Speed Anomalies in VSP Based Emissions

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Why is this important?

- In the development database (up to Tier 1 vehicles)
- Is VSP sufficient for quantifying emissions?
  - How can we compare twin roll, single roll, and on road data?
  - Are modal emissions specific to driving cycle?
  - How important are history effects?
  - If it's good enough for fuel consumption and CO_2, is it good enough for criteria pollutants?

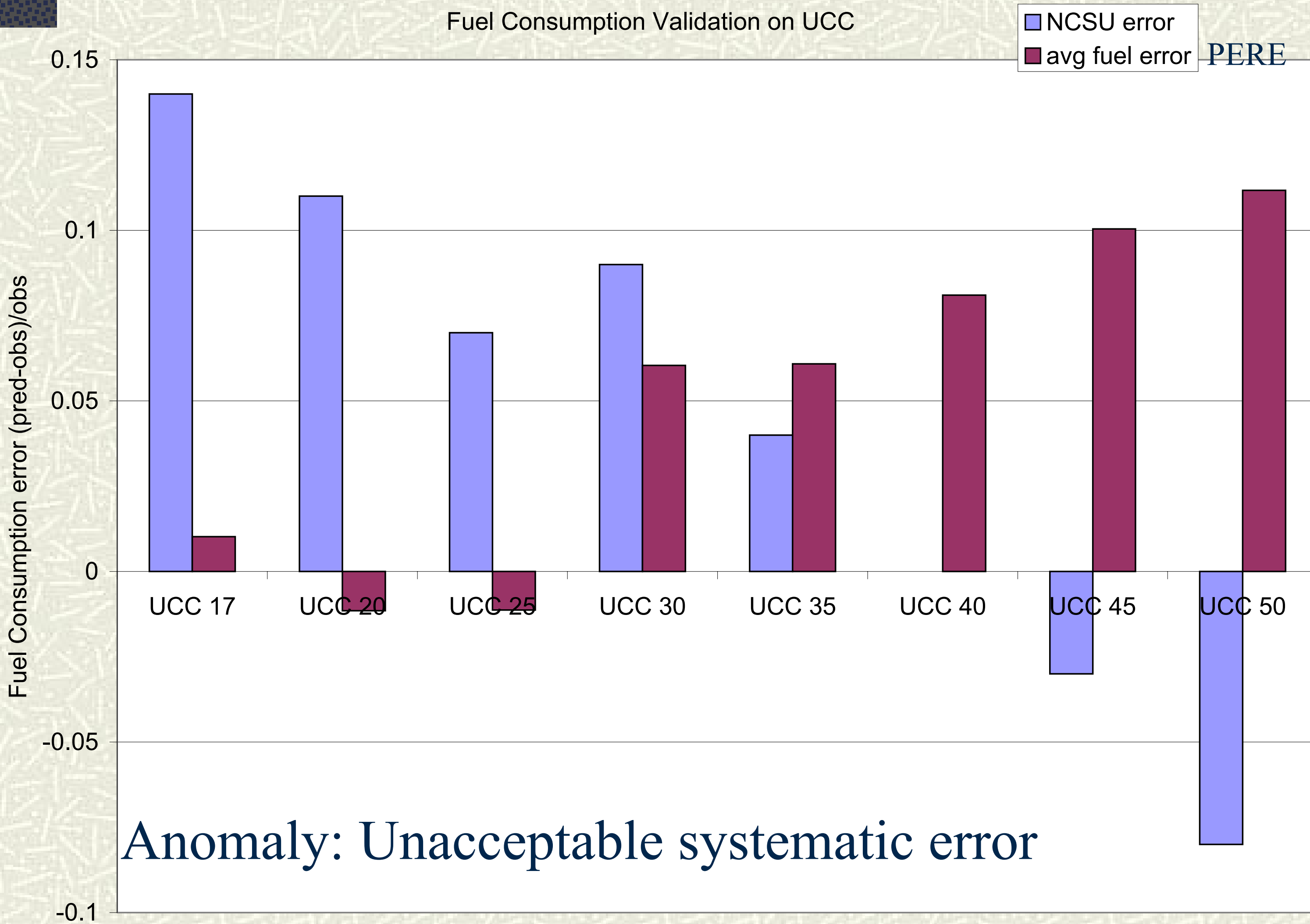
Outline

- Speed Effects in Fuel Consumption
  - Potential Root Causes
  - Road Load Coefficients
  - UCC re-validation
- Speed Effects in Catalyst
  - Potential Root Causes
  - Enrichment History Effects
  - Significance of History Effects in Other Data

Background: UCC Fuel validation

- 21 vehicle set
- Bag emissions only
- Using 8 different driving unified cycles (at different average speeds)
- Tested on twin roll dynamometers
- Systematic error (>10%) in speeds observed in PERE and in NCSU study
- Historic target for fuel consumption < 5%

California Speed Cycle Validation



Anomaly: Unacceptable systematic error

Solution

- Introduce a speed correction bin

Or

- Find the root cause and try to model it

- Being a physical model, we choose the latter approach

Possible Root Causes

$VSP = v(1.04a + 9.8grade + 0.132) + 0.0003v^3$ (Jimenez)

$FR = \phi[KNV_d + (m(a + g(grade) + gC_R)v + 0.5\rho C_D A v^3 + P_{acc})/\eta] / LHV$ (PERE eq based on Ross & An, and CMEM)

- Aerodynamic/rolling resistance approximated and set constant
- Efficiency term (η) too high?
  - Should underestimate at low speeds
- Engine speed (engine friction) model (KNV_d)
- Lack of a speed dependent friction term (α v^2)
- Jerk (da/dt) term?

