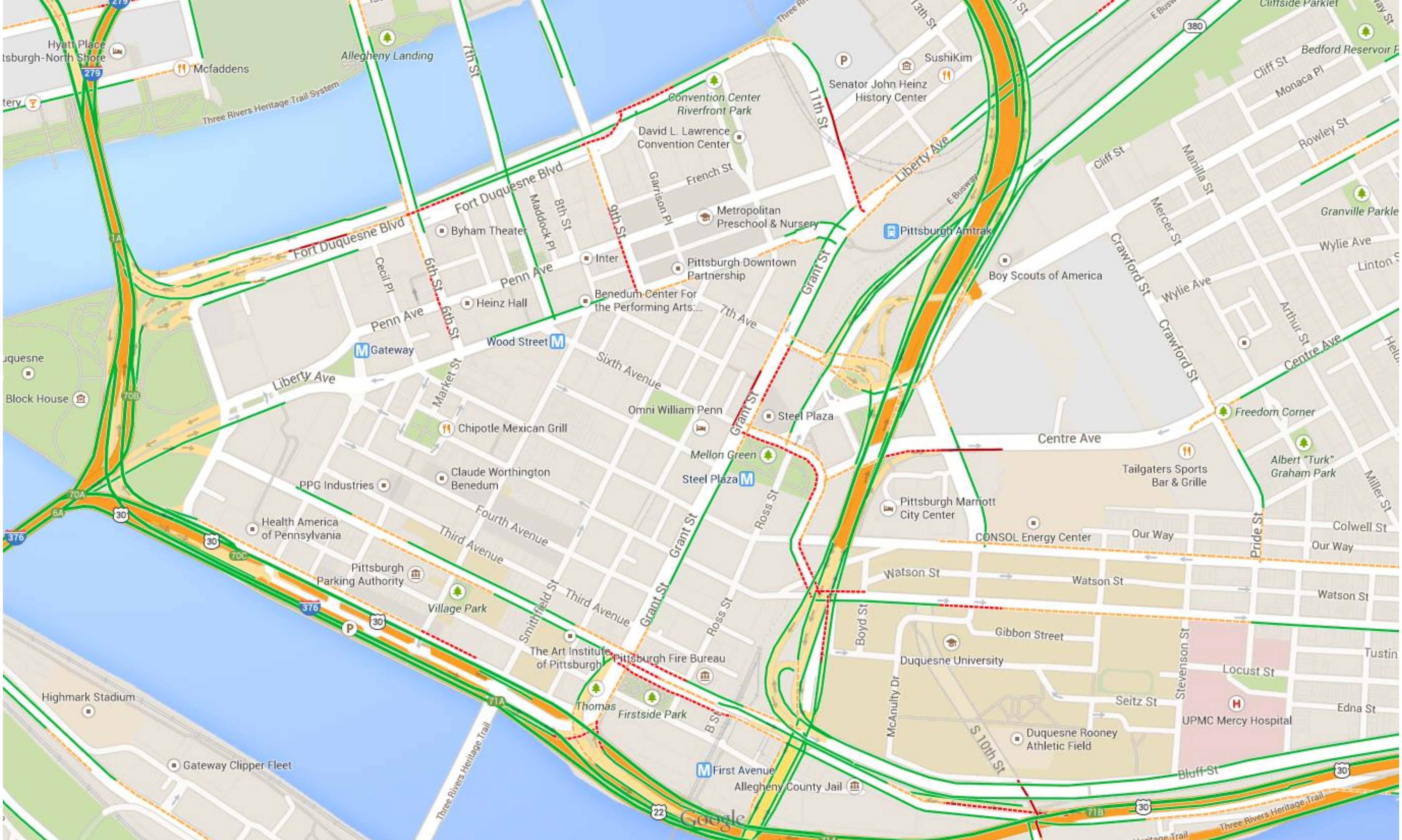


Hyatt Place
tsburgh-North Shore
Mcfaddens
Allegheny Landing
7th St
Three Rivers Heritage Trail System
Convention Center
Riverfront Park
David L. Lawrence
Convention Center
Senator John Heinz
History Center
SushiKim
13th St
11th St
French St
Garrison Pl
Fort Duquesne Blvd
Fort Duquesne Blvd
Byham Theater
Maddock Pl
8th St
9th St
Metropolitan
Preschool & Nursery
Liberty Ave
E Busway
Pittsburgh Amtrak
Inter
Pittsburgh Downtown
Partnership
Penn Ave
Penn Ave
Cecil Pl
6th St
6th St
Heinz Hall
Benedum Center For
the Performing Arts:...
7th Ave
Grant St
Wood Street
Gateway
Liberty Ave
Sixth Avenue
Market St
uquesne
Block House
Omni William Penn
Steel Plaza
Chipotle Mexican Grill
Mellon Green
Steel Plaza
Claude Worthington
Benedum
PPG Industries
Health America
of Pennsylvania
Fourth Avenue
Third Avenue
Grant St
Ross St
Pittsburgh
Parking Authority
Village Park
Smithfield St
Third Avenue
Grant St
Ross St
The Art Institute
of Pittsburgh
Pittsburgh Fire Bureau
Thomas
Firstside Park
Highmark Stadium
Gateway Clipper Fleet
Three Rivers Heritage Trail
First Avenue
Allegheny County Jail
Google
Cliffside Parklet
Bedford Reservoir P
Cliff St
Monaca Pl
Rowley St
Cliff St
Manilla St
Mercer St
Granville Parkle
Wylie Ave
Linton S
Boy Scouts of America
Crawford St
Wylie Ave
Crawford St
Arthur St
Centre Ave
Freedom Corner
Centre Ave
Albert "Turk"
Graham Park
Tailgaters Sports
Bar & Grille
Miller St
Pittsburgh Marriott
City Center
CONSOL Energy Center
Our Way
Colwell St
Our Way
Pride St
Watson St
Watson St
Watson St
Boyd St
Gibbon Street
Duquesne University
Stevenson St
Tustin
Locust St
McAnulty Dr
Seitz St
Edna St
UPMC Mercy Hospital
S 10th St
Duquesne Rooney
Athletic Field
Bluff St
Three Rivers Heritage Trail
279
380
376
376
30
22

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

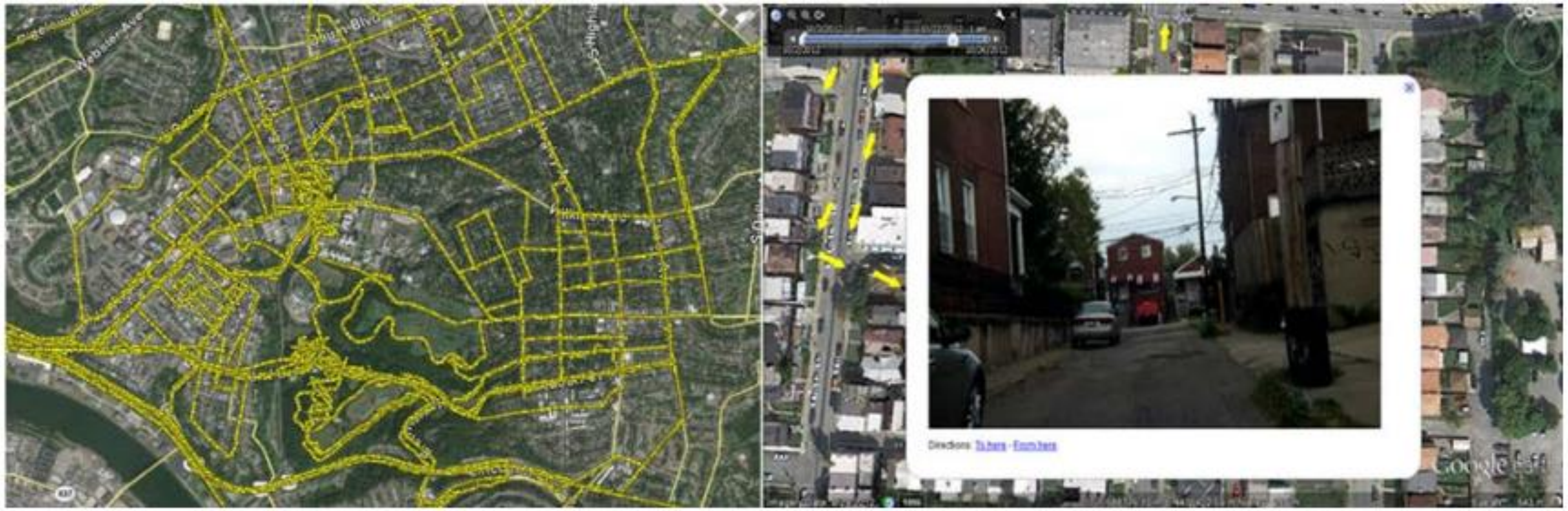
How to sense?

