TOMORROW'S ENGINEER TODAY

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Naturalistic Drive Cycles Analysis and Synthesis for Pick-up Trucks

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CLEMSON UNIVERSITY

VirginiaTech Transportation Institute

Introduction to CU-ICAR

CU-ICAR
CLEMSON UNIVERSITY INTERNATIONAL CENTER FOR AUTOMOTIVE RESEARCH

Allison Transmission | BMW | BOSCH | CHRYSLER | DASSAULT SYSTEMES
DriveSafety | EZGO A Textron Company | ECODUAL | EPRI | GE
GM | GREENVILLE HOSPITAL SYSTEM UNIVERSITY MEDICAL CENTER | JOHN DEERE | MICHELIN | NHTSA
NSF | NEC | NIPPON STEEL | PROTERRA | ROGER C. PEACE REHABILITATION HOSPITAL
SEMA SPECIALTY EQUIPMENT MARKET ASSOCIATION | SimaFore | skypine | THIRD WAVE SYSTEMS | TIMKEN Where You Turn

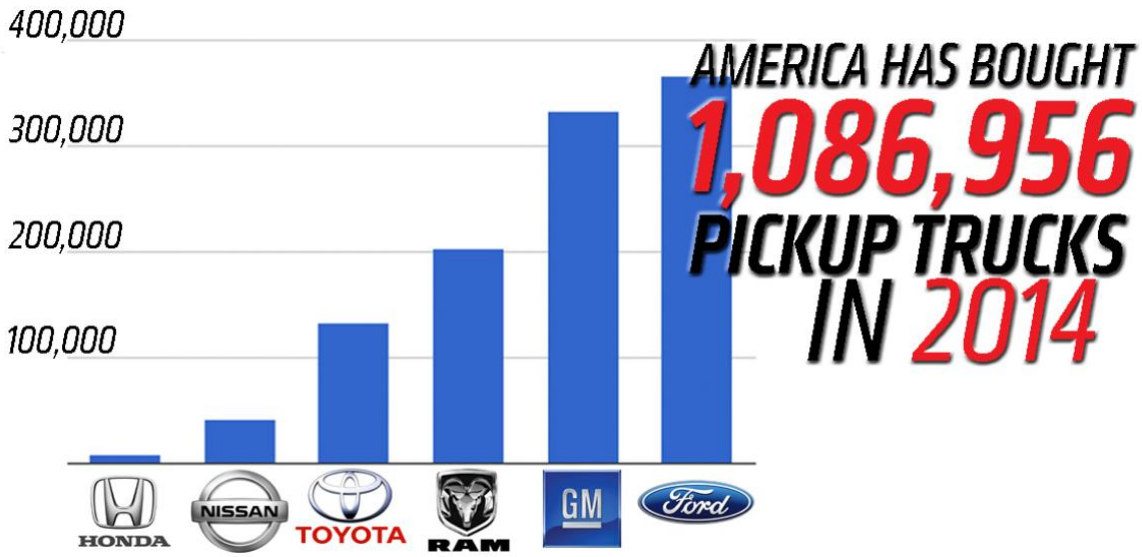
- **Greenville, South Carolina**
- **95%** of students gainfully employed in the Automotive Industry
- **Global** student representing **17** countries
- **183** total M.S. and PhD degrees awarded
- **7** Strategic Research Areas
- **4** Endowed Chairs in **4** key research areas

Pickups in America

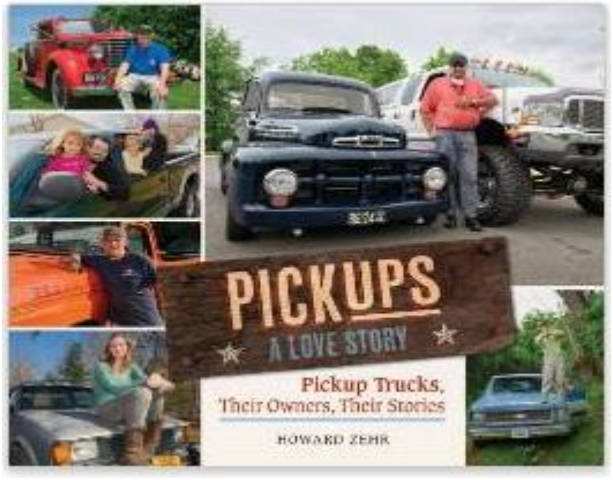
- **Top 2 best-selling light-duty vehicles in America in 2013:**
  Ford F-series and Chevrolet Silverado, combined sales over 1.2 million

A1: ***"90% of truck owners I have met have second jobs …… they may not do all of those things year round but you will be hard pressed to find someone that owns a truck and doesn't use it for it's utility ……"***

A2: ***"It is just a sense of patriotism: Americanization"***



Source: http://truckyeah.jalopnik.com/



You might like this book:
Zehr, Howard. *Pickups A Love Story*. Good Books, 2013. Print

Importance of Naturalistic Drive Cycles

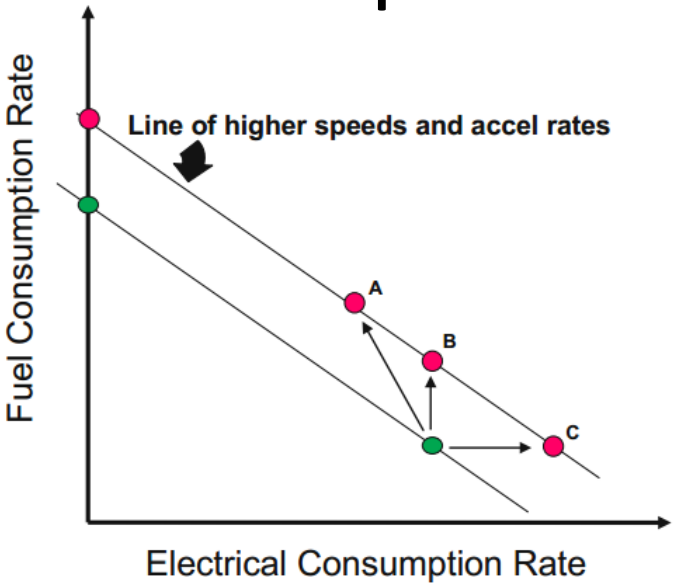
❖ **Real world fuel economy**

Los Angeles Times

Ford to pay C-Max owners after overstating hybrid's MPG rating
August 15, 2013

Hyundai, Kia reach $400-million settlement over inflated MPG claims
December 23, 2013

❖ **Power requirements and component sizing**



- **Consumers judge based on real world usage**
- **Benefits of technology depend on naturalistic cycles.**
- **Certification cycles are not realistic.**
- **Pick-up trucks need to be designed based on how people actually drive in real-life**

Source: *2012 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review*

Objectives

- **Analyze the naturalistic driving data to generate insights about real-world driving.**

- **Implement methodologies for synthesis of representative drive cycles based on large amount of naturalistic drive cycles.**

