Advanced Transmission Impact on Fuel Displacement

2013 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

March, 2013

Namdoo Kim, Aymeric Rousseau

Argonne National Laboratory

Sponsored by David Anderson

Project ID #VSS098

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Start – September 2012
- End – September 2013
- 50% Complete

Budget

- FY13
  - $200K

Barriers

- Lack of updated transmission model
- Constant advanced in technology
  - Data post-processing and analysis for recent produced transmission
  - Develop and validate model and control

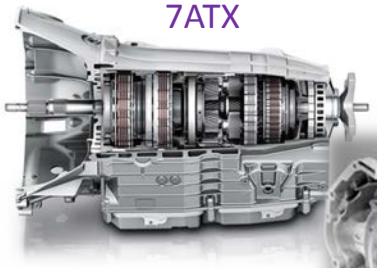
Partnership

- Argonne APRF
- Automotive manufacturer

Relevance

OEMs are Announcing Numerous Advanced Transmission

7ATX



8ATX

The new 7+ speed transmission features a wide ratio spread, high numerical first-gear ratio, and quick shifting.

The transmission efficiency and wide ratio spread improve fuel economy by operating at a lower engine rpm in both city and highway environments

DCT certainly offers smooth acceleration by eliminating the shift shock that accompanies gearshifts in manual transmissions and even some automatics

DCT

Interest in dual-clutch transmissions is particularly strong among OEMs in Europe and major growth markets in Asia, China in particular

CVT

A new continuously variable transmission (CVT) has been developed for midsize vehicles that significantly enhances both driving performance and fuel economy

Relevance

The objective is to update current transmission models and shifting algorithms as well as develop new ones to evaluate the latest and future technologies

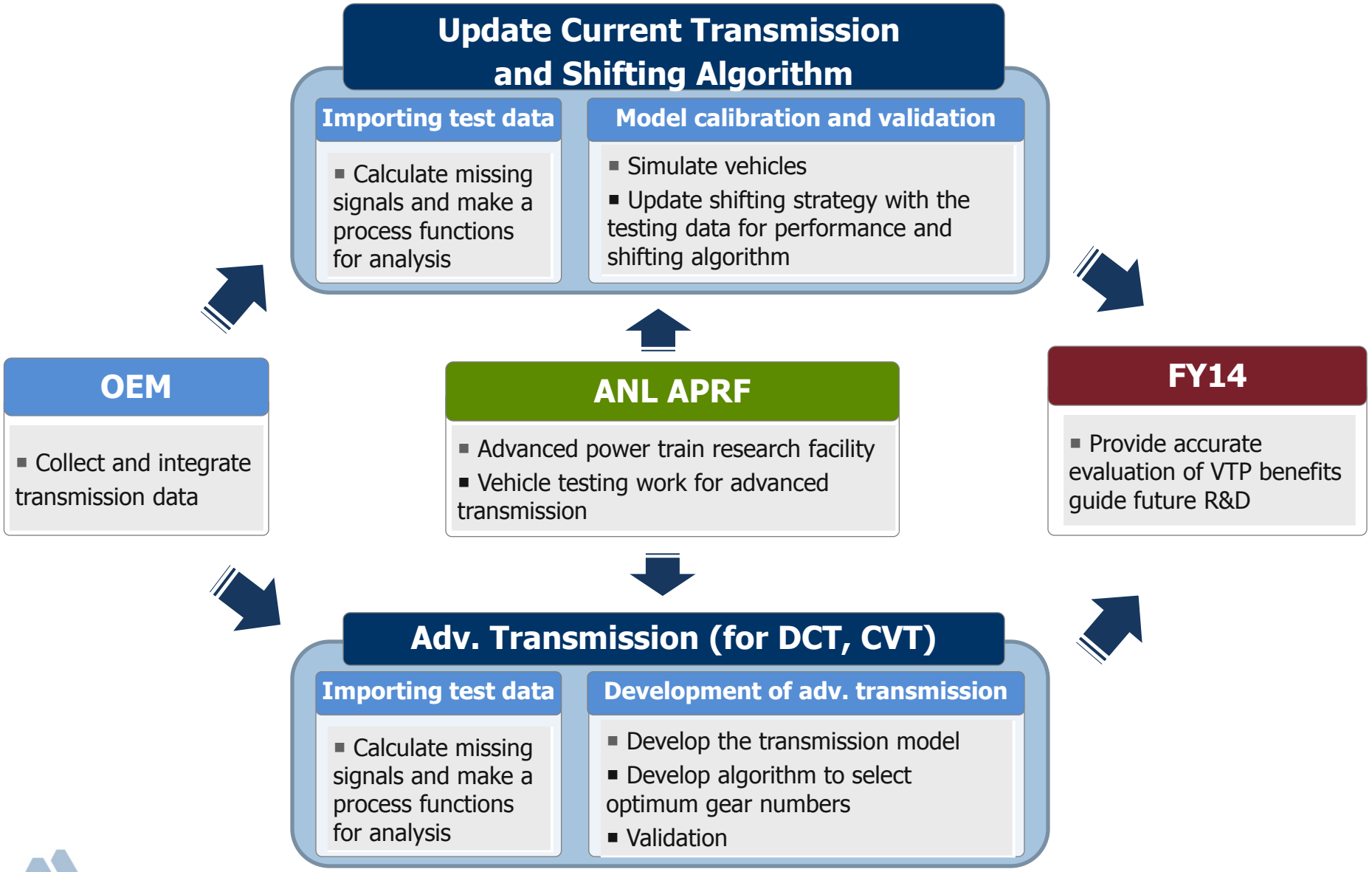
- Argonne has developed and validated shifting algorithms for 4 and 5 speed automatic transmissions, but no extensive work has been done on 6+ speeds or DCTs.
- Transmissions have significantly evolved over the past 5 years and have significant impact on fuel, yet, little work has been done within VTP.
- Validated models and controls will be used to provide more accurately evaluate VTP benefits and guide future R&D.

