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Heavy Duty Vehicle Modeling & Simulation

2009 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 19, 2009

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Sponsored by Lee Slezak

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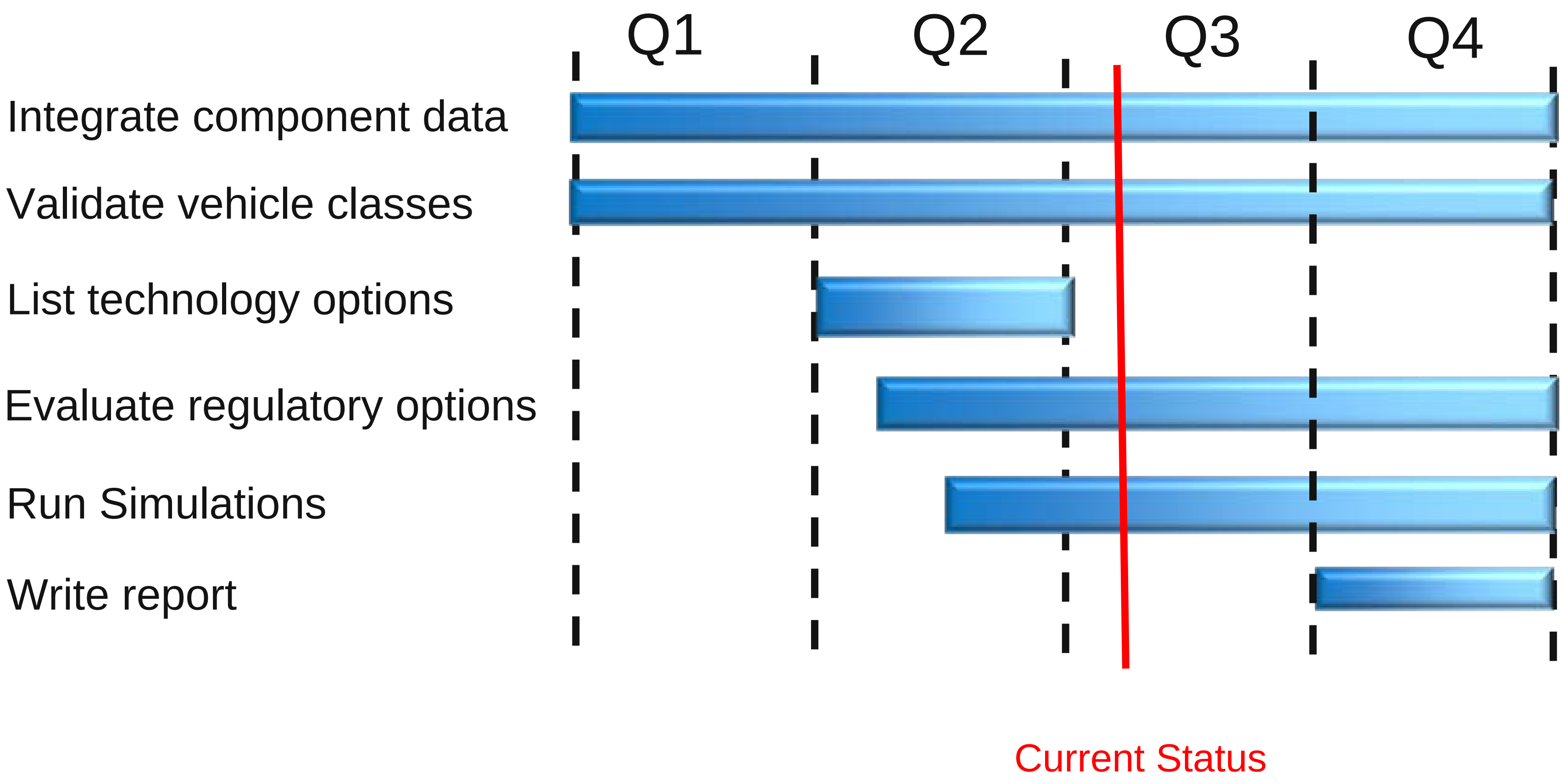
Main Objectives

