EVALUATION OF THE CO_2 EMISSION IMPACTS OF USING VEHICLE SPEED LIMITERS (VSL) ON CLASS 8 HEAVY-DUTY ON-ROAD TRUCKS

California Air Resources Board

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7th International PEMS Conference & Workshop

March 30 & 31, 2017

California Environmental Protection Agency

Air Resources Board

Outline

* Background
* Limited Existing On-Road Data
* CARB In-House VSL Testing Project
  * First On-Road VSL Testing
  * On-Road Data Analysis
  * Main Conclusions

Background

* Long history of limiting vehicle speeds to reduce fuel consumption, and for safety
  * Through roadway speed limits
  * Through on-vehicle speed governors, electronic controls
* Federal Phase 2 GHG standards allow emissions reduction credit for the use of tamper-proof VSL on heavy-duty vehicles

Limited Existing On-Road Data

* Transportation Energy Data Book - Oak Ridge National Laboratory (ORNL)*:
  * Evaluate fuel efficiency as function of vehicle tires
  * However, show an unexpected result – better fuel economy at higher speed
* Available PEMS studies of heavy-duty trucks:
  * Highly transient data between 45 and 70 mph, hence not directly comparable to steady-state highway driving
* EMFAC 2014 (CA on-road emissions modeling) assumptions – lack of emission data at speed > 60mph

→ In-house VSL study needed to assess VSL's impact on emissions

*(ORNL, 2008) Oak Ridge National Laboratory, "Transportation Energy Data Book," Class 8 Trucks Fuel Economy as a Function of Speed and Tractor-Trailer Tire Combination and Percentage of Total Distance Traveled as a Function of Speed (Table 5.11), available at http://cta.ornl.gov/data/chapter5.shtml; "Class-8 Heavy Truck Duty Cycle Project Final Report," available at http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008-122.pdf

CARB In-House VSL Testing Project

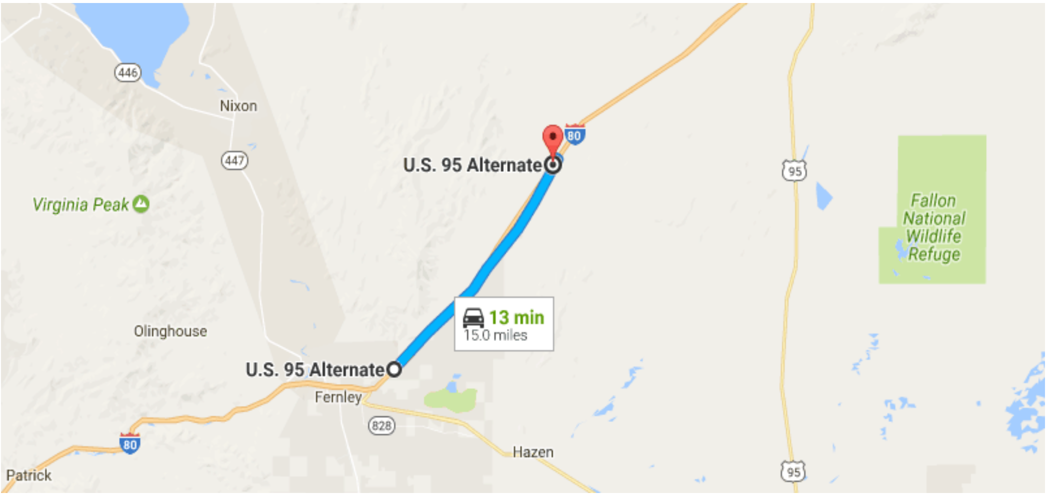
- Objectives: test heavy-duty trucks at various cruising speeds (45-80 mph) under steady conditions
  - Evaluate the applicability and CO_2 impacts of VSLs on Class 8 vehicles at highway speed
  - Support CARB's Phase 2 GHG regulation development – harmonization with federal Phase 2 requirements, with minor California differences
  - Refine assumptions in the EMFAC model
  - Support future sustainable freight strategies
- Still an on-going project

VSL Project Testing Schedule

Test	Number of Tested Tractor-Trailers	Test Month	Status
Chassis Dynamometer Testing	1 (2008 MY Kenworth Sleeper Cab)	September 2016	Completed
First On-Road PEMS Testing: • coast-down test • constant-speed test	1 (2008 MY Kenworth Sleep Cab with 48-foot Curtain Trailer)	October 2016	Completed
• Chassis Dynamometer Testing • Second On- Road PEMS Testing (constant-speed test)	2 (2013 or newer tractors with 53-foot box trailers)	Spring 2017 (Upon procured vehicles' availability)	Not yet done

First On-Road VSL Testing

* Test Site:
  * Straight, flat I-80 highway segment in Fernley, Nevada: between Exit 50 – Nevada Pacific Boulevard and Exit 65 – Nightingale Hot Springs
  * Test length ~7 miles; test stretch average road grade ~ +/- 0.4%, average elevation ~4,030 ft.
  * Highway speed limit for a tractor-trailer up to 80 mph for this road section



Test Vehicle and Instrument Description

* Test vehicle:
  * 2008 Kenworth T660 (CARB-Owned)
  * 48-foot curtain trailer
  * Super single tires on tractor and trailer
  * Total combined weight tractor and trailer: 34,880 lbs.