If road load approximated, how do we fix it?

- Use the real road or dynamometer load terms

Chassis Dynamometer Testing

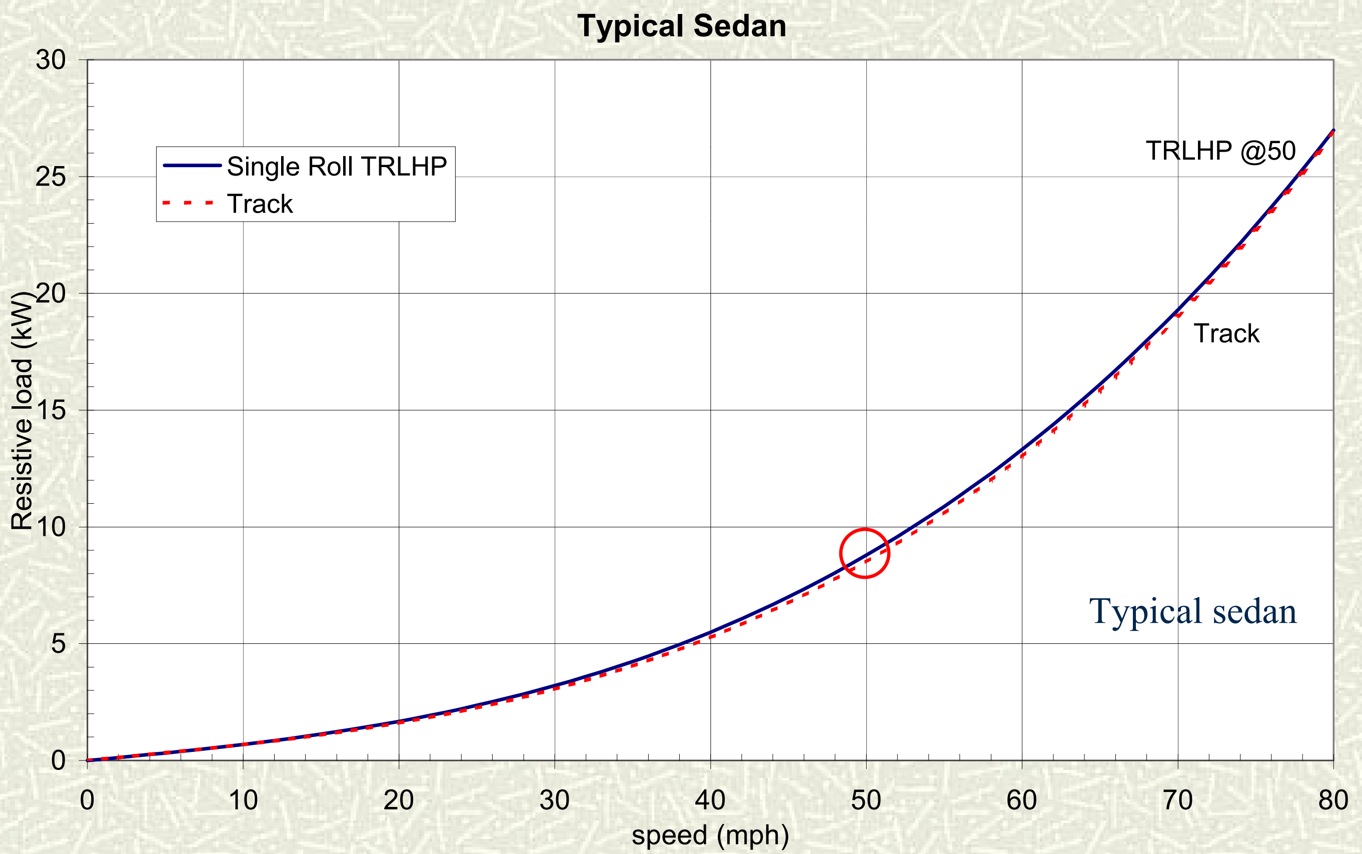
- Is an approximation of real-world
- On road (Track): ***Force = f0 + f1*v + f2*v²* + *Ma***
  - ***f0 ~ Rolling, Tire***
  - ***f1 ~ Rotating friction***
  - ***f2 ~ Aerodynamic Drag***
- Dyno (target coeff): $\boldsymbol{Force = A_T + B_T v + C_T v^2 + Ma}$
  - $\boldsymbol{A_T}$ ***~ Tire breakaway***
  - $\boldsymbol{B_T}$ ***~ Rotating friction***
  - $\boldsymbol{C_T}$ ***~ Aerodynamic Drag***
- Will use Track and target synonymously

