TENNESSEE SECTION INSTITUTE OF TRANSPORTATION ENGINEERS

TSITE 2015 Summer Meeting
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Customizing Driving Cycles for Fuel Economy Estimation

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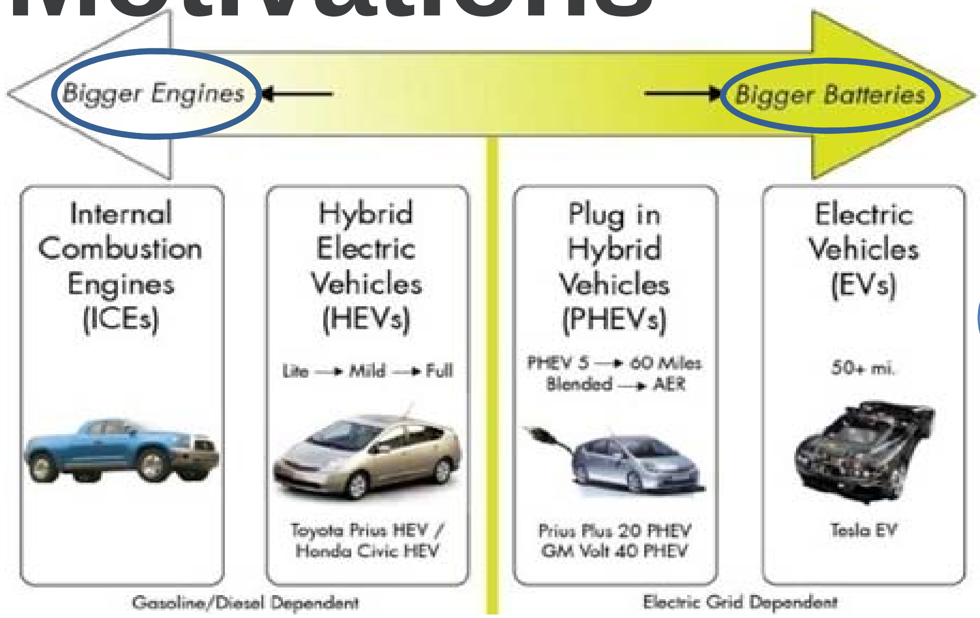
Motivations



Less emissions

Energy savings

Lower operating costs

Sources:
http://phev.ucdavis.edu/about/faq-phev/
http://www.c2es.org/blog/nigron/making-case-plug-electric-vehicles-smart-shopping

BloombergView

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CARS

Automakers Get Caught Not Breaking EPA Rules

3 NOV 6, 2014 2:04 PM EST

By Edward Niedermeyer

U.S. Attorney General Eric Holder rained magisterial judgment this week on Hyundai Motor Co. and Kia Motors Corp., which the U.S. claimed had overstated their cars' fuel economy on the vehicles' window stickers. He said the government's $350 million settlement with the South Korean automakers "will send an important message

This might be a reasonable strategy if the EPA's standards consistently delivered MPG ratings that reflect real-world driving, but the ratings simply don't do that. Consumer Reports has shown that 55 percent of hybrid vehicles fall short of their EPA ratings by 10 percent or more in independent testing, while 28 percent of cars with turbocharged engines have the same problem. The EPA itself acknowledged this shortcoming earlier this year, when it proposed "in-use auditing" -- testing vehicles on the road -- to verify window-sticker numbers as part of its broader effort to bring its test results closer in line with real-world efficiency.