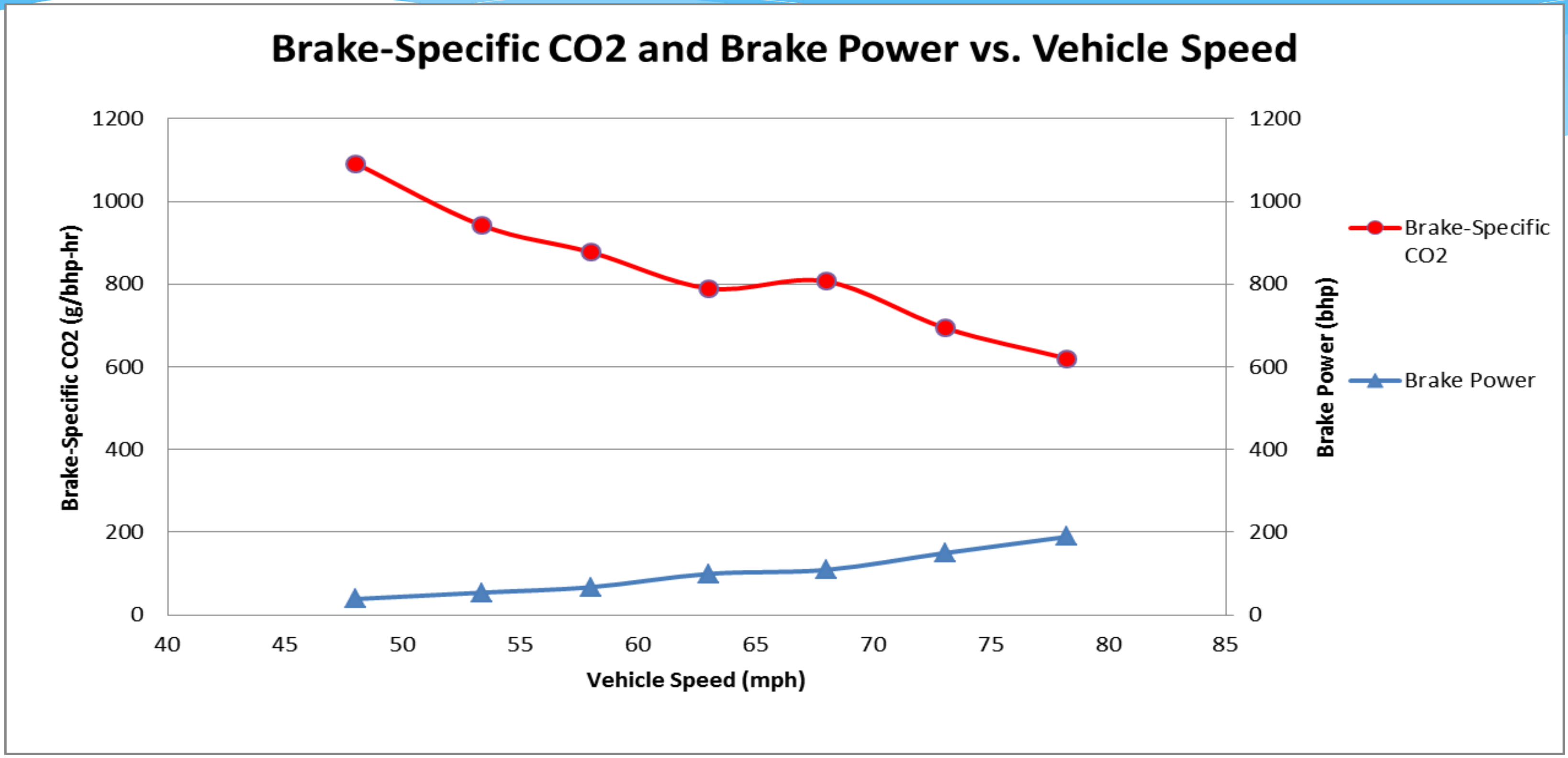
* Test instrument:
  * J 1939 Dearborn Vehicle Interface
  * Sensor Semtech DS
  * Sensor High-speed Flowmeter
  * Zero, Spans, and Audits once every hour
  * Measuring CO, CO_2, NO, NO_2, THC
  * Wireless Weather Station: Davis – 6250 Vantage Vue

