

"Finding "Normal" And "High Emitting" Emissions: Exploring New Emerging Screening Tools and Methodologies for Gathering Real-World Vehicle Data"



US Environmental Protection Agency, Office of Transportation & Air Quality National Vehicle and Fuel Emissions Laboratory, Ann Arbor, MI

## Outline



- Research & Development
- Integrated Design
- Developing a "Suite of Tools"
  - PEMS
  - PAMS
  - Screening Tools (mini-PEMS, RSD, Evap SHED)
- Finding "High" Emitter Vehicle Methods
- Critical Data Fields to Measure
- Outcomes



- Goal: Assess and gather mobile source activity and emission data to better understand the "real-world"
- Focus efforts on improvements in:
  - Data gathering efforts
  - New sampling methodologies
  - Measurement equipment
  - Testing procedures and protocols
  - Modeling efforts

# Integrated "Real World" Test Design With a Suite of Tools





# "Suite of Tools" Development: PEMS

- Portable Emission Measurement System (PEMS)
  - Gathers very detailed activity, engine parameters and emissions in "realworld" operations
  - CFR 1065 capable equipment with independent emission measurement
  - Major advancements over 15 years
    - Improvements in size, weight, power
    - Particulate Matter measurements (both filter and second-by-second)
    - Improvement in Vehicle interface
    - Expanding sensors

# **Quicker PEMS Installation**





Bicycle Rack for nonhitch vehicles





Cargo Platform with Vehicle's Hitch

# "Suite of Tools" Development: PAMS



- Portable Activity Monitoring System (PAMS)
- Small data loggers interface with on-board vehicle computers to gather very detailed activity and engine parameters in "real-world" operations from light-duty, heavy-duty, and nonroad
- Major advancements:
  - Improvements in size, weight, power
  - GPS, Accelerometer (X,Y,& Z = grade)
  - Add-on additional sensors
  - Vehicle interface
- Data Loggers with Cellular Capability
  - Created a web-based "Dashboard" to monitor data logger and vehicle
  - "Real-time" notification of issues on data logger and/or vehicle and resolve them
  - Allows "Real-time" data analysis



# **Improvements to Data Gathering**



- Standardizing Heavy-Duty SAE J1939 Data Files for PEMS and PAMS
  - Known database structure for quick data analysis
  - Gathering "key" vehicle parameter fields at 1 Hz rate
    - Over 150+ channels of engine and aftertreatment parameters torque, engine rpm, temperatures (coolant, oil, intake air, etc), SCR, NOx, DPF, etc.
    - Additional data gathering efforts underway to determine standard engine fields that exist within the fleet by engine manufacturer and vocational use.
- Developed Light-Duty SAE J1979 Data Files for PEMS and PAMS
- Very Important to have the "<u>PID Editor</u>" to allow additional Parameter IDs to be monitored and recorded in both PAMS and PEMS devices.



- Screening Tools
  - Purposes
    - Find "high emitters" within the fleet in the "real-world" and get them repaired
    - Data to support modeling efforts
  - EPA working in partnership to advance these technologies
  - Possible Tools:
    - Remote Sensing Devices
    - Portable SHEDs
    - Mini-PEMS

### **Screening Devices: Finding High Emitters**









# ESP

# HEAT (EDAR) Port

**Portable SHED** 

"High Emitter" Categories

- Tailpipe Emissions from light-duty vehicles
- Tailpipe Emissions from heavy-duty vehicles
- Evaporative Emissions from light-duty vehicles

# **Remote Sensing Devices (RSD)**



- Remote sensing advantages
  - Screens hundreds of vehicles a day
  - "Semi-Invisible" to the driver
  - Obtains all types of vehicles gas, diesel, LD, HD, old, new
  - Can be used to identify "high emitters"
- Limitations of remote sensing
  - Does not tell you whether a vehicle exceeds the certification levels, because it's only one operating condition
  - The operating condition may not be the same for every vehicle or every RSD location

# NOx vs Calendar Year Analysis

(One Vehicle Group's Aggregated Emissions vs Fleet Average)





Each Vehicle Group's emission data aggregated into each month for a vehicle gives a very wide range (95% confidence level)

Note: Concern that the 95% confidence level associated with similar vehicles overlaps fleet average.

Fleet Average for other similar vehicle with same engine size and fuel delivery system with (95% confidence level)

# Vehicle Specific Power (VSP)



- The RSD measurements are based on data that have a different operating condition for each location and each vehicle
- To develop a better comparison, the data was analyzed using Vehicle Specific Power (VSP) which is the instantaneous power per unit mass of the vehicle
- The VSP for each RSD measurement was calculated using a "typical" LD vehicle based on -
  - Vehicle speed and acceleration data from the RSD unit
  - Road grade at each of Colorado's RSD test sites

$$VSP = \frac{\frac{d}{dt}(KE + PE) + F_{rolling}v + F_{aero}(v^{2})v}{m}$$
$$VSP_{LDV} = v\left\{1.1a + g\left(\frac{r}{100}\right) + 0.132\right\} + 0.000302v^{3}$$

VSP	= Vehicle Specific Power (kw/ton)
а	<ul> <li>vehicle acceleration (m/s<sup>2</sup>)</li> </ul>
g	= acceleration of gravity (9.81 m/ $s^2$ )
r	= road grade (%)
V	= vehicle speed (m/s)

# **RSD NOx Emissions by VSP**

(Four different vehicle's emissions plotted)





### "Normal" and "High" Emitter Categories

(Two individual vehicle group's emissions vs Fleet Average)