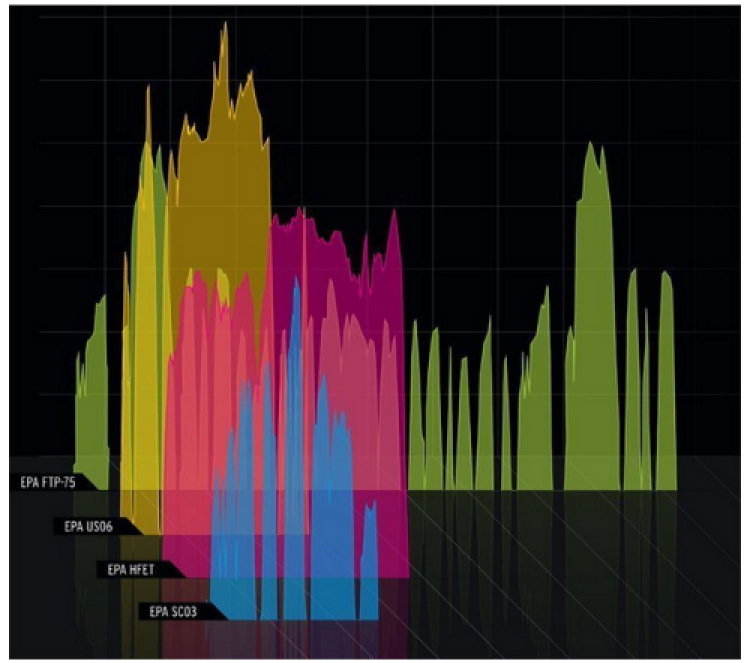
Fuel-economy ratings are a tool for consumers, and the fact that the EPA acknowledges that its tests fail to reflect the numbers consumers are likely to see on window stickers is the real scandal. Rather than shaming Hyundai and Kia for exploiting "latitude" in their testing standards, the EPA should work to eliminate that latitude as part of a wider effort to make its ratings reflect real-world use. In addition to tightening test-condition standards, the EPA should consider verifying a higher percentage of tests, creating a strong in-use

These Tests Failed You: Why Is the EPA So Bad at Estimating Hybrid Fuel Economy?

The fuel-economy numbers look nice, but the testing behind them is flawed.

MAY 2013 | BY CSABA CSERE | MULTIPLE PHOTOGRAPHERS

141 SHARES | 35 TWEETS



From the April 2013 Issue of ***Car and Driver***

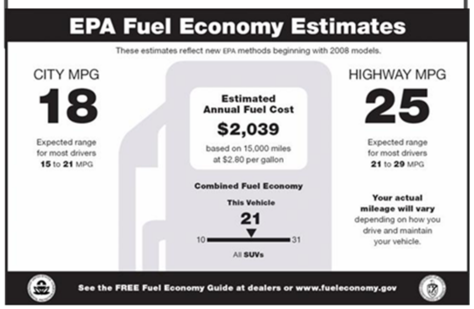
We were impressed when Ford announced that the 2013 Fusion hybrid earned an EPA rating of 47 mpg for both city and highway driving. Here was a generously sized and relatively conventional-looking sedan rivaling the efficiency of the Toyota Prius.

Then we racked up a mere 32 mpg in our road test [December 2012]. That's par for our foot-down driving style, but even when we drove more sedately, we had difficulty coaxing the Fusion's trip computer to show any number that started with a 4. It turns out we weren't alone.

In early December, a California law firm filed a class-action suit against Ford, charging fraud and "widespread misleading and

Motivations

Based on pre-designed and fixed driving cycles
In laboratory conditions



"One size-fits-all" MPG rating

Driving cycles different by car, driver, local conditions…
In Real-world driving

Need convincing fuel economy predictions based on:
- drivers' characteristics &
- contemporary real-world driving

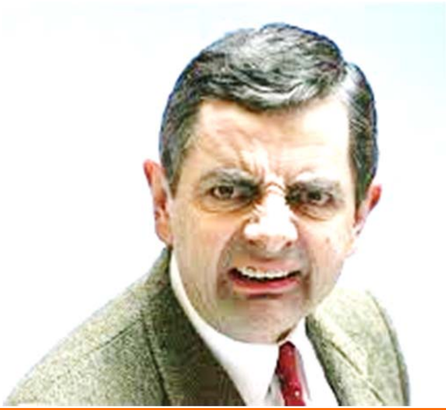
EPA Driving Cycles

Drive Cycle	Description	Data Collection Method	Year of Data	Top Speed	Avg. Speed	Max. Acc.	Distance	Time (min)	Idling time
FTP	Urban/City	Instrumented Vehicles/Specific route	1969	56 mph	20 mph	1.48 m/s^2	17 miles	31 min	18%
C-FTP	city, cold ambient temp	Instrumented Vehicles/ Specific route	1969	56 mph	32 mph	1.48 m/s^2	18 miles	31min	18%
HWFET	Free-flow traffic on highway	Specific route Chase-car/ naturalistic driving	Early 1970s	60 mph	48 mph	1.43 m/s^2	16 miles	12.5 min	None
US06	Aggressive driving on highway	Instrumented Vehicles/ naturalistic driving	1992	80 mph	48 mph	3.78 m/s^2	13 miles	10min	7%
SC03	AC on, hot ambient temp	Instrumented Vehicles/ naturalistic driving	1992	54 mph	35 mph	2.28 m/s^2	5.8 miles	9.9 min	19%

Research Question

- How to design customized driving cycles to capture real-world driving?
  - Different fuel types: Gasoline, EV, Hybrid …
  - Different vehicle body types: Sedan, SUV, Pick-up…
  - Different trips: short/long trip…
  - Different driver attributes: Male/Female, Age…
  - Different driving styles: Calm driving, jerky driving…

Sounds impossible?