Approach

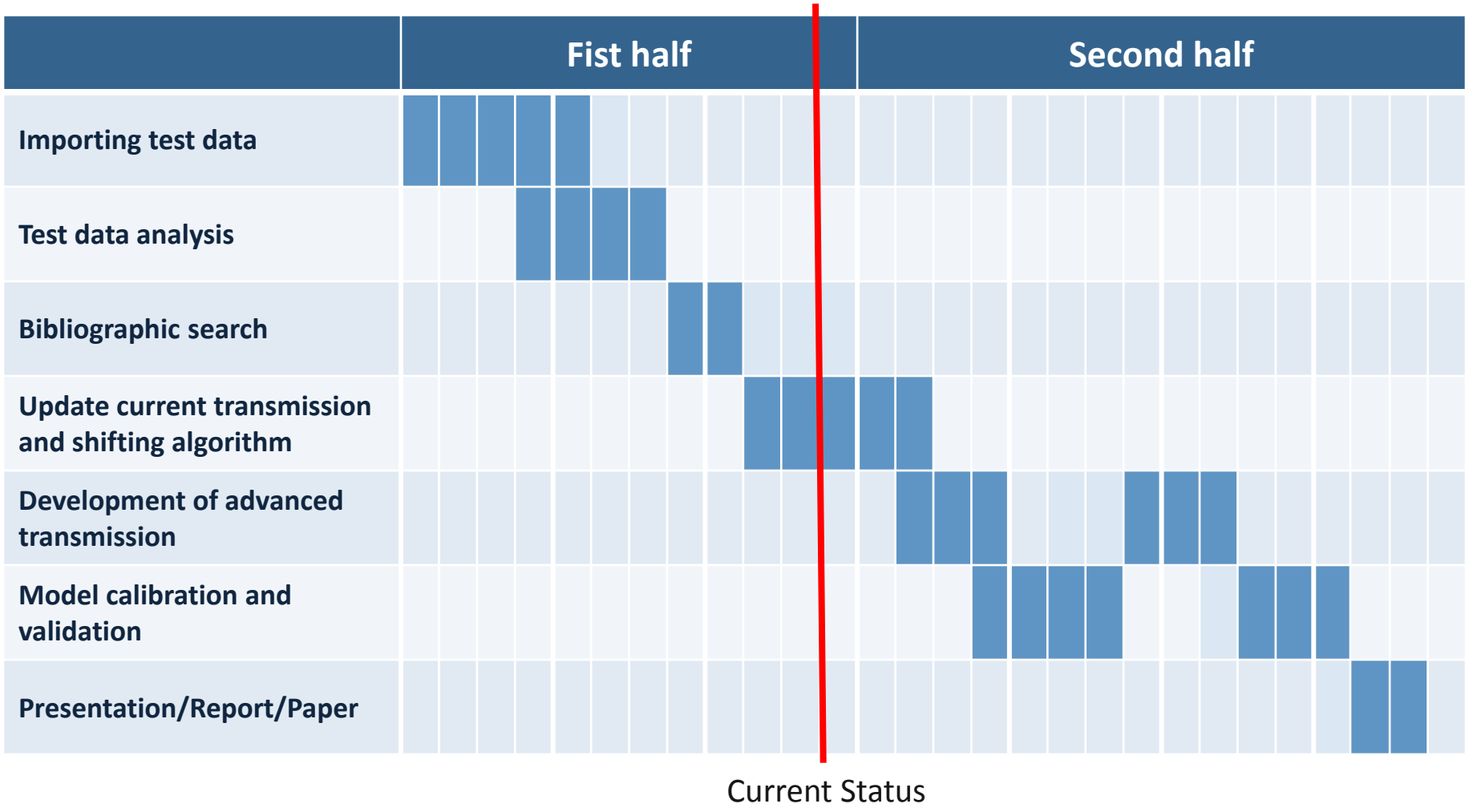
Diverse group of cars/transmissions used for the study

Year	Model	Type	TM	Engine	EM
2006	Honda CIVIC	HEV	**CVT**	L4 1.6L 82kW	15 kW
2007	Nissan Altima	HEV	**CVT**	L4 2.5L 118kW	105 kW
2009	VW Jetta 2.0 TDI	Conv	**DCT 6spd**	Diesel 2.0L 104kW	-
2010	Honda Insight	HEV	**CVT**	L4 1.3L 73kW	10 kW
2011	Hyundai Sonata	HEV	**AT 6spd**	I4 2.4L 154kW	30 kW
2012	Fiat 500	Conv	**AT 6spd**	L4 1.4L 83kW	-
2012	Ford Focus	Conv	**DCT 6spd**	L4 2.0L 119kW	-
2012	Ford Fusion V6	Conv	**AT 6spd**	V6 3.0L 179kW	-
2013	Chrysler 300	Conv	**AT 8spd**	V6 3.6L 224kW	-
2013	Hyundai Sonata	Conv	**AT 6spd**	I4 2.4L 154kW	-
2013	Nissan Altima	Conv	**CVT**	L4 2.5L 136kW	-
2012	Ford F-150	Conv (istop)	**AT 6spd**	V6 3.5L 272kW	-
2010	Mazda 3	Conv (istop)	**MT 5spd**	L4 2.0L 110kW	-
2010	Mercedes S400	HEV (micro)	**AT 7spd**	L6 3.5L 205kW	15 kW
2010	Mercedes Smart	Conv (istop)	**AMT 5spd**	L3 1.0L 44kW	-
2012	Peugeot 3008 Hybrid 4	HEV	**AMT 6spd**	Diesel 2.0L 120kW	27 kW

Approach


Update Current Transmission and Shifting Algorithm
Importing test data
Calculate missing signals and make a process functions for analysis
Model calibration and validation
Simulate vehicles
Update shifting strategy with the testing data for performance and shifting algorithm
OEM
Collect and integrate transmission data
ANL APRF
Advanced power train research facility
Vehicle testing work for advanced transmission
FY14
Provide accurate evaluation of VTP benefits guide future R&D
Adv. Transmission (for DCT, CVT)
Importing test data
Calculate missing signals and make a process functions for analysis
Development of adv. transmission
Develop the transmission model
Develop algorithm to select optimum gear numbers
Validation

Milestones


Fist half
Second half
Importing test data
Test data analysis
Bibliographic search
Update current transmission and shifting algorithm
Development of advanced transmission
Model calibration and validation
Presentation/Report/Paper
Current Status

Technical Accomplishment

Vehicle Test Data Imported in Autonomie for Analysis

ANL APRF

1. Import test data into Autonomie

2. Individual sensor evaluation

3. Sensor comparison

4. Calculate effort/flow from sensors

5. Signal comparison/ data analysis

Quality Analysis (QA)