#### **Possible "High Emitting" Vehicles with Different Slope**



### Possible Category of Vehicles: "Higher " Emitting 1<sup>st</sup> MY and Not Other MYs





1st Year of new Model has higher overall VSP emissions vs subsequent MYs of same vehicle when compared to fleet ("normal" emitting vehicles) with same engine size



# **Screening Devices: Mini-PEMS**





**EPA's Version** 





Sensors: NOx, Exhaust Temperature GPS Vehicle Interface Adding Additional Sensors: CO<sub>2</sub>/CO, NH<sub>3</sub>, Black Carbon, O<sub>2</sub>

**ECM's Version** 



# What Data Fields are Needed to "Screen" Vehicles and Gather "Real-World" Operations?

# Mini-PEMS/PAMS Data Logger:

# **Data Fields**



**Date/Time Clock**: Engine On/Off Date/Time ECU: Vehicle Speed (if not, use GPS)

<u>+</u>

Additional ECU Fields: Engine Load Fields: (RPM/load%/torque%,etc) DPF/SCR Operations (temps, NOx ppm, etc MAF/MAP/Fuel Rate

╧

GPS Fields: (lat./long./altitude/vehicle speed) (Note: Signal blocked by underpasses/tall buildings



#### Allows for Modeling Analysis on:

- Soak times, starts, idle times, VMT, speed distributions, drive cycle development, use patterns, etc.
- Able to calculated VSP if hp and vehicle mass are known

#### ±

- Use Engine load, SCR operation, DPF operation, Engine RPM, etc.
- Able to Use Equations for calculating exhaust flow, VSP & g/power
- Able to get NOx in ppm/grams in VSP(kW/ton), Power (g/bhphr, g/kW)

#### <u>+</u>

- Able to cross checking of ECU's vehicle speed/acceleration w/ GPS
- GPS Fencing (ports, hoteling, county, city boundaries), road types, etc.
- Road Grade load by altitude or enhanced with GIS maps

#### ᆂ

- Able to cross checking of ECU's MAF/MAP equations w/ independent flow measurement
- ECU interface not needed if flowmeter used but losing engine data.

#### <u>+</u>

Able to gather Diagnostic Messages, DTCs and Monitor Readiness

Note: All Data Gathered at 1Hz – second-by-second

# Mini-PEMS/PAMS Data Logger: Emission Sensors Data Fields

NOx Sensor (ppm)

CO2/CO Sensor (ppm)

THC Sensor (ppm)

BC Sensor (ppm)

**Environmental Sensor** 

NH3 Sensor (ppm)

Wide Lambda O2 Sensor (ppm)



### Allows for Modeling Analysis on:

- Able measure NOx measurement in VSP, ECU data or by flowmeter
  Able to measure O2 in exhaust
- Able to conduct carbon balancing with default fuel properties and fuel rate by ECU plus reweight NOx measurements in VSP
- Able to look at cold/warm/hot start or vehicle soak emissions
- Able to know DPF regeneration events
- Able to calculate independent vehicle fuel economy
- Able to know if DPF is cracked for diesel vehicles
  Able to know relative if vehicle is PM "high" emitter (diesel/gasoline)
- Able to relate environmental conditions to emissions. (relative humidity, temperature & barometric pressure)
- Able to relate diesel "slip" or gasoline cold emissions

Note: All Data Gathered at 1Hz - second-by-second



# Min-PEMS Characteristics: Screening Vehicles



- Not PEMS (CFR 1065 Compliant)
- Flowmeter: ??
  - Yes and No, if you have proper ECM engine fields being recorded
- ECU (Vehicle Interface)
  - Yes and No, if you have other ways to gather the proper data fields
- Quicker to Install than PEMS
  - Under 30 minutes would be best
- Smaller in size, weight and power
  - Run with LiFePO4 battery for all day multiple vehicle testing
- Quicker calibration by "auto-zeroing" of sensors
- Vehicle Testing time: ~ less than 1 hour depending on type of "screening"
   Enough time to give data for VSP (0-60 kW/ton) profile
- Overall Accuracy: ±10%
- Length of Performance of Sensors & accuracy range: ??





- EPA is actively seeking partnerships to help gather better data to address present and future research.
- EPA wants to <u>enhance local data gathering efforts</u> to improve our models
- EPA is actively developing tools and methodologies to further support gathering activity and emissions data.
- This includes improvement and support:
  - Better integration and understanding "real-world" emissions on different vehicle and engine technologies
  - Better understanding of engine parameters to emissions in "real-world" operations
  - Better understanding of fleet "high emitters" by screening vehicles



# Questions

# **Contact Information**



### Mobile Source Emission Factor Research

https://www.epa.gov/moves/mobile-source-emission-factors-research

Carl Fulper **US Environmental Protection Agency** Office of Transportation and Air Quality Assessment and Standards Division National Vehicle and Fuel Emissions Laboratory 2000 Traverwood Drive Ann Arbor, MI 48105 734-214-4400 fulper.carlr@epa.gov



# **Old Slides**

# Improvements to "Meta" Vehicle Data

- Developed new standardized vehicle profile documentation forms to accompany test programs using PEMS or PAMS
  - Fleet information: such as vocation and information on other vehicles in the fleet
  - Vehicle Parameters: such as axle ratio, engine information, and transmission information to enhance modeling efforts