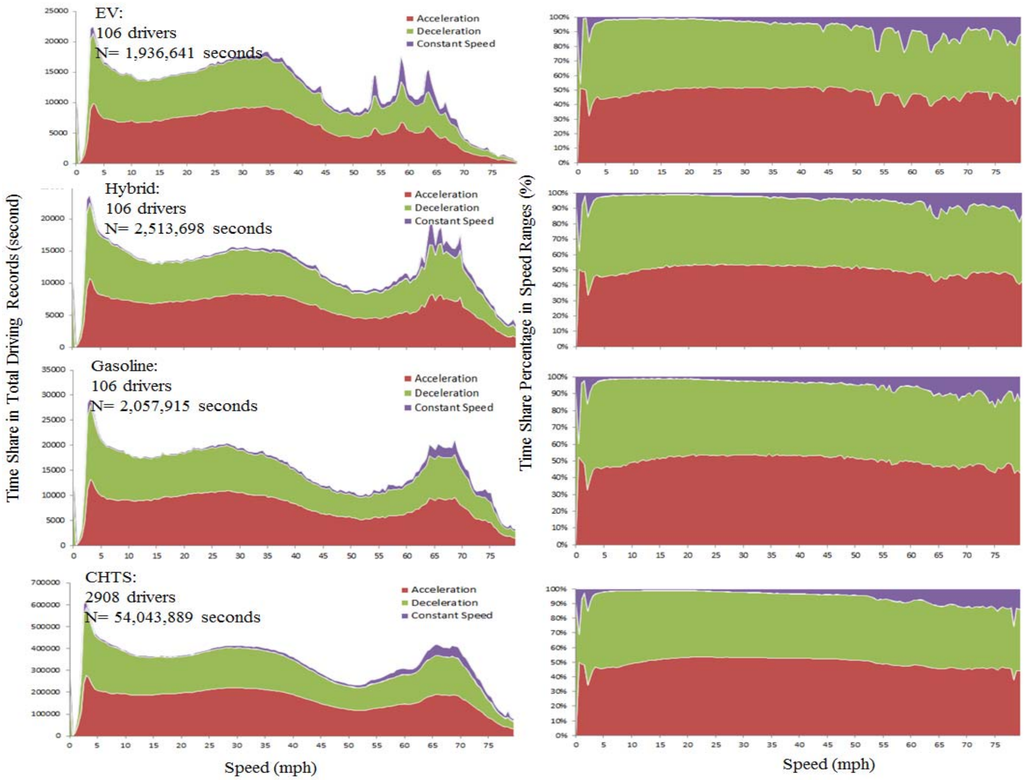
Unless we have the data!

- Large-scale driving data now available
  - California Household Travel Survey (CHTS)
  - Jan 2012-Jan 2013
  - Data collected by in-vehicle GPS or OBD & survey
- 54 million seconds of vehicle trajectories
  - More than 65,000 trips
  - Made by 3,000 drivers
  - 2,200 GV, 364 HV, 109 EV, 110 Diesel