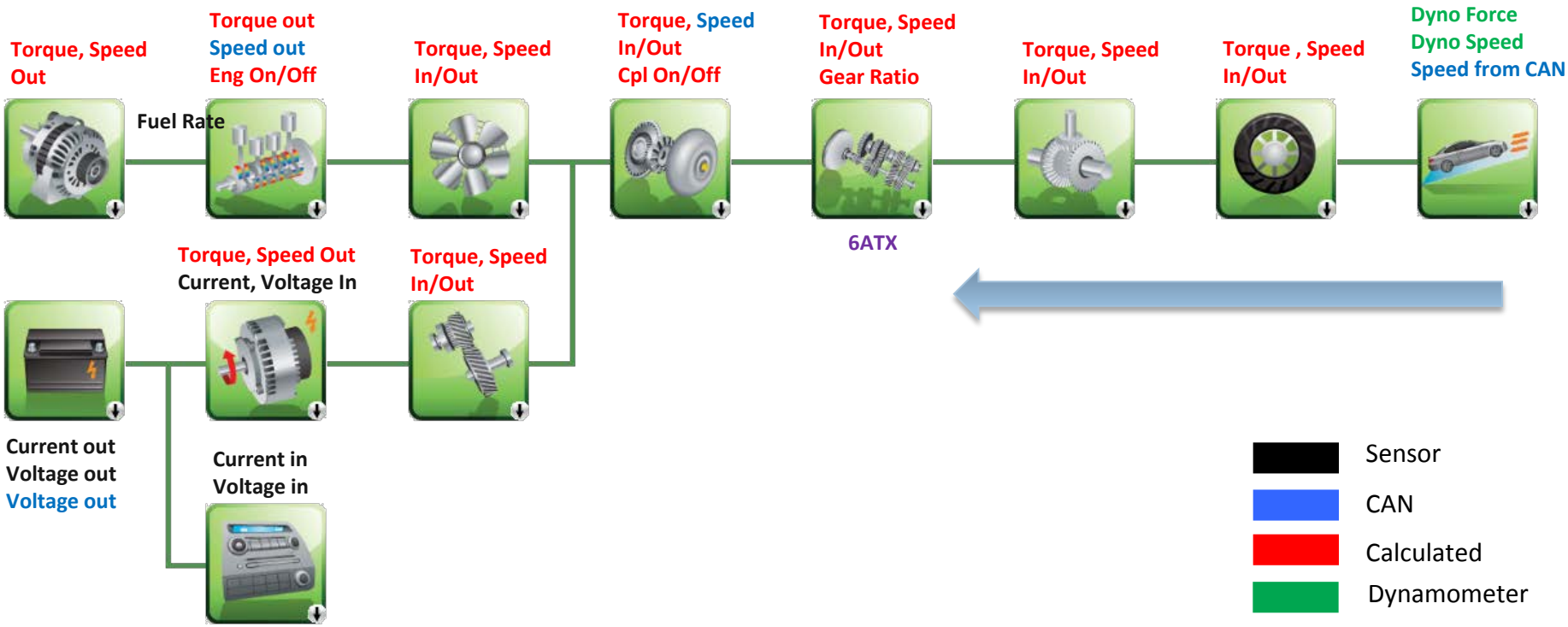
6. Shifting strategy

7. Model validation

Analysis & Validation

Technical Accomplishment
Missing Signals Calculated

- 2013 HMC Sonata Conv. I4 6 speed Automatic Transmission Example



- Calculate missing signals and make a process functions for analysis : Missing signals are computed from measured signals (using component data from Autonomie or OEM)
- The gear ratio is often not present in the data, so an algorithm has to be developed.

Technical Accomplishment
Algorithm Developed to Calculate Gear Ratio

- 2013 HMC Sonata Conv. I4 6 speed Automatic Transmission

Sonata 6ATX Gear Ratio : 4.212 2.637 1.800 1.386 1.000 0.772

Speed In (Measured from Turbine Speed)

Speed Out (Calculated from Vehicle Speed)

Gear Ratio Calculation

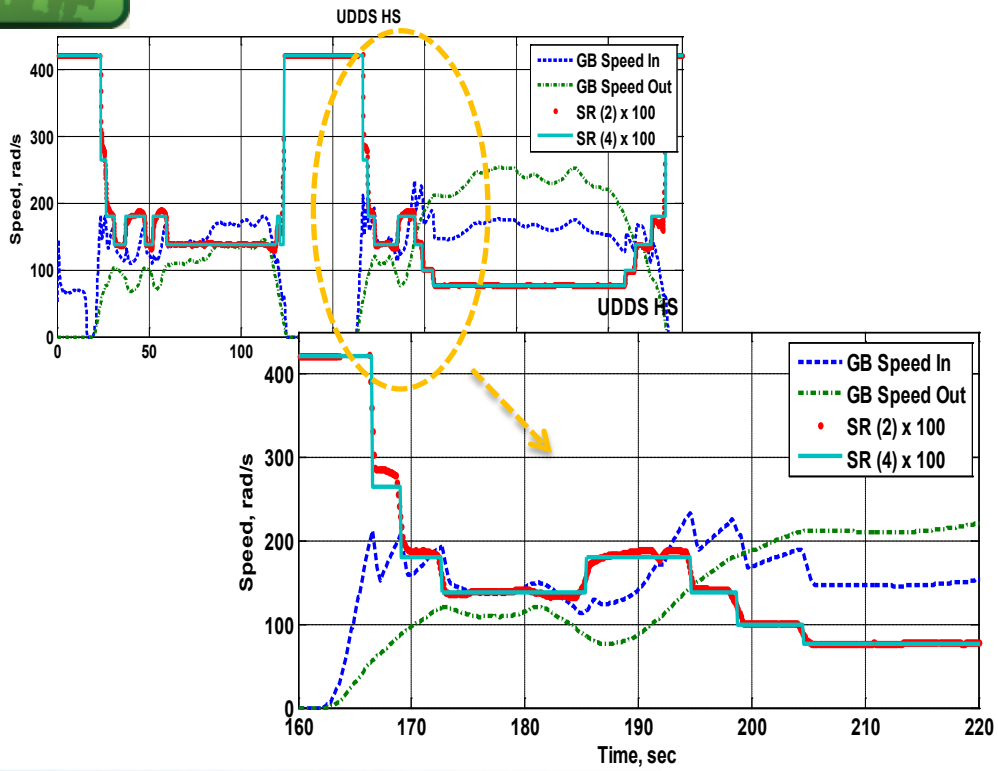
0) Signals are aligned based on vehicle speed

1) SR = Speed In (Measured from Turbine Speed) / Speed Out (Calculated from Vehicle Speed)

2) SR = 1st Gear Ratio when Vehicle Speed =0 & Engine speed < idle speed

3) Rounds the elements of SR to the nearest value of gear ratio that we know.