- 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

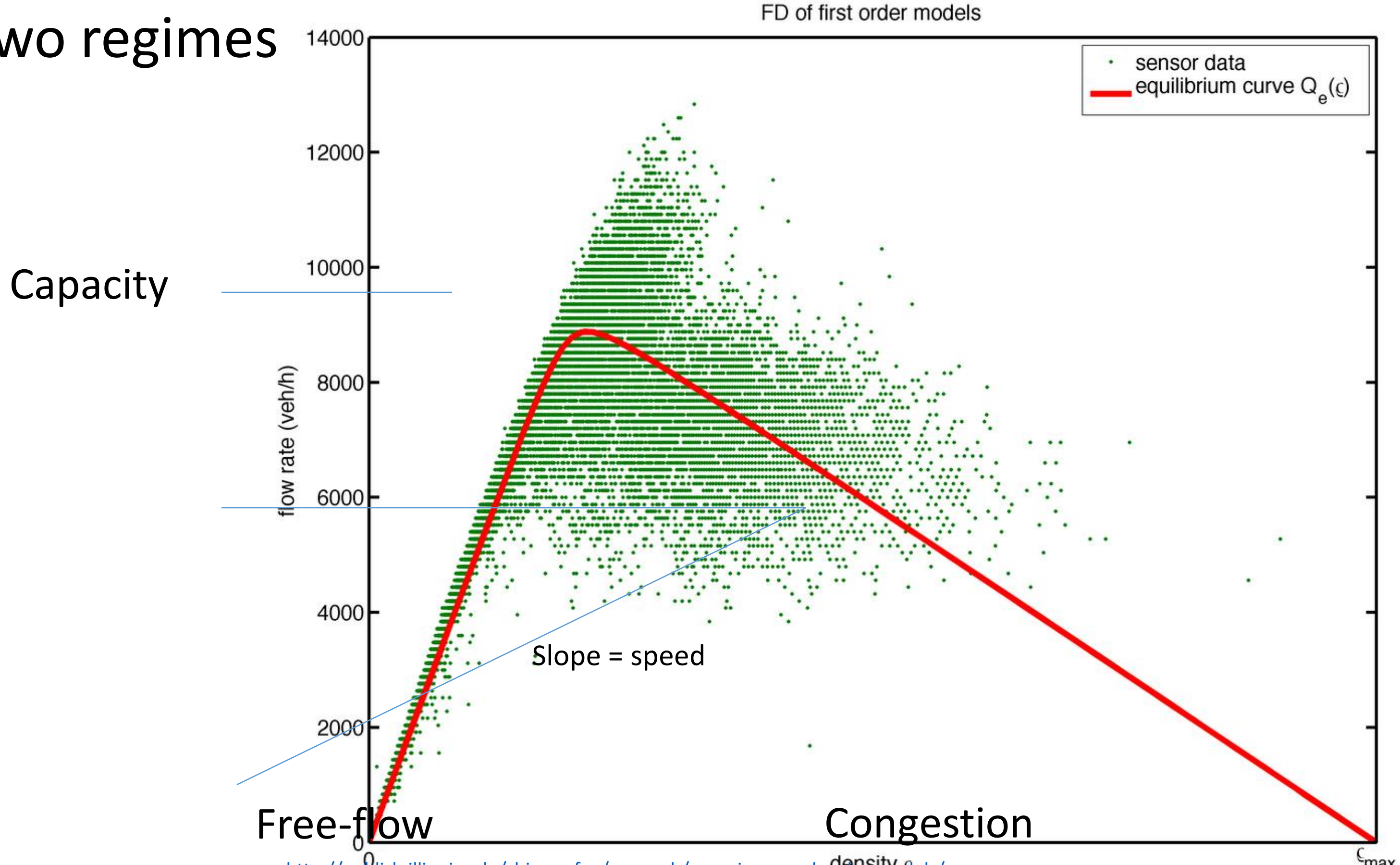
Turning flow (veh/sec)
Pedestrians
Bicyclists

- Others?
  - Parking
  - Vehicle class
  - Vehicle occupancy
  - Transit ridership by stops
  - …

Spatio-temporal flow

Fundamental diagrams

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



http://publish.illinois.edu/shimao-fan/research/generic-second-order-models/

$Q = U * K$

How do we measure traffic flow?

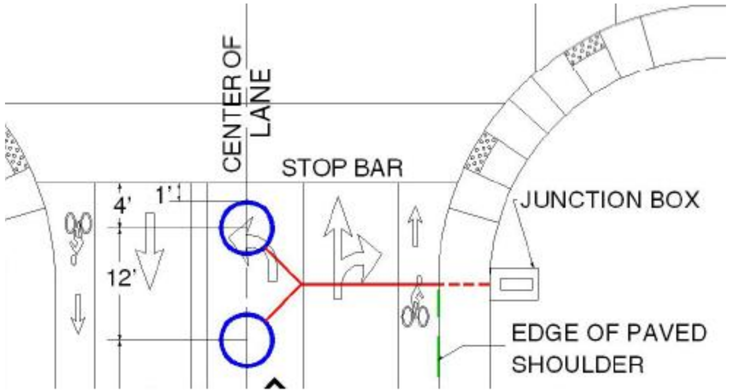
- Inductive loop detectors
- Video image processing
- Magnetometers
- Pneumatic tubes
- Acoustic/Ultrasonic sensors
- Cell tower
- GPS
- …

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

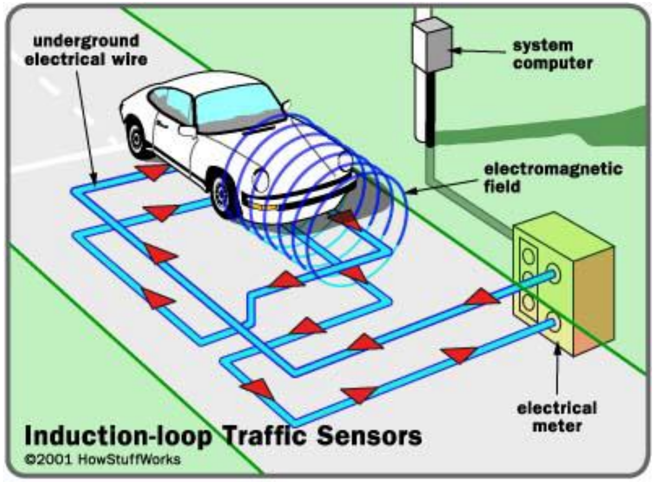


(a) Schematic design of loop detector design

(b) Physical representation of loop detectors

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'

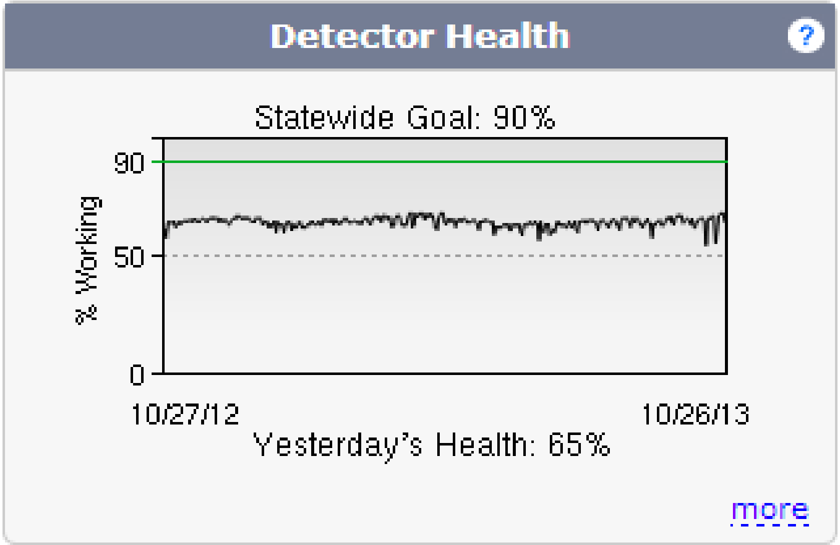


Inductive loop detectors

- 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

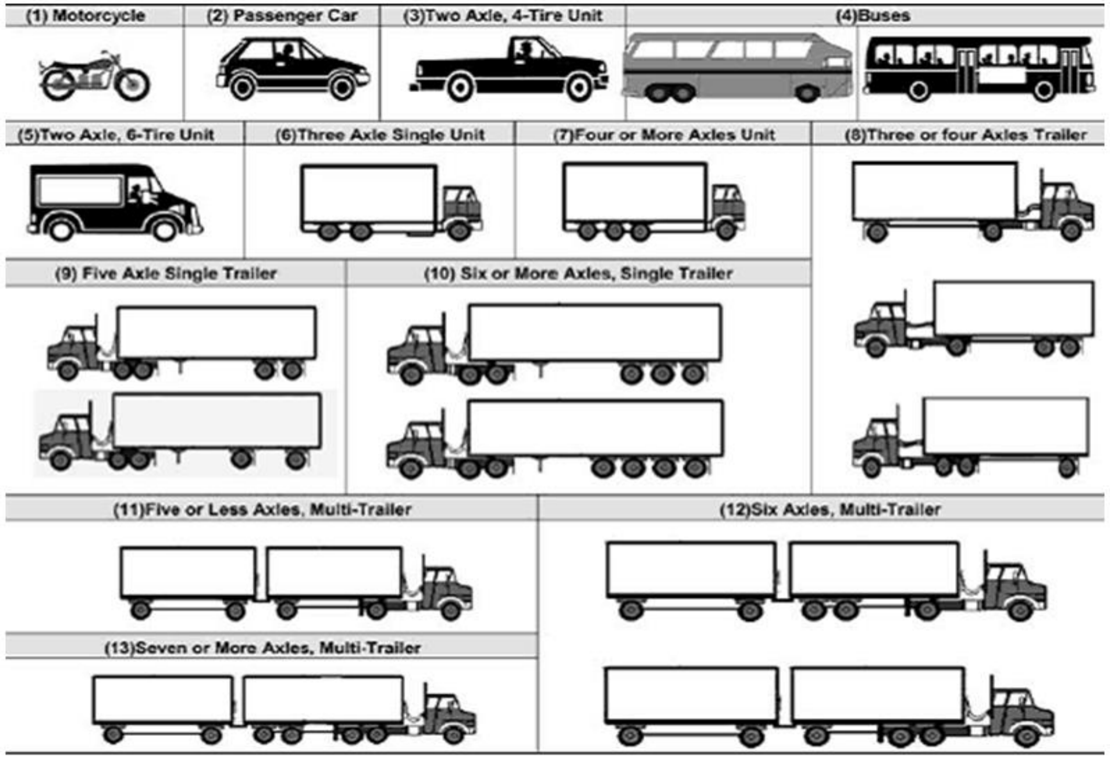


PeMS


PeMS 12.3
Mainline VDS 311974 - 15th St.
Current Location
Maps: Real-Time | Performance | Inventory
US50-E @ CA PM L1.35 (Abs PM 4.5)
District 3, Sacramento County, City of Sacramento
Station Details
Aliases MS ID TA-102
LDS 311905
Owner Caltrans
Assoc. Traffic Census Station None
Comm Type (LDS) Wireless
Speeds Estimated
Max Cap. 190.2 Veh/Min (07/30/2010)
Vehicle Classification N/A
Lane Detection
Lane Slot Sensor Tech Type
1 1 Dual Loop Mainline
2 2 Dual Loop Mainline
3 3 Dual Loop Mainline
4 4 Dual Loop Mainline
5 5 Dual Loop Mainline
Diagnostics
Threshold Set Urban
Flow = 0, Occ > 0 (Intermittent) 2%
High Flow Threshold 20
High Occ Threshold .7
High Occupancy (High Val) 20%
Occ = 0; Flow > 0 (Intermittent) 50%
Repeat Occupancy (Constant) 50
Occupancy = 0 (Card Off) 59%
Change Log | Performance | Data Quality | Events
Performance > Aggregates > Time Series
ABOUT THIS REPORT
From Oct 21 2013 0
Max Range: 3 months
To Oct 28 2013 17
Time of Day All 00:00 to 00:59
Include Days Su Mo Tu We Th Fr Sa Holidays
Quantity Flow
Granularity Hour
Lanes Agg 1 2 3 4 5
Second Quantity -- None --
DRAW PLOT
VIEW TABLE
EXPORT TEXT
EXPORT to XLS
Flow (Veh/Hour)
11,100 Lane Points (89% Observed)
Mainline VDS 311974 - 15th St. - US50-E
Mon 10/21/2013 00:00:00 to Mon 10/28/2013 17:59:59
Flow (Veh/Hour)
10/21 00:00
10/22 00:00
10/23 00:00
10/24 00:00
10/25 00:00
10/26 00:00
10/27 00:00
10/28 00:00
Lane 1 Flow (Veh/Hour)
Lane 2 Flow (Veh/Hour)
Lane 3 Flow (Veh/Hour)
Lane 4 Flow (Veh/Hour)
Lane 5 Flow (Veh/Hour)
Y-Scale: Auto Min Max
Lines Points Grid
Related Aggregates Reports: Time Series • Time of Day • Day of Week • Quantity Relationships