“Equivalent” Groups

Vehicle Group	Demographics		Mean	Std. Dev.	Min	Max
EV (N=106)	Age (years)		49.415	10.403	16	71
	Gender [Male]		0.575	0.497	0	1
	Household Income	< 74,999	0.038	0.191	0	1
		75,000 - 99,999	0.123	0.330	0	1
		100,000 - 149,000	0.264	0.443	0	1
		>150,000	0.575	0.497	0	1
Hybrid (N=106)	Age (years)		49.394	9.767	20	68
	Gender [Male]		0.575	0.497	0	1
	Household Income	< 74,999	0.038	0.191	0	1
		75,000 - 99,999	0.123	0.330	0	1
		100,000 - 149,000	0.264	0.443	0	1
		>150,000	0.575	0.497	0	1
Gasoline (N=106)	Age (years)		49.415	10.403	16	71
	Gender [Male]		0.575	0.497	0	1
	Household Income	< 74,999	0.038	0.191	0	1
		75,000 - 99,999	0.123	0.330	0	1
		100,000 - 149,000	0.264	0.443	0	1
		>150,000	0.575	0.497	0	1
All drivers (N=2908)	Age (years)		48.804	13.490	16	88
	Gender [Male]		0.480	0.500	0	1
	Household income	< 74,999	0.312	0.216	0	1
		75,000 - 99,999	0.187	0.390	0	1
		100,000 - 149,000	0.232	0.422	0	1
		>150,000	0.269	0.443	0	1

Comparing acceleration-speed & time use



Time spent on accelerating or braking varies with speeds

PEVs spent less time >60 mph

Distinct spikes in EV time use distribution

Comparison of driving performance-trip level

Vehicle-Trip Groups	EV (N=2371)		HV (N=2652)		GV (N=2397)		Regional (all trips) (N=65,652)		Existing Drive Cycles					
Drive Cycle Parameters	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	FTP	HWY	US06	SC03	LA92	NYCC
Total duration (hrs)	0.26	0.23	0.30	0.30	0.27	0.31	0.26	0.30	0.17	0.40	0.52	0.21	0.17	0.17
Driving duration (hrs)	0.22	0.21	0.26	0.27	0.24	0.29	0.23	0.28	0.15	0.33	0.42	0.21	0.13	0.11
Total average speed (mph)	26.89	10.91	28.07	12.61	27.80	12.16	27.28	12.37	47.97	24.61	21.20	48.20	21.44	7.09
Driving average speed (mph)	27.22	10.89	28.38	12.59	28.14	12.13	27.62	12.35	51.85	29.40	26.20	48.58	26.62	10.92
Maximum speed (mph)	49.30	15.83	51.96	17.83	51.45	17.11	50.22	17.43	80.30	67.20	56.70	59.90	54.80	27.70
Average acceleration (ft/s^2)	2.13	0.68	2.07	0.65	2.22	0.71	1.46	0.47	2.20	2.21	1.68	0.64	1.65	2.04
Average deceleration (ft/s^2)	-2.19	0.64	-2.24	0.68	-2.38	0.76	-1.58	0.50	-2.39	-2.47	-1.89	-0.72	-1.98	-1.99
Maximum acceleration (ft/s^2)	9.34	2.24	8.84	1.84	8.82	1.92	5.91	1.31	12.32	10.12	4.84	4.69	7.48	8.80
Maximum deceleration (ft/s^2)	-9.94	2.36	-10.25	2.47	-10.37	2.47	-6.91	1.70	-10.12	-12.91	-4.84	-4.84	-8.95	-8.65
Root mean square acceleration (ft/s^2)	1.47	0.43	1.46	0.44	1.56	0.48	1.03	0.32	3.24	2.61	2.07	0.98	2.26	2.21
Average positive vehicular jerk (ft/s^3)	0.77	0.29	0.77	0.30	0.80	0.30	0.54	0.21	1.32	1.25	0.78	0.28	1.02	1.41
Average negative vehicular jerk (ft/s^3)	-0.60	0.20	-0.60	0.20	-0.63	0.20	-0.42	0.14	-1.22	-1.19	-0.66	-0.27	-0.80	-1.28
Maximum positive vehicular jerk (ft/s^3)	6.48	2.08	6.35	2.05	6.40	2.19	4.25	1.51	11.15	9.53	5.13	2.93	6.31	8.21
Maximum negative vehicular jerk (ft/s^3)	-2.94	0.81	-2.92	0.72	-2.94	0.76	-1.97	0.52	-8.65	-12.32	-3.81	-2.35	-4.11	-6.16
Root mean square jerk (ft/s^3)	0.69	0.18	0.69	0.19	0.71	0.19	0.47	0.13	1.82	1.52	0.93	0.37	1.18	1.50
Acce./dece. events (no. per mile)	16.90	14.39	16.86	14.55	16.84	15.33	17.62	17.12	16.73	10.90	9.56	2.24	15.64	39.44
% time on idling	20.64	13.06	20.00	13.02	21.03	13.46	20.85	13.93	11.15	24.58	23.84	1.57	24.46	51.75
% time on acceleration	37.89	6.82	39.50	6.84	38.97	7.21	39.10	7.33	44.09	34.96	37.28	43.86	40.27	24.87
% time on deceleration	40.71	9.27	39.75	8.64	39.25	8.85	39.26	9.21	39.27	28.76	31.47	38.12	31.45	21.87
% time on stable driving	5.60	7.85	4.76	6.16	4.41	6.16	4.57	6.34	5.49	7.38	3.52	16.45	2.16	0.00
% time on outlier accel./decel.	4.46	3.75	4.69	3.96	5.59	4.77	5.15	4.52						
% time on outlier vehicular jerk	4.79	4.11	4.80	3.91	5.32	4.30	5.00	4.18						
Kinetic Intensity	3.29	8.53	3.35	5.50	3.30	5.36	3.68	22.88						