Naturalistic Drive Cycle Analysis for Pick-up Trucks

Public NDS Database for Pickup Trucks

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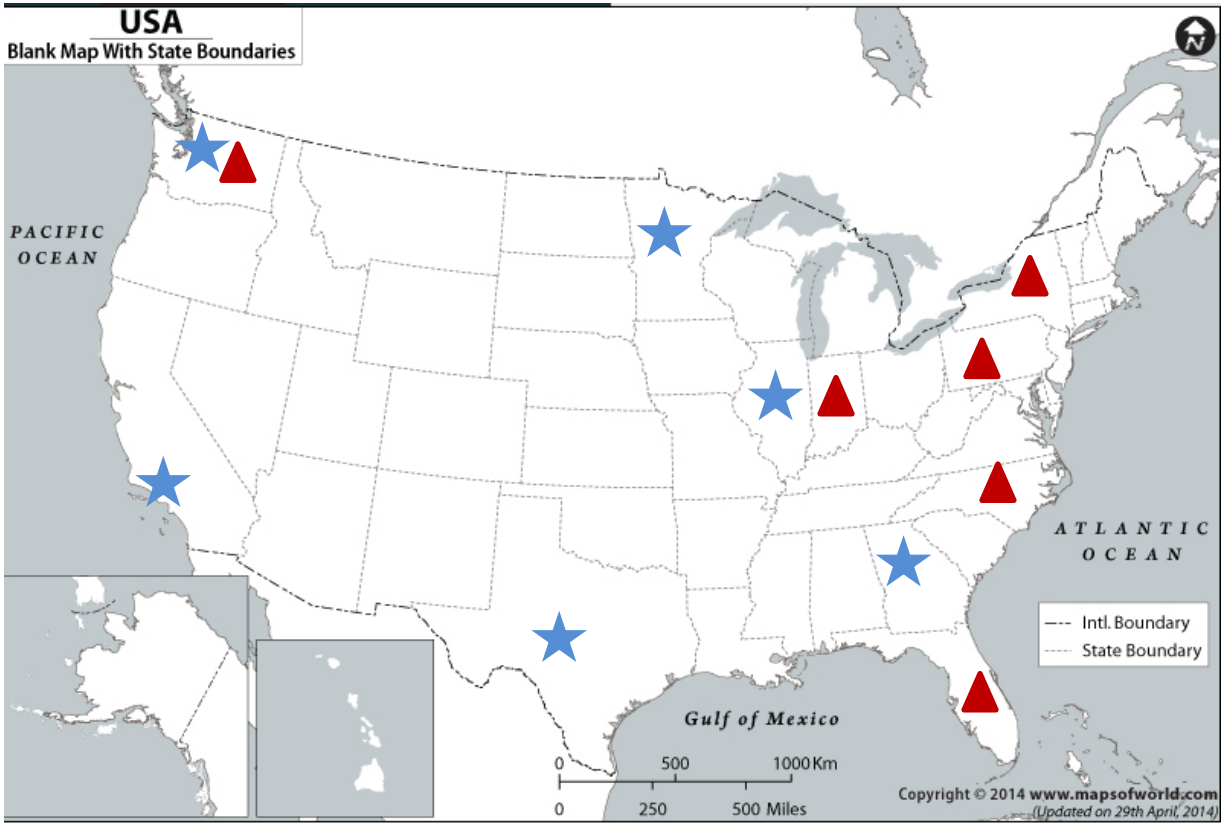
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

TRB TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

VirginiaTech TRANSPORTATION INSTITUTE

SHRP2
STRATEGIC HIGHWAY RESEARCH PROGRAM

- Free, web-based access to detailed second-by-second speed traces across the nation
- Free, web-based access to summarized transportation data across the nation; detailed data upon request.



NREL data collection sites:
- California
- Atlanta
- Texas
- Minneapolis/St. Paul
- Chicago
- Puget Sound Regional

SHRP2 data collection sites:
- Buffalo, NY
- State College, PA
- Durham, NC
- Bloomington, IN
- Tampa, FL
- Seattle, WA

Pickups in SHRP2 Database

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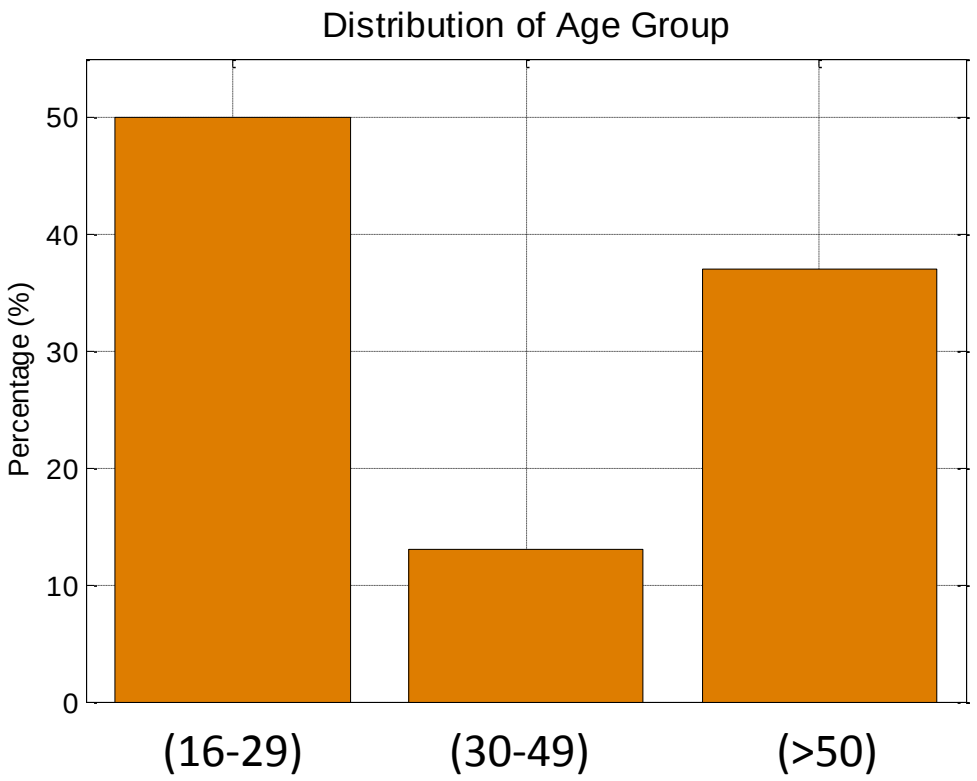
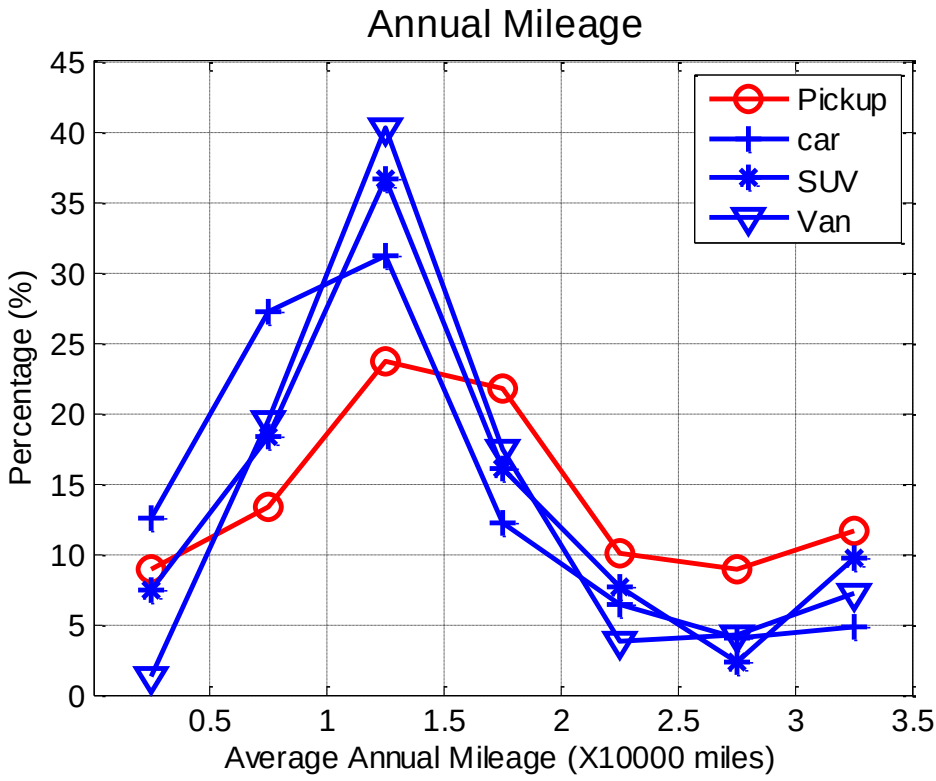
165 Drivers, 167 Pickups