		, .,								
Establishment Information										
Name of establishment	Interview	date								
Site location Main U Other	Site represent	ative								
Representative phone ( )	Interviewer na	ame								
Address where inventory was performed										
Attempt made to get establishment's fleet records (c	or service record	15) 🗆								
				81						
License plate(1" proto)		Photo	o taken & verified							
Truck Company ID (usually on arte or noos)	in malk in her to	Phote with the area 3	o taken & vermen							
Truck ownershin Company owned I Lease	Other:									
Axle configuration (i.e., 2-axle four-tire, 2-axle six-		Photo	o of entire truck ta							
tire, 3 axie, 3-axie compo, 4-axie, etc.)		& ver	rified 🛛							
Truck Make Mode	1	M	iodel Year		CE C 50	CCR Study UD On cond	Tertion and An	a har ir	Establishment	au entra au
Primary Fuel Type	Hybrid	Yes 🗆 🕴 🕴	No 🗖	Please c	UE-CEN	T SCR Study HD On-road	vhere an invento	erysis, iratis c	onducted Much	of this information.
SCR tank picture taken (identify by blue cap)	Yes L	<u> </u>	No tank 🗖	nailable	remutely (i.e., in	formation collected throw	he-mail Lansmis	siano	of inventory files r	naintained by the
Drive-axle tire sidewall alpha-numeric size		Photo	taken & verified	establish	ment). All local	ites for each establishmen	t will be inventori	ed, Ir	wentories will onl	y be performed for
VIN	\	/IN plate photo t	taken & verified	sites (in	other cities or sta	tes) if the information can	be obtained remo	otely (	i.e., by e-mail, wit	hout an-site visits).
Odometer (if possible),,	km 🛛 mile	s 🖬 🛛 Odo photi	o taken & verified	Establ	shment inform	ation				
CAN connector type 6-pin Deutsch (11587)	9-pin Deu	tsch (J1939) 🛛	I LD OBDII 🗆	Name	of establishmer	t	In	tervie	ew clate	
Axle ratio () sted on door (amb)	A	xle ratio label ph	10to taken & verifi	Site lo	alion		Inter	viewe	er naune	
Transmission Type	# of Ge	ears		Repres	entative phone	1 1	Site re	prese	intative	
Ensure ALL door jamb labels photographed and & ph	iotos verified for	r legibility 🖵		Truck	nformation					
Engine Mfr. Engine Model		Engine	e Year							
Engine Serial # E	Engine Family	1 011-2.22	to the second second	Licen	se plate		] []	licens	e plate	
Engine Displacement Inº L	Configuration	V-block	Inline 🗆	True	k co. ID			hu	k no. ID	
Rated Former	Units	HP U Other	) wrt		VIN		7 [		VIN	
Rated Speed (for Power) PDM	Rated Speed /	tor Torque)	DDF			,	- 1			
Ensure All, engine labels photographed and & photo	is verified for lea	ibility 🔲		Startt	me	End time		tart t	me	End time
Emission control equipment: TWC/OC/WU D N	AC SCR		PTOX 🗆	1	License plate		¬	1	License plate	
		_		1	Full Iront			1.2	Lull frunt	
HO25/O25 EGR/EGR-C Other							- '	<u> </u>		st.
HO25/O25 EGR/EGR-C Other TWCCC/W = three-way wilding cross-trive cativative: "ACENV adds III a considering and a HIV/PURCHARM again particular trivers	scrption catalyst: SCR =s	elective catalytic reducts (cooled DDP	ion; SPF=diesel particulate	_ 3	Front left angle	side	- ;	.1	Tront left angles	NDP
H025/025 EGR/EGR-C Other Troc/SC/04 = there-may/additing catalytif warm-to catalyti; NAC=N0xada PL02 = pendic targe and arc; H029025-heater/exages amount. EXMLU-C-war HEM Data Logger Installed; Yes No Logger	scrption catalyst: SCA as charactiges the realistion of TD (if installed ):	elective catrixt c reducts / cooled LGR	ion; SPF=diesel sarticulate	- 3	Front left angle Front right ang	side e side	'   '	.1	Front left angle : Front right angle	side
HO25/O25 EGR/EGR-C Other TVCCCCV4 therework dividing construct and construct. SNCKNO add PUS-senad charge and an INTERNATIONAL Construction of the Construction HEM Data Logger Installed; Yes No Logger If Leased and HTM Data installed; date truck to be ref	erption catalyst; SCR as chaining an increal incom if ID (if installed); turned to lease o	elective catristic recurci / cooled tate company?	ion; 3PP=diesel aartikulate	- 3 - 1 - 5	Front left angle Front right ang Truck (m. 11)	side e side	י  - י  - י  -	.1 4 5	Front left angles Front right angle Truck Co. ID	side
H025/025 C EGR/GBR-C O Other STACCOV theremad valing match warms at high XSCOV at FUX pend c mp and an (HUX)UD-hands/chape more tai/UL Co- HEM Data Logger Installed: Yes No O Logger If leased and HEM Data installed, date truck to be ret Comments:	erption catalyst; SCR on chaining in more allocation of ID ((finistalled)): turned to lease of	elective catrixt a reduct / cooled but company?	ion; 3PF=diesel aarticulate	- 3 - 4 - 5 - 0	Front left angle Front right ang Truck Cn. ID Additional outs	side e side ide door information	י	.1 4 5 6	Front left angle : Front right angle Truck Co. ID Additional nutsi	ine side le duor information
H025/025 ⊆ EGR/EGR-C ⊡ Other_ TVCCSCVU terrodivatiling craftsharmen cathler StocKNO.adb TVCS and transit transit and an explosion of the stockNo.adb TVCS and the stock of the stockNo.adb TVCS and the stock of the stock of the stock of the stock of the stock HMD Data Logger Installed: the stock of the stock of the stock of the stock If leased and HLM Data installed, date truck to be ref Comments:	eerption catalyst: SCR es character more alexan rr ID (if installed): turned to lease o	elective catrixt or recurci / asolied USE company?	ion; SPF=diesel aarticulate	- 3 - 4 - 6 - 7	Front kitt angle Front right ang Truck Cn. ID Additional outs Door jamb labe	side e sicle ide door information Is	י ני י ער א	.1 4 5 6 7	Front left angle Front right angle Truck Co. ID Additional nutsi Door jamb label	iae side le duor information s
