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Map Matching and Real World Integrated Sensor Data Warehousing



www.nrel.gov/tsdc
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NREL–Real World Vehicle Drive Cycle Database

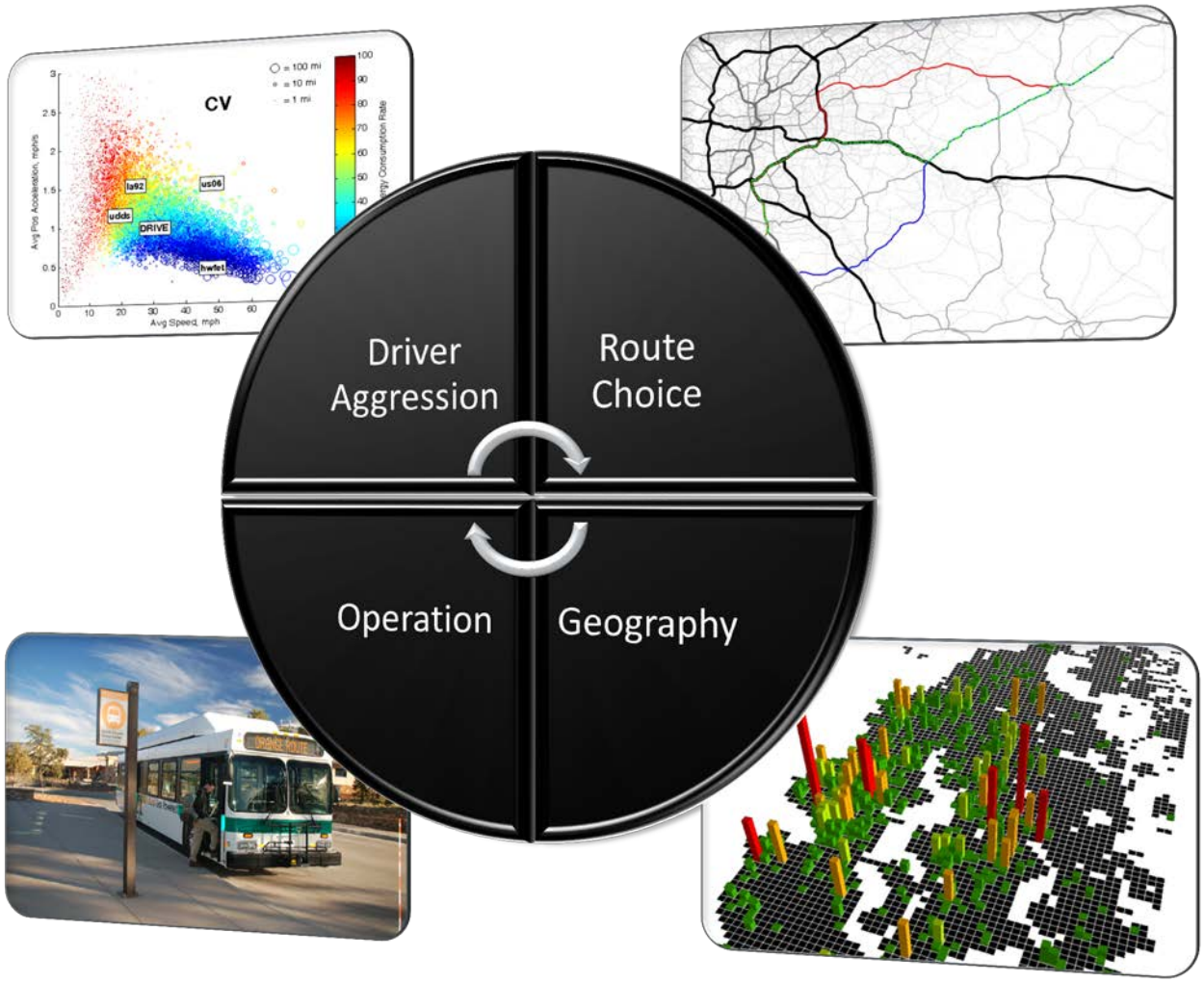
Quantifies otherwise overlooked variables in vehicle analysis.

Map matching sensor data appends additional variables at second-by-second increments :

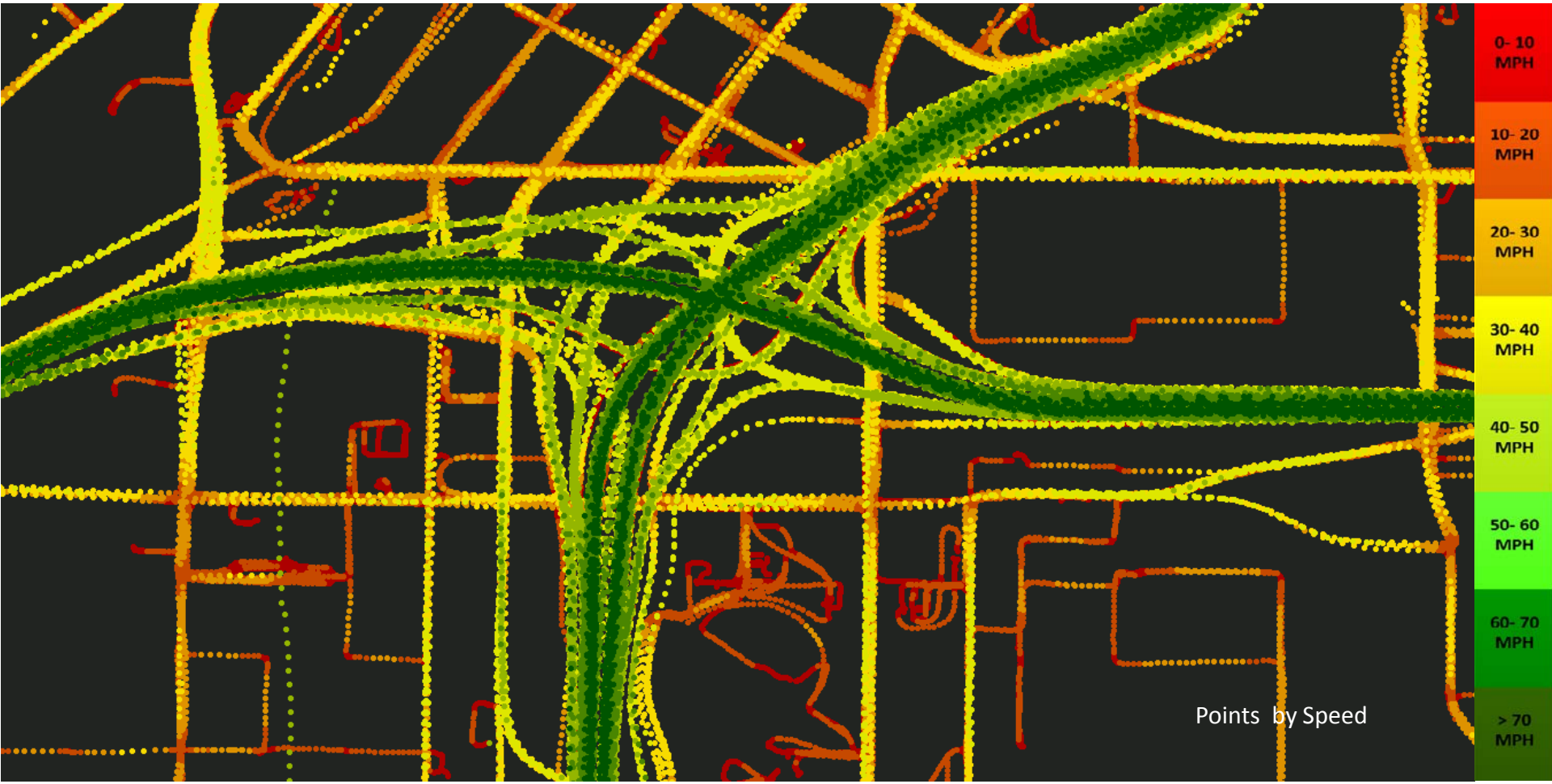
- Allows for scalability of analysis
- Incorporates route choice and geography into results

Uses a significant sample group of both personal and commercial vehicles to provide a resource for engineers and researchers focusing on:

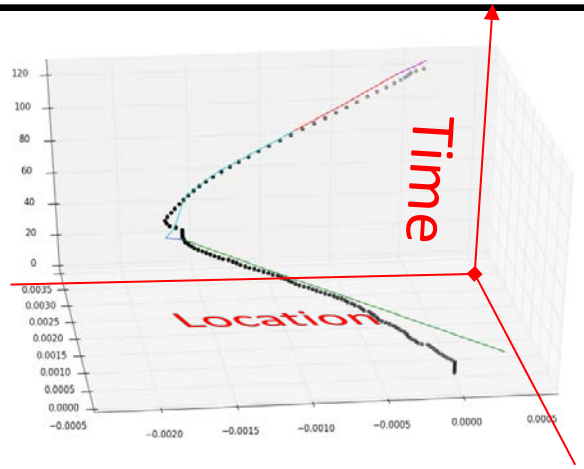
- Regional vehicle emissions modeling
- Alternative vehicle application identification
- Vehicle-to-grid electrification
- Regional transportation demand modeling
- Green routing
- Intelligent route-based control strategies for hybrid electric vehicles
- Long-term battery degradation analysis