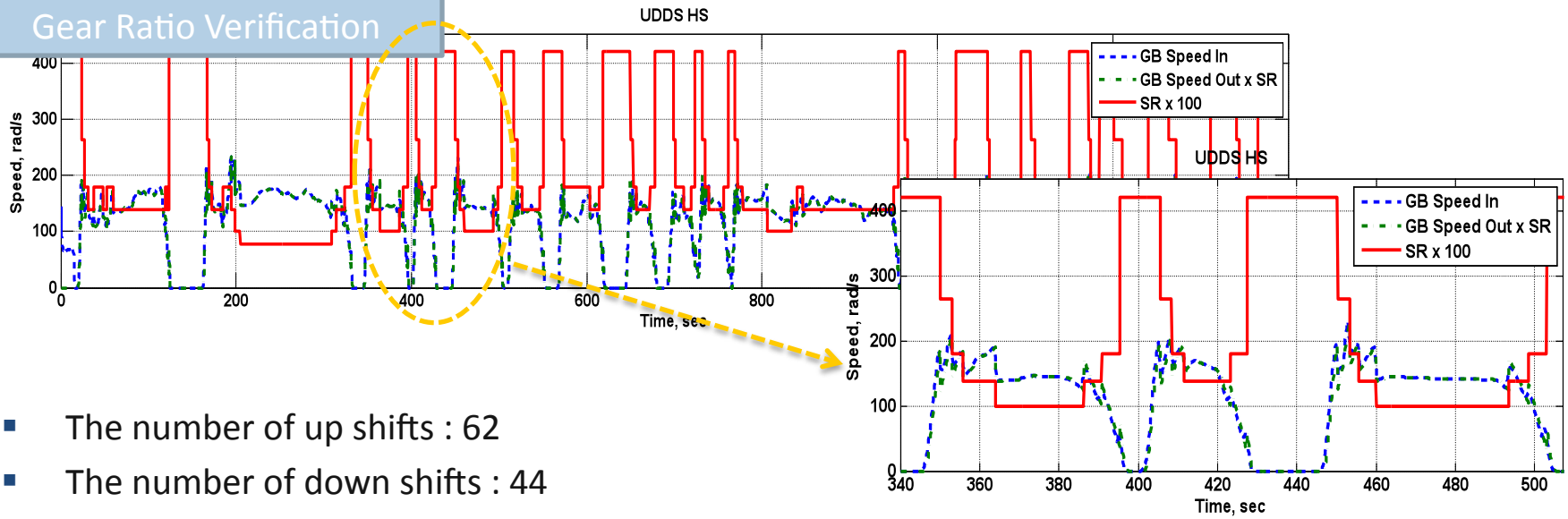
4) Filter out SR to keep current gear ratio for 0.8 sec (minimum)



Technical Accomplishment
Gear Ratio Algorithm Analyzed

- 2013 HMC Sonata Conv. I4 6ATX

Gear Ratio Verification



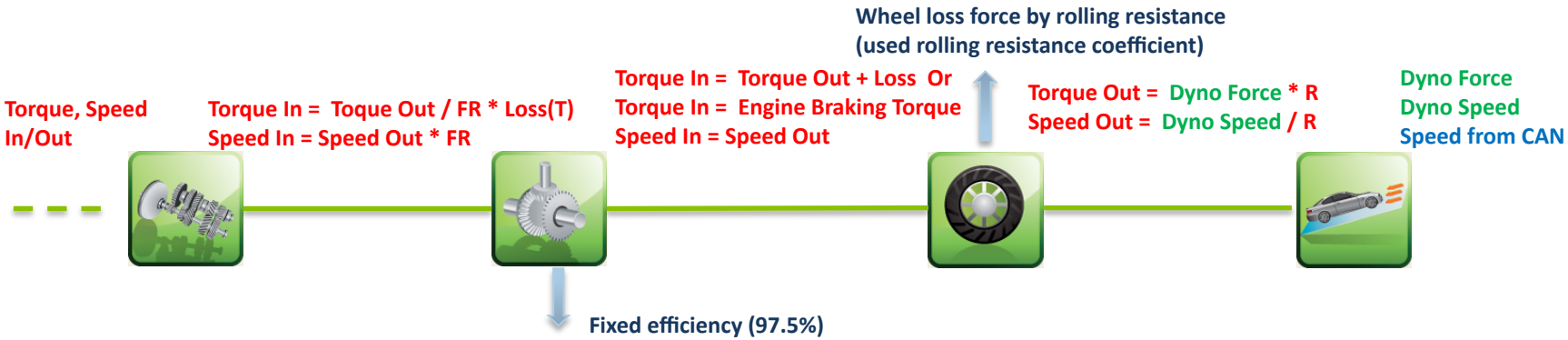
- The number of up shifts : 62
- The number of down shifts : 44
- The number of total shifts : 106

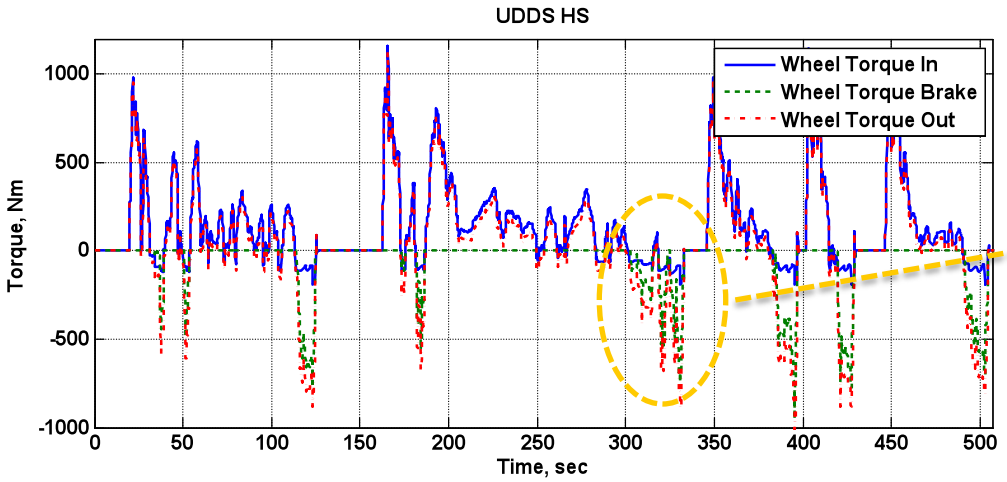
From ANL DOT NHTSA VOLPE Report : Numerous conventional vehicles were tested on the FTP cycle at Argonne's APRF. including the Fusion (6-speed); the Toyota Echo (5-speed); the Mercedes Benz S400 (7-speed); and the Volkswagen Jetta (7-speed DCT) .

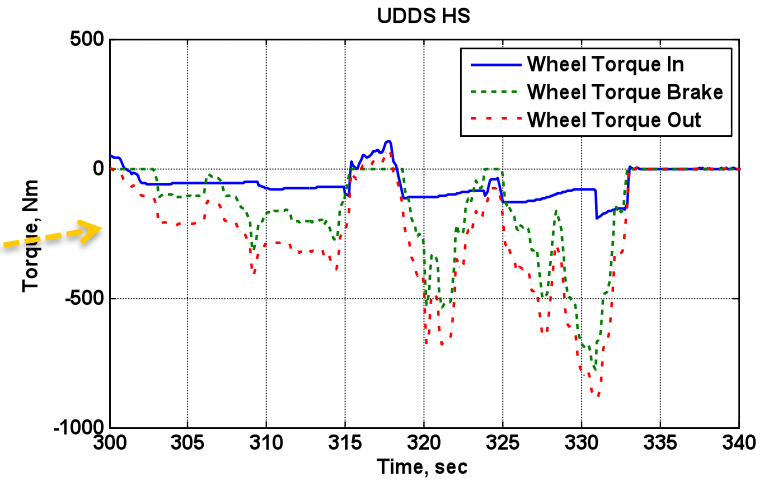
1) 5-speed automatic: 110 to 120
2) 6-speed automatic: 110 to 120
3) 7-speed automatic: 130 to 140
4) 7-speed DCT: 130 to 140