136 Drivers, 130 Vans

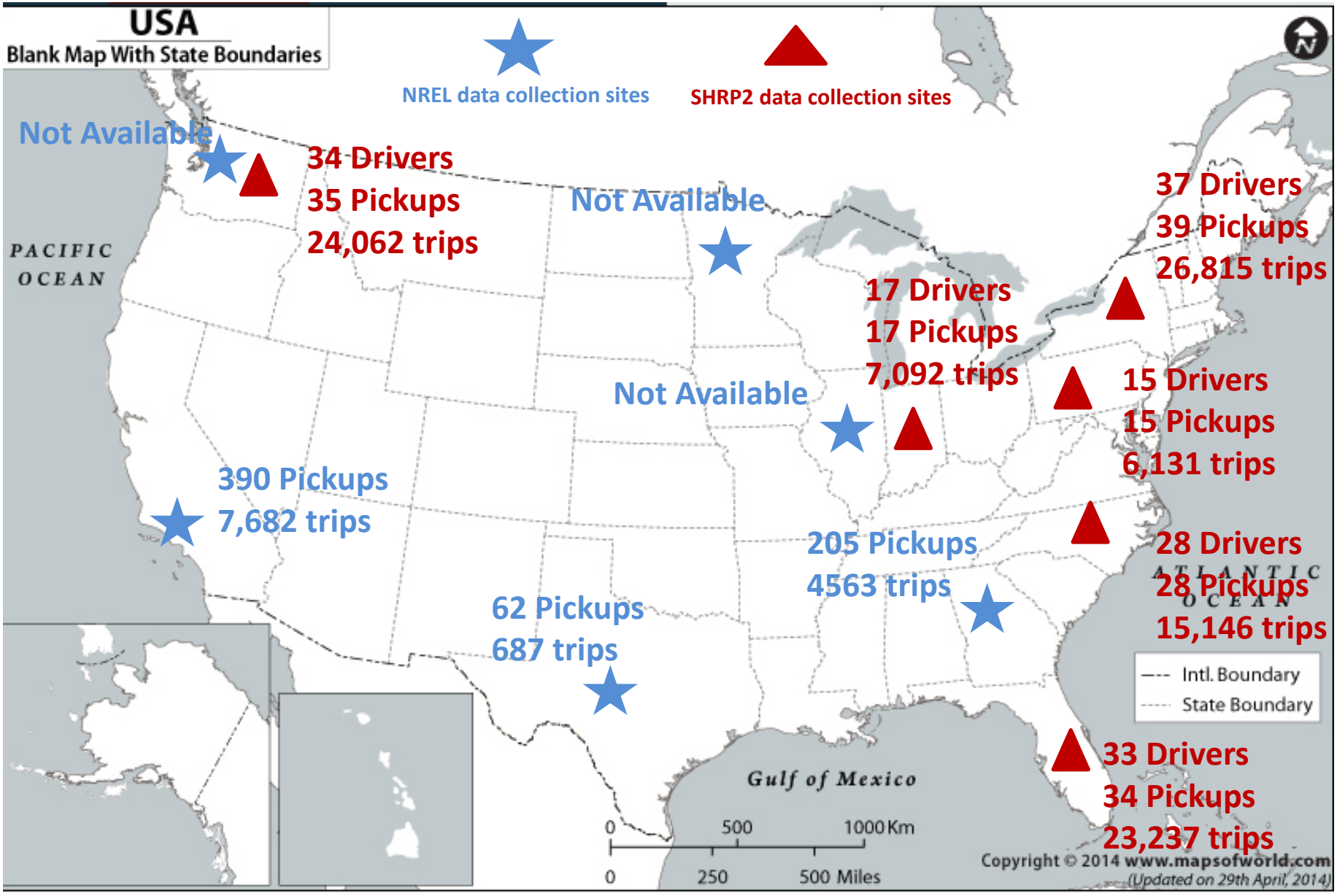
667 Drivers, 650 SUVs

2387 Drivers, 2387 cars

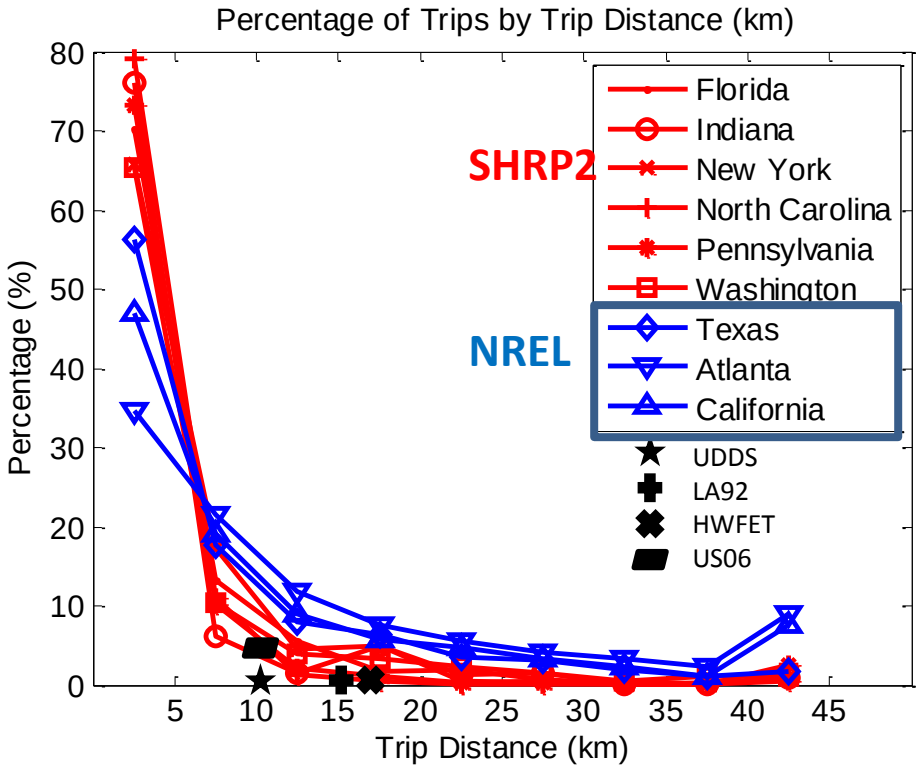


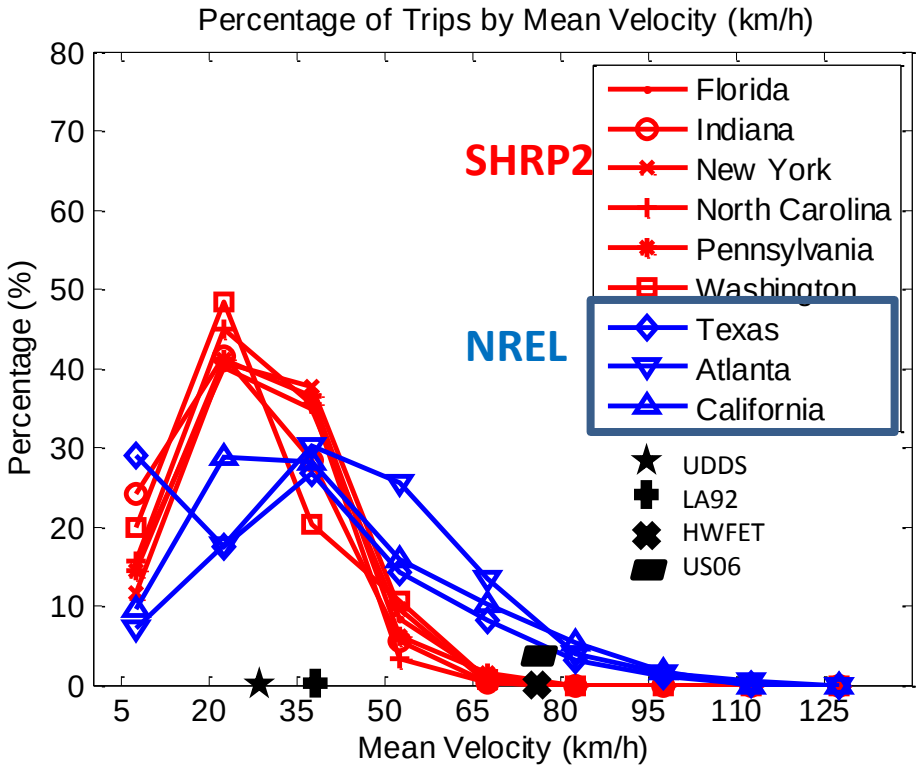


Naturalistic Driving for Pickup Trucks



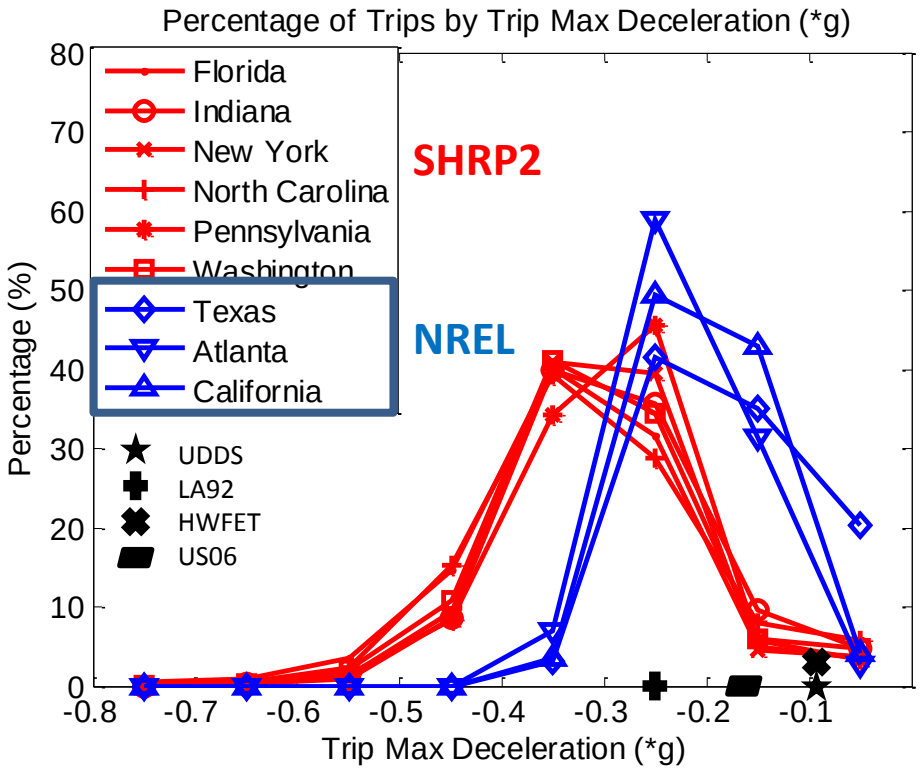
Naturalistic Driving for Pickup Trucks

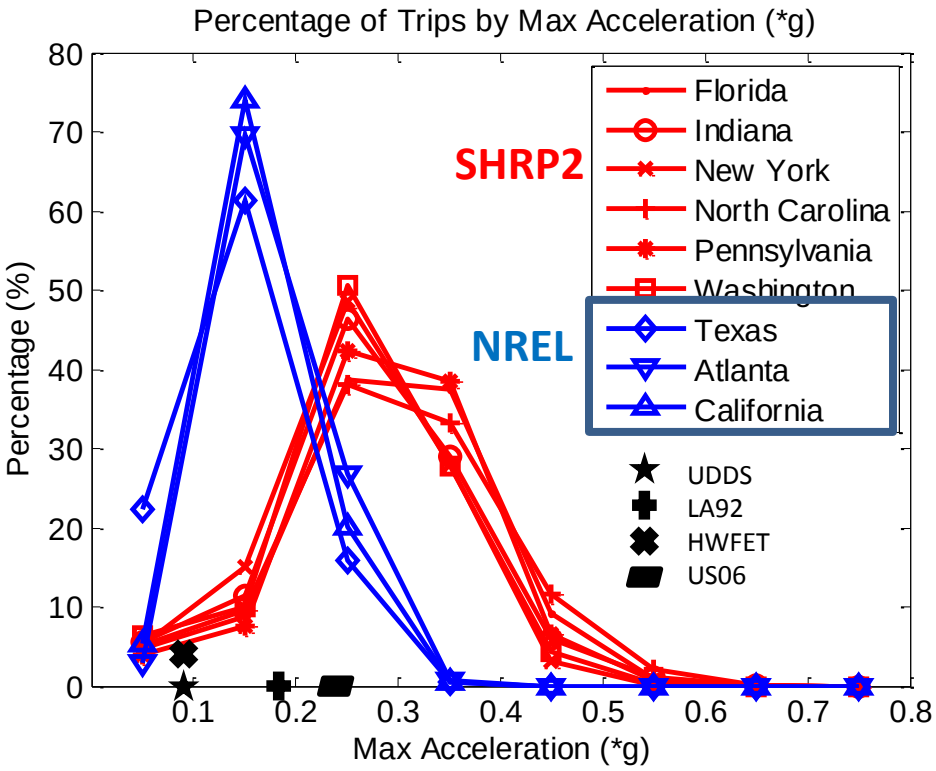




- **Trips from SHRP2 are more consistent.**
- **Trips from NREL have more variations between locations.**
- **Fewer pickups yet higher trip-per-truck in SHRP2, enhanced personal pattern?**