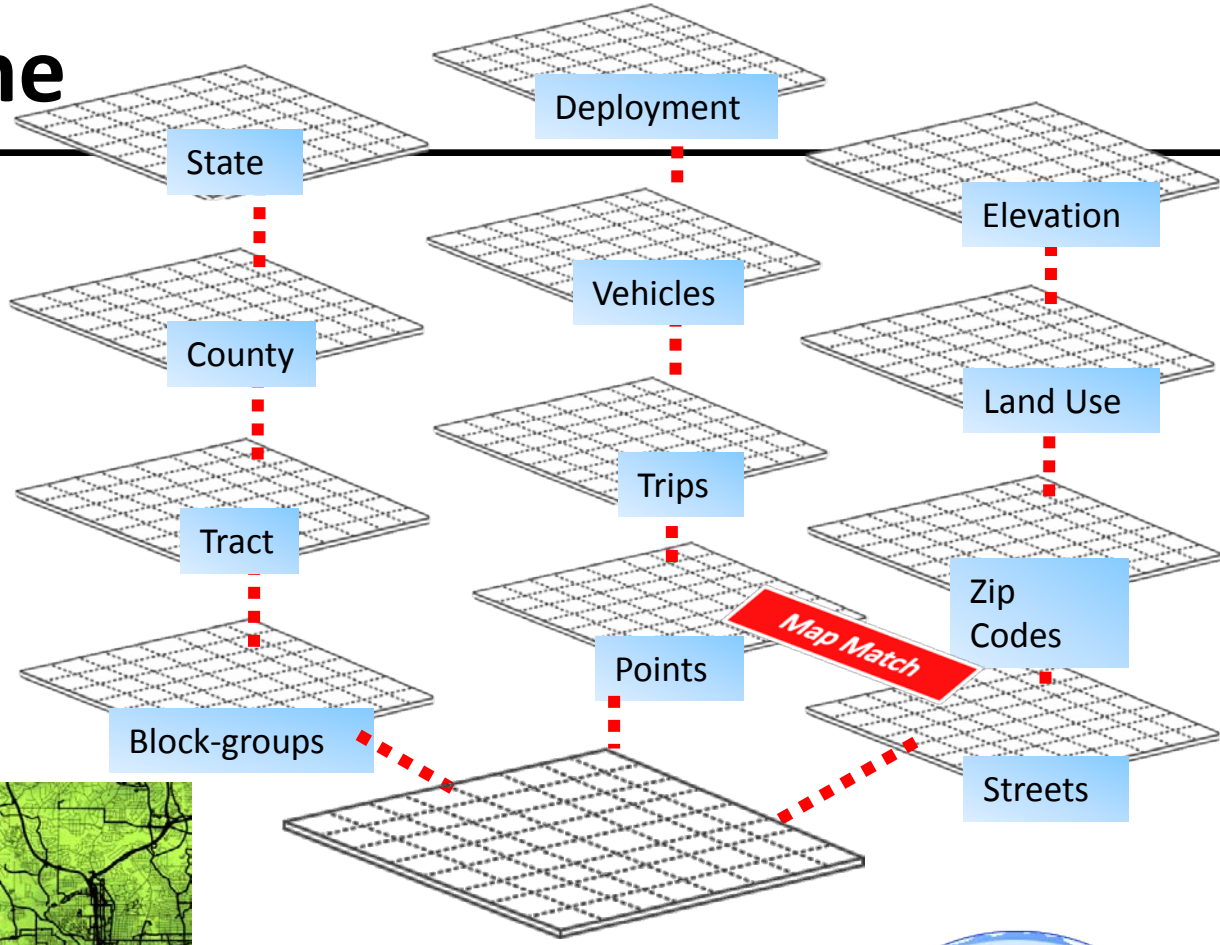


The Data – Location/Speed/Time



Location and Time





Spatial Reference Data:

- 2010 Census
- 2011 ACS
- USGS 1/3 DEM
- NAVTEQ Streets

- All data sets are linked using an XY coordinate system (Earth)
- Links established by passing primary keys through records
  - Trip 1 ended at tract 3
- Time provides the final link for moving objects
  - Vehicle 1 enters road 1 at time A and exits at time B

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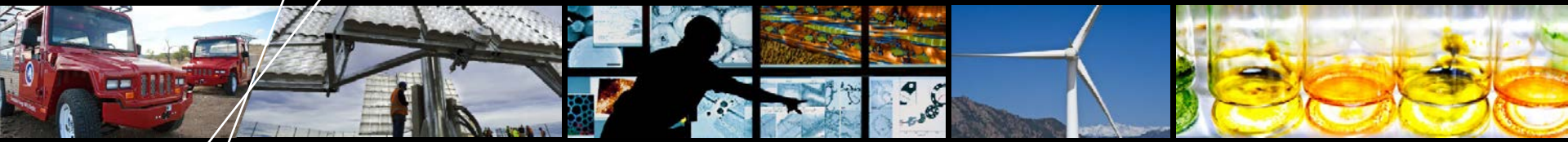


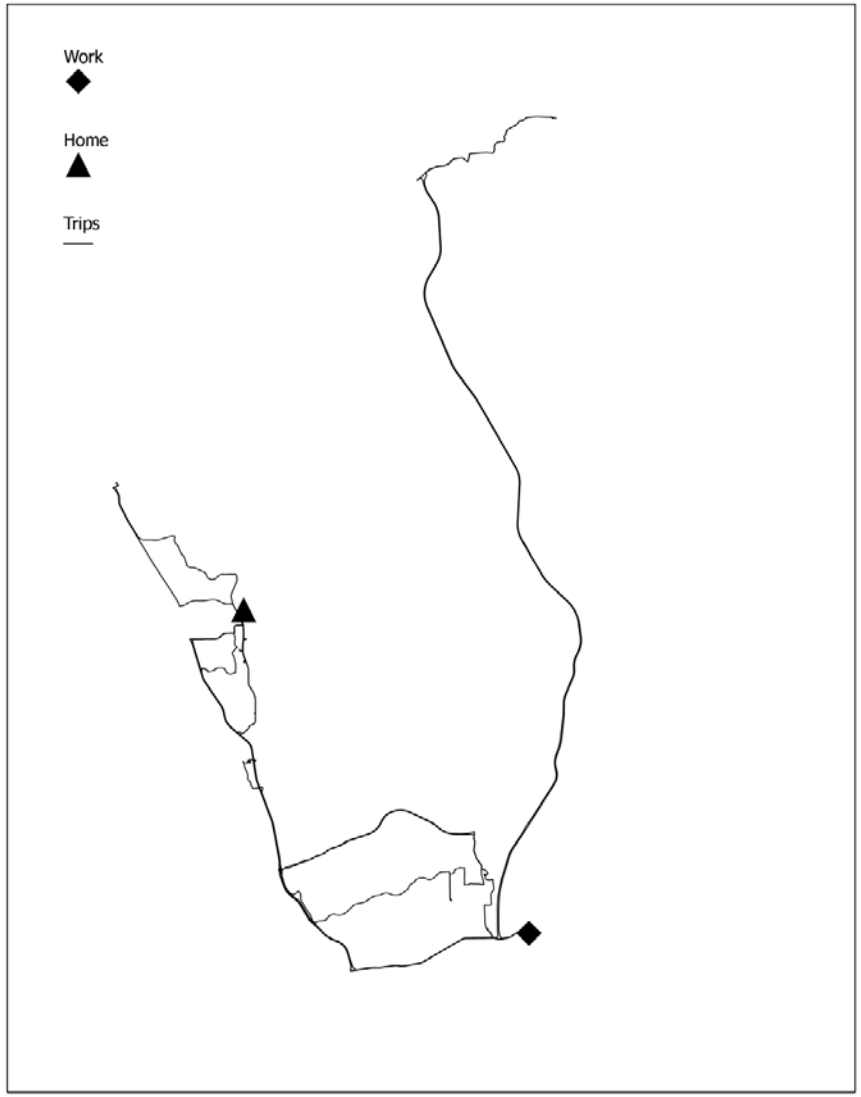
Map Matching

Vehicle Processing – End Product

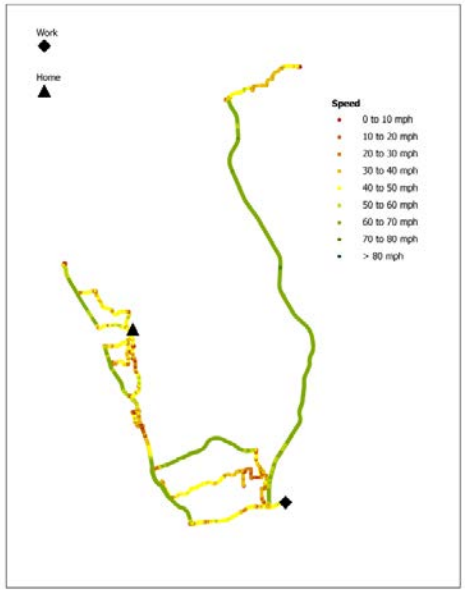
- **Second-by-second data are summarized at the trip level**
  - Trips are also categorized by end and start type (home/work/school)
- **Vehicle processing of the second-by-second data includes:**
  - Filtering the recorded data
  - Appending data from additional data layers to second-by-second data
- **Summary statistics are generated at the vehicle, day, and trip levels**
- **Trip classifiers are grouped to vehicle and day levels**

Vehicle Processing (Next Slide)

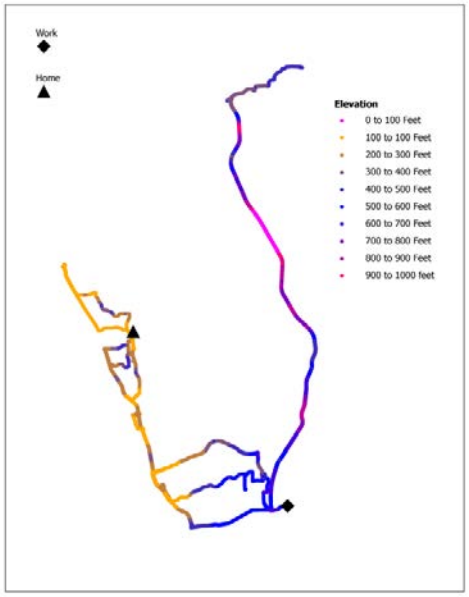
1. Speed – Filtered
2. Location – Filtered
3. Elevation – Appended
4. Grade – Appended
5. Street ID – Appended
6. Street Functional Class – Appended
7. Street Speed Category – Appended