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Findings based on comparison

- Trips in EVs are shorter in terms of driving duration
- EVs have lower average speed/driving speed
- Average maximum trip speed of EV trips is near 50 mph (lower than similar HV and GV, and substantially lower than four EPA standard driving cycles and LA92)
- Average vehicle jerk level is similar for EV, HV and GV (close to US06, significantly higher than other EPA driving cycles)

- Existing driving cycles do not represent AFV driving very well

Customizing driving cycles

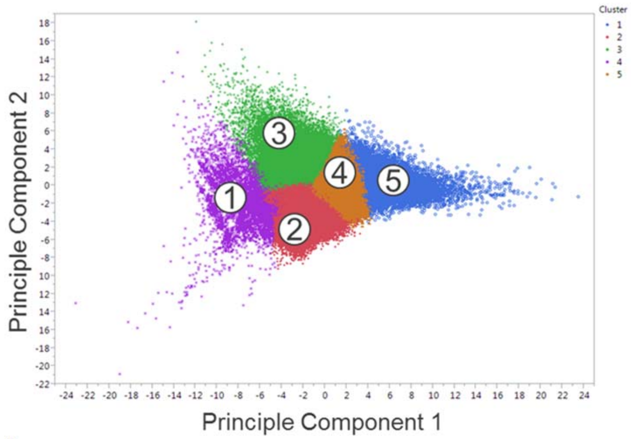
- Break trip into components (micro-trips)
- Micro-trip → Base element for driving cycle design
  - Starts and ends at zero speed
- Trip consists of micro-trips chained together
- It is critical to have:
  - Sufficiently large collection of historical cases
  - Mechanism for chaining together micro-trips

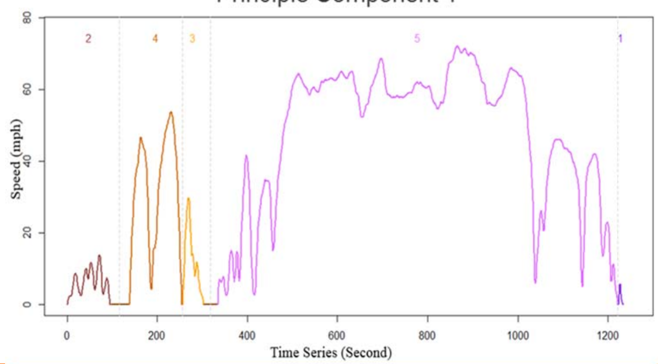
Solution:
Case Based System for Driving Cycle Design (CBDCD)

What is CBDCD?

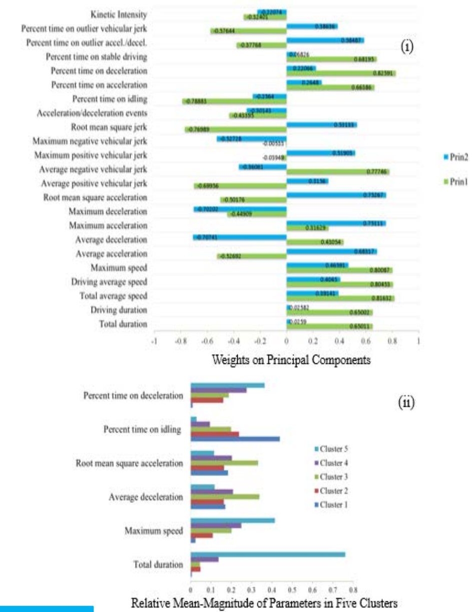
- A computer-based machine learning tool
  - Retain richness of historical micro-trip cases
  - Synthesize new candidate driving cycles that are closest to the user
- CBDCD is able to:
  - Apply clustering based on 23 performance parameters to develop the micro-trip collection
  - Match, rank, & synthesize micro-trip cases into sequence which forms customized driving cycle