- **Different from certification cycles**

Naturalistic Driving for Pickup Trucks



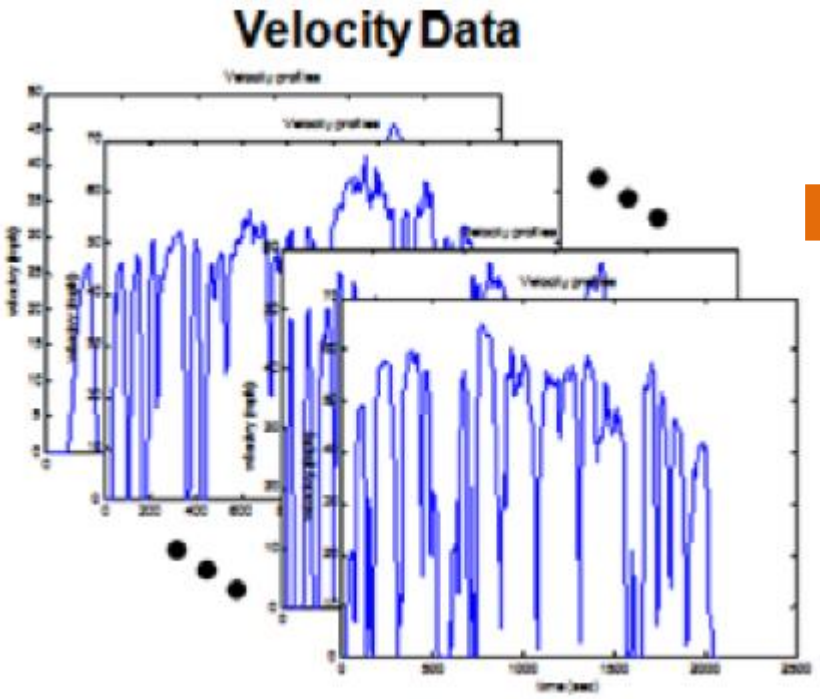


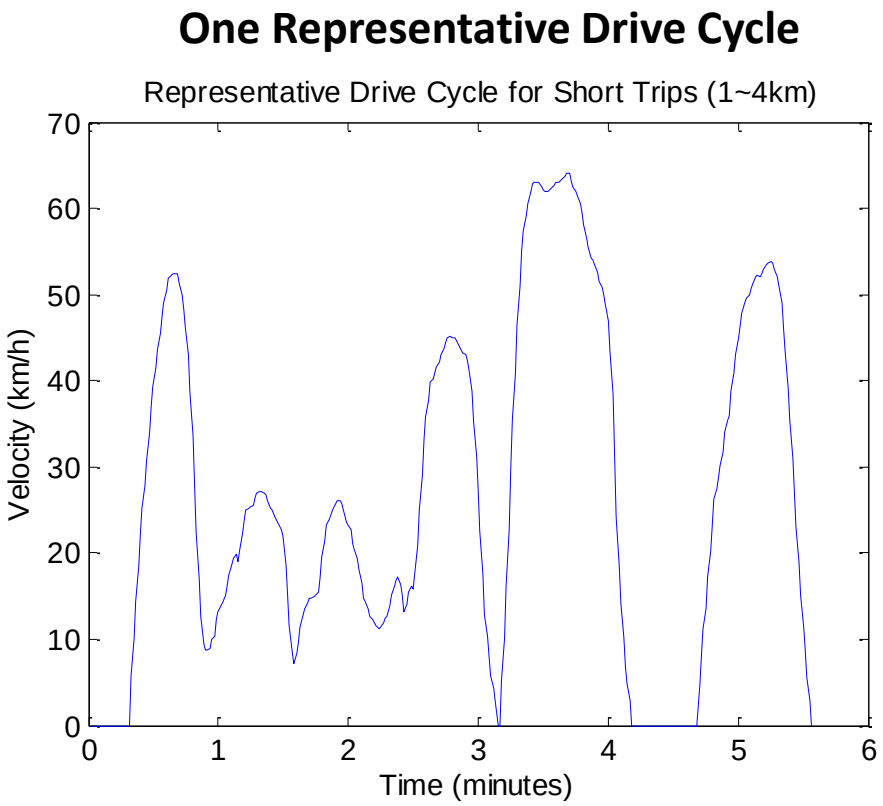
- **Trends are similar in nature.**
- **Actual distributions of peak values are different.**
- **Different drivers or different data pre-processing techniques?**

Naturalistic Drive Cycle Synthesis for Pick-up Trucks

- Reduce the amount of data to enable efficiency in vehicle design and control development