Dynamometer vs. Track

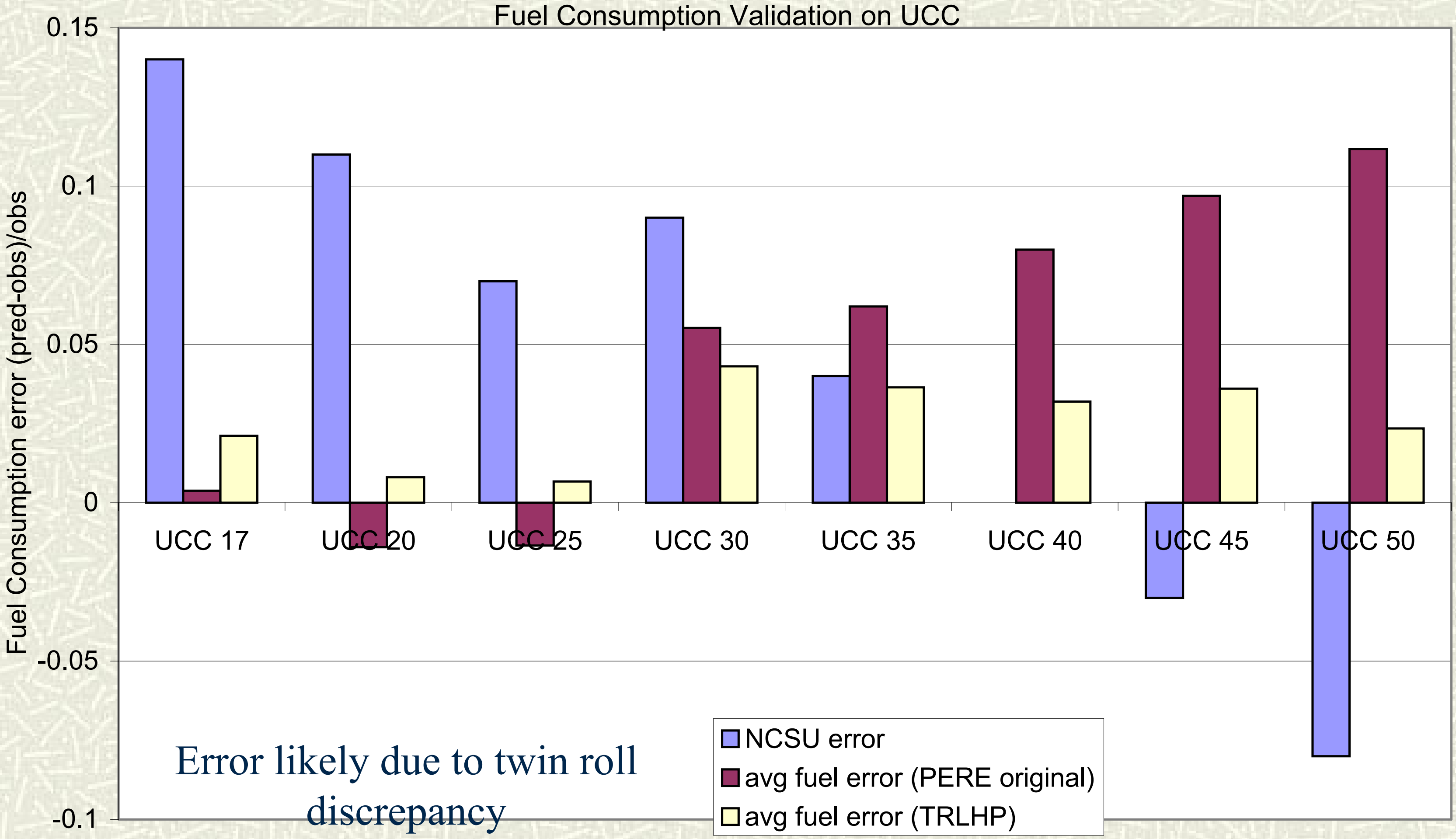
- Target coefficients NOT to be confused with Dyno *Set* coefficients
- Target (or track) = Vehicle dyno Loss + Dyno Set
- Coefficients determined from track coast-downs
  - TRLHP (Track Road Load Horsepower) @ 50 mph reported

IM Dyno Testing

- Given TRLHP @50, distribute power to A,B,C
  - A (.35), B (0.1), C (0.55) (fractions)