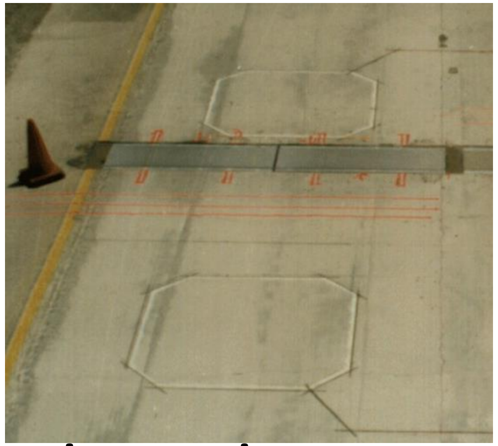
Vehicle classification

- Data used for traffic and pavement management



Vehicle classification

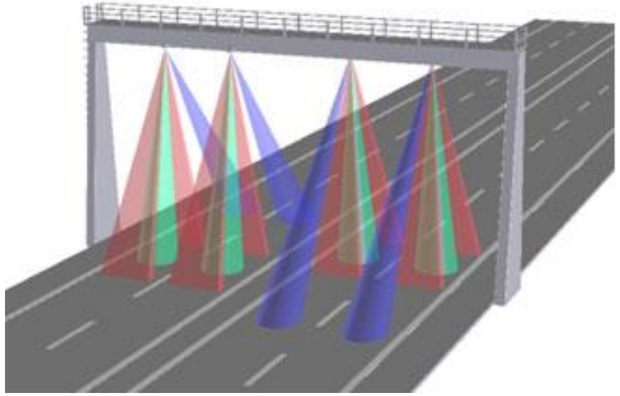
- Intrusive



load cells

Weigh-in-motion

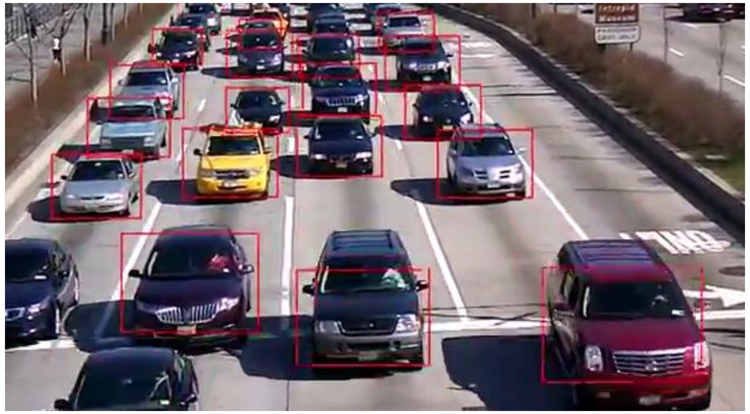
- Non-intrusive

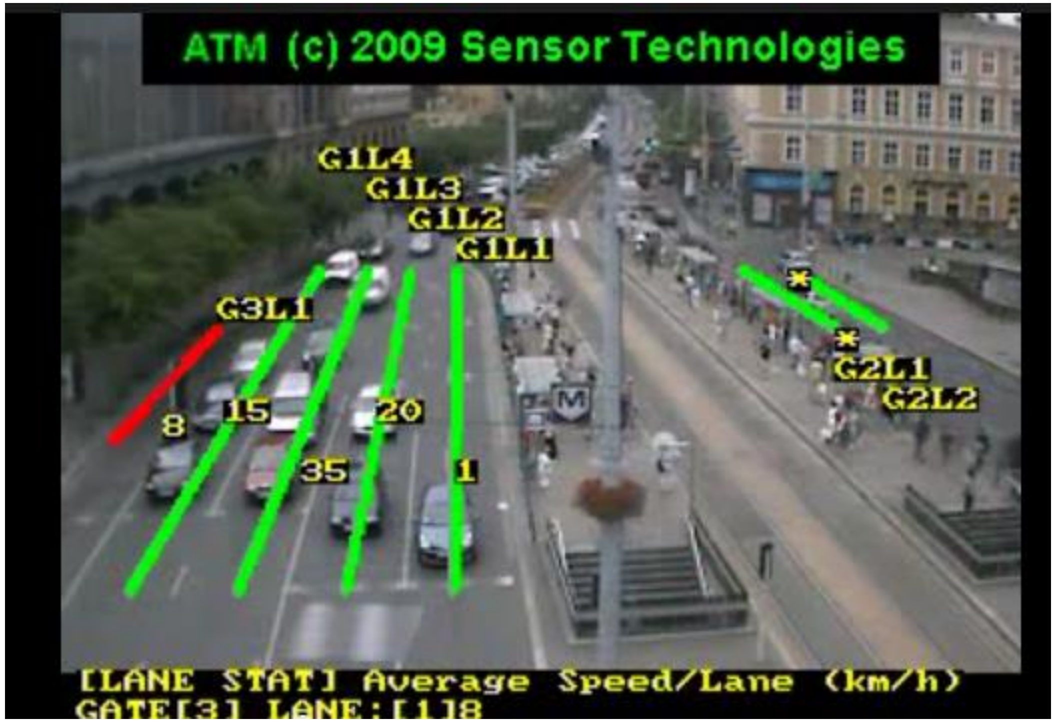


Imaging based

Video image processing

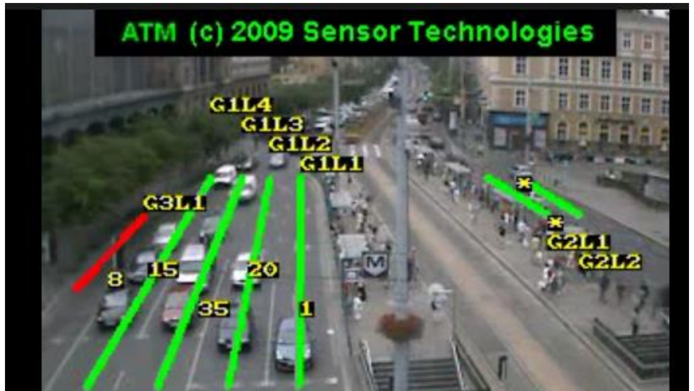
- Traffic camera
- Monitoring camera





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

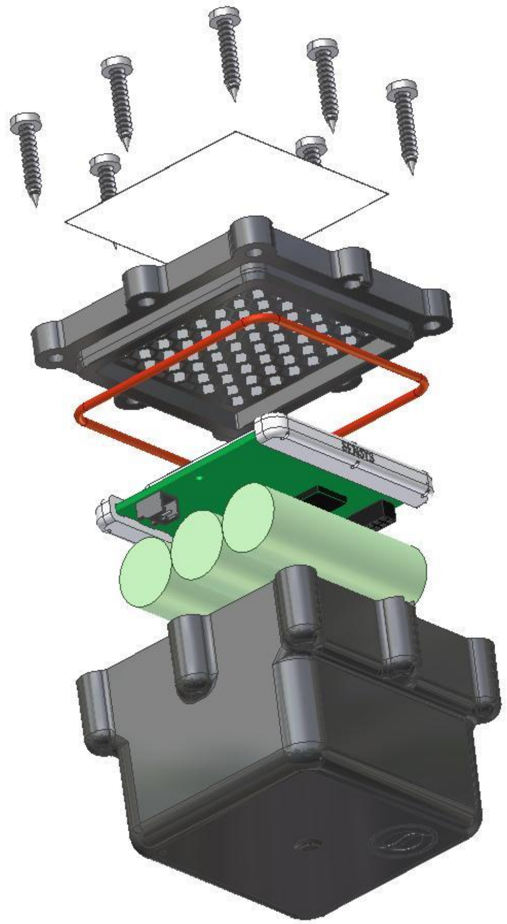
- A rubber tube with a diameter of about 1 cm
- When a vehicle passes, the wheel presses the tube, and the air inside is pushed away.
- The air pressure moves the membrane and engages the switch

Pneumatic tubes

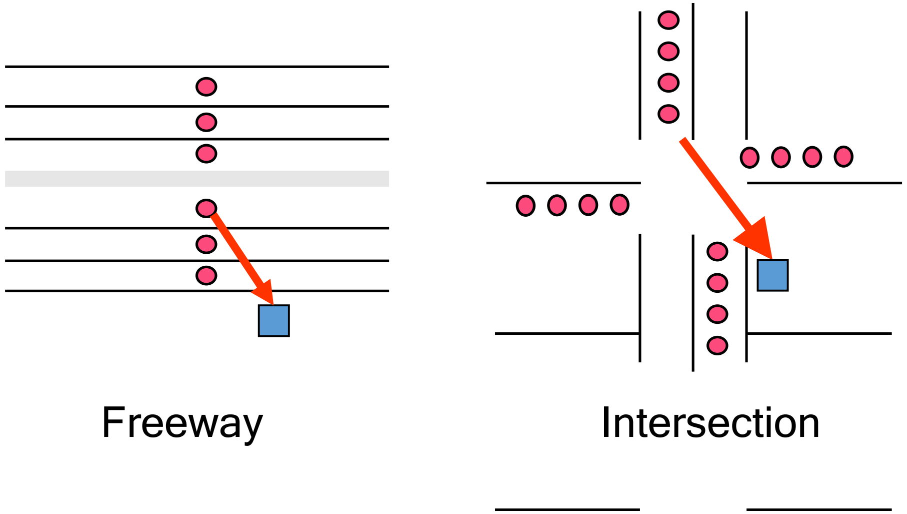
- (Classified) counts, instantaneous speed, flow direction
- Very portable, ideal for short-term studies
- System can be reused at other locations
- Fast installation
- Moderately expensive
- Limited lane coverage, not intended for long-term