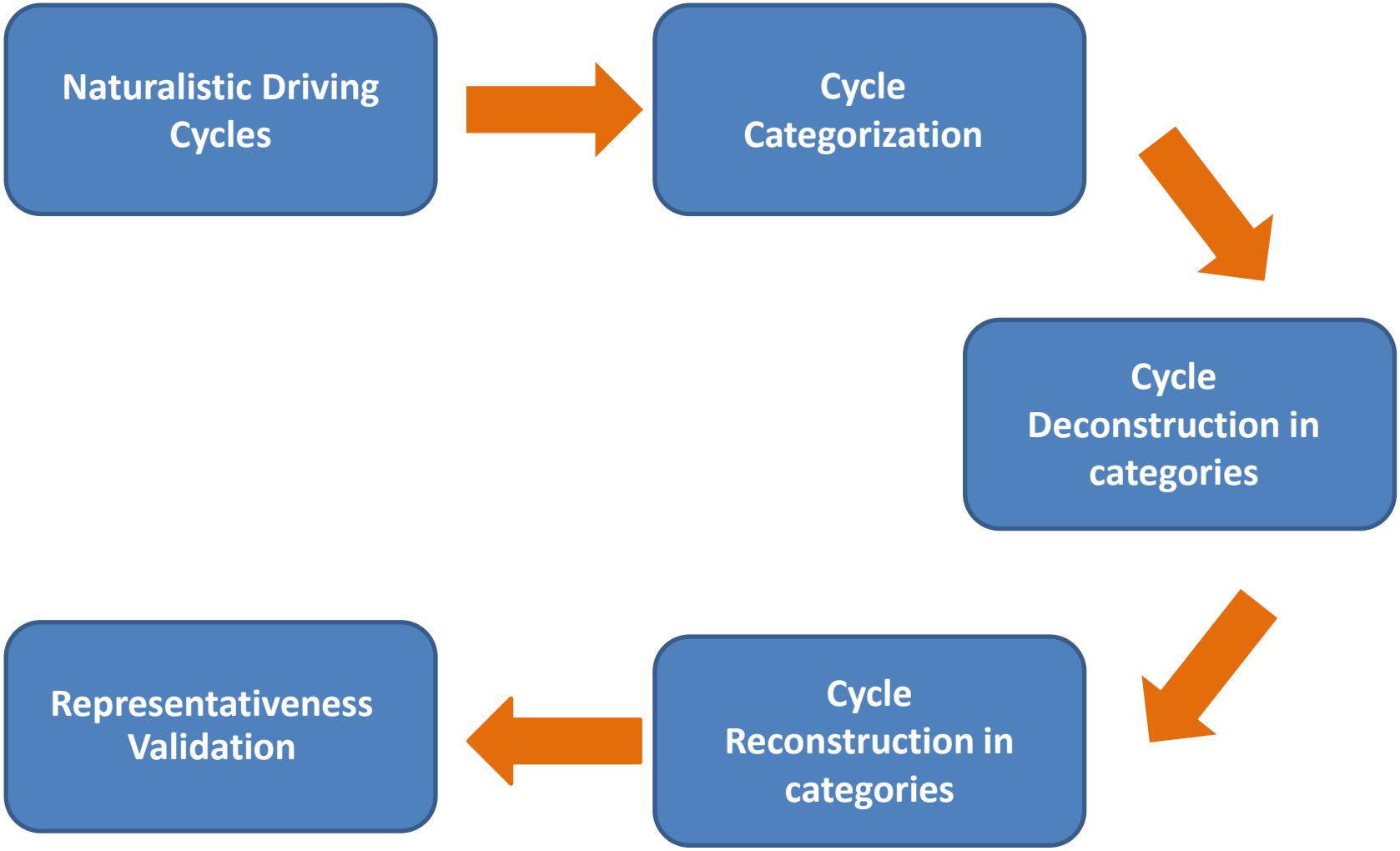
Basic Philosophy:



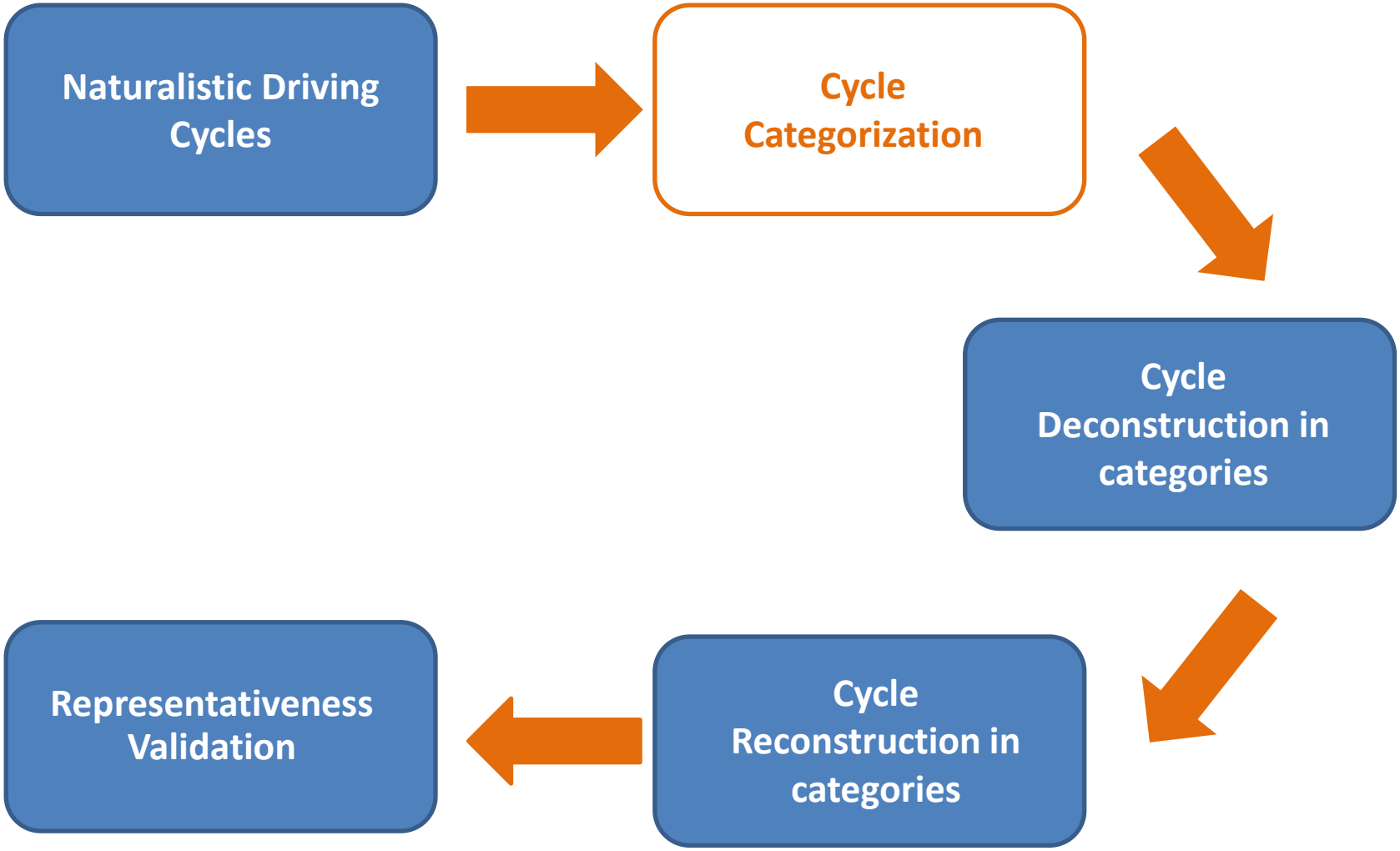


- **Use the Pick-up truck trips from the NREL's California Database: 2010–2012 California Household Travel Survey.**