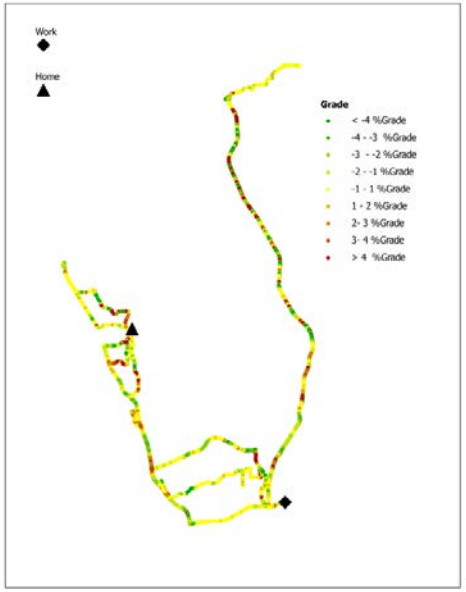
Vehicle Processing – End Product



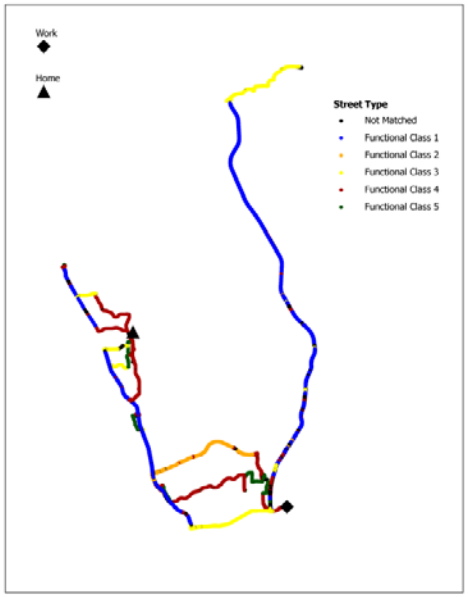
Speed – Filtered
Location – Filtered



Elevation – Appended



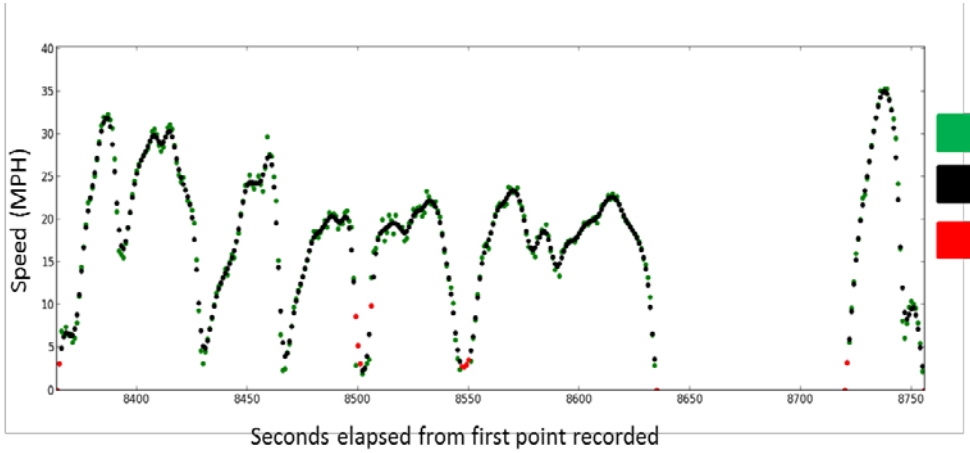
Grade – Appended



Street ID – Appended
Street Functional Class – Appended
Street Speed Category – Appended

Speed & Location Filters

1



Speed Filtration

- *Flags unrealistic speed*
- *Backfills missing points*
- *Interpolates missing and flagged data*

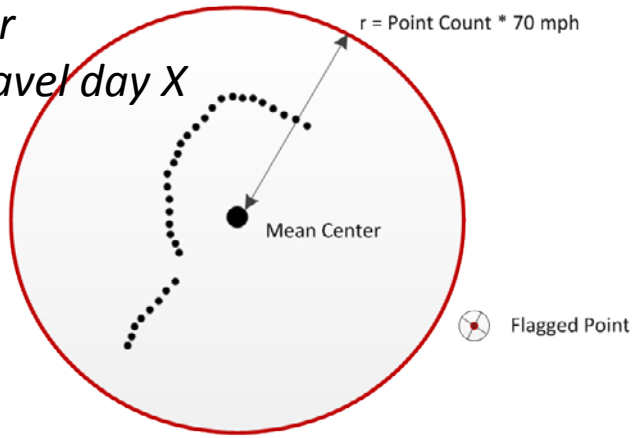
Severe outlier filter

- *Removes points falling outside a data defined buffer*
- *Radius = Hours of travel day X 70 mph*

2

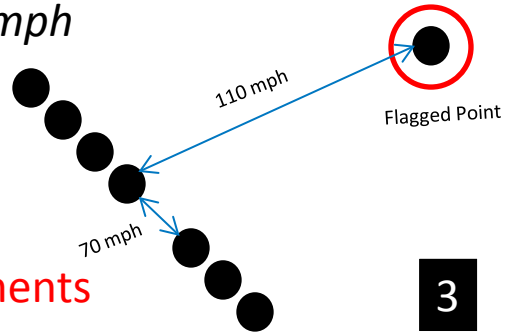
Mean Center

- *The mean latitude and longitude independently*



GPS Jumps Filter

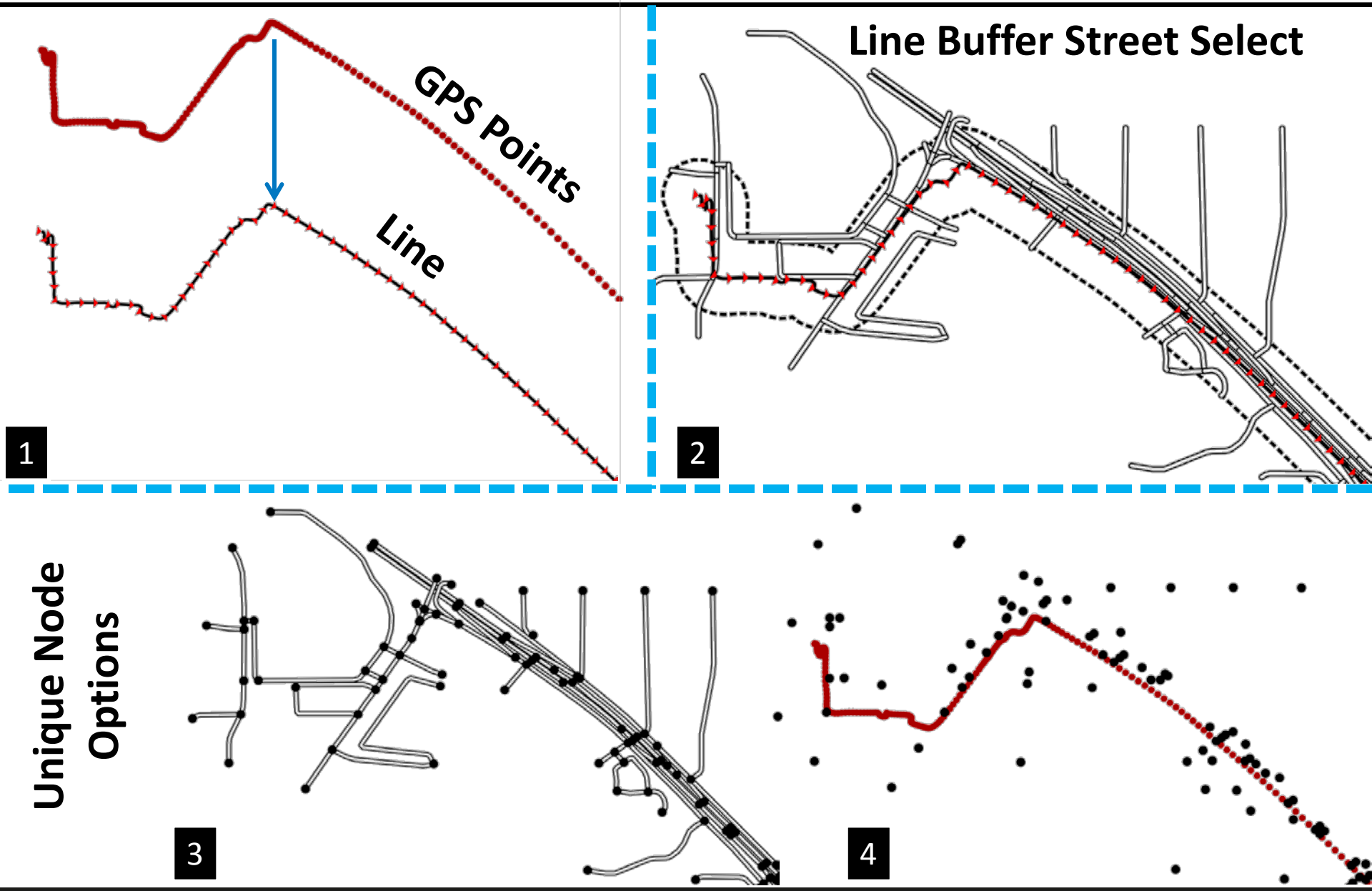
- *Calculates a rough speed value from distance and time*
- *Points where the calculated speed is > 100 mph are flagged until calculated speed falls under 100 mph*



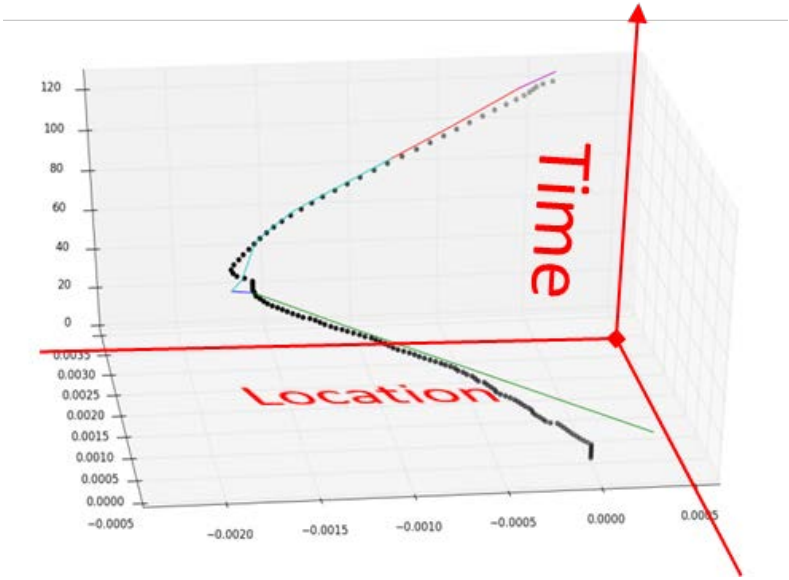
Typically less than 2% of GPS points require these processing adjustments