New inventions: Magnetometers

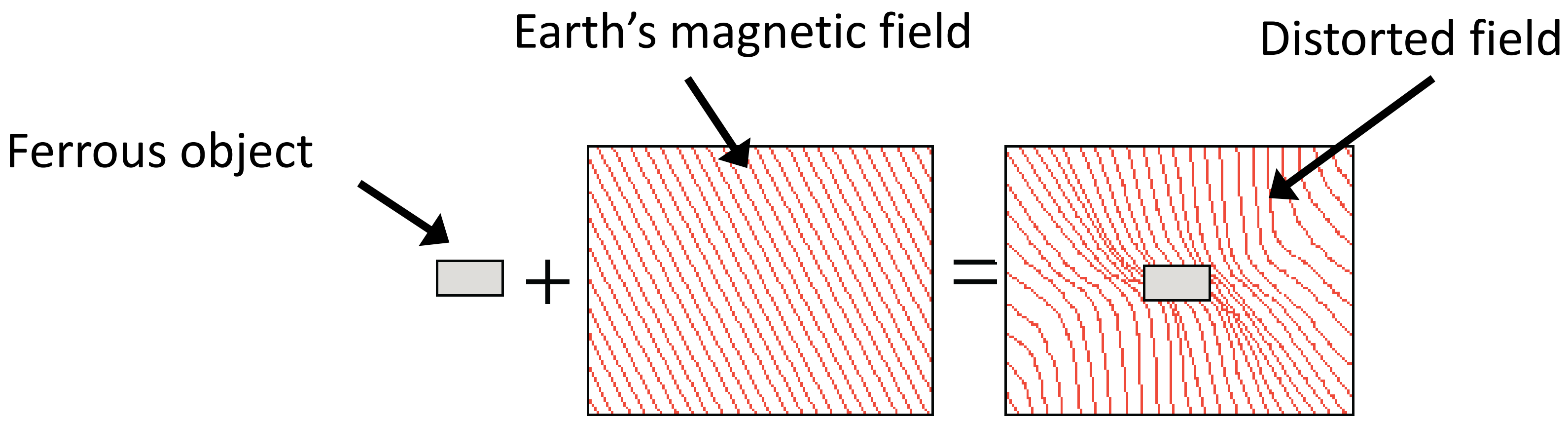
- Developed by Sensysnetworks
- 5 min installation
- 10 years battery life
- Reliable measurements
- Water proof
- Under test