Technical Accomplishment
Effort-Flow for Each Component

- 2013 HMC Sonata Conv. I4 6ATX



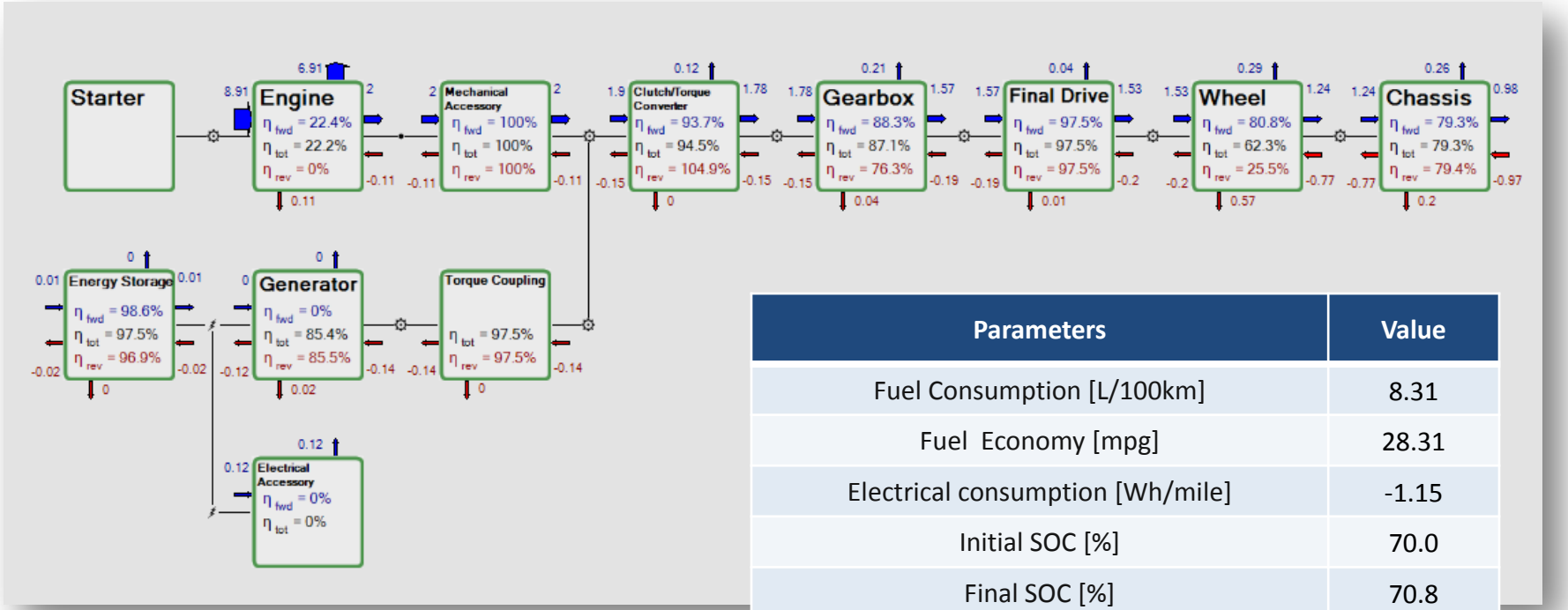




Technical Accomplishment

Energy Balance based on Available and Calculated Signals

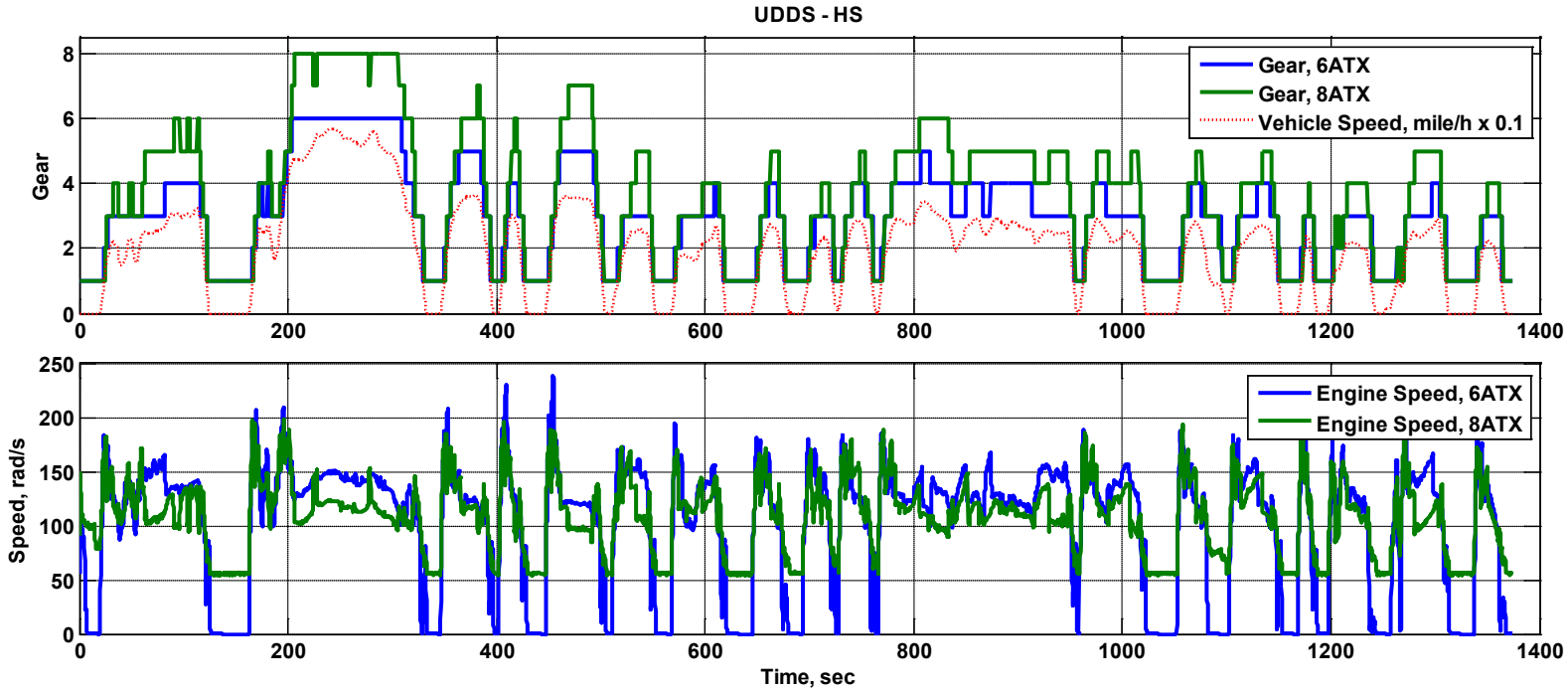
- 2013 HMC Sonata Conv. I4 6ATX – UDDS under 72F ambient temperature



Parameters	Value
Fuel Consumption [L/100km]	8.31
Fuel Economy [mpg]	28.31
Electrical consumption [Wh/mile]	-1.15
Initial SOC [%]	70.0
Final SOC [%]	70.8
The number of up shifts	62
The number of down shifts	44
The number of total shifts	106

Technical Accomplishment
Impact of Higher Gear Number

- F-150 6ATX vs. Chrysler 300 8ATX



Percent. (UDDS)	Gear 1	Gear 2	Gear 3	Gear 4	Gear 5	Gear 6	Gear 7	Gear 8
6 ATX	28.5	5.9	34.6	18.2	5.2	7.6	-	-
8 ATX	29.4	4.5	16.0	15.8	19.0	5.9	2.8	6.7

By lowering the engine rotational speed, the engine operating torque is expected to increase, leading to lower fuel consumption.