3

Map Matching: Dynamic Node Selection



Map Matching: Solve



Point-to-node links are established using time

- *Each point is linked to the nearest node within 500 feet of a road*
- *Link is established by appending the node identifier to the point data (time)*
- *Points are down sampled to a discrete time at which the vehicle passed the node*
- *Vehicle x passed this node at this second*

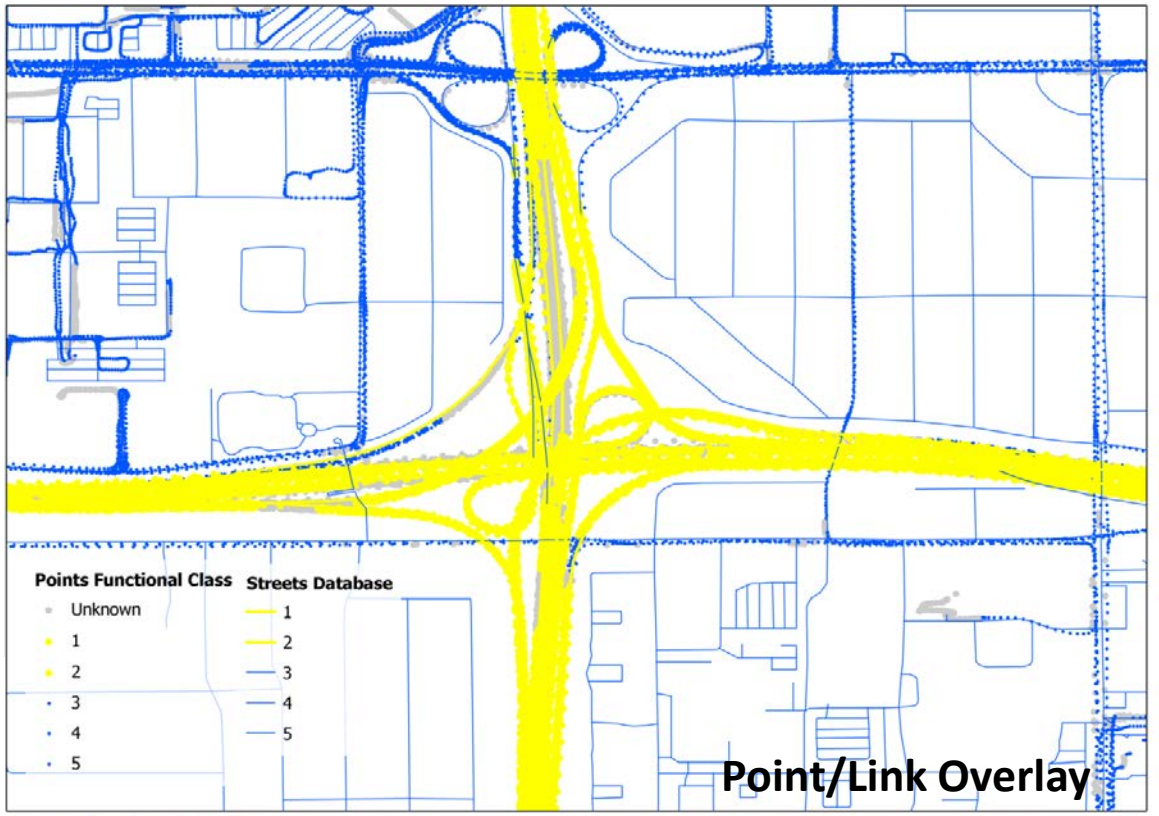
Solving connections logically (topology)

- *The segments connected to the node and the possible exit node options for each entry node are identified independent of previous or next known results*
- *Options are then tested logically in order using multi-step decision tree*
  - *Identifies and removes latent links*
  - *Fill gaps in connection of consecutive segment links*
- *Appends attributes from the linked street segment to the data points falling within the entry and exit time of the matched segment*

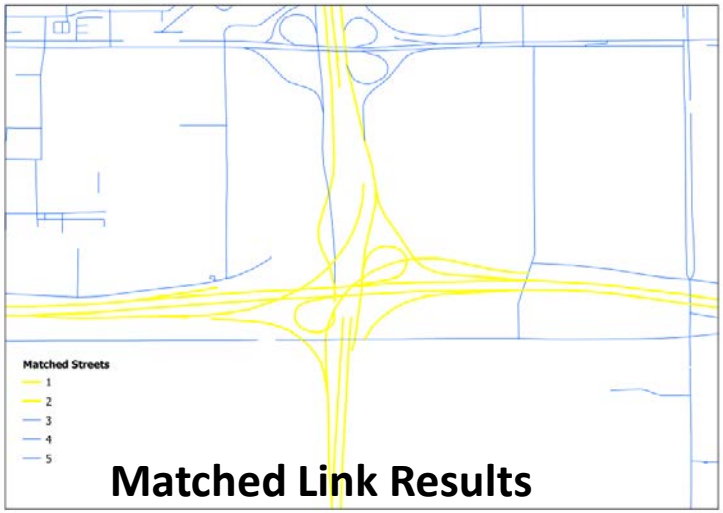
Map Matching: Accuracy

Complex overpasses

- *Connectivity can become ambiguous when so many options are available*
- *95% of distance matched across all data sets*
- *Cleaned up post processing during road based analysis*

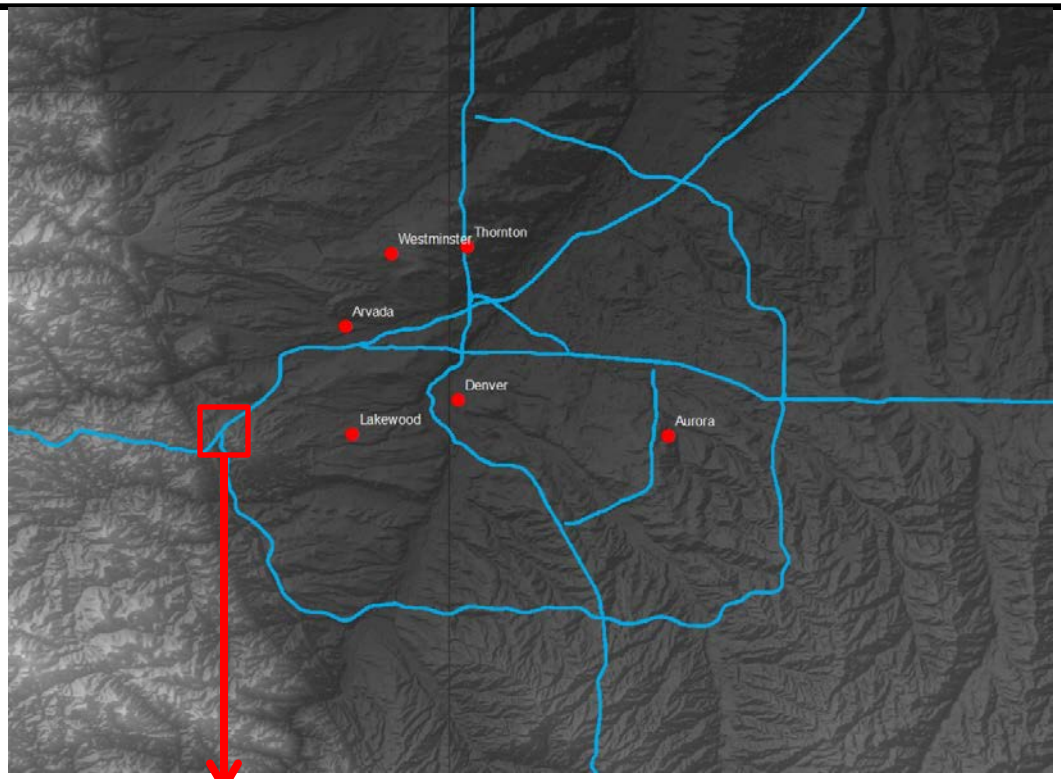


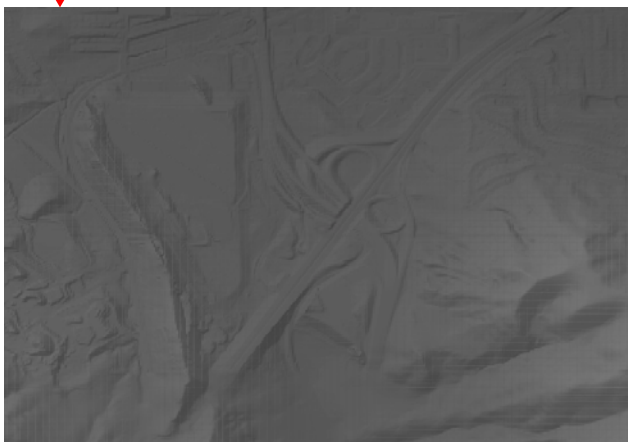
Point/Link Overlay

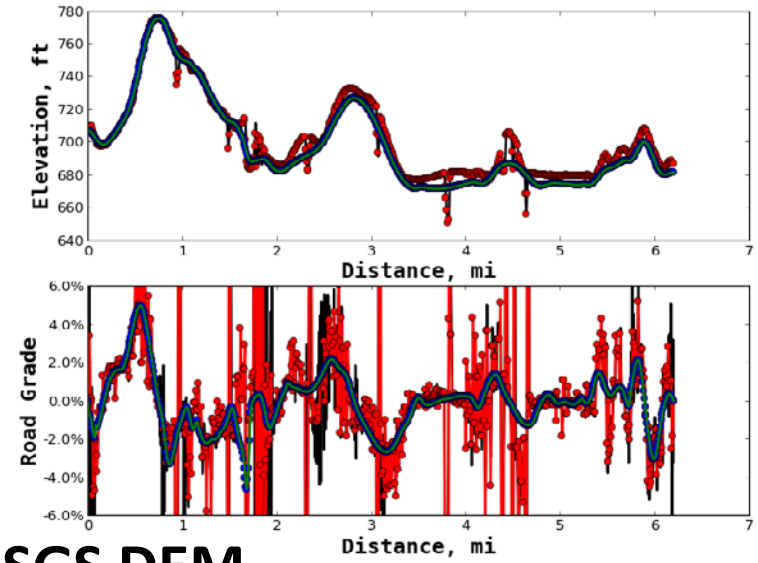


Matched Link Results

Elevation/Grade







USGS DEM

- *The elevation for each location recorded is looked up from the USGS Digital Elevation Model (DEM)*
- *The elevation profile returned is smoothed*
- *Down sampled to normalize for distance to calculate grade*
- The processing accuracy has been validated against roads with available ADAS grade measurements