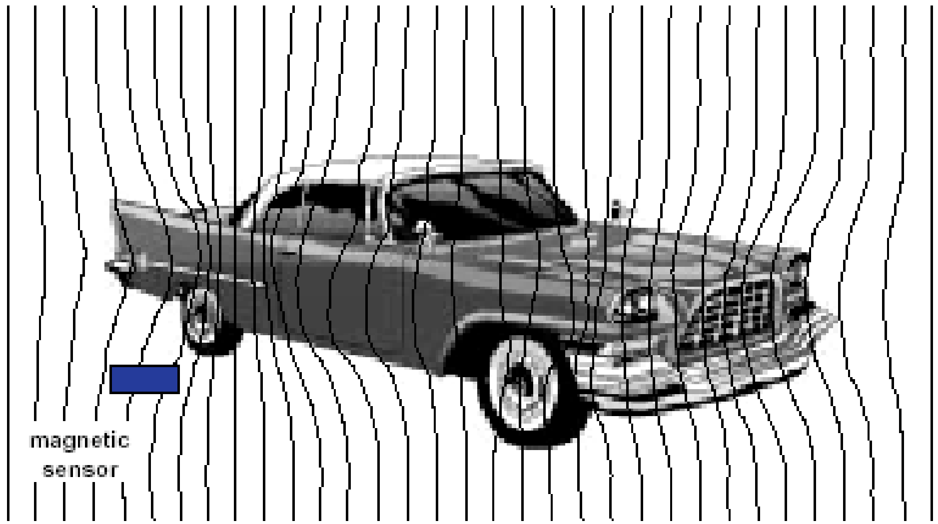


Magnetometers



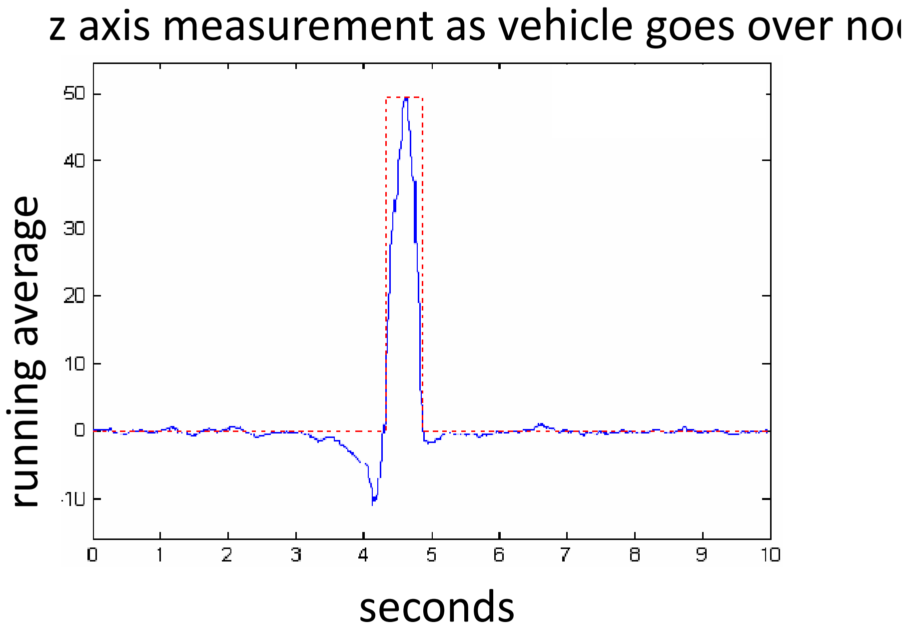
Magnetometers

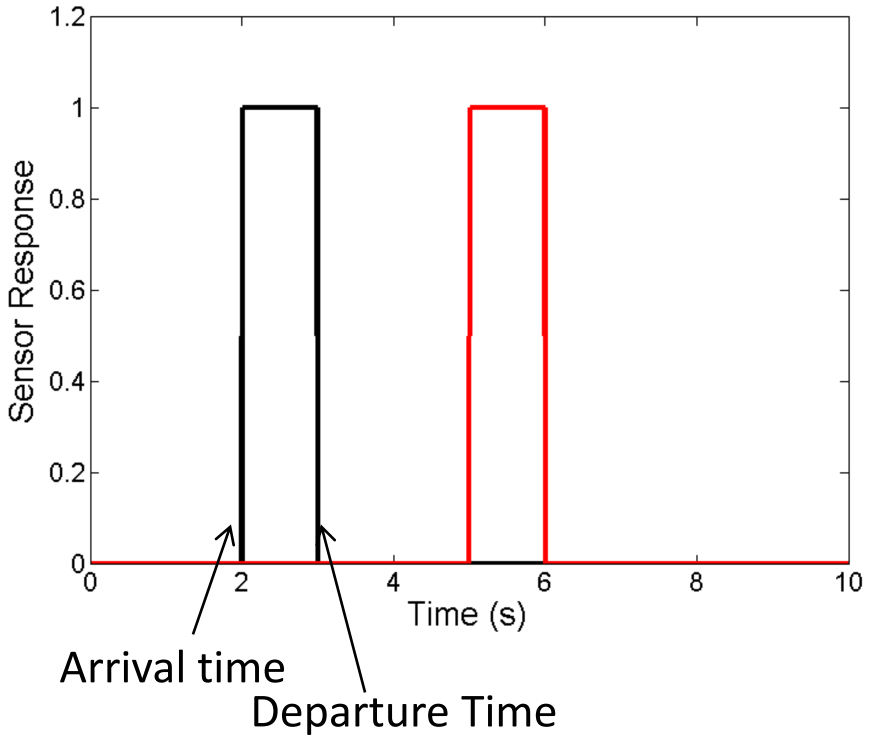




Magnetometers

$$v = \frac{\Delta x}{\Delta t}$$





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

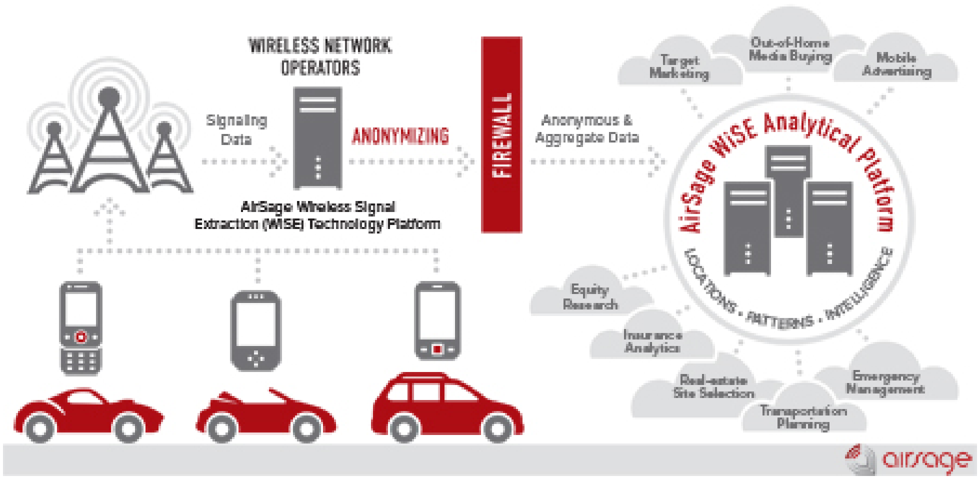
GPS/Cell tower

- 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

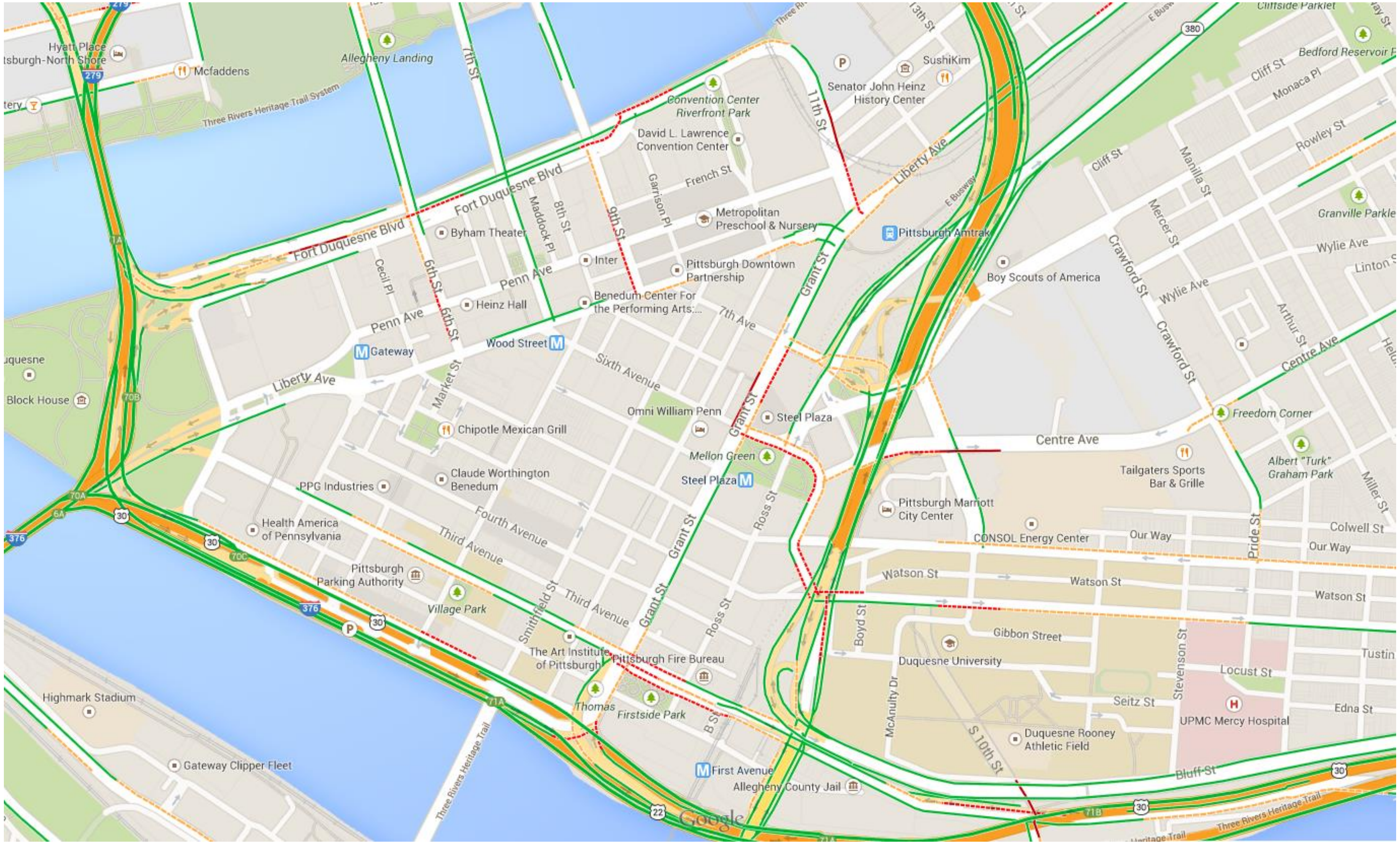
AS LONG AS A MOBILE PHONE IS ACTIVE on the cellular network, AirSage receives wireless signals and uses them to anonymously determine location. With AirSage's carrier and partner relationships, we have nationwide coverage – more than any other location-based services (LBS) provider.