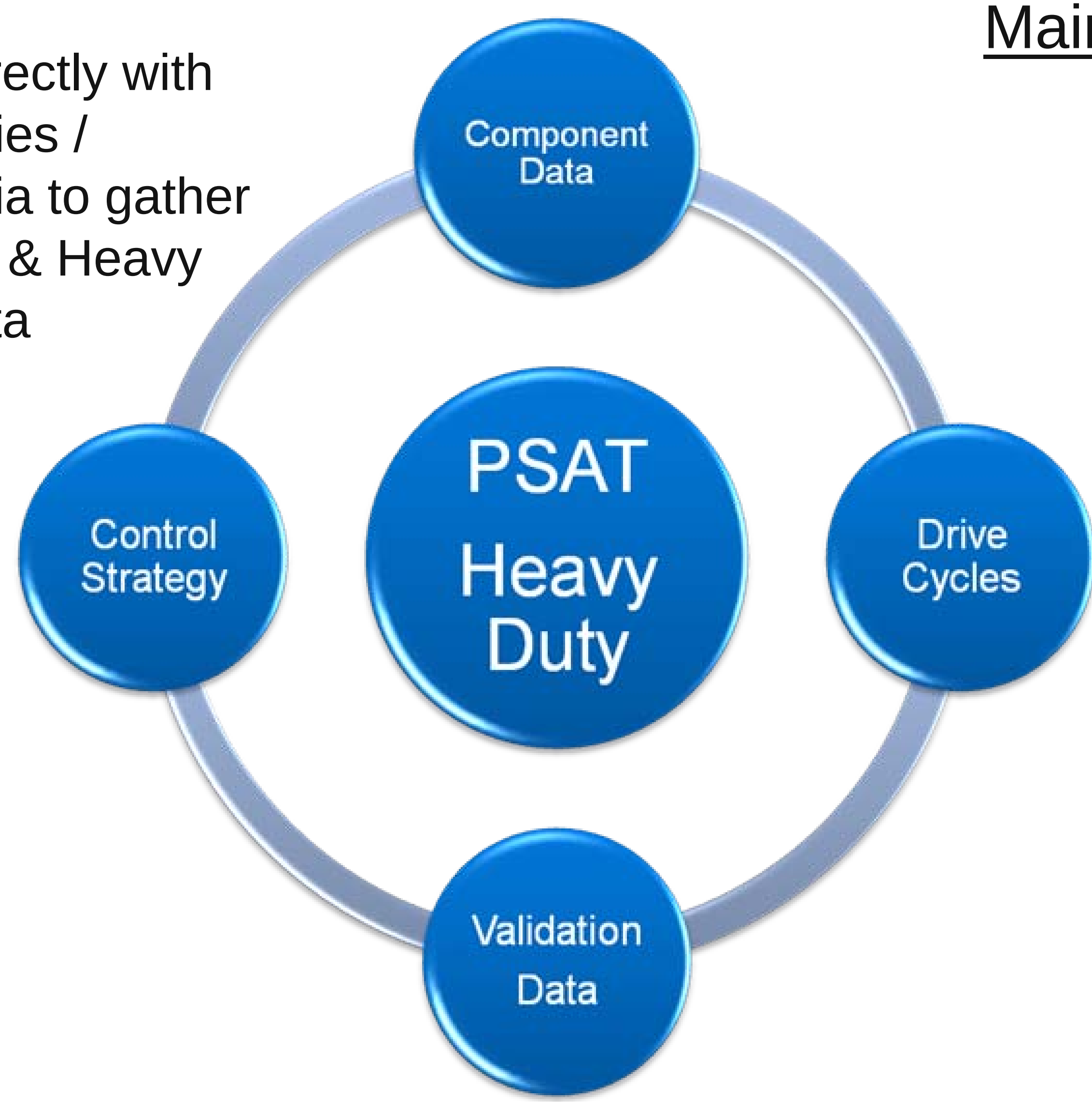
- Evaluate benefits of DOE research on medium and heavy duty vehicles
- Develop heavy duty version of PSAT/Autonomie to support DOE R&D activities
- Integrate specific data, models, controls for heavy duty
- Validate several heavy duty vehicle classes
- Integrate specific features for heavy duty
- Support future regulatory needs
- Support EPA SmartWay activities