On-Road Testing

* Coast-down testing: from 80 mph to 40 mph
* Constant-speed testing:
  * 7 test speeds (48, 53, 58, 63, 68, 73, and 78mph)
  * Chose optimal gear for each speed (11^{th} gear for 48 mph, 12^{th} gear for 53 mph, and 13^{th} gear for 58-78 mph)
  * Used cruise control to maintain constant speed
* Ambient Condition:
  * Temperature : 50-76F; atmospheric pressure: 26in. Hg; wind speed: 0-11mph

On-Road Data Analysis

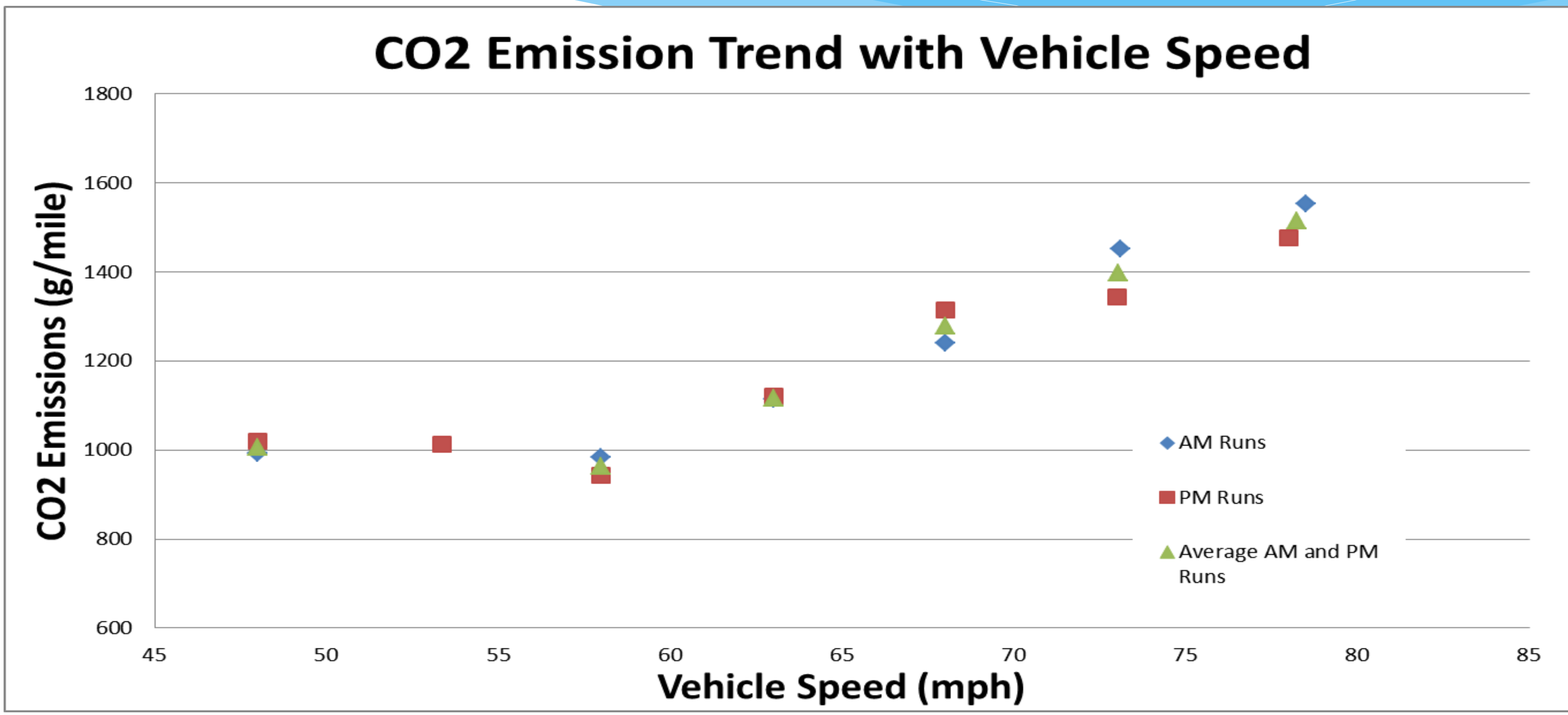
Brake-Specific CO2 and Brake Power



Brake specific fuel efficiency improved at higher speed; however, power demand increased at higher speed.