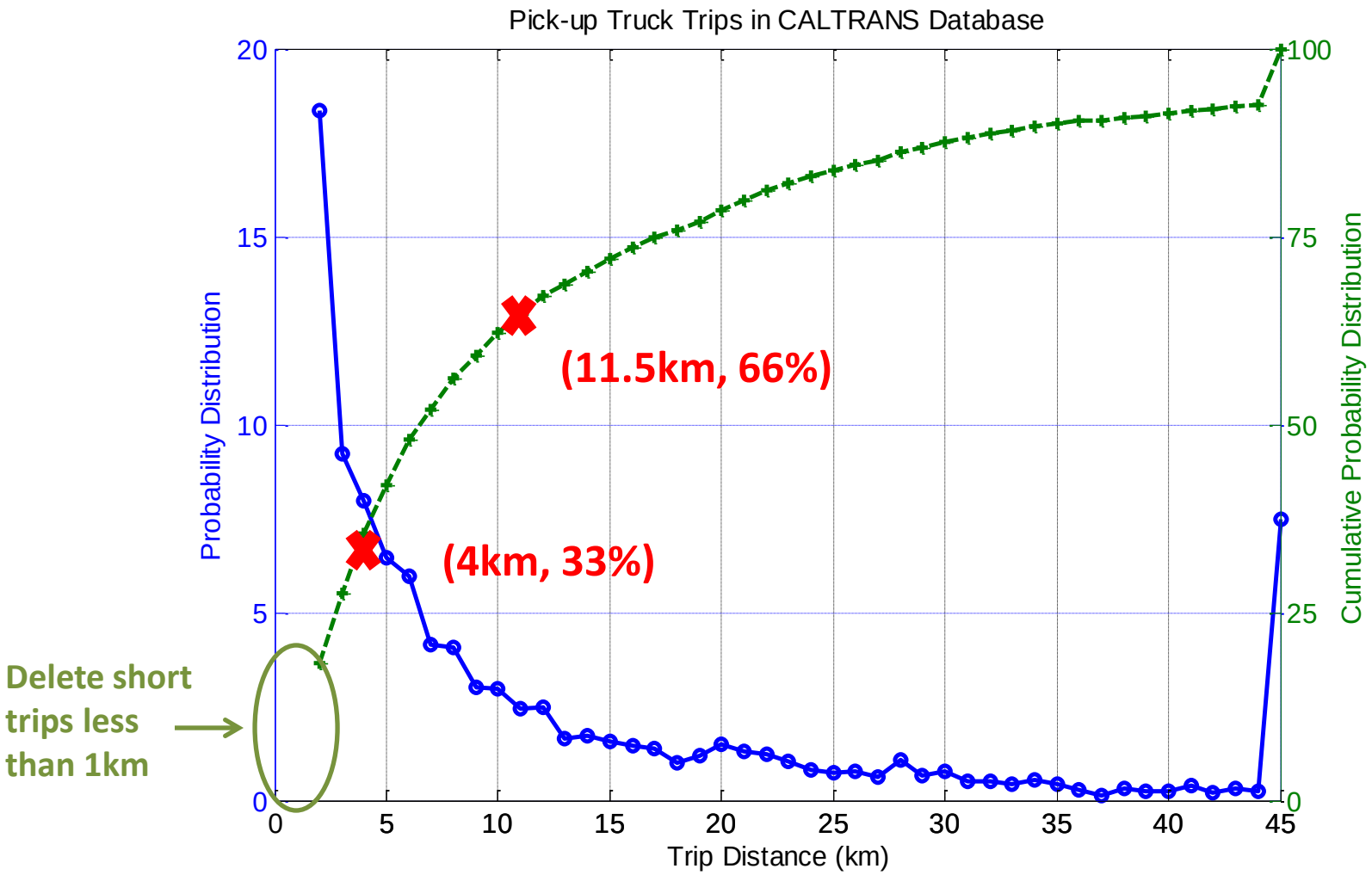
Naturalistic Drive Cycle Synthesis Flow Chart



Naturalistic Drive Cycle Synthesis Flow Chart

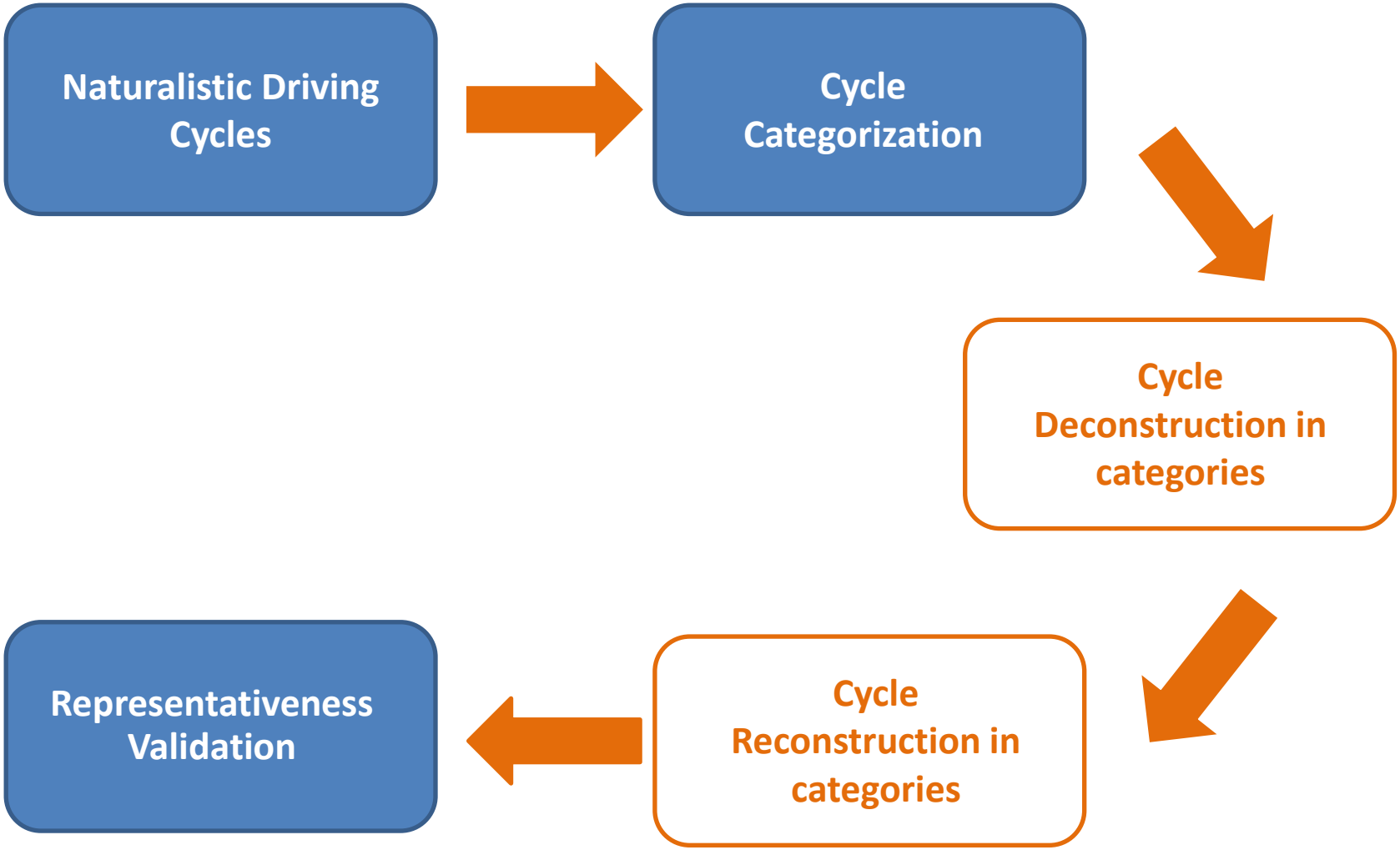


Cycle Categorization



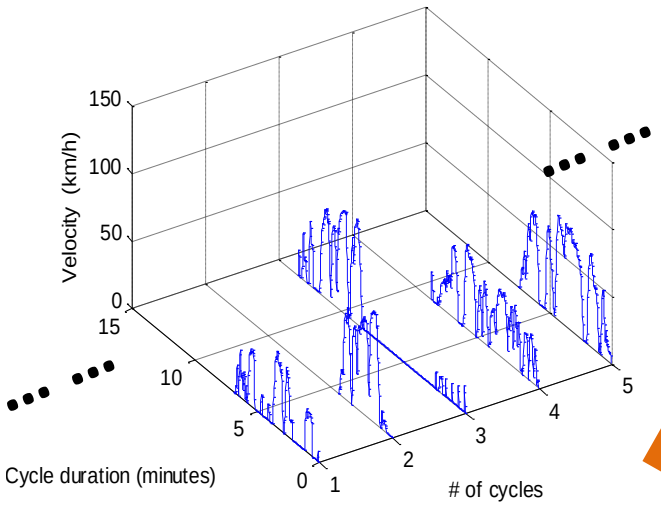
- **Categorization by trip distance, in equal probability interval of trip distance distribution (1~4 km), (4~11.5 km), (>11.5 km) with mean values of 2.4 km, 7km, 35 km respectively.**

Naturalistic Drive Cycle Synthesis Flow Chart



Naturalistic Drive Cycle Synthesis

Short trip Category (1~4 km)



- Counting the number of occurrences of V_{k+1} with previous velocities as V_k and V_{k-1}.
- Fill the number into the Transition Probability Matrix
- From start to complete stop, numerous drive cycles are generated stochastically in-between.
- How to choose the most representative?