Milestones


Q1
Q2
Q3
Q4
Integrate component data
Validate vehicle classes
List technology options
Evaluate regulatory options
Run Simulations
Write report
Current Status

Approach

Work directly with companies / academia to gather Medium & Heavy Duty data

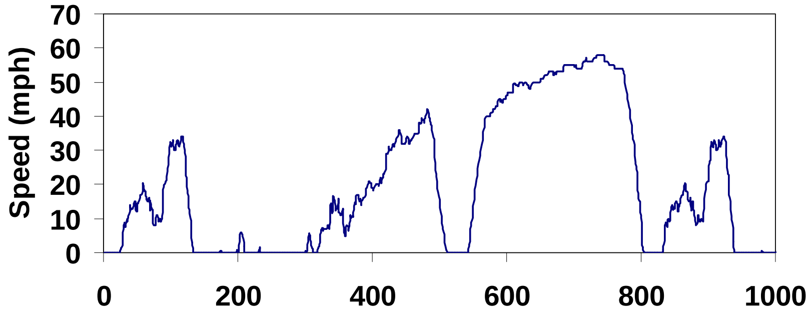


Main Partners / Users

Allison Transmission
CAFEE Center for Alternative Fuels, Engines & Emissions West Virginia University
Cummins
International
PACCAR Inc
CAT
KENWORTH
ArvinMeritor
DANA
OSHKOSH
Enova
John Deere

PSAT Validation: Details of Tractor Truck Data from Chassis Dynamometer Tests and On-Road Tests

Vehicle Model Year	1996
Test weight (lb.)	56000
Odometer Reading	441097
Transmission Type	Manual
Transmission Model	RTLO 20918, 18 speed
Engine Type	Caterpillar 3406E
Engine Model Year	1996
Engine Disp. (Liter)	14.6
Number of Cylinders	6