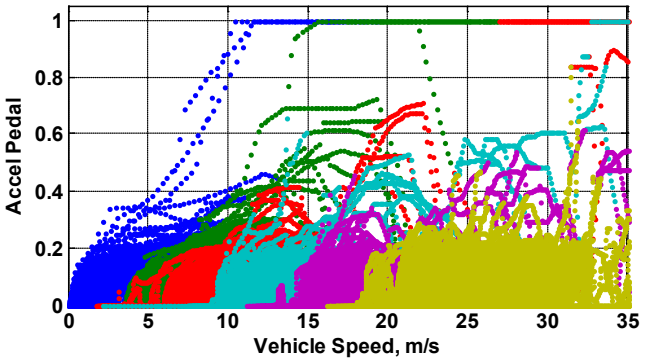
Technical Accomplishment
Impact of Transmission Technology

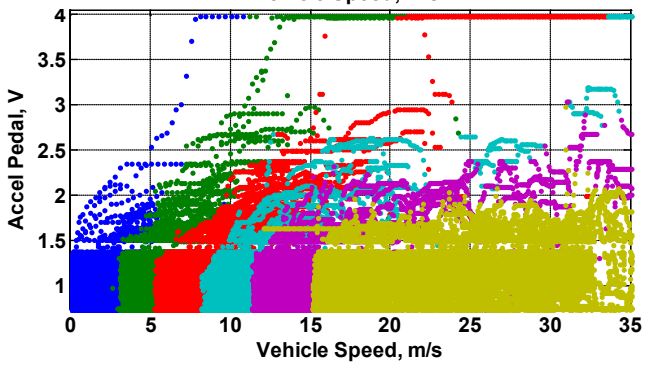
- Sonata conv. 6ATX vs. Focus 6 DCT vs. Altima conv. CVT

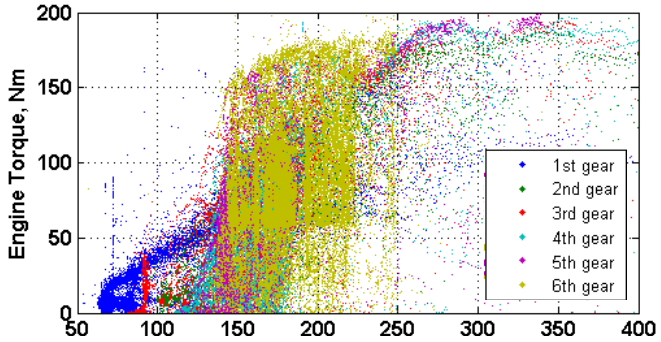
Sonata 6ATX

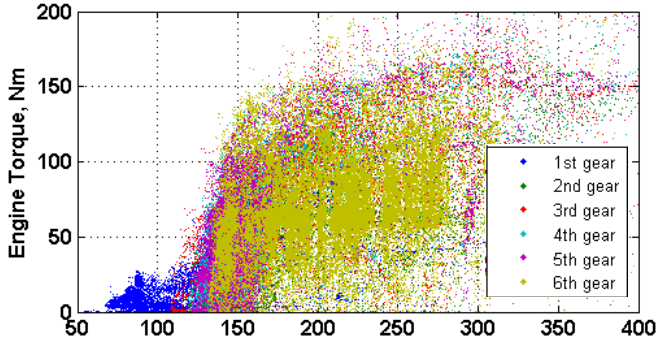
Focus 6DCT

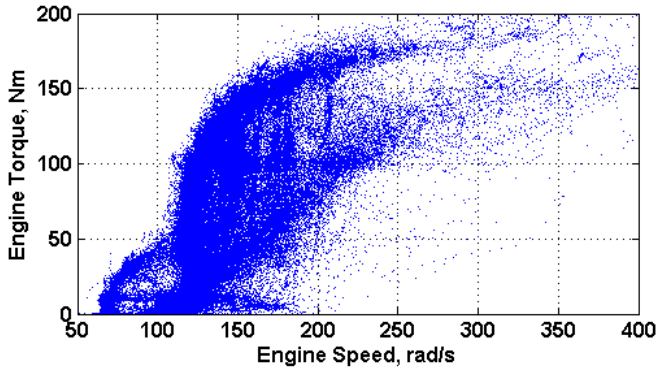
Altima CVT











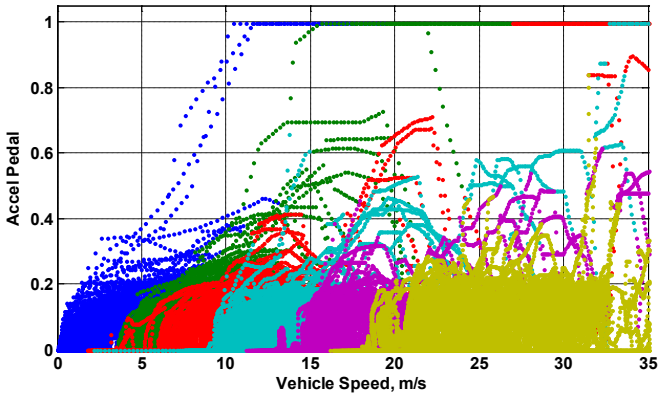
Shifting control rules can be discerned from pedal, v.speed and engine data

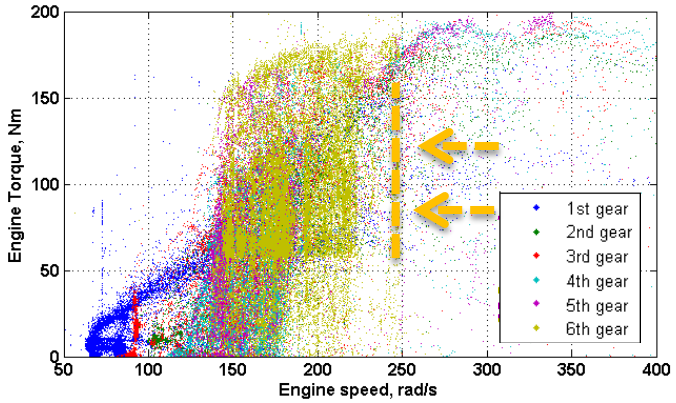
Technical Accomplishment
Impact of Powertrain Configuration for Similar Transmissions