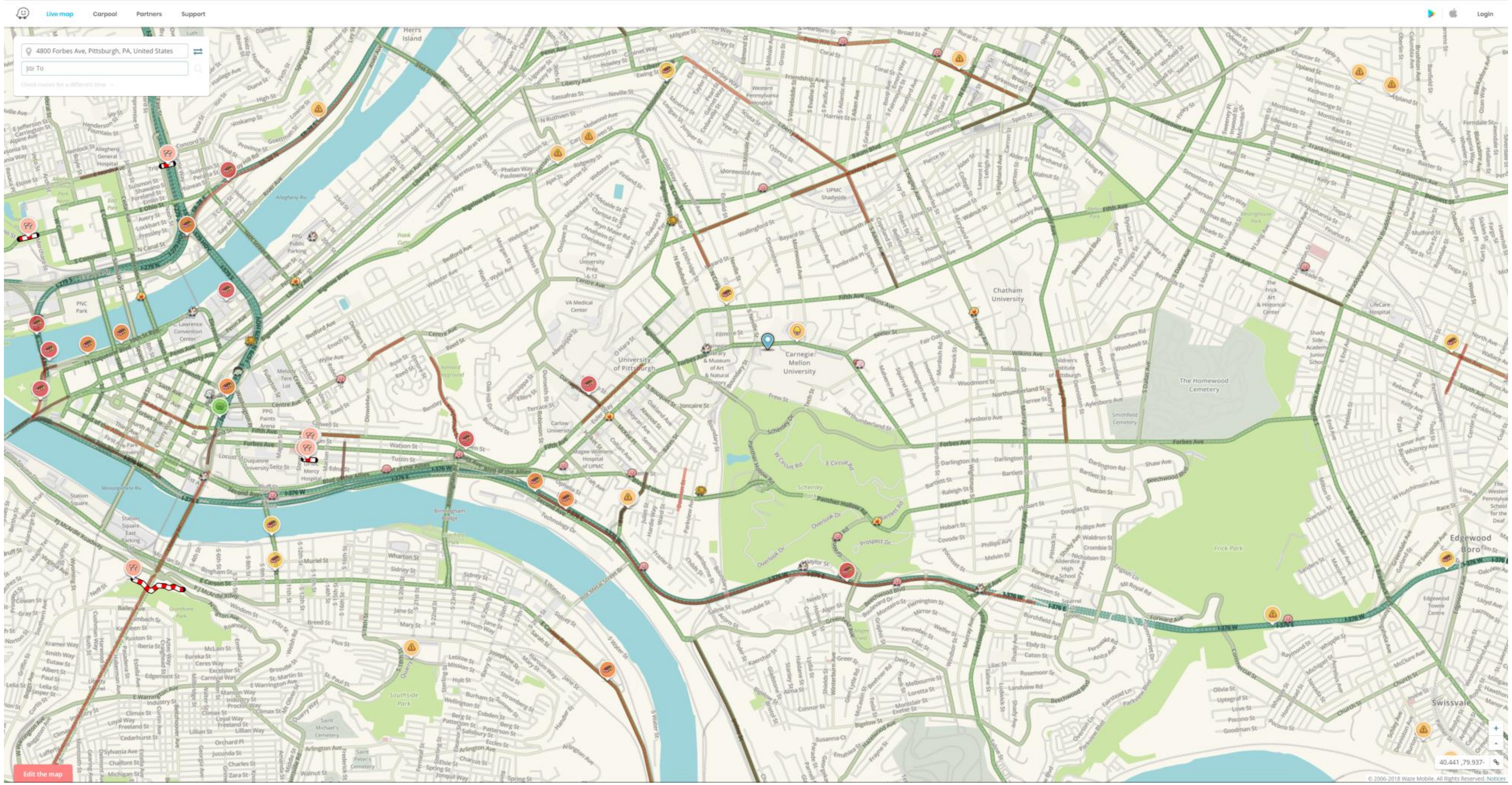


Click image to enlarge

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




Live map
Carpool
Partners
Support
Login
4800 Forbes Ave, Pittsburgh, PA, United States
To
Carnegie Mellon University
University of Pittsburgh
Chatham University
The Homewood Cemetery
Frick Park
Edgewood Boro
Swissvale
Herrs Island
PNC Park
PPG Paints Arena
Forbes Ave
Fifth Ave
I-376 W
I-376 E
Edit the map
40.441 ,79.937-
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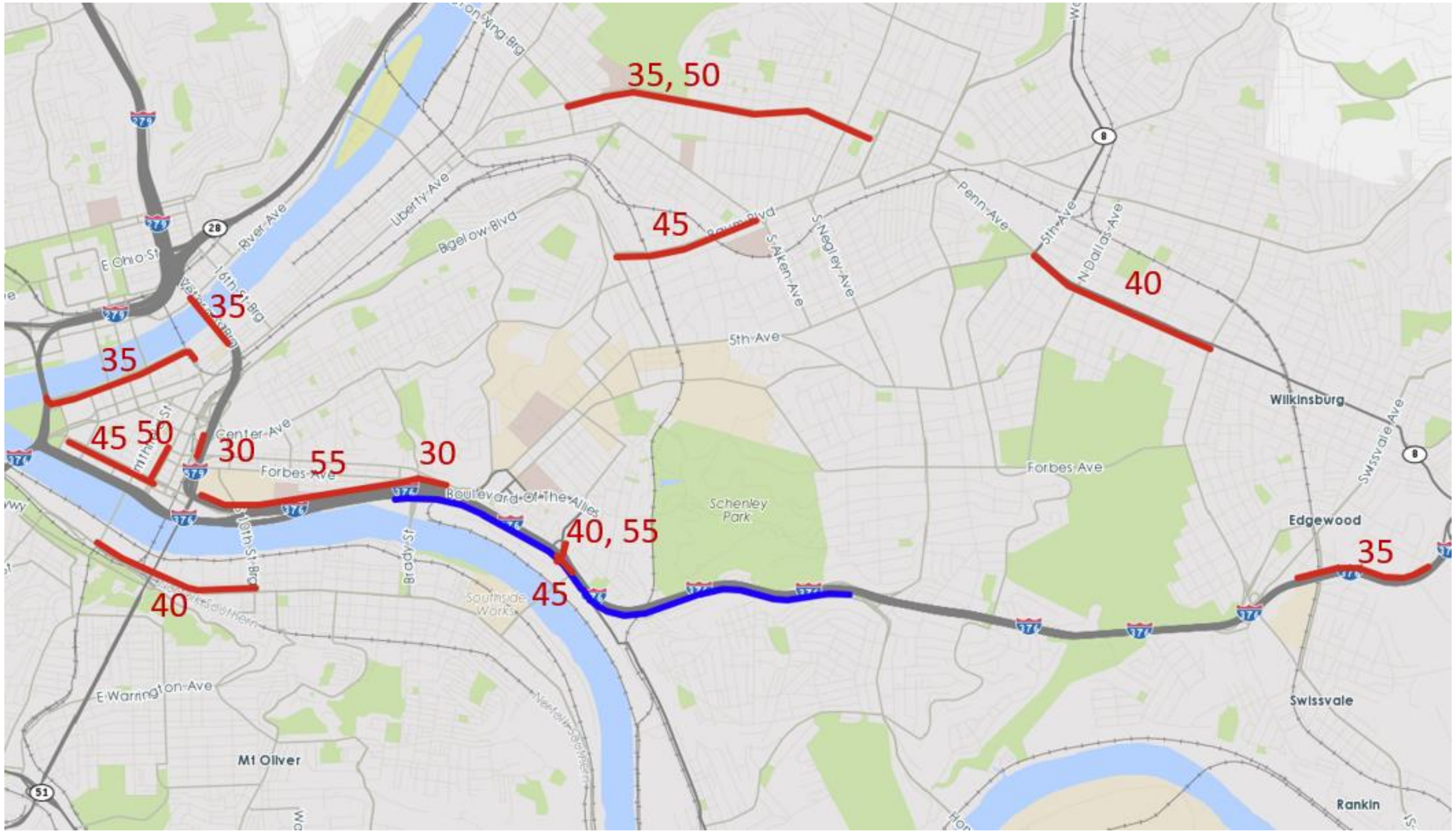
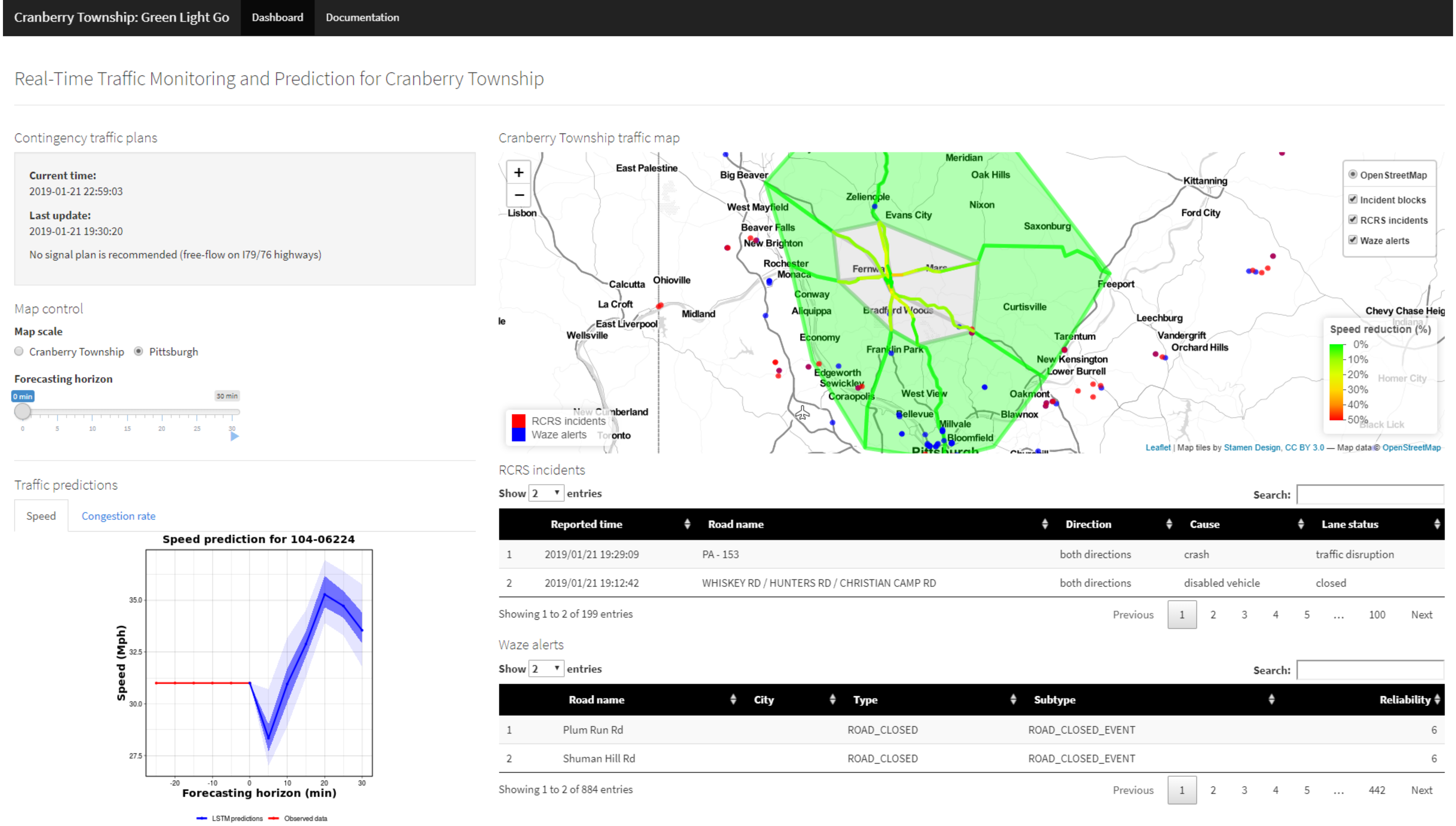
Now what? Some use cases

Travel time prediction and reliability analysis

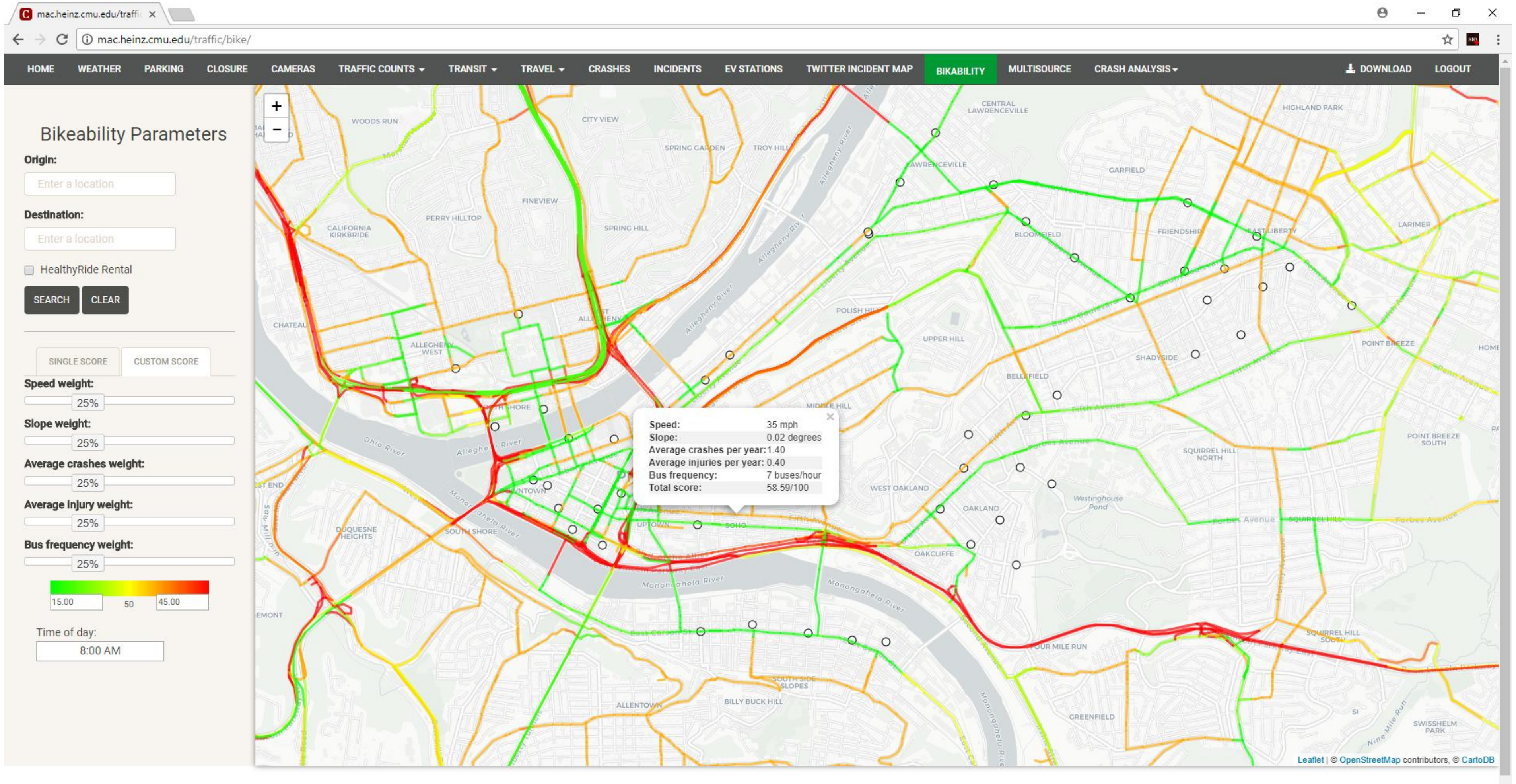
- What causes/relates to day-to-day and within-day travel time variation?
  - INRIX/HERE
  - Counts
  - Weather
  - Incidents
  - Events
  - All in high spatial and temporal resolutions (5-min, lat/log)