UCC Validation



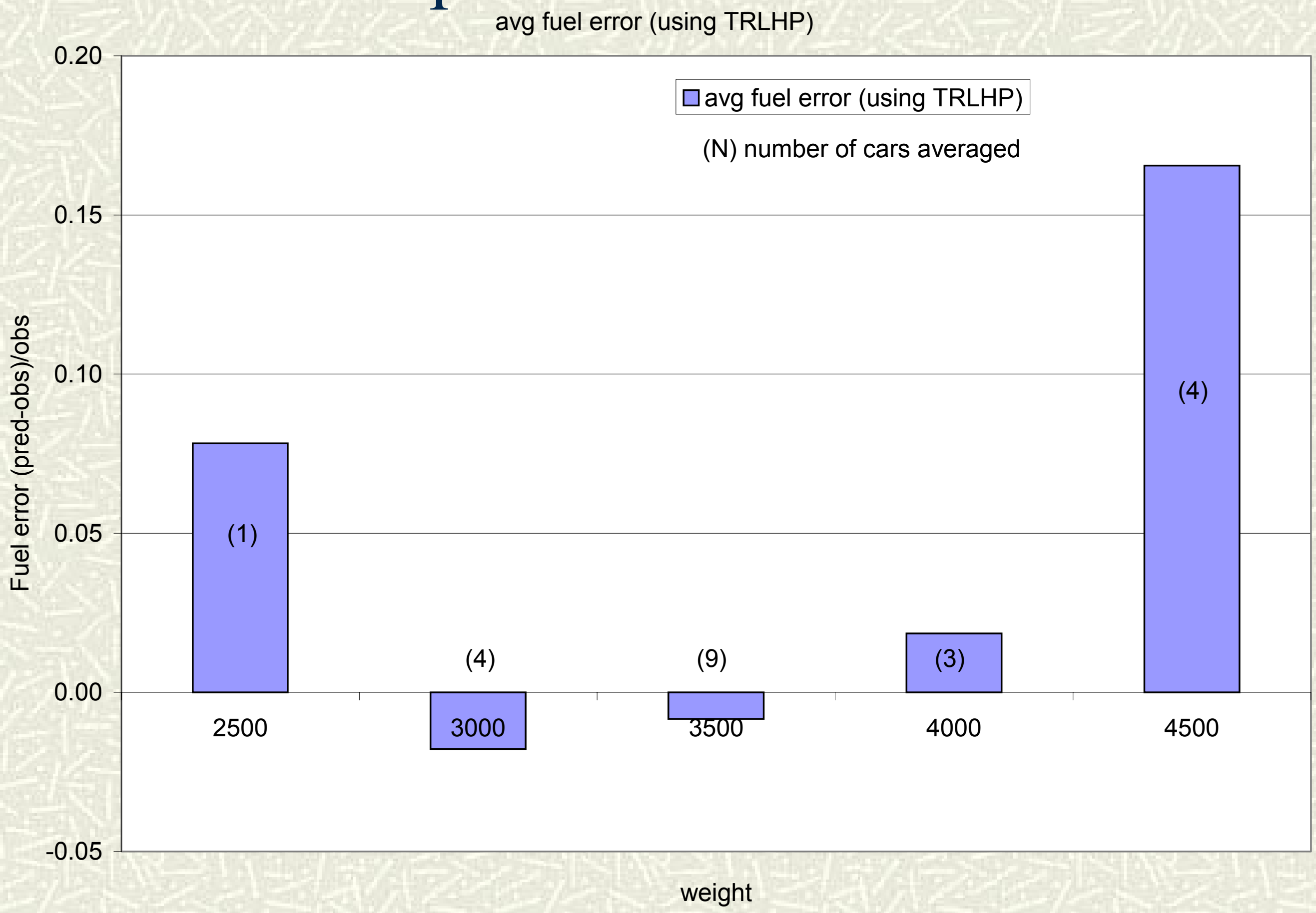
Error likely due to twin roll discrepancy

Hydrokinetic Twin Rolls

- Dyno Set A = B = 0
- Loss terms difficult to obtain
- Results good enough without
- May not be true of other data sets

New can o' worms (?)

- Heaviest vehicles are more efficient than the model would have predicted



Small sample size

PERE/MOVES recommendations

- Use Testing specific coefficients:
  - Use Manufacturer's track coefficients if available (>1999)
  - Use IM TRLHP otherwise (.35/.1/.55)
  - If unavailable, estimate (as in PERE)
- For further refinement (if necessary):
  - Use speed (or power) dependent efficiency term (η)
  - Use separate equation for twin roll (estimate losses)
  - Explore weight dependence

Modified VSP equation

- $VSP = [Av + Bv^2 + Cv^3 + mv(a+g\sin\theta)(.447^2)]/m$
- *Use track coefficients where available (>MY1999):*
  - *f0, f1, f2* provided by manufacturer. Adjust units accordingly.
- *Otherwise Single Roll Dynamometer kW/tonne (CMEM approach):*
  - $A = 0.35*0.746*TRLHP/(50)$
  - $B = 0.1* 0.746* TRLHP /(50)^2$
  - $C = 0.55* 0.746* TRLHP /(50)^3$