- Sonata conv. 6ATX vs. Sonata HEV 6ATX

Sonata Conv 6ATX

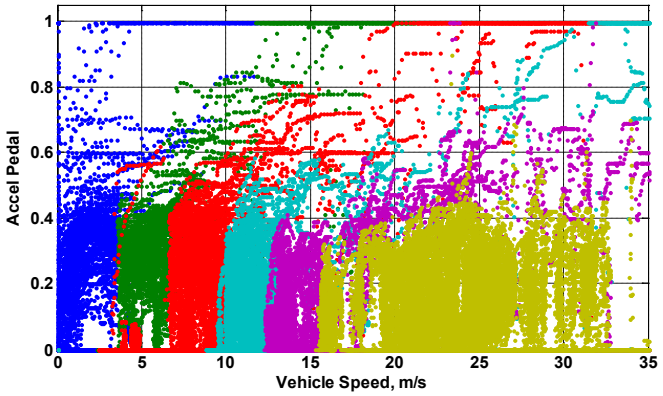
1st : 4.21
2nd : 2.64
3rd : 1.80
4th : 1.39
5th : 1.00
6th : 0.77
FD : 2.89

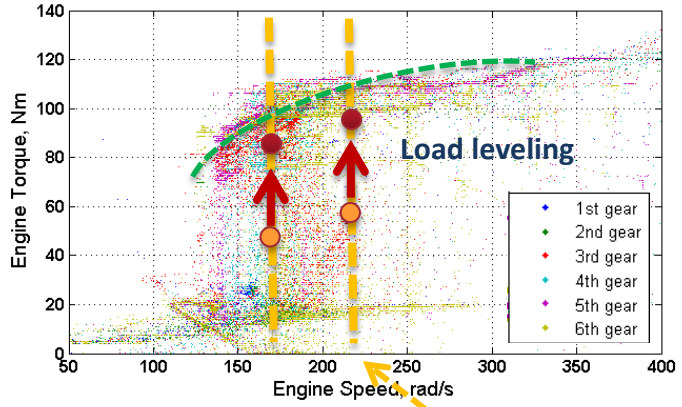




Sonata HEV 6ATX

1st : 4.21
2nd : 2.64
3rd : 1.80
4th : 1.39
5th : 1.00
6th : 0.77
FD : 3.32

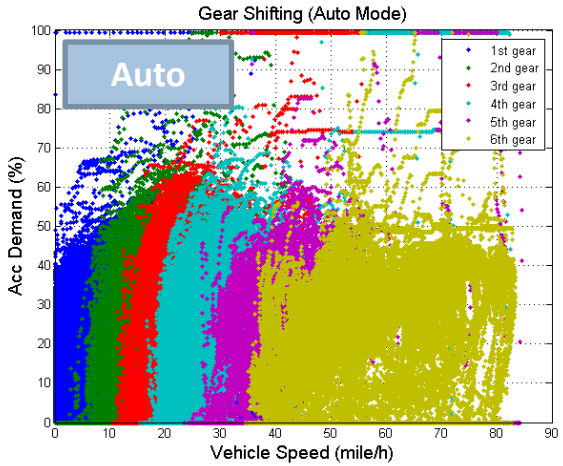


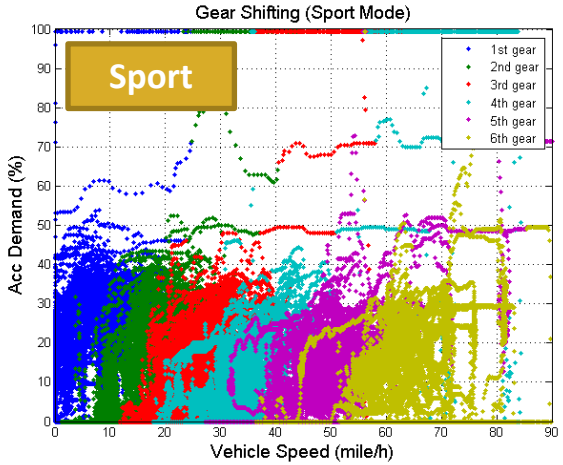


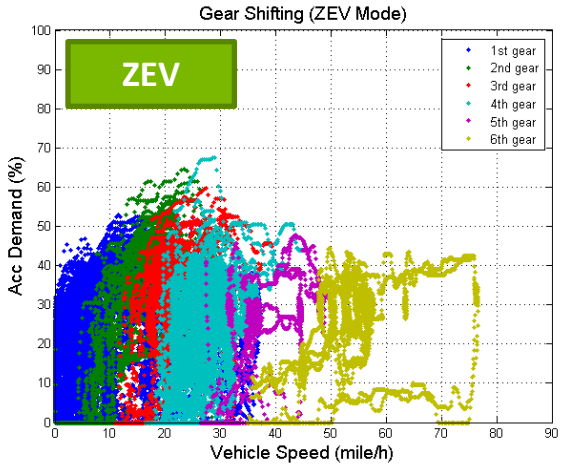
By shifting maps

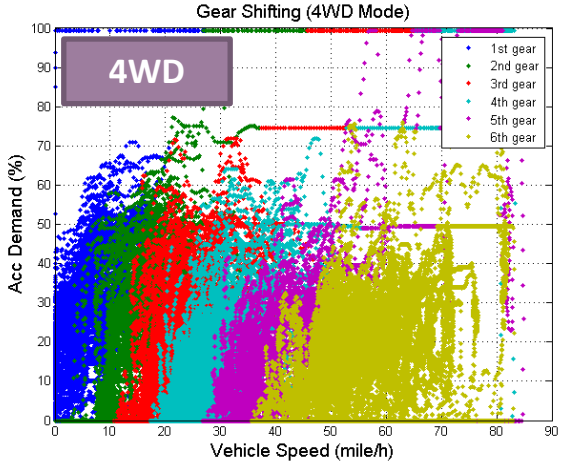
Technical Accomplishment
Impact of Shifting Modes

- 2013 PSA HEV4 6AMT – One of the modes can be selected manually.