H025/025 □ 668/658.C □ Other TWC550W thereadwides crangely-sense tables (Condousto TWC550W thereadwides crangely-sense tables (Condousto TWC550W thereadwides (Condousto) TWC550W thereadwides (Condousto) T	eeption catalyst; SCR os charactiges more alexant rr ID (if installed): turned to lease o	elective catrixtic recurci / soolad UGE company?	ion; OPFodiese) sarticulate	- 3 - 4 - 6 - 7	Front kitt angle Front right ang Truck Cri. ID Additional outs Door jamb labe	side e side ide door information Is		.1 4 5 6 7	Front left angles Front right angles Truck Co. ID Additional notain Door jamb label	side le duor information s
HO25/O25      EGR/EGR-C Other Three controls and the second	erptien estatyd; SCR as ebauer gen menschrien r TD (if installed): turmed to lease e	elethe catrict resuct / seeled ton: company?	ion; JPF-diccel aarticulate	- 3 - 4 - 6 - 7	Front kH angle Front right ang Truck Cn. ID Additional outs Door jamb labe - VIN Adle ratio	side e side ide door information Is	י עניי עיי עיי עיי עיי עיי עיי עיי	4 5 6 7	Front left angles Front right angles Truck Co. ID Additional notsin Door jamb label UN Asile ratio	side le duor information s
H025/025 C EGR/EGR.C C Other CVCCCVD Head water grant even in the VCMOL at VCCCVD Head water grant even in the VCMOL at HEM Data Logger Installed: Yes C NO Logge Floased and Ht M Data installed, date truck to be ret Comments: A 3-12 tstablishment Inventory Pages 1 and 2 2010/11	erption catalyst; SCR as charanger more closen er ID (if installed): turned to lease of turned to lease of 14.docs	elective catriystic recursi / asoline tate company?	kn; 7PF=diest sarticulate	- 3 - 4 - 6 - 7 - 7 - 8	Front kH angle Front right ang Iruck Cn. ID Additional outs Door jamb labe - VIN Aderatio OBD connectio	side e side lide door information ls		1 4 5 6 7	Tront left angle : Front right angle : Truck Co. ID Additional notsi Door jamb label UN Note ratio OBD connection	side le duor information s
HO25/025 C EGR/EGR.C C Other TWI Start St	serption estatyst: SC4 as chaine ges more altream rr ID (if installed): turned to lease o 4.doox	elective catriystic recursi / asolied 1888 company?	ion: 5#Folicel sariouble	$= \frac{3}{4}$ $= \frac{4}{5}$ $= \frac{6}{7}$ $= \frac{8}{5}$ $= \frac{3}{5}$	Front Istt angle Front right ang Truck (m. II) Additional outs Deor jamb labe - VIN Adle ratio OBD connectio HEM logger ID	side e side ide door information ls 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2		1 4 5 6 7 7 8 9	Tront left angle : Front right angle : Truck Co. ID Additional notai Door jamb label UN Note ratio OBD connection HEM logger ID	side side s nd CERT ID
HO25/025 C EGR/EGR-C Other TWOCKNUM Heads while provide more a birth 10-00-0046 TWO and the provide strategic strategic strate (10-00-0046 TWO and 10-00-0046) If leased and H1 MI Data installed, date truck to be ref Comments: WA 3-12 Istablishment Inventory_Pages 1 and 2_2016011	erption catalyst: SC4 as chain get meta-listen rr ID (if installed): turmed to lease o 14.docs	elective catriyst e recurci / accled Date company?	Page 1 of 2	$\frac{3}{-\frac{3}}{-\frac{3}{-1}}}{-\frac{3}{-\frac{3}{-\frac{3}{-\frac{3}{-1}}}{-\frac{3}{-\frac{3}{-1}}}}{-1}}}}}}}}}}}}}}}}}}}}}}}}}}}$	Front kitt angle Front right ang I ruck (n. II) Additional outs Door jamb labe - <u>VIN</u> Adle ratio OBD connectio HEN logger ID (Xharnele)	side e side ide door information Is not CERT ID		1 4 5 6 7 7 8 9 10	Tront left angle : Front right angle : Truck Co. ID Additional notain Door jamb label u VIN n Asla ratio OBD connection HEM logger ID a Odometer Isrid a safe in .	inne side ie duor information s nd CERT ID
H025/025 C EGR/EGR.C C Other TOCCOMPARENT System and the Comparent shares to Compare TOCCOMPARENT System and the Comparent System and the Comparent Head Comparent System and the Comparent System and the Comparent Theorem and Intro total installed, date truck to be ref Comments: WA 3-12 Istablishment Inventory_Pages 1 and 2_2015011	serption ostalyti: SCA no obsurg get merculation r ID (Finitalited): lurined to lease o 14.docx	ektive antyte ne ret / solid tat	kn; 5#=dleet sarkouble	$ = \frac{\frac{3}{3}}{-\frac{4}{5}} $ $ = \frac{\frac{6}{5}}{-\frac{7}{7}} $ $ = \frac{\frac{8}{5}}{-\frac{10}{11}} $	Fronk ktt angle Fronk ktt angle Fronk right ang I ruck (m. II) Additional outs Door jamb labe - <u>VIN</u> Adle ratio OBD connectio HEM logger ID Ochameter Inside cabli (m.	side e side ide door information is n n defensed inn)		1 4 5 6 7 7 8 9 10 11	I ront left angle : Front right angle Truck Co. ID Additional not si Door jamb label u VIN n Asla ratio UBD connection HEM logger ID a Odometer Inside cabin (mo	inte side s nd CERT ID ddle section]
HO25/025 C EGR/EGR-C O Other TWC50001 Head withing transformation which to Monitor Labor TWC50001 Head within the transformation which to Monitor Labor HEM Data Logger Intellect Yes O NO Logger If leased and HTM Data installed, date truck to berret Comments: WA 3-12 Istablishment Inventory_Pages 1 and 2_2010013	serption astuly#: SCR to chause an two calcium or ID (Printatiled): Lumned to lease of Madeox	elective consyste nec a cris	ker; 59Fodleet sartouble	$\frac{3}{3}$ = $\frac{4}{5}$ = $\frac{6}{5}$ = $\frac{7}{7}$ = $\frac{8}{10}$ = $\frac{10}{11}$ = $\frac{12}{11}$ = $\frac{12}{12}$ = $\frac{12}{11}$ = $\frac{12}{11}$ = $\frac{12}{12}$ = $\frac{12}{11}$	Fronk lett angle Fronk lett angle Fronk right ang I ruck (m. II) Additional outh Deor jamb labe Deor jamb labe — <u>VIN</u> Adle ratio OBD connectio OBD connectio OBD connectio (Admeter Inside cabin (m Tire and tire siz VII) addet siz	side e side ide door information is and tERT ID iddle section)		- 4 5 6 7 7 8 9 10 11 11 12 13	Iront left angle: Front right angle: Truck Co. ID Additional nutrial Door jamb label J VIN CASE ratio OBD connection OBD connection MEM logger ID a Odometer Inside cabin (min line and the side	side side s nd CERT ID Idle section