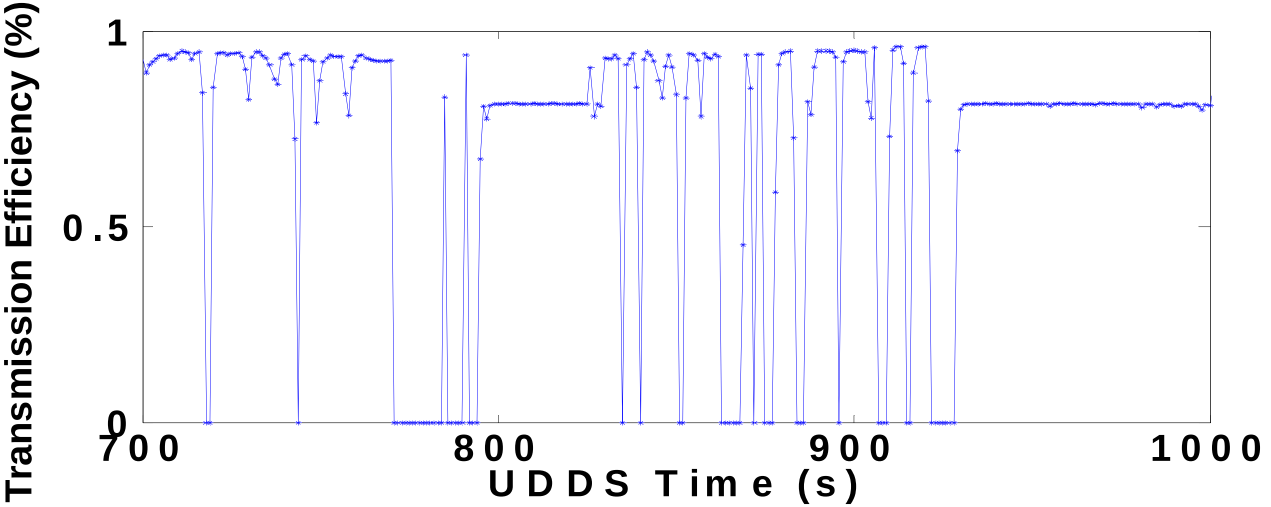


UDDS Used for Chassis Dynamometer Testing

Modeling and Validation of Peterbilt Truck

Component data development

- Engine map
- Auxiliary loads, including fan load.
- Vehicle losses developed to match chassis dynamometer.
- The transmission ratios and efficiencies were documented.



- **This vehicle was also simulated on a road route, PA43, as well as chassis dynamometer cycles.**

Comparison of Actual and Predicted Results

On-road result variability can be attributed in part to lack of knowledge of real rolling resistance and aerodynamic factors. For the chassis UDDS these factors were known.

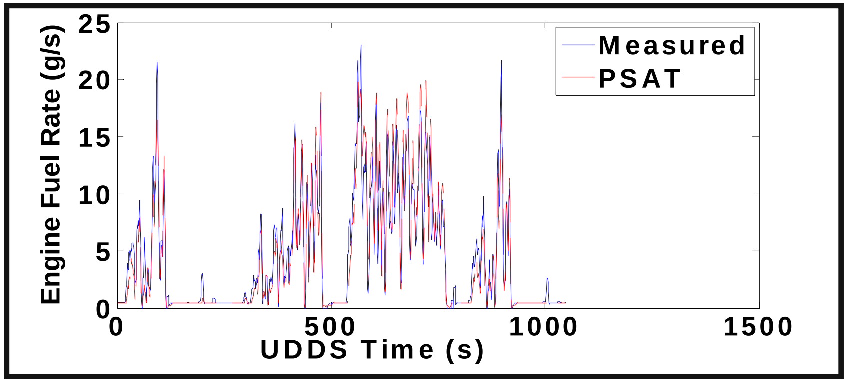
PSAT Validation With Chassis (Test weight 56000 lb)

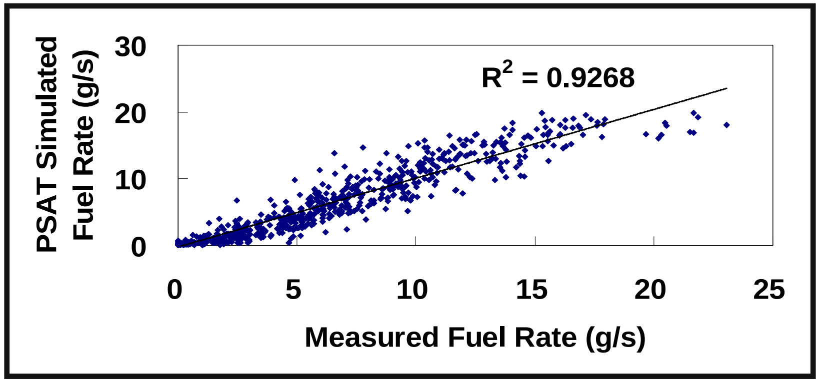
Parameters	Measured	PSAT Simu.	Relative % Error
UDDS Cycle (mile)	5.44	5.37	1.29
Fuel Econ. (MPG)	3.82	3.82	0.00
Fuel Mass (kg)	4.58	4.52	1.31
Eng. Fuel Rate (g/s)	4.40	4.30	1.27
CO_2 (g/mile)	2639.8	2685.5	-1.73

PSAT On-road Test Results (Test weight 79700 lb)