Bottlenecks

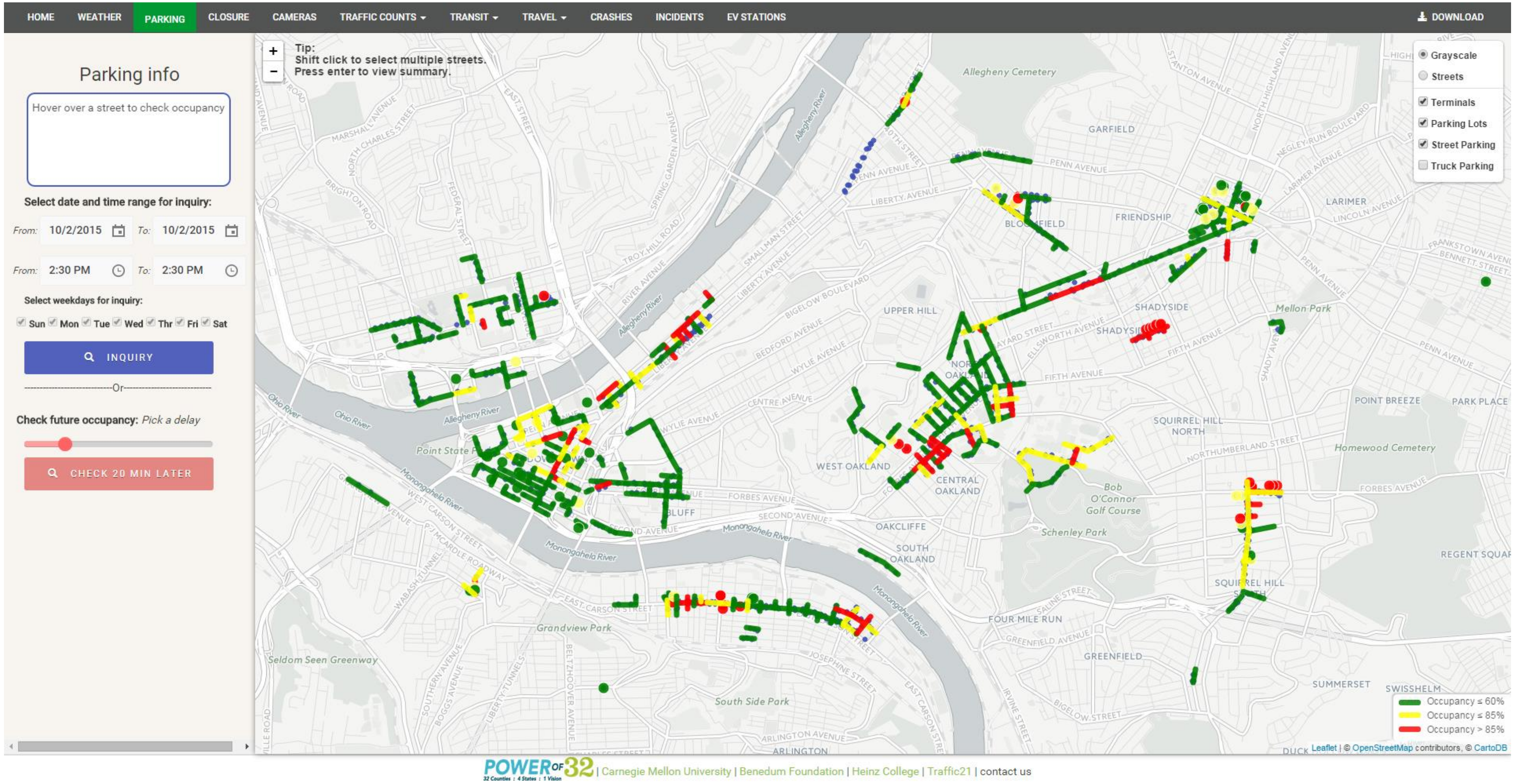



Cranberry Township: Green Light Go
Dashboard
Documentation
Real-Time Traffic Monitoring and Prediction for Cranberry Township
Contingency traffic plans
Current time:
2019-01-21 22:59:03
Last update:
2019-01-21 19:30:20
No signal plan is recommended (free-flow on I79/76 highways)
Map control
Map scale
Cranberry Township
Pittsburgh
Forecasting horizon
0 min
30 min
Traffic predictions
Speed
Congestion rate
Speed prediction for 104-06224
Speed (Mph)
Forecasting horizon (min)
LSTM predictions
Observed data
Cranberry Township traffic map
OpenStreetMap
Incident blocks
RCRS incidents
Waze alerts
Speed reduction (%)
0%
10%
20%
30%
40%
50%
RCRS incidents
Waze alerts
Leaflet | Map tiles by Stamen Design, CC BY 3.0 — Map data © OpenStreetMap
RCRS incidents
Show 2 entries
Search:
Reported time
Road name
Direction
Cause
Lane status
1
2019/01/21 19:29:09
PA - 153
both directions
crash
traffic disruption
2
2019/01/21 19:12:42
WHISKEY RD / HUNTERS RD / CHRISTIAN CAMP RD
both directions
disabled vehicle
closed
Showing 1 to 2 of 199 entries
Previous 1 2 3 4 5 … 100 Next
Waze alerts
Show 2 entries
Search:
Road name
City
Type
Subtype
Reliability
1
Plum Run Rd
ROAD_CLOSED
ROAD_CLOSED_EVENT
6
2
Shuman Hill Rd
ROAD_CLOSED
ROAD_CLOSED_EVENT
6
Showing 1 to 2 of 884 entries
Previous 1 2 3 4 5 … 442 Next