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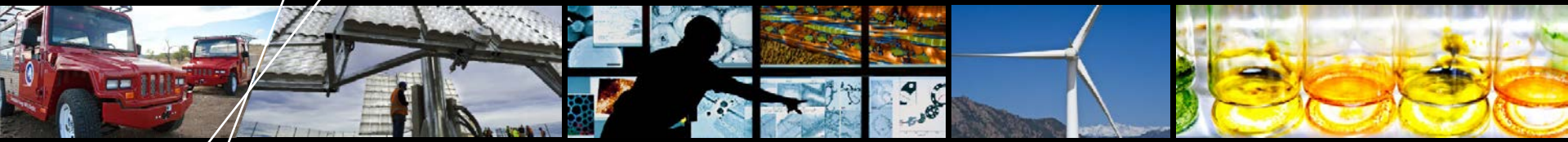
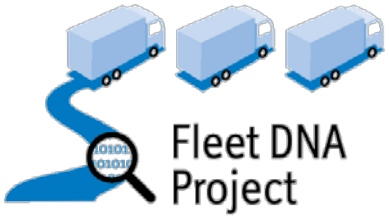


Integrated Sensor Data Warehousing

NREL - Real World Vehicle Data Warehousing

- **Fleet DNA – DOE**
  - Warehouses medium- and heavy-duty fleet vehicle operational data across vocations, drivetrains, fuel type, and vehicle types
    - Has the ability to crowd source data collection, allowing for large-scale comparative analysis
  - Removes identifying information and provides data to public for vehicle performance comparisons




Transportation Secure Data Center (TSDC)

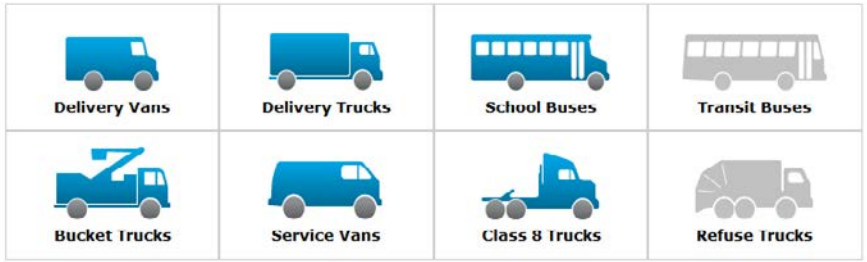
- **Transportation Secure Data Center (TSDC) – DOT and DOE**
  - Securely archives and provides public access to detailed regional transportation survey data
  - Speed/time/location data for personal vehicle samples

- **Reporting is specific to project using the same source data, but different ways of looking at it**
  - TSDC – Trip starts and ends are classified relative to the home, work, school location
  - Fleet DNA – Trip starts and ends are classified relative to the depot location

Geography: Sample Groupings

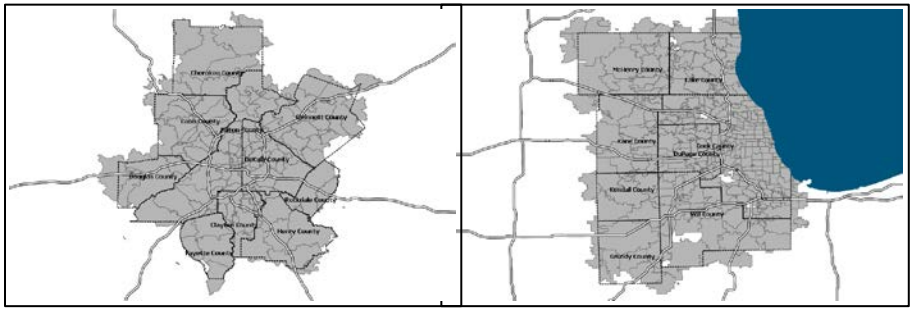
Fleet DNA categorizations (vehicle specs):

- *Make/Model/Year*
- Class
- Vocation
- Type
- Drivetrain
- Fuel Type
- City
- State



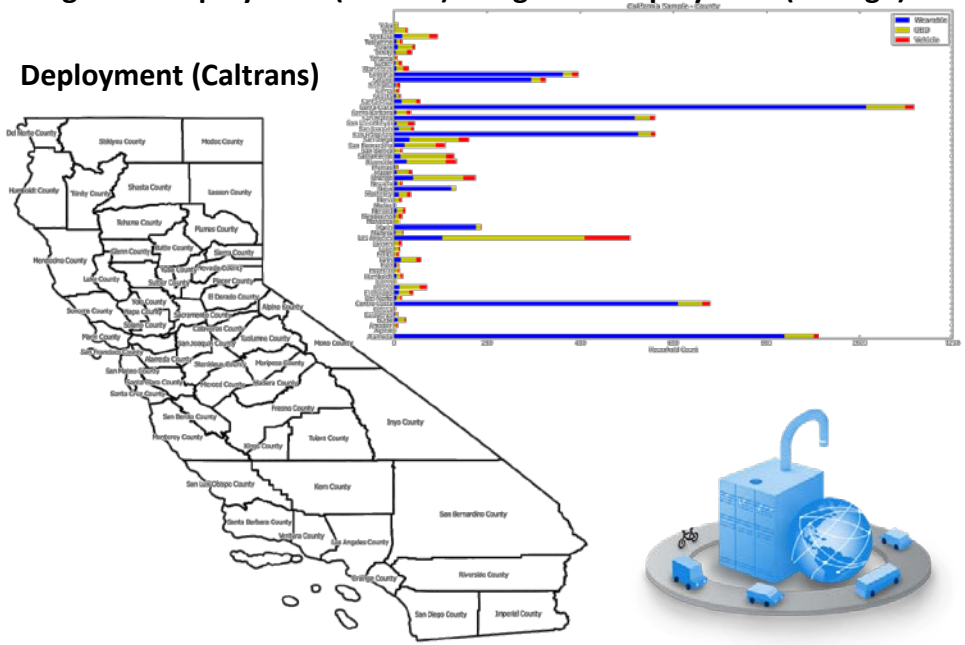
TSDC categorizations (geographic)

- Regions for data collection
- *Make/Model/Year*



Region of Deployment (Atlanta) Region of Deployment (Chicago)

Deployment (Caltrans)



Privacy & Data Security

- **Both TSDC and Fleet DNA data sets contain extreme detail regarding the travel of the vehicles**
  - Vehicles equipped with GPS sensors require certain precautions to be taken to ensure privacy and data security
- **Each public distribution portal has specific controls in place**

Fleet DNA	TSDC – Public	TSDC – Controlled
• *Reports and downloads are grouped by vocation* • *Allows comparative analysis between deployments* • *Deployments can be identified within the data through an identifier, but the lookup is not made available* • *NREL processing is applied to the vehicle GPS samples, and 360+vehicle travel statistics are provided by vocation*	• Personally Identifying information is removed from source data • Spatial reference identifying any geographic identification below the census tract is removed • Vehicle model is removed • Original study data are provided for download • NREL processing is applied to the vehicle GPS samples, and 360+vehicle travel statistics are provided by vehicle	• Following a approval process, researchers gain access to the full TSDC data sets through a virtual desktop (VM – Virtual Machine) • An NREL administrator acts as the gatekeeper for all data in and out of the environment • Users can work within NREL's databases within the VM using software provided • Data may only be removed by the NREL administrator

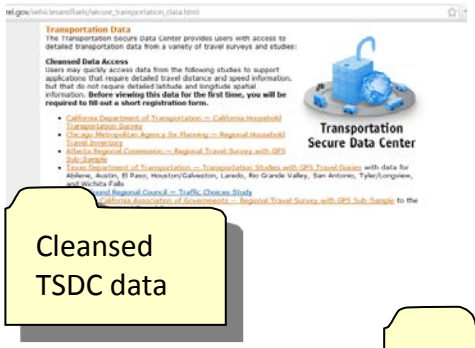
Fleet DNA Project

Transportation Secure Data Center (TSDC)

Data Center Infrastructure

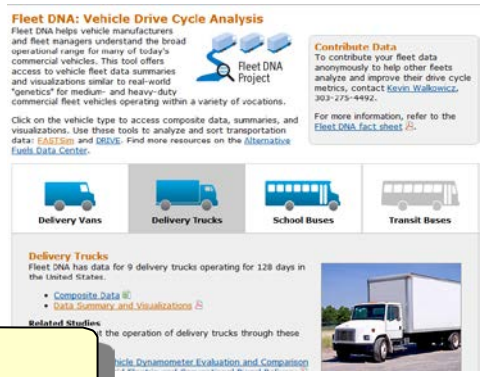
Data Center Servers

TSDC Website



Cleansed TSDC data

Fleet DNA Website



NREL Firewall

TSDC Virtual Machines

Processing Server

Visualization and Reporting Server

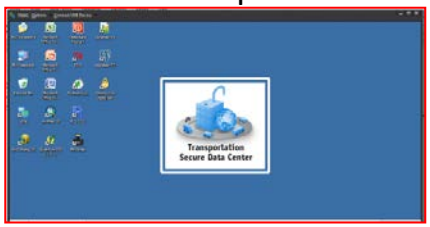
Data Server

Secure Connection

File sharing over secure network

Secure file transfer

Virtual Desktop User's PC



VM Server

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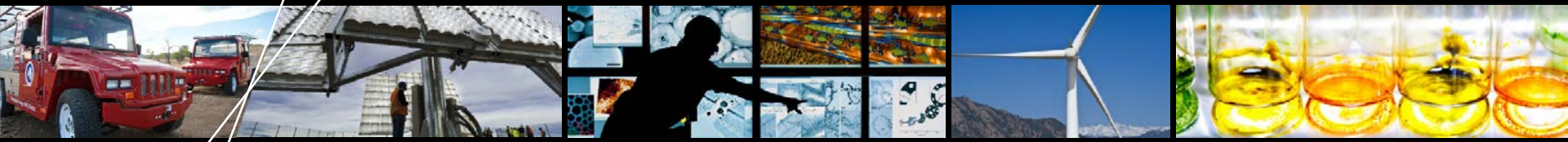