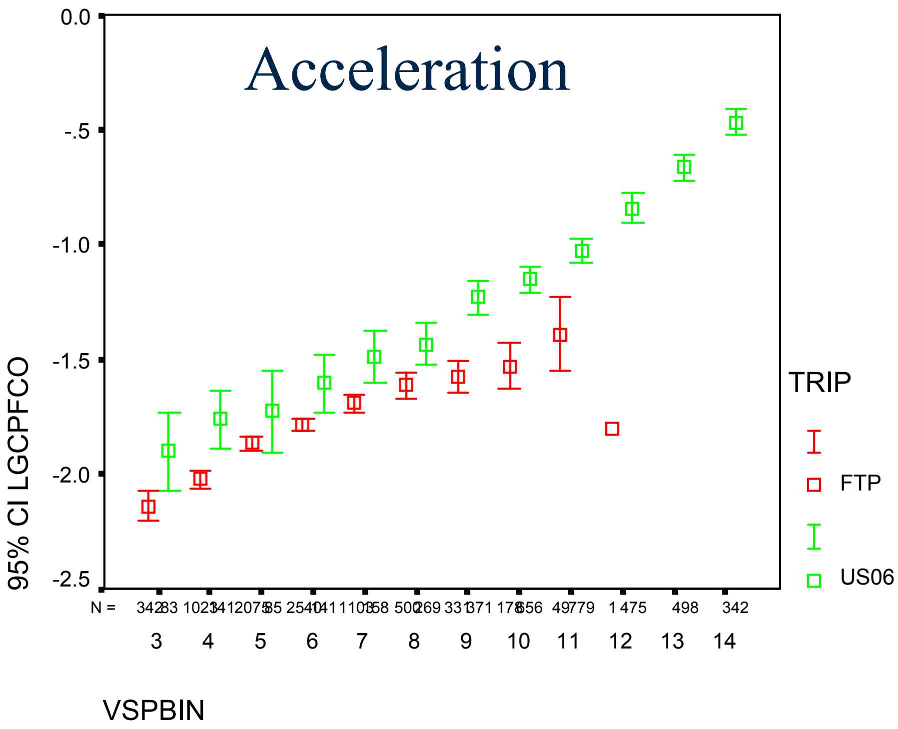
Part 2 - Catalyst Pass Fractions

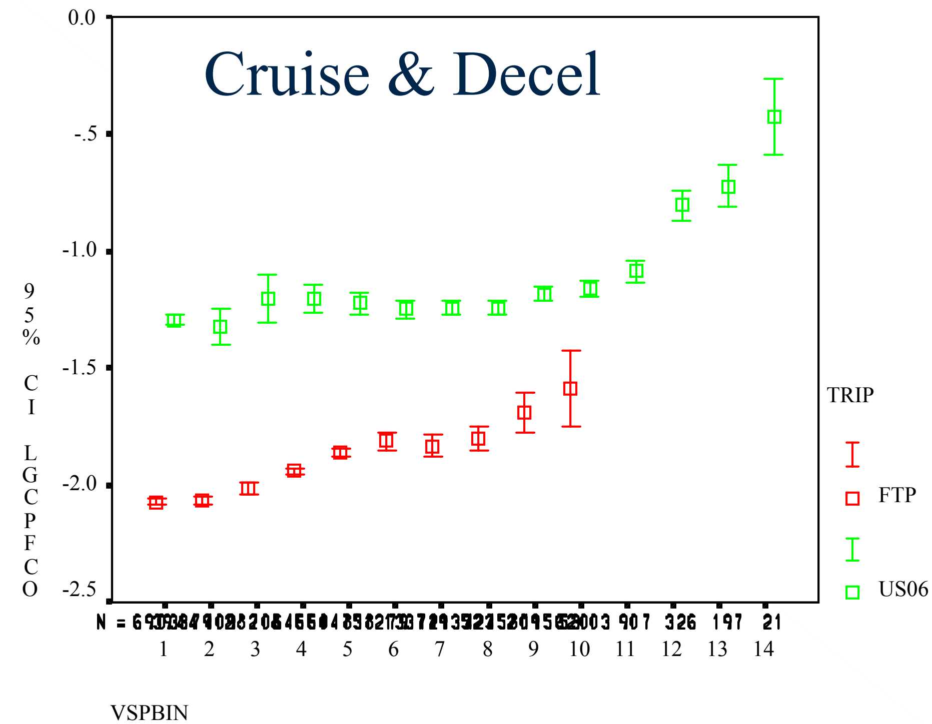
- Anomaly defined as differing levels of emissions within the same VSP bin (operating condition)
- Anomalies due to deceleration are expected, but cruise?
- Do we need history effects in MOVES?

CPF speed anomaly

- CPF = TP / EO
- Speed anomaly observed in cruise mode for CO
  - US06 higher than FTP in the same VSP bins
- Deceleration effect seen in CO and HC
  - Enleanment, hydrocarbon puff
- second by second NCHRP database taken at CE-CERT over FTP, US06, and MEC cycles