CO_2 Emission Trend

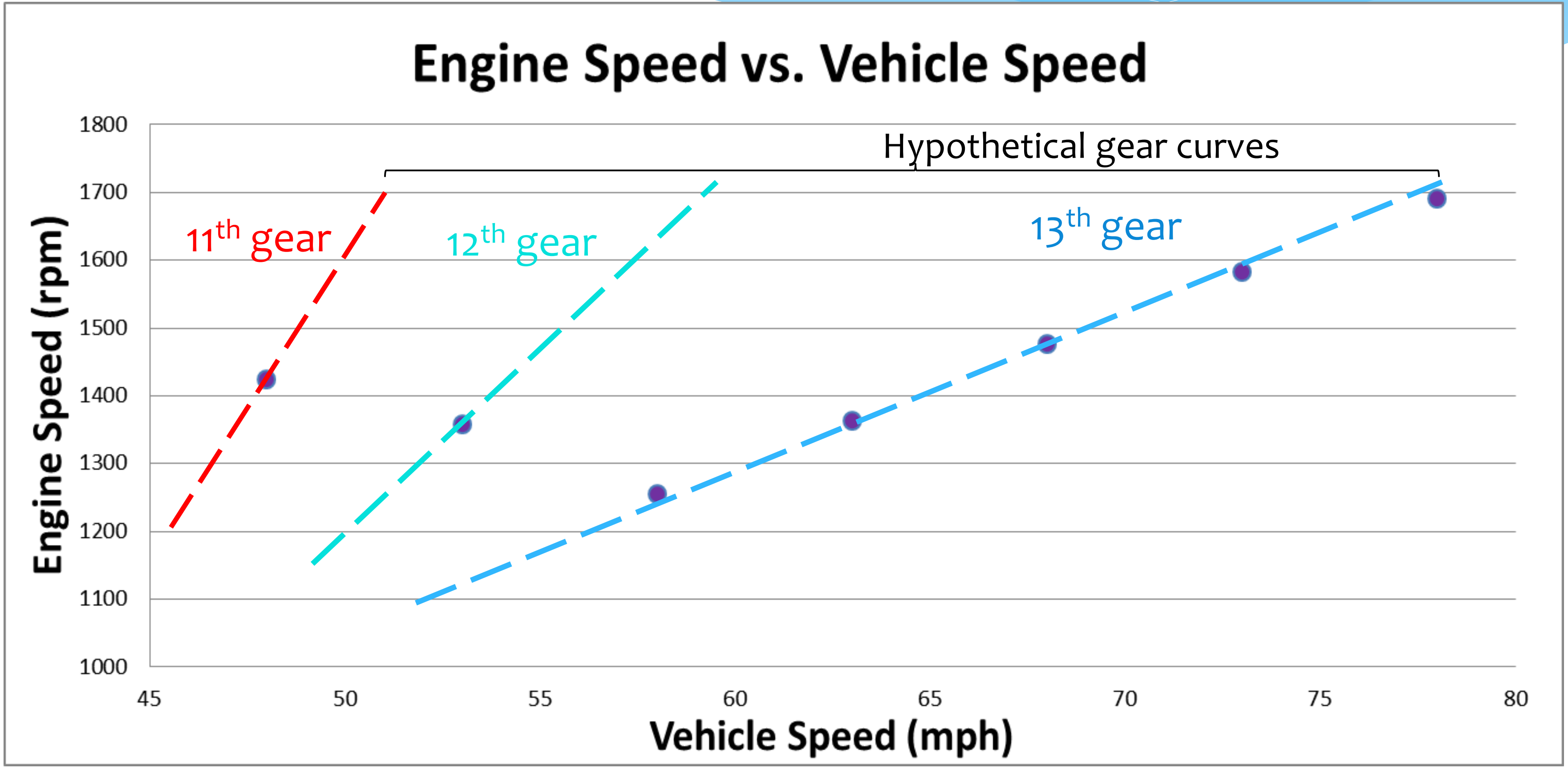
2008 KW Tractor with 48-ft Curtain Trailer



- Sweet spot w.r.t. fuel efficiency around 58 mph (engine speed ~1250 rpm)

Engine Speed vs. Vehicle Speed

2008 KW Tractor with 48-ft Curtain Trailer



Main Conclusions

Optimal Cruising Speed

- Vehicle fuel efficiency is a function of not only vehicle speed but also engine speed
  - Drive truck at engine’s sweet spot for optimal fuel efficiency
- Important to consult with manufacturer on optimal cruising speed
  - For a given transmission gearing, axle ratio, and tire size, there is a speed that truck can be driven that matches ideal engine speed