H025/025 C EGR/EGR.C C Other_ WCC52001 Hereadwalking mark/exerce mathef NorMousta HEM Data Logger Installed: Yer No Logge Flexed and Int N Ibita installed, date track to be ret Comments: WA 3-12 Istablishment Inventory_Pages 1 and 2_2016013	serption estubjet: SCR to charar get the colorism of ID (Finitalited): furmed to lease of Autoex	elective consiste ne recipite / and lat it:	Page 1 of 2	$= \frac{3}{3} - \frac{4}{5} - \frac{6}{7} - \frac{7}{7} = \frac{8}{10} - \frac{10}{11} - \frac{10}{11} - \frac{12}{12} -$	Fronk left angle Fronk left angle Front right ang Inteck (n. II) Additional outs Door jamb labe - VIN Adle ratio OBD connectio HEM logger ID Othurneter Inside cabin (m Tire and tire siz X31Lank cap	side e side ide door information is in nu CERT ID dolle seet inn)		- - - - - - - - - - - - - - - - - - -	I reort lieft angle : Front right angle : Front right angle Door jamb label J VIN J Add ratio OBD connection HEM logger ID a Odometer Inside cabin (mm line and tire size SCR tank cap Sc/c rank tan Sc/	ide side s nd CERT ID idle section
HO25/025 C EGR/EGR.C C Other W025/021 Beneficial with grandware motion build be and 100 - part of the and the angle of the angle of the angle of the angle If leased and HTM Data installed, date truck to be ret Comments: MA 3-32 tstablishment Inventory_Pages 1 and 2_2016033	serption astaly#: SER as charar gar ware classes of the service of the service of the service turned to lease of 4. docx	elective antiyte ne vet / andiat us: company?	Page 1 of 2	$ = \frac{3}{3} = \frac{4}{5} = \frac{6}{7} = \frac{3}{7} = \frac{3}{7} = \frac{3}{7} = \frac{3}{7} = \frac{3}{12} = \frac{13}{12} = \frac{13}{12} = \frac{13}{12} = \frac{14}{12} = 14$	Fronk icht angle Fronk icht angle Fronk (m. II) Additional outs Door jamb labe - <u>VIN</u> Adle ratio OBD connectio HEM logger ID Okhmeten Inside cabin (m Tire and tire siz SOU tank cap Back right angle	side side door information is n 1 CERT ID ddle sect im) c side		- - - - - - - - - - - - - - - - - - -	I reont lieft angle : Front right angle : Fruck Co. ID Additioned notai Door jamb label J VIN Mark Co. ID Additioned in the OBD connection HEM logger ID a Odomeeter Inside cabin (min line and tim ske SCR tank cap Back right angle bull back	ian side le duor information s nd CERT ID idle section
H025/025 C EGR/EGR.C C Other_ WCC52001 Thereas obligg in anythere in the first MCN us to WCC52001 Thereas obligg in for the second se	serption cataly#1.904 to change an exclusion of D10 (Frintal Burnell Turned To lease of 4.docx	elethe attrict ne recret / sedier ton	Page 1 of 2	$ = \frac{3}{3} = \frac{4}{9} = \frac{6}{9} = \frac{3}{9} = \frac{3}{10} = \frac{3}{10} = \frac{10}{11} = \frac{12}{11} = \frac{14}{12} = \frac{14}{15} = \frac{14}{15} = \frac{14}{15} = \frac{14}{15} = \frac{15}{15} =$	Fronk iskt angle Fronk iskt angle Fronk (m. II) Additional outs Deor jamb labe Deor jamb labe — <u>VIN</u> Adderation OBD connection OBD connection OBD connection OBD connection OBD connection DO dumeter Inside cabin (m Tire and tire size XXII tank cap Isack right angle Full beck	side side de door information is and CERTID ddle section) contention side		1 4 5 6 7 7 8 9 10 11 17 13 14 15 16	I reort lieft angle : Front right angle : Front right angle Door jamb lake! Door jamb lake! John John John John John John John John	aan side le chor information s nd CERT ID kille section
H025/025 C EGR/EGR.C C Other TOCSCR01 Thereas while grand/team mining the Conton TOCSCR01 Thereas while grand/team mining the Conton TOCSCR01 Thereas while the Conton of the Conton Ref Data Logar mining the Conton Thereas and Inthe Total installed, date truck to be ref Comments: WA 3-32 Istablishment Inventory_Pages 1 and 2_2016013	ergten staljet; SCI to chang av socialism (TD (*installet Turned to leave o (4.docx	elective activitie necoret / aediat toot company?	Page 1 of 2	$\begin{array}{c} & & \\$	Fronk istt angle Fronk istt angle Fronk (m. III) Additional outs Door jamb labe - VIN Addiration OBD connectio HEM logger ID Ochumeter Inside cabin (m Tire and tire siz Müttank cap Iback sight angle Full beck Tailipipe Back light angle	side side de deor information is and CERT ID delle seel inn) c side		1 4 5 6 7 7 10 11 11 12 13 14 15 16 17	I reort lieft angle: Front right angle Door jamb labot J VIN VIN Vin Ada ratio UBD connector Inside cabin (mm line and tim ske SCR tank cap Back right angle I all back Tailpipe Back Inghe angle	aan side le duor informatiur s nd CERT ID ddle section side
H025/025 C EGR/EGR.C C Other CNUCCOUNTERCOMMENT and ACCOUNT AND A STATE HEM Data Logger Installed: Ves N NO Logger Tensead and it M Data installed, date truck to be ref Comments: WA 3-12 Establishment Inventory_Pages 1 and 2_2010013	serption cataly?: SCA to chank gas were drawn of the second second second second to provide the second second second to provide the second sec	eletive ontrofe ne zeta zaolar ton company?	Page 1 of 2	$\begin{bmatrix} & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & $	Fronk istt angle Fronk istt angle Fronk istt angle Fronk in 10 Additional outs Door jamb labe - <u>VIN</u> Adle ratio OBD connectio HEM logger ID Ckharnele Inside cabin (m Tirs and tire sig Ckharnele Inside cabin (m Tirs and tire sig Ckharnele) Inside (sight angle Full beck Tallpipe Back left angle	side side de door information is and CERT ID delle seet inn) c side side del door information		1 4 5 6 7 7 10 11 11 12 13 14 15 16 17 18	I reort lieft angle : Front right angle : Front right angle : Door jamb label J VIN Additional notisi OBD connector Inside caban (mor Inside caban (mor Insi	aan side le duox information 5 nd CERT ID idle section  side