Database preparation (Clustering and PCA)





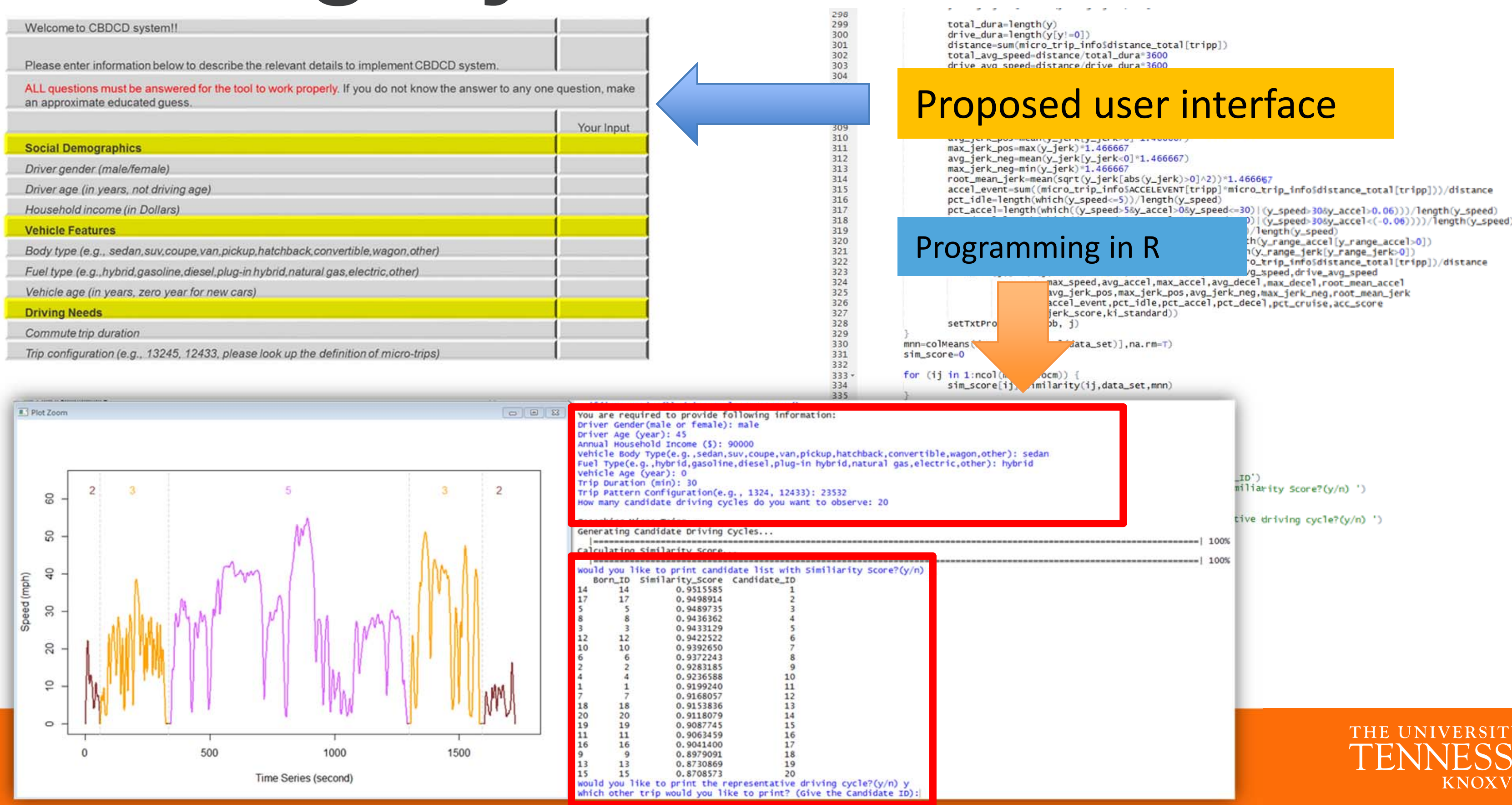
Group these micro-trips based on the various driving parameters extracted