❖ **Markov Chain:**

$$Pr\{x_{k+1} \mid x_k, x_{k-1}, x_{k-2} \ldots x_1\} = Pr\{x_{k+1} \mid x_k\}$$

❖ **By vehicle dynamics,**

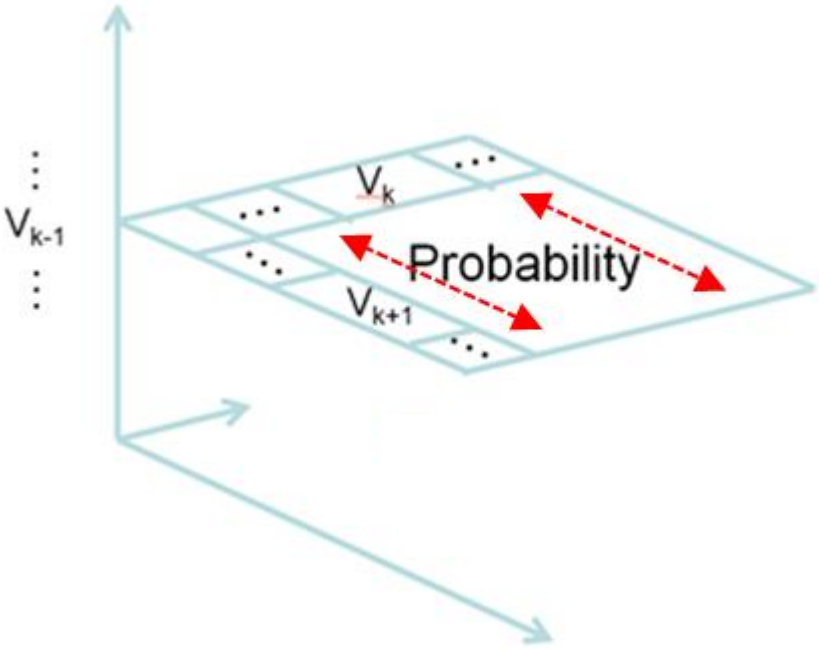
$$X_k = (a_k, V_k),$$

a is the acceleration, V is the velocity

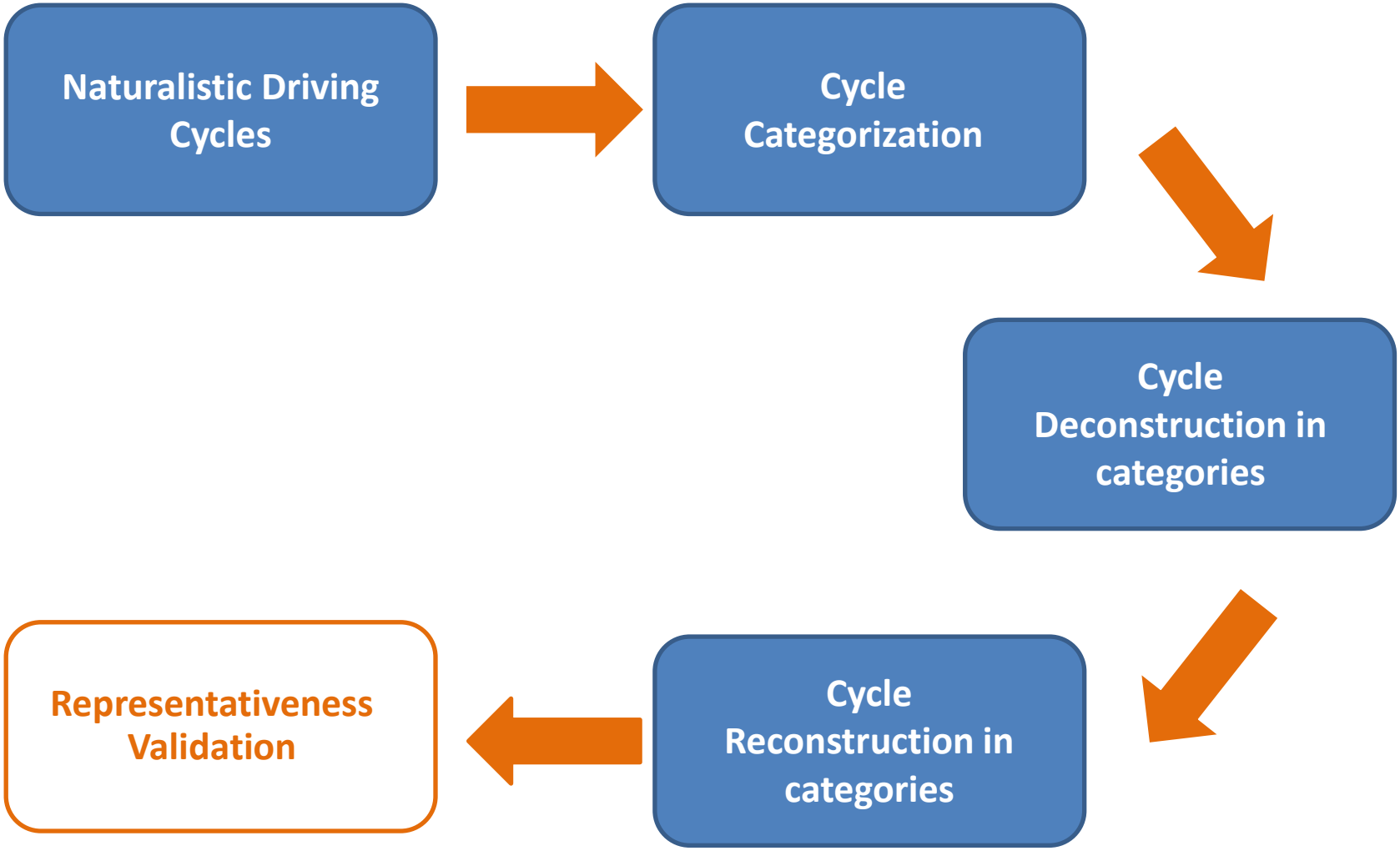
❖ **For speed traces, $a_k = V_k - V_{k-1}$,**

$$X_k = (V_k, V_{k-1}),$$

$$Pr\{V_{k+1} \mid V_k, V_{k-1}, \ldots V_1\} = Pr\{V_{k+1} \mid V_k, V_{k-1}\}$$