H025/025 C EGR/EGR.C C Other WCC5001 Heread withing market wear which for Homoson In COCCOUNT Heread was an experimentation of the Concord In Concord was an experimentation of the Concord If leased and In the total installed, date truck to be red Comments: WA 3-12 tstablishment inventory_Pages 1 and 2_2016011	septen orbitett, son an often an encodern often an encodern of D (*installed): hurned to lease of 4.decx	olethol danyer ne zet zaolar tok	Page 1 of 2	$\begin{array}{c} & & \\$	Front ktt angle Front inght ang Irock (m. 10) Additional outst Door jumb labe - <u>VIN</u> Adler rabla OBD connection Hick logger ID Uskamete Insider cabin (m Tire and tire six SQL lamk cap Itack tight angle Fall beck Taileipe Back left angle Additional outs	side side de door information is and CERT ID delle sect inn) c s side side de door information		1 4 5 6 7 7 10 11 17 13 14 15 16 17 18 19	I rooti lieft angle : Front right angle Fruck Co. ID Additional notesi Door jamb laisel J VIN N Ade ratio UBD connection HEM logger ID a Odomether Inside caban (mm line and line skin SCR tank cap Back right angle I all back Tailpipe Back left angle s Additional outsis I ngine body	ann le chior informatiur s nd CERT ID ddle section  side side le door information
H025/025 C EGR/EGR.C C Other TOCSCR01 Present while predetermine shifts 50-00000000000000000000000000000000000	sergen stalget ST as often are services of the internet of the internet turned to lease a 4. doox	define on yr ne (ci 2 oddir lost company?	Page 1 of 2	$\begin{array}{c} & & \\$	Fronk ickt angle Fronk inght ang Lincek (n. 10) Additional outs Door jumb labe - VNA Ader ratio OBD connection HKM logger 10 Ckharneten Inside cabin (m Trea and tires 30 CKL and kop Dack tight angle Back left angle Back left angle Additional outs	side side defension is and CERT ID definered inn') c c side is definered inn' c		1 4 5 6 7 7 8 9 10 11 11 12 13 14 15 16 17 18 19 20	Irent lieft angle i Front right angle Truck (c. ID Additional nubilisma Door jamb label a VIN i Add ratio OBD connection HEM logger ID a Odometer Inside cabin (mm SCR tank cap Back right angle all back Tailpipe Back left angle s Additional autsi Ingine back	ann e duor informatian s nd CERT ID idle section] side ide ide cloor information
H025/025 C EGR/EGR.C C Other WCXCSQU therappen shifts "Dorthous shifts" Dorthous NEM Data Logger Installed: Ver No Logge Flexed and In the tasta installed, date track to be ret Comments: WA 3-12 tstablishment Inventory_Pages 1 and 2_2016013	enview only first of a billion of source of the source of	eletta ott yr ne (rc) (melet toot company?	Page 1 of 2	$ \begin{array}{c} & & \\ & & $	Fronk Ist angle Fronk Ist angle Fronk Ist angle Trock (n. 10) Additional outs Door jumb labe - VH Addretation OBD connection HEM logger ID Charnele HEM logger I	side side do door information is and CERTID ddle section) c side side dde door information sudrol resourcest		I         I           4         5           6         7           8         9           10         11           12         13           14         15           16         17           18         19           20	Iron Infer angler, Front right and Truck Co. ID Zorg and Neider Dorg and Neider Mark Co. ID Dorg and Neider Add can you Infer and Consoler Mark Consoler Infer and Consoler Infer and Consoler Back right angle Cal back Tailipes Back left angle S Additional outsi Ingine tody Engine takets	ann le cluor informatiur s nd CERT (D kille section) side le cloor information
HO25/025 C EGR/EGR.C C Other W025/021 Head with grand head with the formation of the formation 100 - and the formation of the formation of the formation of the formation HEM Data Logger installed. Yes ON O Logger If leased and HTM Data installed, date truck to be ref Comments: WA 3-12 tstablishment investory, Pages 1 and 2_2016033	verter only (1970 to verter only (1970 to	detta on yr in (ri) 2 osidd roz company?	Page 1 of 2	$\begin{array}{c} 3\\ -3\\ -3\\ -4\\ -6\\ -6\\ -7\\ -7\\ -7\\ -7\\ -7\\ -7\\ -7\\ -7\\ -7\\ -7$	Fronk ikt angle Fronk ikt angle Fronk right ang I rouk (n. 10) Additional outs Door jumb labe - VHA Addreatale OBD connection Hikk logger 10 Kalurate I maider cabin (m Trea and tire sit MC Lank (ap Hack right angle Full back T alipipe Back left angle Additional outs Engine Labels I missionv. Back left angle Addreatale Addreatale I missionv. Back left angle I missionv. I missionv.	side side de door intermation is and CERTID delle seel inn) c c side side side side side side side side		1 4 5 6 7 7 10 11 11 12 13 14 15 16 17 18 19 20	Iron life anglet Front right anglet Front right angle Door jamb laide Joor jamb laide Joor jamb laide VIN Joor jamb laide CBD connection NEM logger (1) Joden etar Inside cabin rijm Inside cabin rijm Inside cabin rijm Inside cabin rijm Inside cabin rijm Inside cabin rijm ScR tank cap Back raght angle Inside cabin rijm Back raght angle Inside cabin rijm Back raght angle Inside cabin rijm Back raght angle Inside cabin rijm Inside cabin rijm Back raght angle Inside cabin rijm Inside cabin rijm Ins	aan le duor information s nd CERT ID ddle section side side de door information ontrol equipment e information