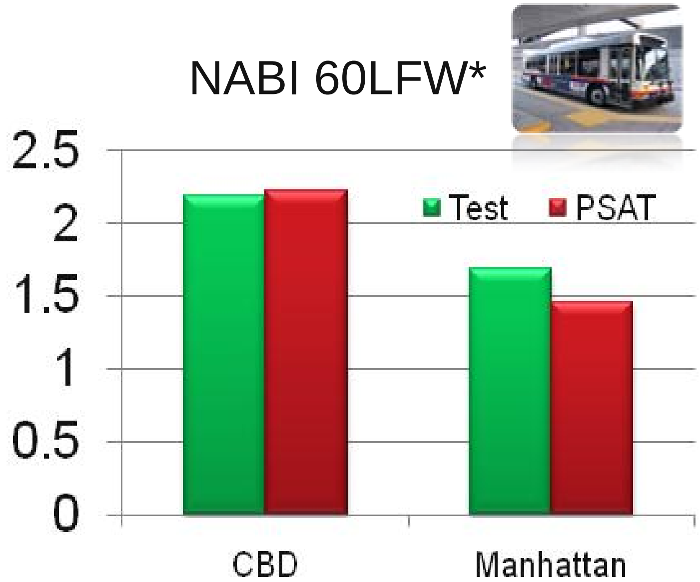
Parameters	Measured	PSAT Simu.	Relative % Error
P 43 Route (mile)	19.54	19.44	0.61
Fuel Econ. (MPG)	4.26	4.20	1.41
Fuel Mass (kg)	14.42	14.88	-3.19
Eng. Fuel Rate (g/s)	9.40	9.80	-4.26
CO_2 (g/mile)	2180.7	2445.4	-12.13

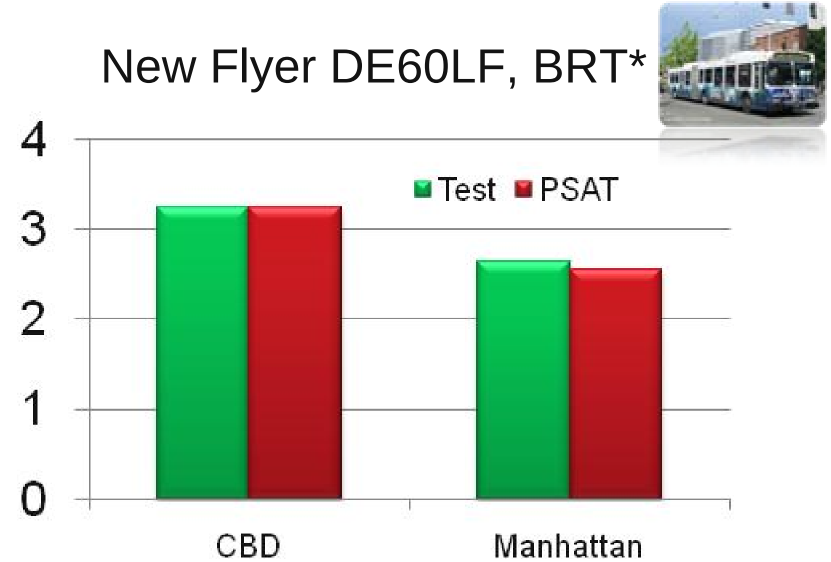
*Note: Engine fuel rate, engine torque, engine speed, engine power and vehicle speed are all average values