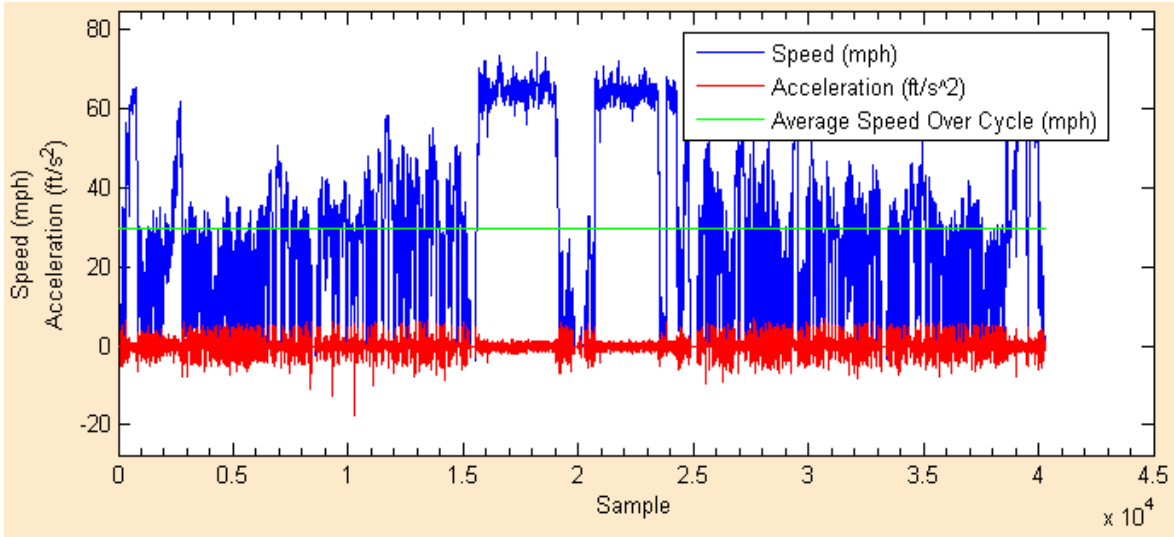
Analysis Examples

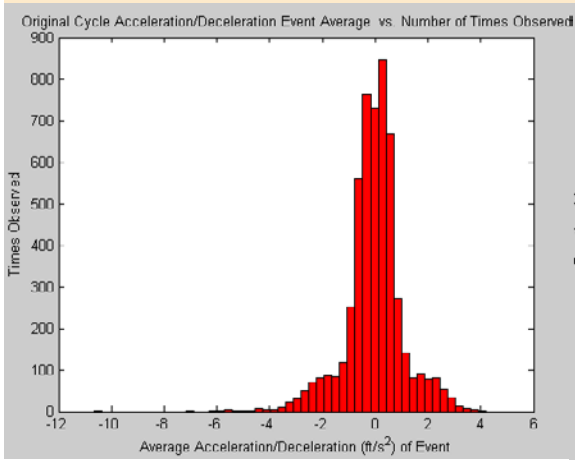
Vehicle Drive Cycle Characterization

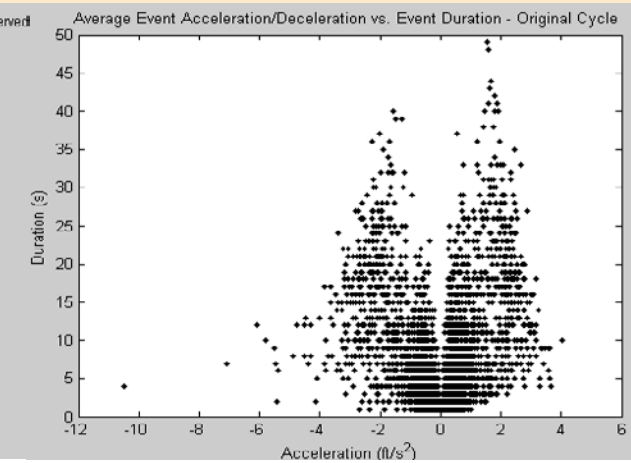
Analysis Level: Vehicle

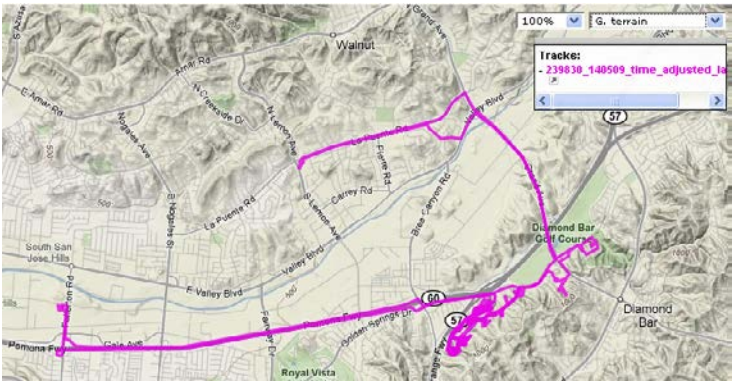
Drive Cycle Visualization

- Generate graphs of speed vs. time to observe vehicle operation
- Display histograms of useful statistics such as acceleration for analysis of performance envelopes
- Output latitude and longitude data for route visualization and mapping to ensure route/data consistency







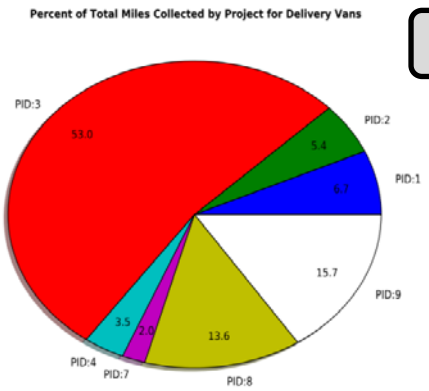


Fleet Drive Cycle Characterization

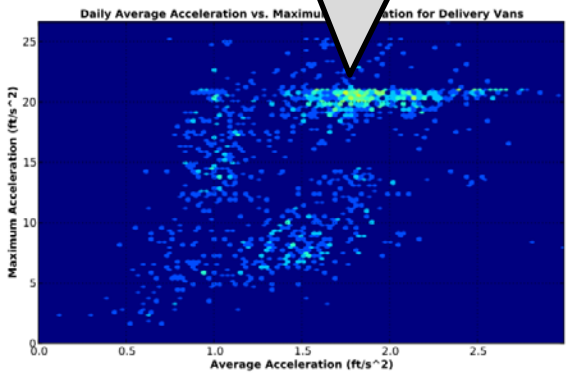
Analysis Level: Deployment

Delivery Van Vocational Database:

- Class 3–6 delivery van vehicles
  - Parcel, Linen, Food and Product vocations
- 92 unique vehicles-
  - Two conventional fuels (diesel/gas)
  - Four hybrid configurations (PHEV, GHEV, HEV, HHV)
  - ~600 EVs to be added
- 1,282 individual operating days
- Over a dozen unique geographic operating locations