Naturalistic Drive Cycle Synthesis Flow Chart

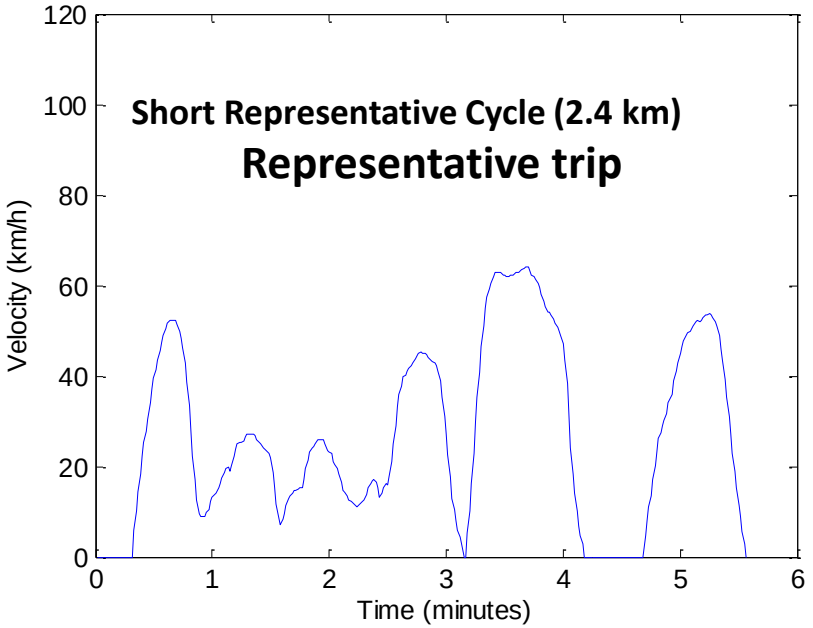


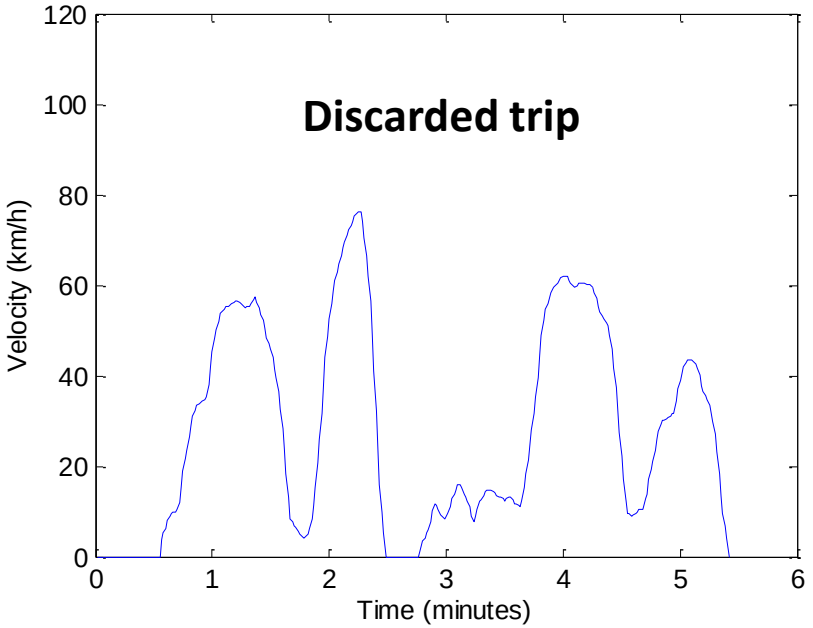
Representativeness Validation

- **Use the significant cycle metrics to choose the most representative drive cycle.**

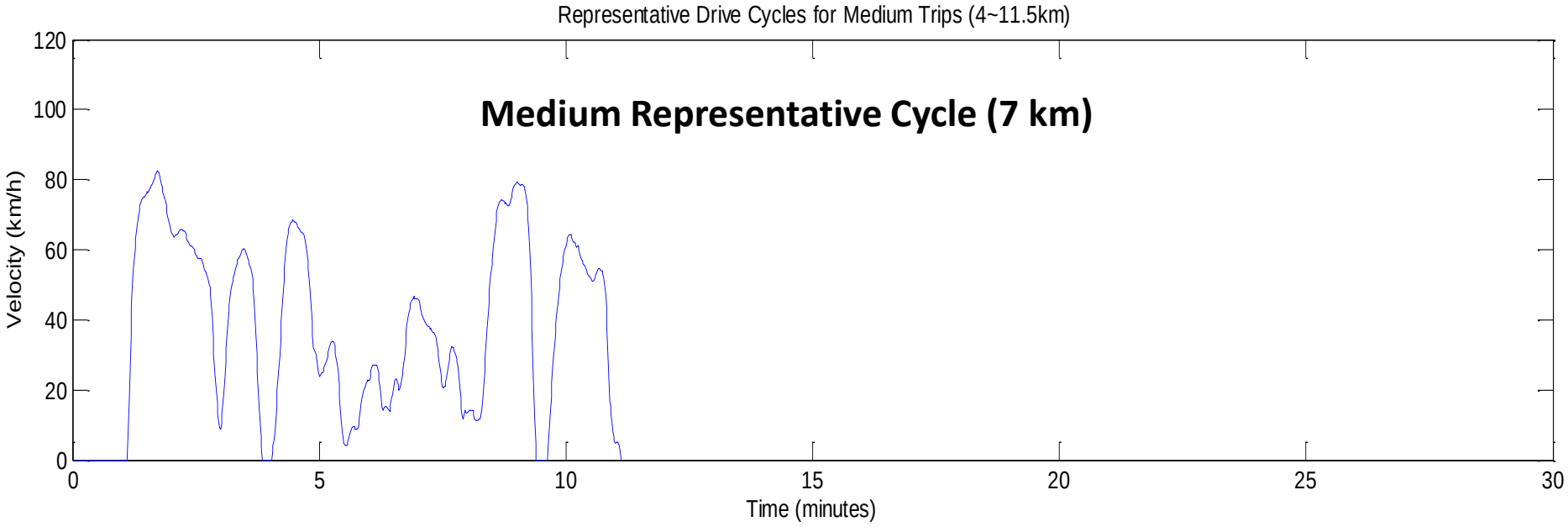
Significant Cycle Metrics*	Mean Values for Trips (< 4 km)	Representative Trip	Discarded Trip
Standard deviation of velocity (km/h)	26.07	22.01	22.79
Mean positive velocity (km/h)	31.92	31.70	33.07
Standard deviation of acceleration (m/s^2)	0.60	0.61	0.64
Mean positive acceleration (m/s^2)	0.47	0.47	0.46
Percentage of driving time under negative acceleration (%)	40.61	37,31	33.85
Percentage of idle time (%)	15.10	15.87	16.00
Percentage of driving time under positive acceleration (%)	44.94	44.31	45.23
Number of stops/km (1/km)	0.99	1.20	0.84

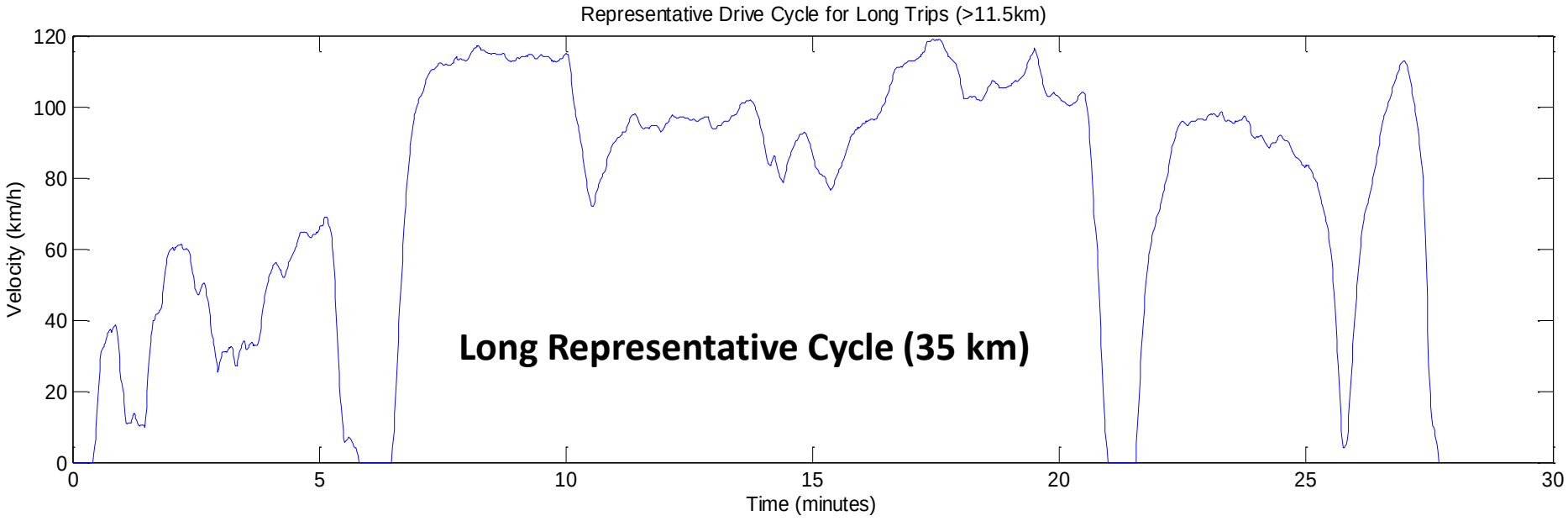
*Source: Lee, T.-K. and Z. S. Filipi (2011). "Synthesis of real-world driving cycles using stochastic process and statistical methodology." International Journal of Vehicle Design 57(1): 17-36.





Examples of Representative Drive Cycles





Conclusion and Future Works

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Pick-up truck cycle Analysis:

- Pick-up trucks are driven more than other types of vehicles.
- Real-world driving patterns are different from certification cycles.
- Trips from SHRP2 database and NREL database show differences.

Pick-up truck cycle Synthesis:

1. Categorized naturalistic trips by distance
2. Reconstructed discrete naturalistic driving data using Markov Chain.
3. Chose the representative cycle whose significant cycle metrics approximate the averages of bulk data.

Future Work:

1. Apply above methods to SHRP2's detailed naturalistic cycles; including the valuable road grade profiles.
2. Other cycle analysis, such as driver aggressiveness, with car-following distance, acceleration recordings,… .

Thank you !