H025/025 C 66/K/68/C O Other H025/025 C 66/K/68/C 0 Other H025/021 Hereadwalks great/weak-use starts 100/0006 HEM Data Logger Installed: Yes C No Logge If loaded and HLM Data installed, date truck to be ref Comments: VA 3-12 tstablishment Inventory_Pages 1 and 2_2016/011	vergies only (5,57 et al. vergies only (6,57 et al. et al. (7,57 et	eketrus ans str insc.i i sociel cost company?	Page 1 of 2	$ \begin{array}{c} 3 \\ -3 \\ -4 \\ -6 \\ -6 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7$	Fronk Ist angle Fronk Ist angle Fronk Ist angle I rock (n. 10) Additional outs Door jumb labe - VHI Adder tails OBD connection HEAI logger ID Othermetei HEAI logger ID Otherm	side side de door information is and CERTID delle section) c side side de door information autral expountment as information		.1           4           5           6           7           8           9           10           11           12           13           14           15           16           17           18           19           20	Irron link anglei. Front right angle Front right angle add lismed methods and lismed methods and lismed methods and lismed methods and lismed methods and lismed and	ann le cluor informatiur s nd CERT ID ddle section) side ide de cluor information ontrol equipment e unformation
HO25/025 C EGR/EGR.C C Other MO25/025 C EGR/EGR.C C Other MO25/021 Standards (Englewine state), Standards (100 - state) and (11 M Data installed, date track to be ref Comments: NA 3-12 tstablishment inventory, Pages 1 and 2_2016013	verter origin;p:0 = d verter origin;p:0 = d	detta on y tri nc. (-1 ) zoslat uzi company?	Page 1 of 2	$ \begin{array}{c} 3 \\ -3 \\ -3 \\ -4 \\ -6 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7$	Fronk ikk angle Fronk ikk angle Fronk right ang Truck (n. 10) Additional outs Door jamb blow WH Adderston OBD connectio HEM logger ID (Admetel mader cabin (m Ke and tirk spi Mick angle) angle Inski sight angle Additional outs Engine blobe Engine blobe Engine blobe Engine blobe	side side de deor information is and CERT ID delle section) c r sider side		.1           4           5           6           7           8           9           10           11           12           13           14           15           16           17           18           19           20	Tron I fea angle: Front i yist angle Front i yist angle Door; amb labet d kill kinan d norise Add kinan d norise CRB cases and the sources and the sources Back rept angle and kinangle Back rept angle angle Back rept angle and kinangle Back rept angle angle Back rept angle and kinangle Back rept angle angle Back rept angle angle Angl	ann Ie dhor information s and CERT ID Adle section stide side de door information ontrol equipment e mformation
H025/025 C EGR/EGR C C Other WOCKCOULTBEEN Configuration of the Configu	vogista odnjeg 150 to dovanje vojeka odnjeg 150 to dovanje v marilova na po v marilova i tra (j v installed) L umred to lease o 4. doce	ekettu an yö ne, etti i soolei tosi company?	Page 1 of 2	$ \begin{array}{c} 3 \\ -3 \\ -4 \\ -6 \\ -6 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7 \\ -7$	Fronk icht angle Fronk icht angle Fronk inght ang I ruck (m. 10) Addrittional outs Deor jumb behav Addrentiel Madrentiel Insäder cabin (m Tire and tire sit XCI Lunk up I tuck inght angle Fall beck. Tallejoe Back left angle Addritional outs Engine body. Engine lubels I missien v. Raited engi	side side door information is and CERTID dolle section) c side side door information antrol repurent se information		.4           5           6           7           8           9           10           11           12           13           14           15           16           17           18           19           20	Iron life angle i Front i fight angle Front i fight angle Additional on angle Additional on angle Additional on angle Odometer Inside cabin fight SGR tank cap Back right angle Back right angle Back right angle Back right angle Additional outsit Ingine tody Engine tody Engine tody Engine tody Engine tody Engine tody	ann Ie dicer information s nd CEPT ID Alle section ide section ide te door information information
H025/025 © EGR/EGR.C © Other WCC52001 Head withing market wave mathef 10-200 and 1 Control to the second within the second wave market for the second REM Data Logger in tradiced: Vec 0 No © Logger If leased and Int No Lota installed, date track to be ref Comments: WA 3-32 tstablishment inventory Pages 1 and 2_2016013	vergies only (1) for a	detruant yé ne rei rei rei rei rei rei rei rei rei re	Page 1 of 2	$ = \frac{3}{10} $ $ = \frac{10}{10} $	Fronk Ikh angle Fronk Ikh angle Fronk Ikh angle Maditational outs Deor jamb blev Adartation OBD connectio MEM Logger ID Adartatio OBD connectio MEM Logger ID Adartatio MEM Longer ID Adartatio MEM Longer ID Adartatio MEM Longer ID Adartatio MEM Longer ID Adartatio MEM Longer ID Adartatio MEM Longer ID Mem Long	side side door information in and CERT ID ddle section) sector into the section sector into the section sector into the sector into the sector int		1 4 5 6 7 7 10 11 11 12 13 14 15 16 17 18 19 20 Com	Tron life angle: Front infly angle Front infly angle Door jamb label additional outside Additional outside Additional outside Additional outside Back presh angle Additional outside Back life angle Additional outside Ingine hordy Engles how Back life angle Additional outside Ingine hordy Engles how Back life angle The Engles Deck Additional outside The Engles Deck	le drier information s nd CERT ID kille section skile section skile de door information mitrol equipment e information