Split out Cruise from Accels



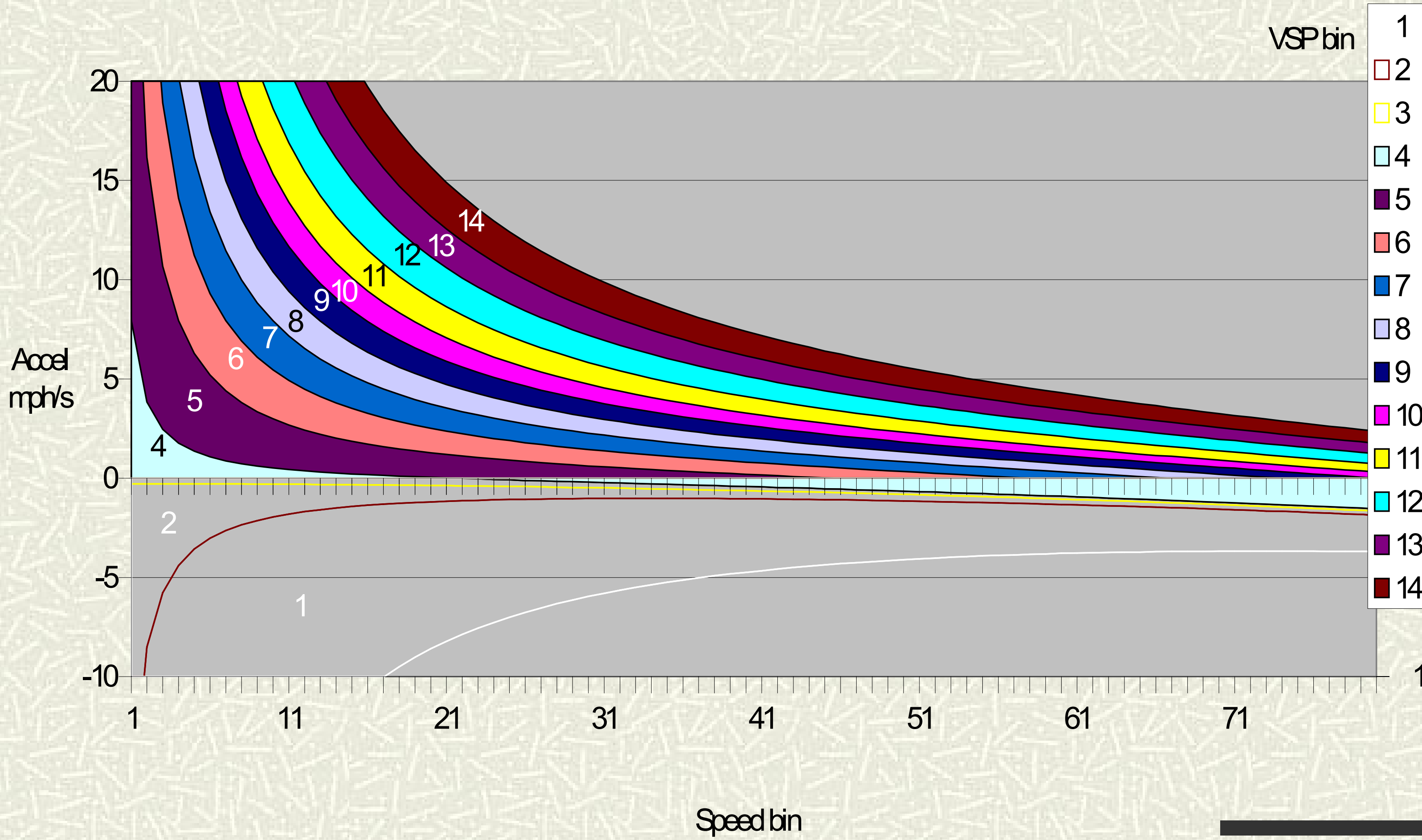


Potential Root Causes

- ✓ High mileage (deterioration)
- ✓ A few oddballs
- High speed throttle dither (normal tip-out)
- ✓ US06 peak on central hill
- Data not synchronized
- ✓ High speed sporadic enrichment
- High speed catalyst breakthrough (oxygen storage)
- ✓ Definition of modes
- ✓ Enrichment history (enrichment tip-out)