Trip: code sequence 24351

Micro-trip cluster identified（sample trip）

Driving Cycle Generator



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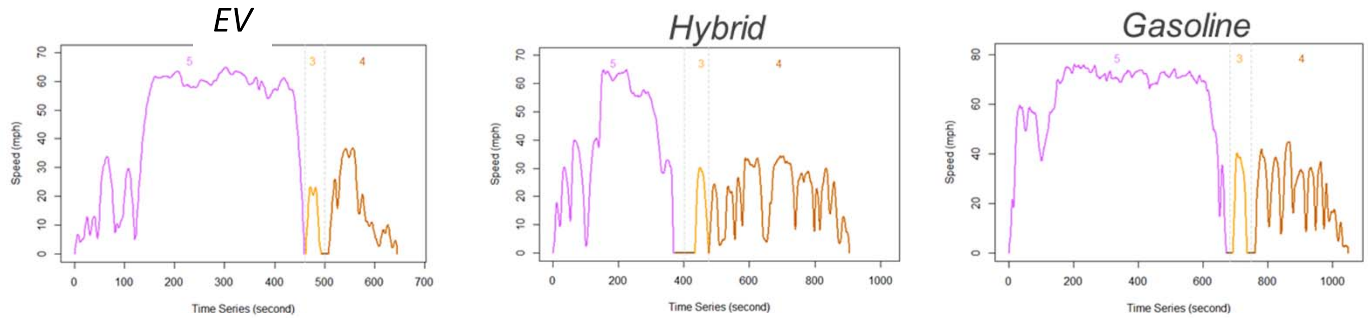
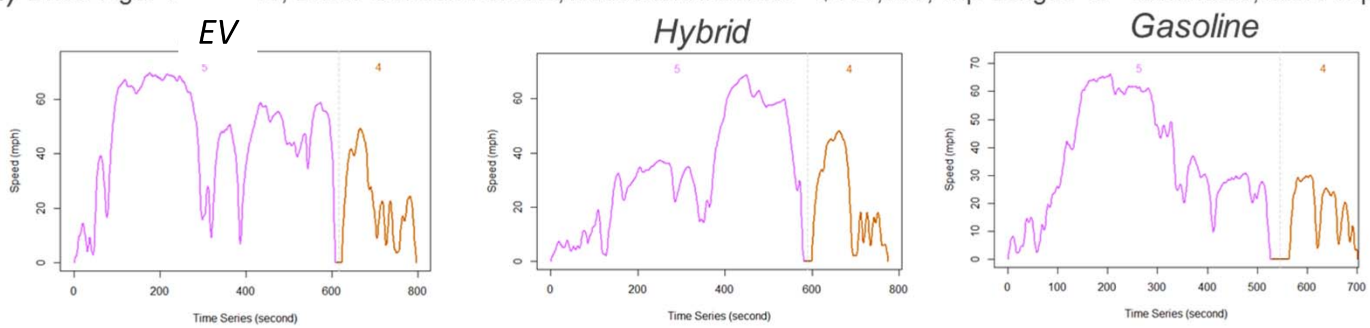
Case Study: Driving cycles for EV and HV

(i) Driver Age: 40 ~50 yrs, Driver Gender: Male, Household Income: > $150,000, Trip Length: 10~15 minutes, Micro Trips : 534



(ii) Driver Age: 40 ~50 vrs, Driver Gender: Female, Household Income: > $150,000, Trip Length: 10~15 minutes, Micro Trips : 54



Driving cycle and fuel economy

- Two options to get fuel economy

Use VSP equation to calculate fuel consumed/emissions (Zhai, NCSU)

$VSP = v \times (a + g \times \sin\phi + \psi) + \zeta \times v^3$

Where:
v = vehicle speed (meters per second)
a = vehicle acceleration (meters per second square)
g = acceleration due to gravity (meters per second square)
ϕ = road grade
ψ = rolling resistance coefficient (meters per second square)
ζ = drag coefficient (reciprocal metres)

Use the cycles to predict MPG rating based on dynamometer tests

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Summary

- AFV driving cycles have significant differences from conventional driving cycles
- Application
  - A Case Based System for Driving Cycle Design
  - Provide customers with more accurate estimation of fuel economy information
  - Make more informed vehicle purchase and use decisions

Thank YOU

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