PSAT Has Been Correlated for Several Additional Vehicle Classes





Other correlated vehicle classes include, but not limited to

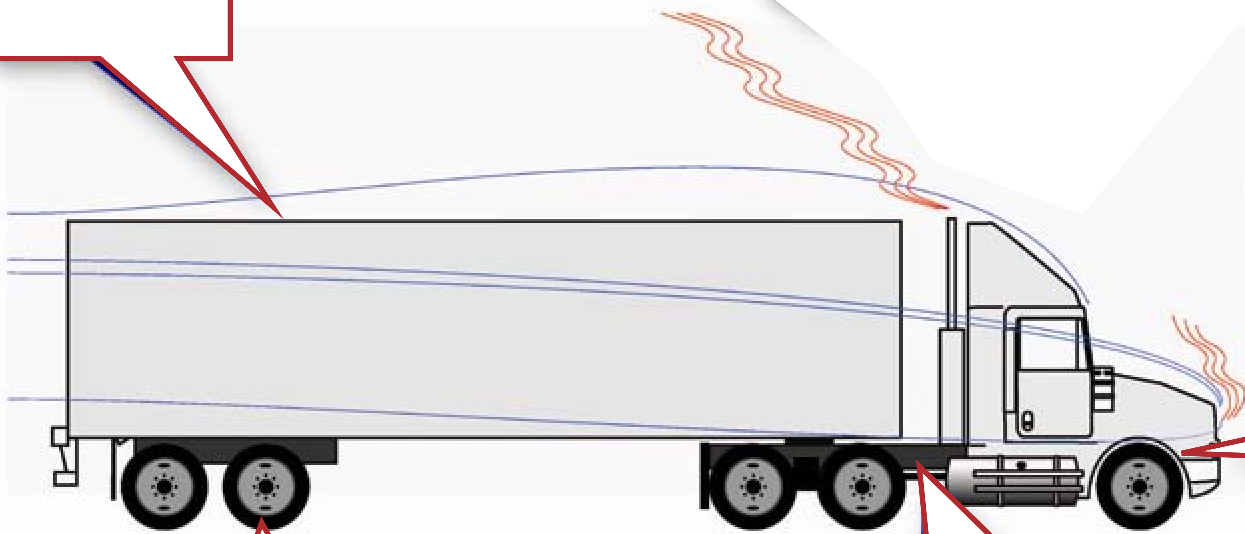
* Data provided by Herbert Fox (NYIT)

Study Performed to Update Class 8 Energy Balance for 21CTP

Total Fuel Energy Consumption Rate
(65 mph, 80000 lbs)
440 kW

- Engine Power Required
  183 kW
- Engine Efficiency
  41.3 %
- Engine Losses
  257 kW