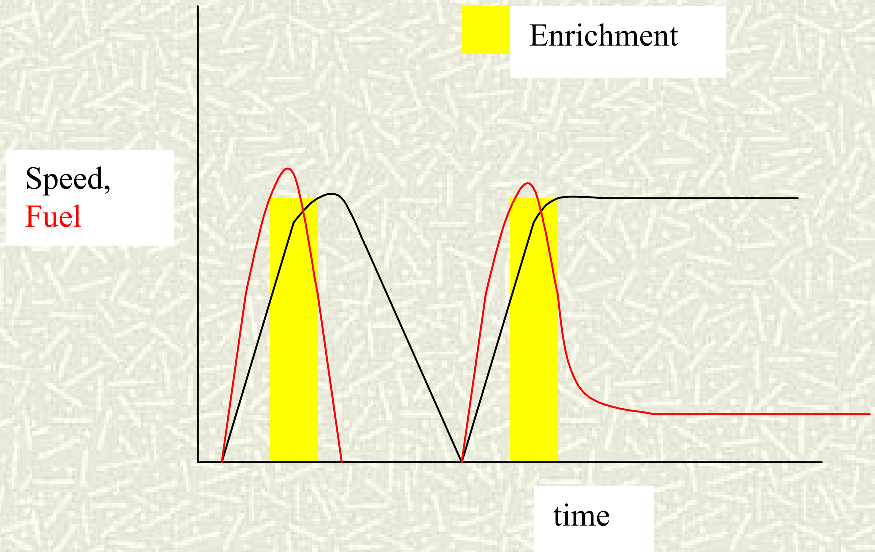
VSP bins

- Most VSP bins have some cruise and decels



RESULTS: Enrichment history effect

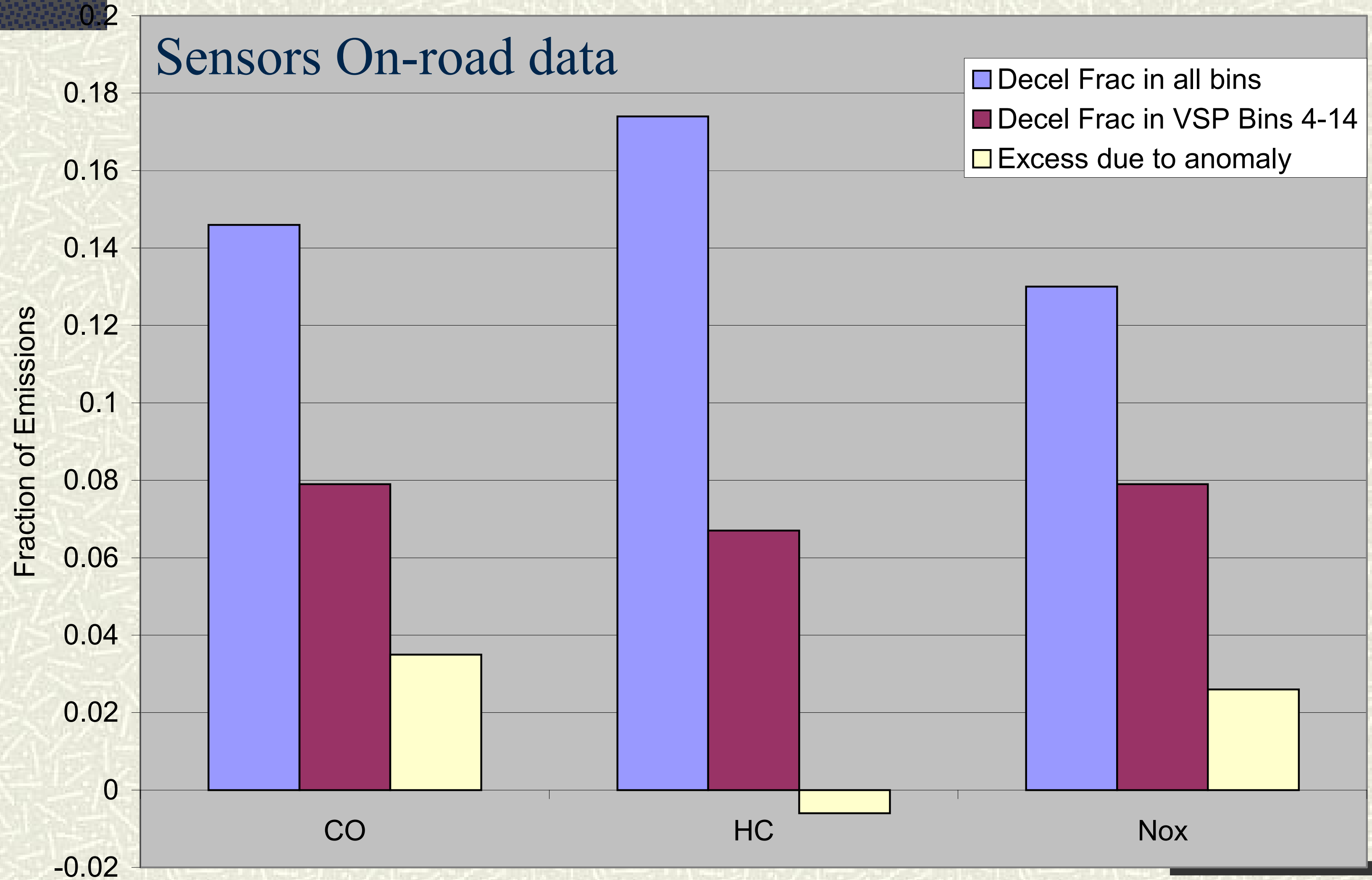
- After examining s-b-s traces...
- CO anomaly due to history effects:
  - Continuing Enrichment after hard accel
  - Mild enrichment at high speeds (flippers?)
  - Toggling between strategies



How significant is this cruise effect? Look at other Tier 1 data sets

- Sensors on-board data (72,000 seconds, 13 vehicles):
  - Cruise CO anomaly NOT observed
  - Decel HC puffs NOT significant
  - Decel CO higher
- FTPRP data (s-b-s FTP, US06, 10 vehicles):
  - Cruise CO anomaly NOT observed
  - Decel & US06 HC lower
  - Cruise & US06 NO higher
  - Decel CO higher