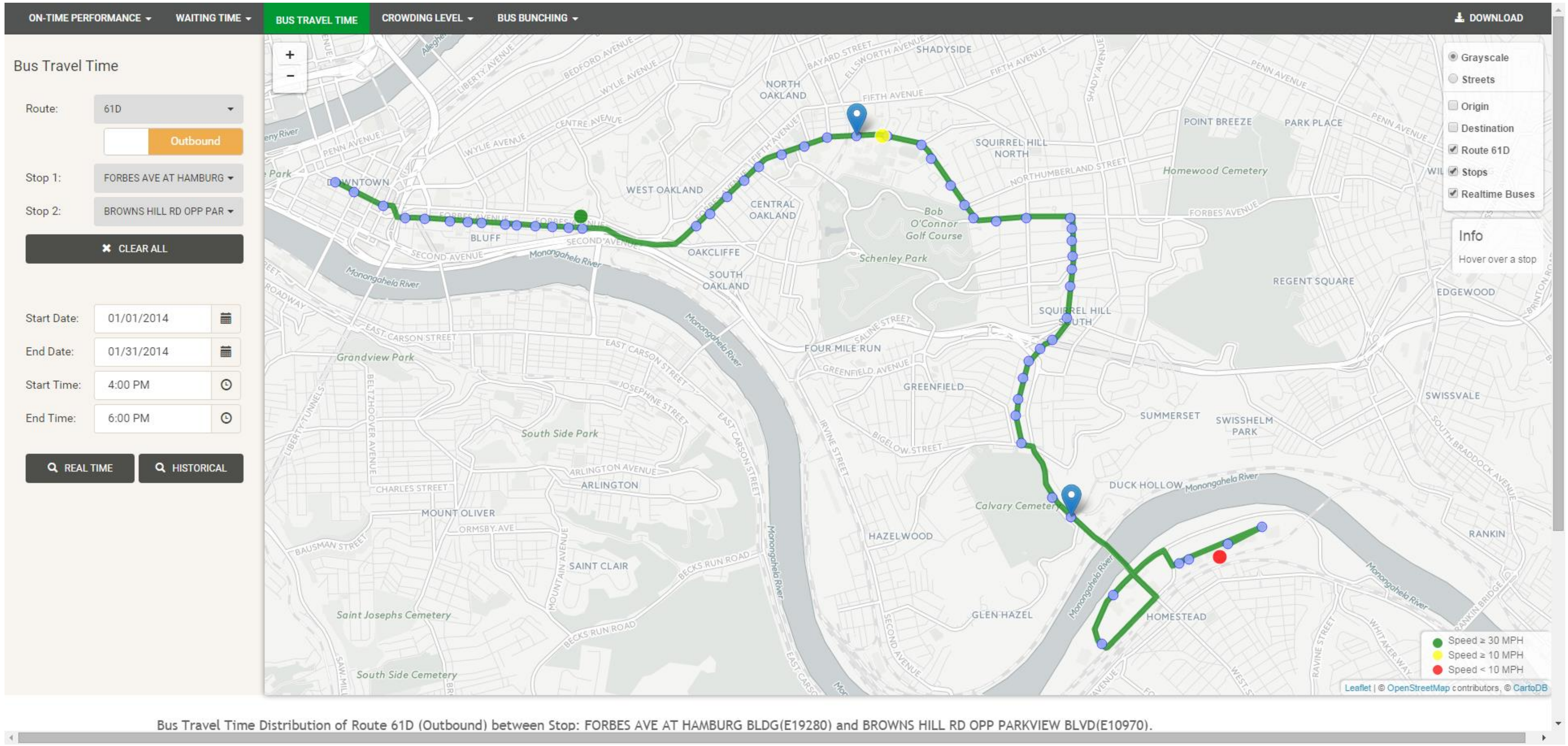
Bikability score

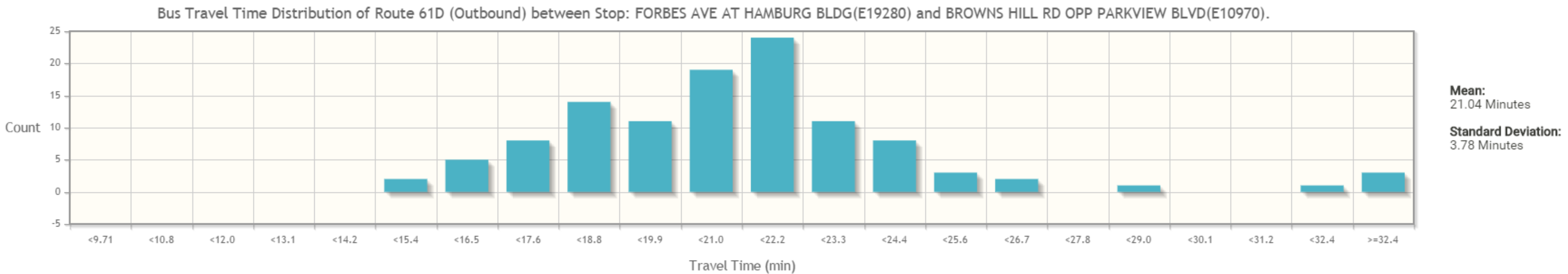


Pittsburgh Public Parking

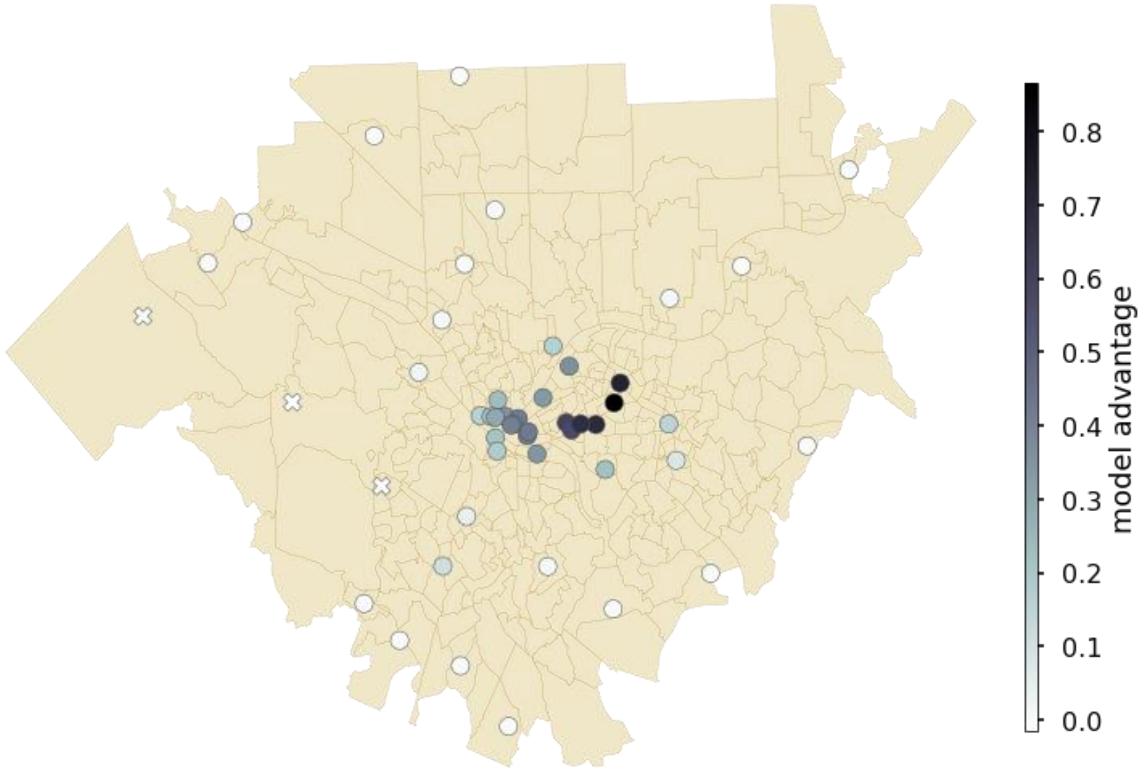


Pittsburgh transit system



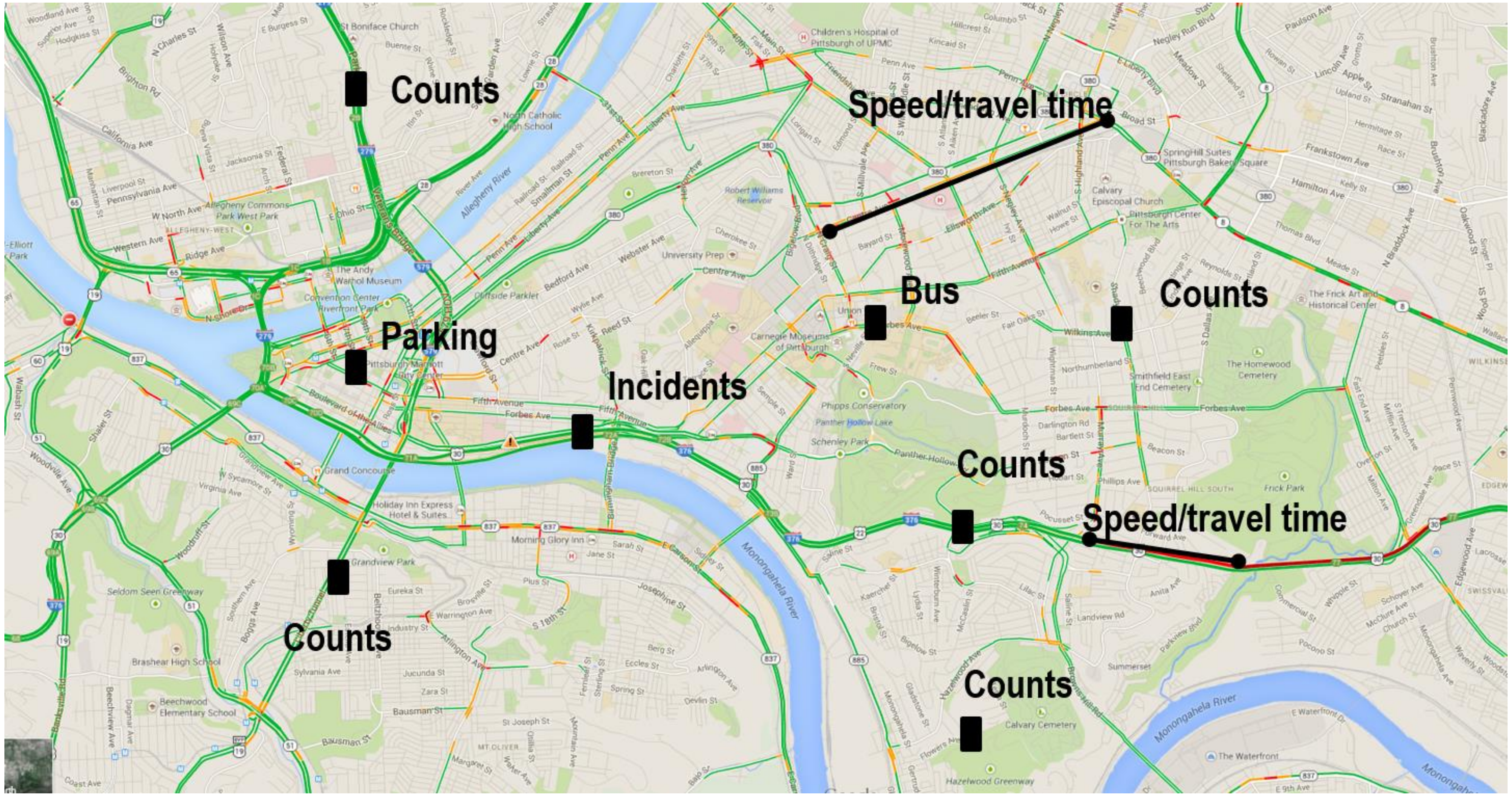


Surge pricing prediction

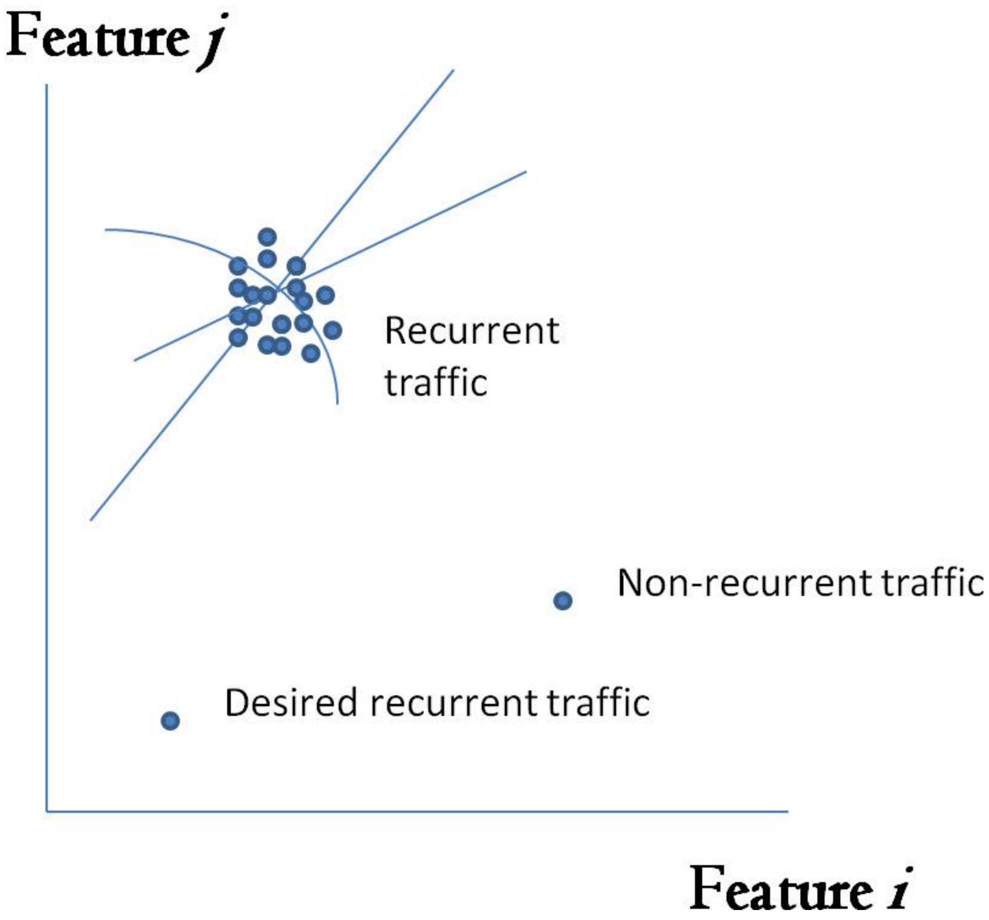


Issues of ML applications in transportation

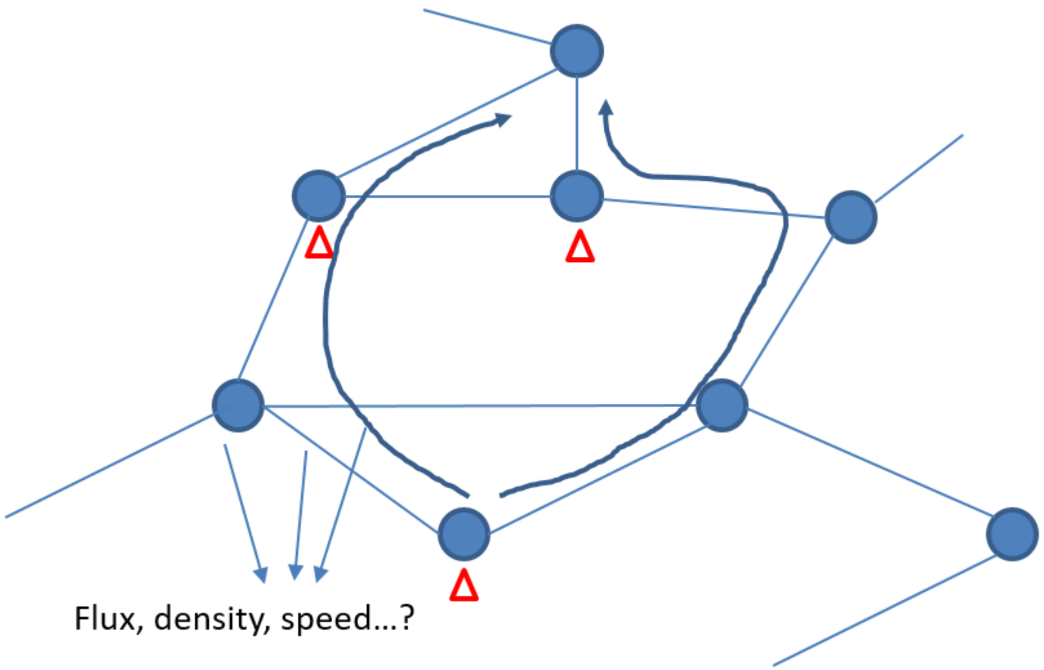
- Fusion. Bias. Sparsity. Computation. Unexplored space.



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 $(x, f, c) = G(\text{supply}, \text{demand})$

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)

	Statewide mainlines	City streets	Multi-modal	Data sharing	Data learning and forecast	Transportation system management
PeMS	×			×		×
RITIS	×	×		×		×
DriveNet	×			×		×
511PA	×					×
Google Map	×	×	×			
MAC	×	×	×	×	×	×

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