Aerodynamic losses
93 kW



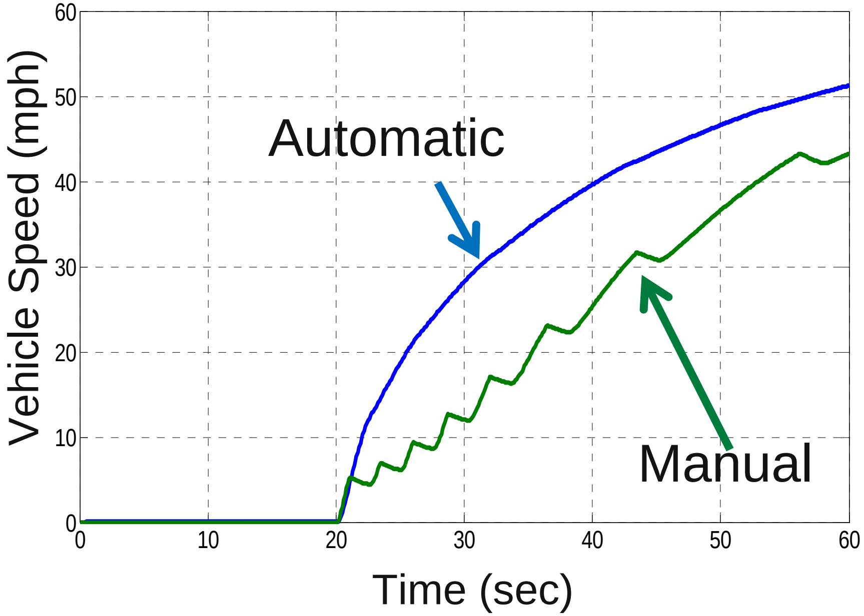
Auxiliary Loads
10 kW

Rolling
Resistance
70 kW

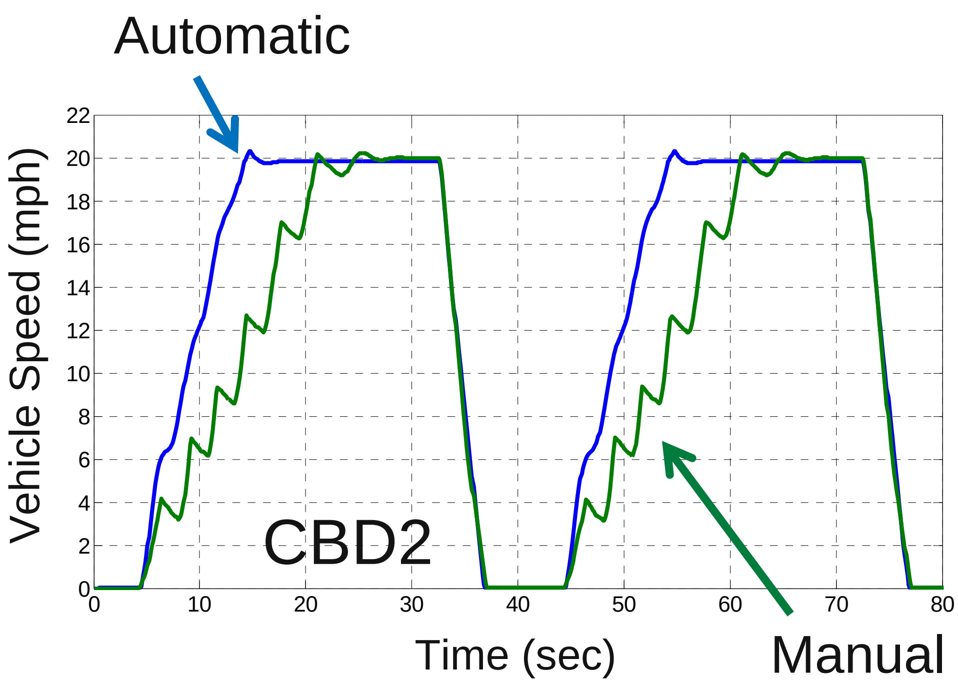
Drivetrain
9 kW

Powershifting Automatic Transmission Follows the Trace Better…

Performance Comparison



Drive Cycle Comparison



Conventional City Bus
Same engine used

But Achieves Lower Fuel Economy

	Distance (miles)	Average Vehicle Speed (mph)	Fuel Consumption (mpg)
Automatic	1.99	12.6	3.89
Manual	1.66	10.5	3.99

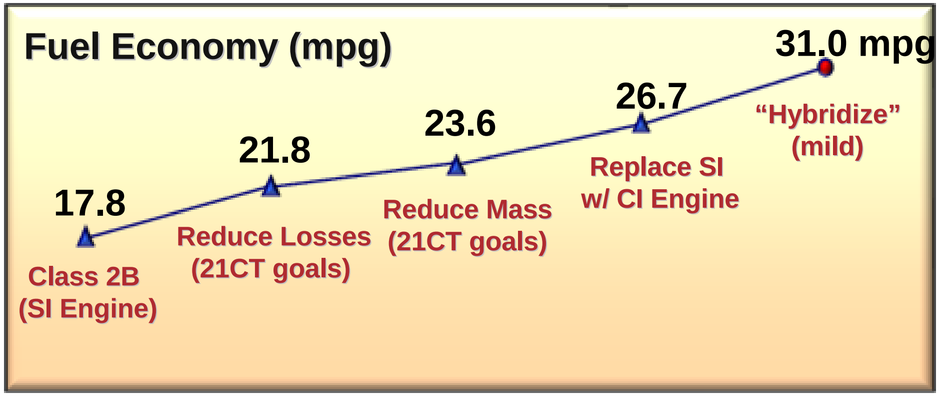
The manual does not follow the drive cycle!