Preliminary VSL Benefit Quantification

* Cost Benefit Equation

$$\Delta S = 2.69 \cdot 10^{-3} \cdot \delta \cdot D \cdot p + D \cdot w\left(\frac{1}{v+\delta} - \frac{1}{v}\right)$$

Where: D – distance traveled (mile); p – diesel price ($/gallon); w – labor rate ($/hr); δ – speed increment (mph); v – speed (mph)

* Savings Analysis

$$\delta > \frac{372w}{p \cdot v} - v$$

* Emissions Benefit (gCO2)

$$27.343 \cdot \delta \cdot D$$

* Analysis
  - Sac to LA (~380 miles)
  - Labor ~ $20 / hr
  - Diesel ~ $2.58 / gallon
  - Compare trip at 63 mph to trip at 58 mph
* Results
  - $3 lower cost
  - Lower emissions (~52 kg CO_2)

Note: Cost benefit equations were derived based solely on the results from the tested truck

VSL Emission Benefit

* In Summary
  * Increased fuel consumption at higher speeds
    * Leads to fuel saving and emissions reduction with the use of VSL
  * Cost Benefit
    * Under certain driving conditions there is a cost benefit to VSL as well
* Caveat
  * VSL benefit analysis assumes that truck speeds generally exceed the VSL
  * However, trucks have varying duty cycles some of which are well below VSL, which would lower the cost benefit of a VSL

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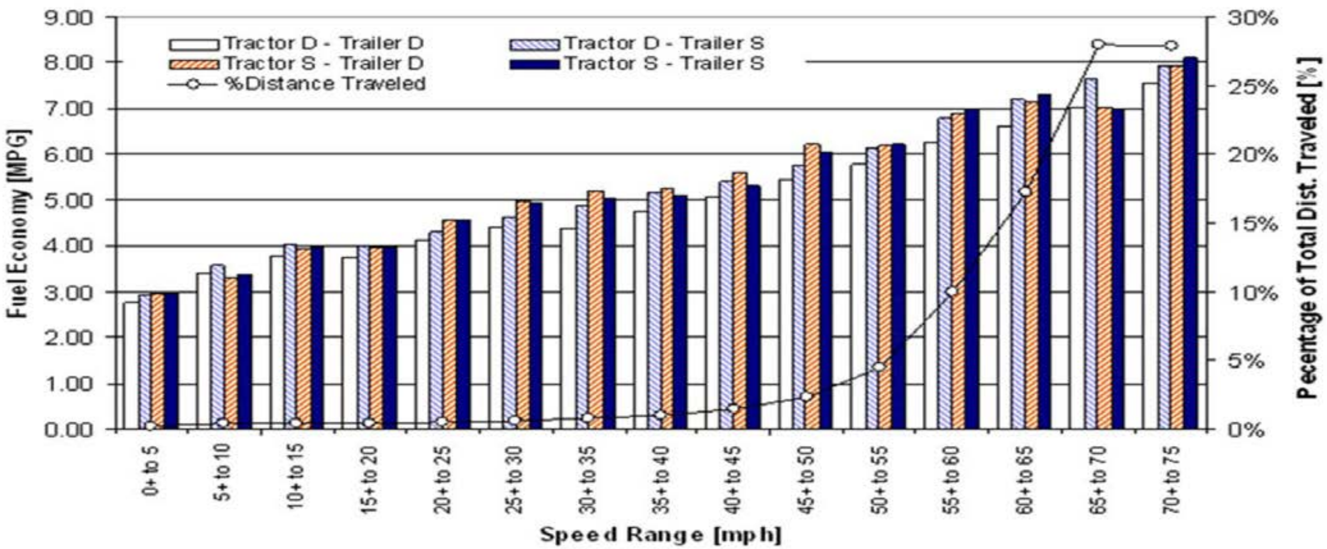
Backup Slides

Available Data: Transportation Energy Data Book - Oak Ridge National Laboratory (ORNL)

Figure 5.3. Class 8 Truck Fuel Economy as a Function of Speed and Tractor-Trailer Tire Combination and Percentage of Total Distance Traveled as a Function of Speed

NOT ADJUSTED FOR TERRAIN: See note below.



Note: D = Dual tire. S = Single (wide) tire.

- Show better fuel economy at higher speed
- Data is the combination of transient and steady-state operation data
- The observed increased fuel efficiency at higher speed could be due to travelling downhill at higher speed or more efficient truck operation under steady condition

Current EMFAC Assumptions

- EMFAC 2014 assumptions (emissions flatten out from 60-80 mph)