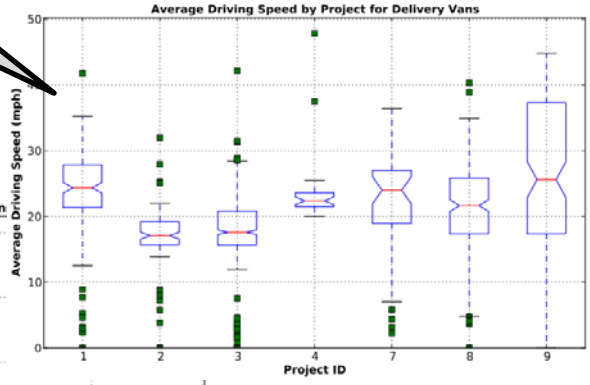


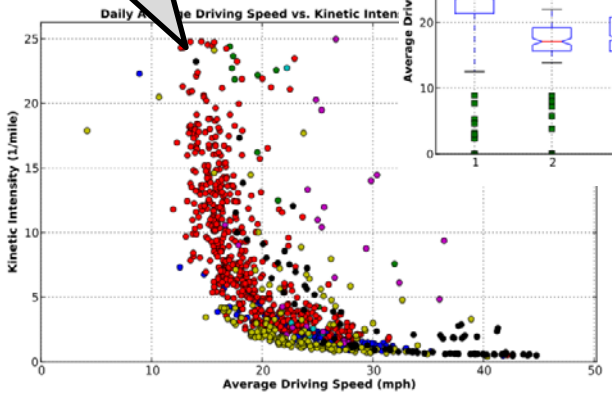
Common performance threshold



Wide range of operating speeds depending on location

Strong exponential relationship between speed and intensity





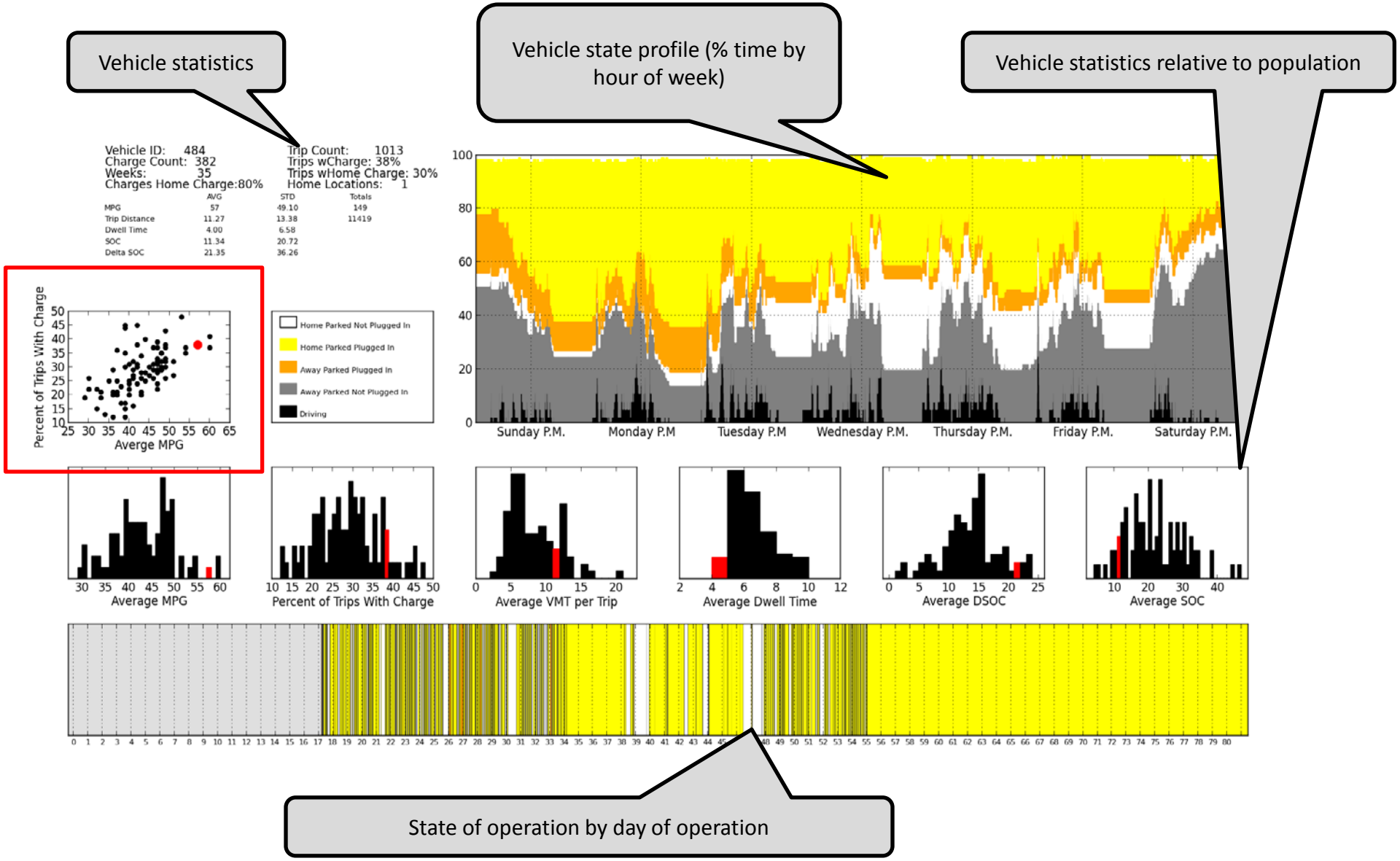
Charger Utilization: PHEV

Analysis Level: Vehicle relative to population

Vehicle statistics

Vehicle state profile (% time by hour of week)

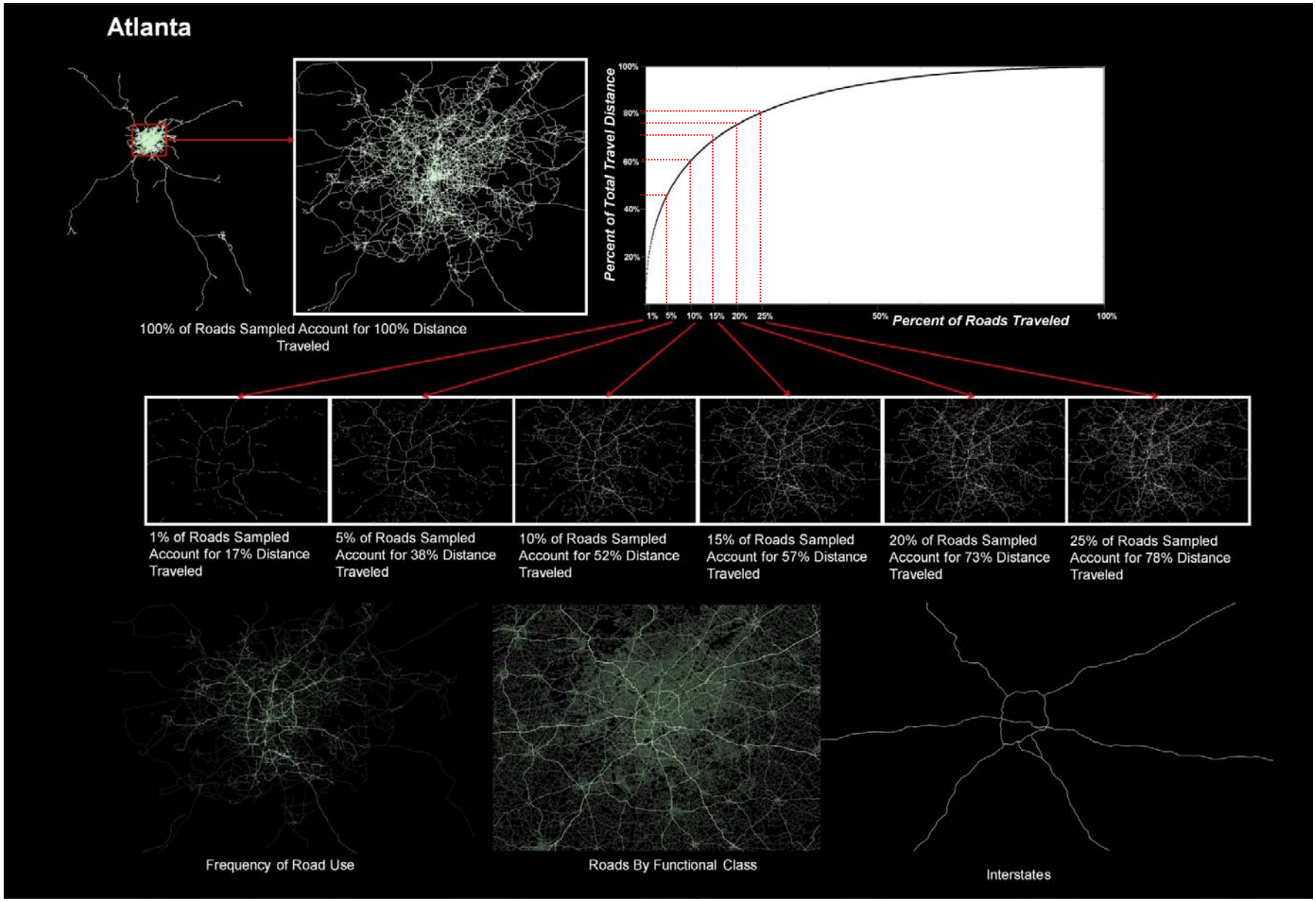
Vehicle statistics relative to population



State of operation by day of operation

Regional Road Usage

Analysis Level: Regional Infrastructure Utilization



Daily Road Utilization

Analysis Level: High resolution daily vehicle road use

Cumulative Daily distance vs. Distance on Functional Class

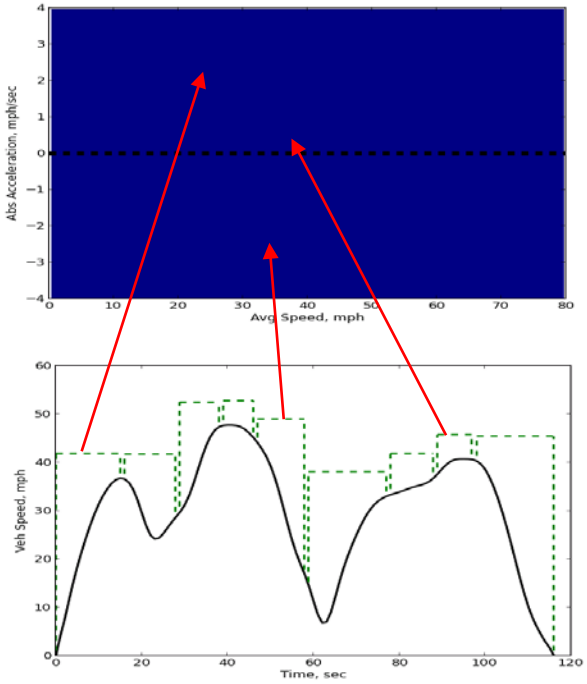
- *X axis is cumulative distance*
- *Y axis is cumulative distance functional class 1*

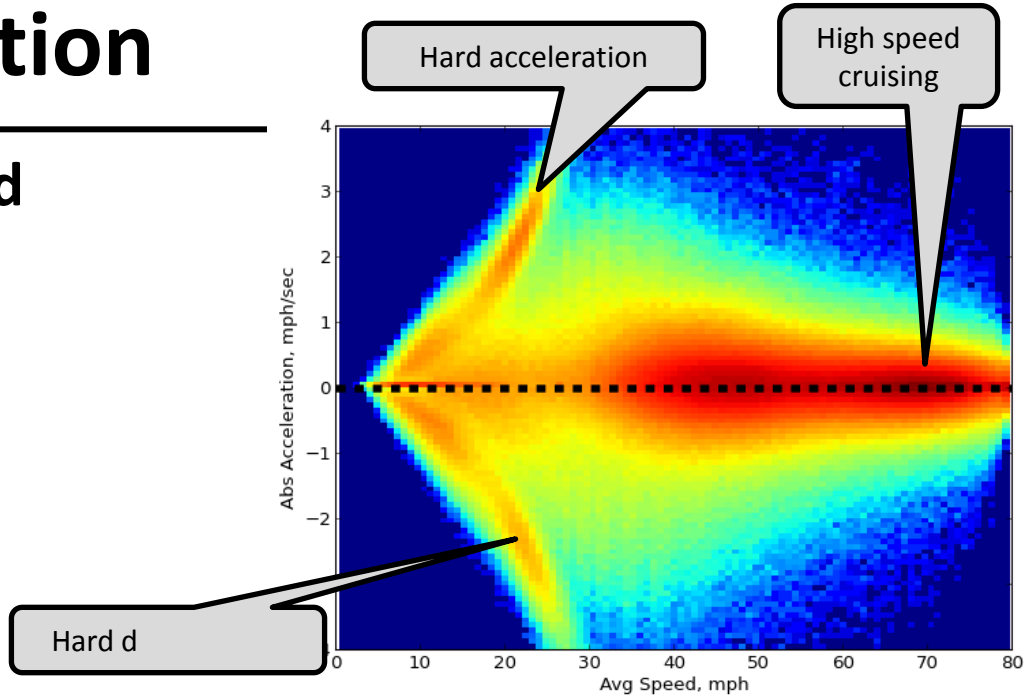
Vehicle Sub-sample Road Use

- *A small sample of vehicle days where the daily distance traveled exceeds 50 miles*