• Goal: Quicker QA/QC and then quicker analysis of the data

- Currently developing and implementing an open database and open data analysis structure with our partners
  - Standard database structure: MySQL
  - Standard data analysis and QC/QA techniques: modular designed Scripts in Python and MySQL
  - Standard graphics: R

# Improvements to Data Analysis



• Modular QA/QC Design

Step 1	Step 2	Step 3	Step 4	Additional	
Data Structure & Nomenclature Checks	Date/Time & Vehicle Speed Checks	Engine Parameter Checks	GPS Parameter Checks	Analysis	
Define field names, definitions, etc.	Proper fields defined and validation	Proper field		V	
Allows for immediate data analysis on a per trip and					
	Soak times, starts, idle times, VMT, speed distributions, drive cycle development, use	Engine load, SCR operation, DPF operation, Engine RPM, etc.	GPS Fencing (ports, hoteling, county, city boundaries), road types_etc		
	patterns, etc.			30	



- Emissions are measured by infrared (IR) and ultraviolet (UV) light beam across roadway
  - ESP RSD4000, RSD4600 and RSD5000 units are used
- Specific concentrations of HC, CO, CO2, NO and smoke are measured in 50 milliseconds (50 individual measurements recorded).
- Emissions reported as ratios to CO2:
  - CO/CO2
  - CH4/CO2
  - NOx/CO2

# **Colorado's RSD Program**



- RSD program
  - 18 22 RSDs used year round
  - Weather: >20F and dry conditions
- Over time, Colorado's RSD has measured ~ 90% of Colorado's fleet of I/M vehicles
- Shared the RSD data with us through existing CRADA
  - EPA will share data results with Colorado
- Data Being Analyzed
  - 5.8 years of data (January 1, 2009 to December 31, 2015)
  - Over 10 million vehicles representing over 40 million valid records

# Vehicle Specific Power (VSP)



VSP is defined as the instantaneous power per unit mass of the vehicle

$$VSP = \frac{\frac{d}{dt}(KE + PE) + F_{rolling}v + F_{aero}(v^{2})v}{m}$$
$$VSP_{LDV} = v\left\{1.1a + g\left(\frac{r}{100}\right) + 0.132\right\} + 0.000302v^{3}$$

- *VSP* = Vehicle Specific Power (kw/ton), <sub>LDV</sub> = for typical light duty vehicle
- a = vehicle acceleration (m/s<sup>2</sup>)
  - = acceleration of gravity (9.81 m/  $s^2$ )
    - = road grade (%)

g

r

v = vehicle speed (m/s)

# Data Analyzed Methodology



- Methods Used:
  - VIN Decoded: MY, Make, Model, Engine Size, and Fuel Type
  - Reclassified vehicles into MOVES (Car/Truck Regulatory Classes)
  - Applied vehicle speed and acceleration through the RSD unit
  - Applied grade slope for each Colorado's RSD test site
  - Applied average NOx (ppm) concentration for each measurement
- Analyzed by NOx concentration (ppm) vs VSP (kW/ton)
   Also analyzed by NOx g/kgfuel vs VSP(kW/ton) same results
- Limited to new MY vehicles (MY2009 MY2015)
- Limited data to minimum 10 different vehicles with 25 valid RSD NOx measurements

### **Accuracy of RSD NOx Emissions by VSP**