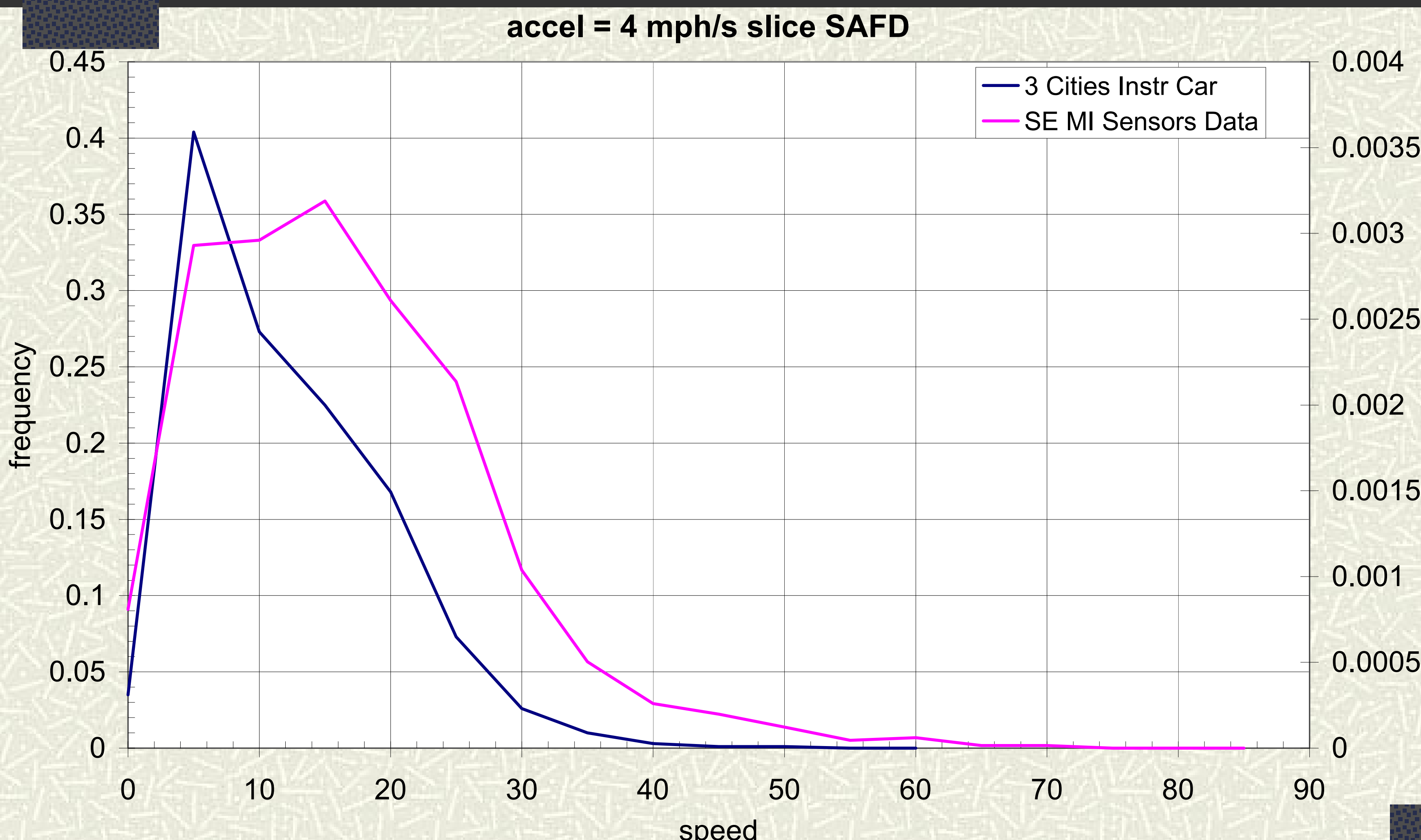
Deceleration history effect



Tangent

- Is the Sensors on-road data “real-world”?
- Compare to 3 cities instrumented vehicle survey (early 90s)

Comparison with 3 cities instr car data in accel=4 mph/s bin



Significantly more aggressive accelerations

What does this mean?

- CO speed anomaly may be isolated to NCHRP data
- US06 is an extreme cycle (not representative of real world driving) - care should be taken if/when used to calibrate model
- Decel puffs may not be significant for properly functioning Tier 1 vehicles
- VSP history effects are mainly limited to cold start
- BUT - RSD has seen evidence of limited enrichment events: “flippers”
  - Flipping between strategies to protect catalyst
  - This behavior seen on non-SFTP certified vehicles

Conclusions

- Use testing coefficients in Power (VSP) equation where available
- Explore weight effect?
- CPF CO speed anomaly in NCHRP (US06) data due to
  - Enrichment history
  - Light enrichment at high speed cruises (toggling strategy)
- Not evident in two other datasets (real-world)
  - CO, HC anomaly still observed in decels (minor)
  - No need to model this explicitly at this time
- Be careful when using US06 to calibrate model
- Be careful when making generalizations from a single dyno data set

Future concerns?

- Are there still speed issues with VSP based emissions? (Koupal)
- But a modified VSP equation is a sufficient basis for emissions modeling in PERE for hot tier 1 vehicles…
- How will current (clean Tier 1) and vehicles meeting future standards be modeled?
  - Criteria pollutants are not likely to follow a VSP trend
  - Need to revisit the methodology for clean technologies (SFTP Tier 1, Tier 2 etc)