- The manual produces a lower average vehicle speed, which means the manual does less work.
- Fuel Efficiency is the ratio of work to fuel, which fuel economy (mpg) alone does not measure

Fuel Economy alone is a NOT good metric for trucks
=> Need to evaluate different cycles and metric options

PSAT Has Been Successfully Used to Assess Heavy Duty Vehicle Fuel Efficiency

Impact of Advanced Technologies
for Class 2B



- **Additional Studies Performed with Companies Include:**
  - Drivetrain configuration comparison
  - Control strategy development
  - Performance during acceleration and grade
  - Drive cycle impact

Assessing Options for Fuel Efficiency Regulations

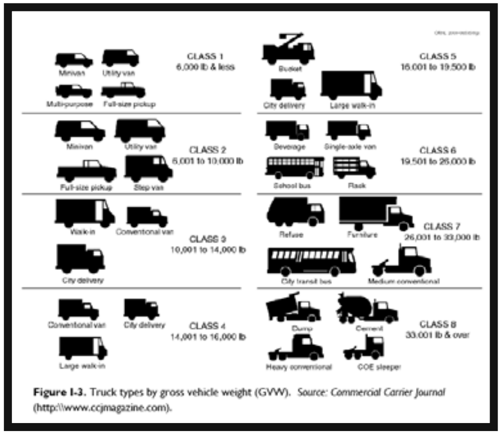
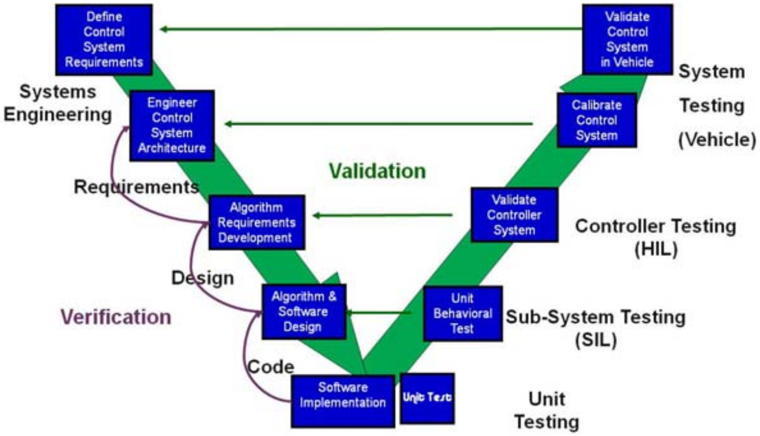


Figure I-3. Truck types by gross vehicle weight (GVW). *Source: Commercial Carrier Journal* (http:\\www.ccjmagazine.com).

Too many vehicle options
=> Combination of model & test should be used

V&V Model Applied to Software



Maturity of technology and model will define what process should be used (MIL, SIL, HIL, RCP, vehicle testing…)

Heavy Duty Vehicle Simulation Challenges

- How do we manage hundreds or thousands of possible options? (e.g., powertrain options, auxiliaries…)
- How do we ensure common definition of processes (e.g., what does validation mean?)
- How do we decide appropriate level of modeling?
  - Should drive quality be included since it influences fuel efficiency?
  - Should steady-state, zero-dimensional or 1D plant models be used?
  - Does the level of modeling different for each Class?
  - How do we allow model reusability and sharing?
- How do we manage information from so many different sources?
  - What type of database management?
  - How do we handle proprietary information?
- How do we ensure that we can seamlessly perform MIL, SIL, HIL, RCP?
- How can we minimize number of drive cycles?
- How do we compare dynamometer and real world results?

Future Activities

- Continue collaboration with Medium & Heavy Duty companies to accelerate validation of considered vehicle classes.
- Define list of component and powertrain technologies to be considered for each classes.
- Define the drive cycles for each application.
- Analyze the efficiency benefits of different technologies.

Summary

- Several vehicle classes correlated using company's test data.
- Specifics of heavy duty application assessed:
  - Model requirements
  - Fuel efficiency…
- Evaluation of advanced technologies on-going.
- Consider options to fairly compare efficiency when vehicles do not follow drive cycles.
- Evaluation of different metric options.
- Requirements were added to Autonomie to ensure specific needs needs of Heavy Duty Trucks are better