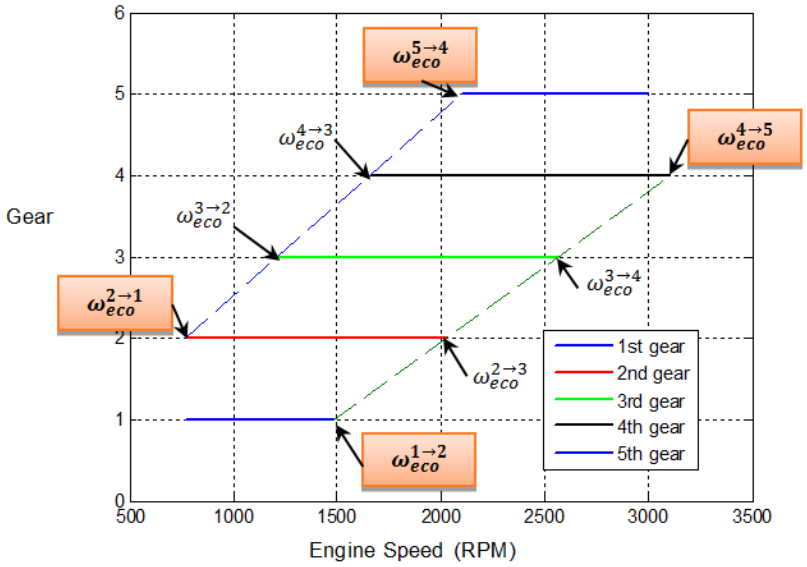
Sport mode uses an agressive shifting map.

Auto mode map is similar to ZEV mode

Technical Accomplishment
Shifting Control Algorithms in Autonomie

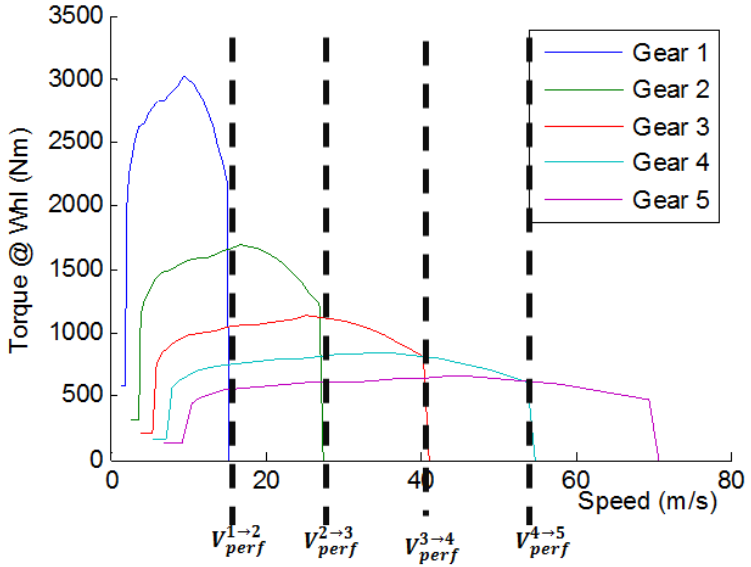
- The shifting initializer defines the shifting maps (i.e., values of the parameters of the shifting controller) specific to a selected set of component assumptions.

Economical Shifting Speeds — At very low pedal position



Example of engine speed range in economical driving, and economical shift

Performance Shifting Speeds — At high pedal position



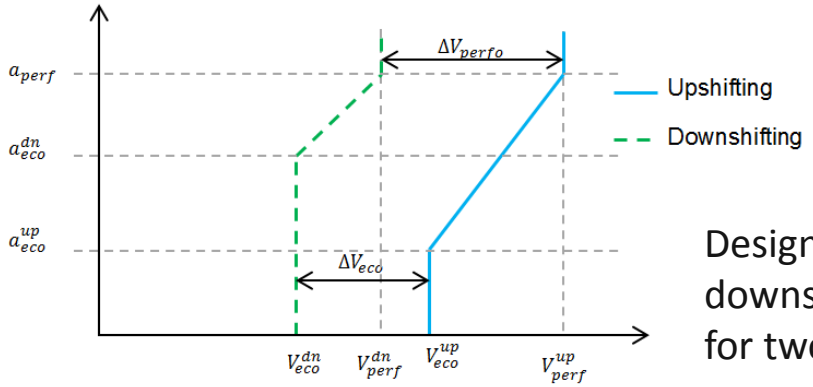
Maximum engine torque at wheels and performance upshift speeds

Technical Accomplishment
Shifting Control Algorithms in Autonomie

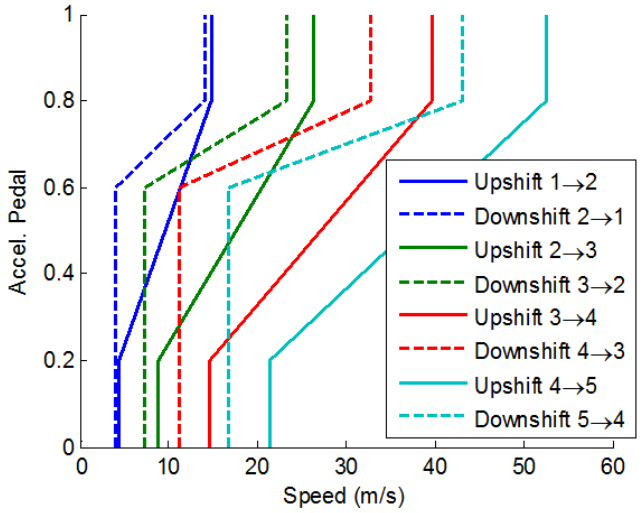
- Final shifting curves

Economical Shifting Speeds

Performance Shifting Speeds



Design of upshifting and downshifting speed curves for two adjacent gears



Shifting speed curves for a default light-duty vehicle in Autonomie

Collaboration and Coordination with Other Institutions

Vehicle Testing Data (APRF)

Component Data (OEM)

AUTONOMIE

Fuel Consumption & Cost Analysis

R & D Directions

DOE technology evaluation

Proposed Future Activities

- **On going work for FY13**
  - Update current transmission models and shifting algorithm in Autonomie
  - Calibrate and validate the models and controls
  - Develop advanced transmission model (i.e. Dual clutch transmission)
  - Develop and validate shifting algorithm to select optimum gear numbers for future transmissions

- **Proposed Future Work**
  - Expand collaborations
    - Validate additional transmission technologies (e.g., 8+ ATX, wet DCT, dry DCT) working with OEMs, government agencies and ANL's APRF (testing of vehicles with several powertrain)
    - Continue to develop specific advanced transmissions by integrating higher fidelity models, including thermal behavior
    - Evaluate fuel consumptions benefits of advanced technologies
  - Support future medium and heavy duty regulations

Summary

- A process has been developed and implemented to import a wide range of vehicle test data from Argonne APRF representing different transmission technologies in Autonomie.
- Algorithms were developed to calculate missing signals (i.e. gear number).
- Post-processing tools were developed to quickly analyze shifting algorithms from the wide range of data sets, including:
  - Impact of gear number (i.e. AT 6spd vs. AT 8spd)
  - Impact of transmission technology (i.e. 6ATX vs. 6DCT vs. CVT)
  - Impact of powertrain configuration (i.e. Conv 6 ATX vs. HEV 6 ATX)
- Future work will focus on validating the current shifting algorithm in Autonomie for the wide range of transmission considered.
- The updated/new models and controls will be used to evaluate the benefits of VTP developed technologies.