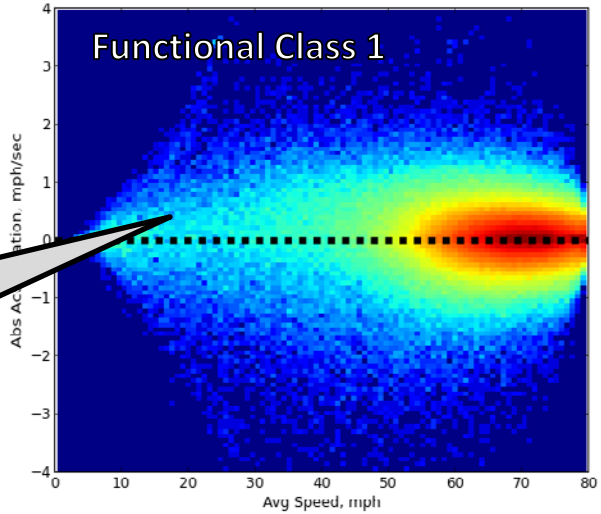
Drive Cycle Prediction

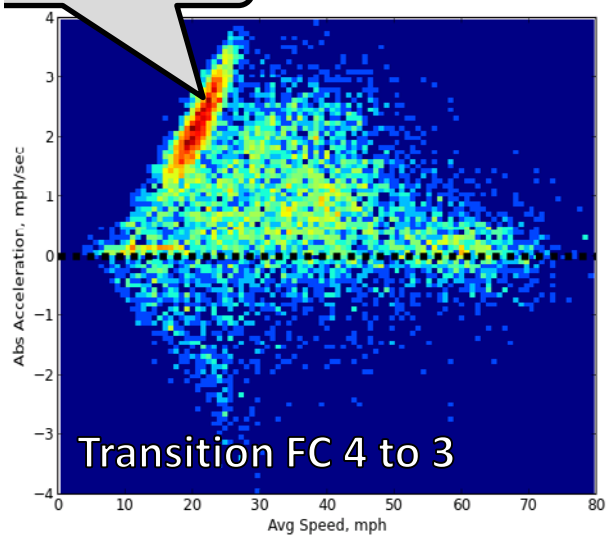
Analysis Level: Vehicles and infrastructure interaction





Near exclusive existence of data at positive acceleration

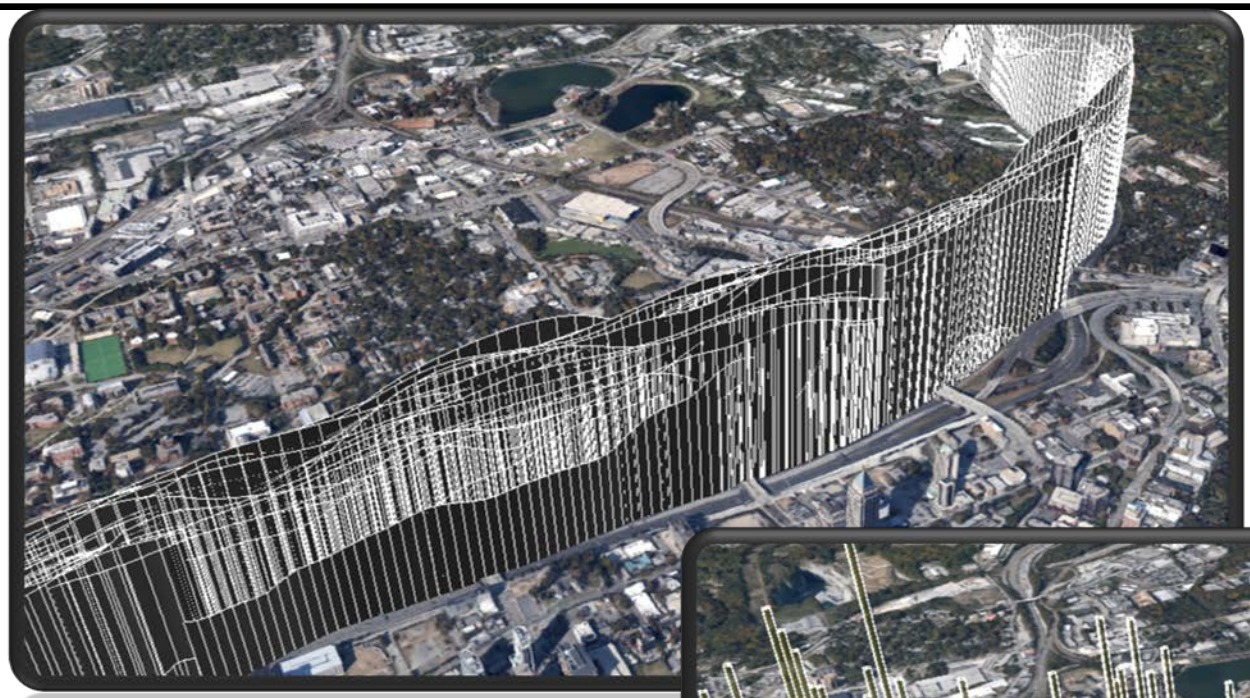




Low-speed data on FC1 assumed to be symptomatic of real-time road conditions (congestion, weather, etc.)

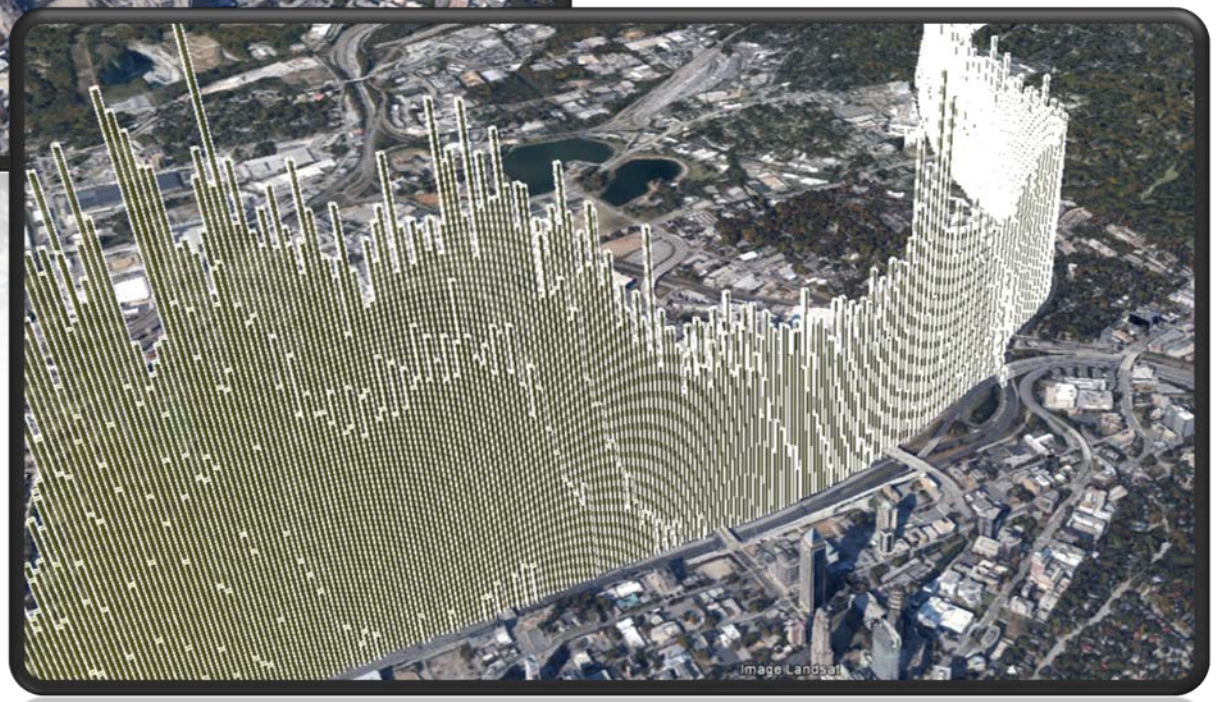
Road Use by Lane

Analysis Level: High resolution infrastructure utilization by time of day (5 a.m. to 10 a.m.)



Street Segments Driver Profiles

- *All point data collected for a grouping of roads ordered by trip visualized where speed is the z axis (left)*



Road Grid Segments Lane Summary

- *Road segment is divided into grid cells by lane*
- *Speed data are summarized by grid cell*
- *STDDEV of speed of travel by grid cell is visualized (right)*

Conclusion

- **By organizing sensitive, high-resolution data appropriately and linking the data to additional data sets using location and time, the quality and quantity of data available for researchers can be greatly improved while still maintaining restrictions placed upon the data**
- **Benefits**
  - Results in an infinite number of ways to group and sort the data for reporting
  - Increases the number of applications for the data, and the amount of data distributed without violating restrictions
- **Why never before?**
  - Location data are very restricted and have a high value, so very little data of this kind are available publicly
    - In-vehicle navigation systems utilize similar approach to analysis, but do not provide it publicly
  - Programming languages and databases now incorporate spatial analysis capability, providing free and open source tools with which to perform analysis