OPENING THE “CAN”

11th Annual International PEMS Conference

March 17-18, 2022

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Outline

- Background
  - What is the CAN and how to access the data?
  - Tools for opening the CAN
- Different CAN Data Fields Available
  - Ability to get “Static” and “Live” Data
- Examples of available data
- Examples of test programs gathering both Static and Operational data
- Development of Tools for gathering CAN data
- Conclusions

Multiple Modules are on the Vehicle's Controller Area Network (CAN)

Engine Control Module, Transmission Control Module, Other Controllers (multiple modules per vehicle)

"Static" Data

- **ID and Calibration Info**
- **Health & Diagnostic Info**
- **Cumulative Historical Data**

"Live" Data

- **Operational (SBS) Data**

Question to All:

Why are we not recording this “Gold Mine” of CAN Data?

Diff'rent Strokes for Different Folks (or Different Protocols for Different Vehicles)

- Protocols have been standardized for on-road vehicle networks that support and manage the vehicle's powertrain, emission control technologies and other systems (i.e., chassis, instrument cluster, body, brakes, etc.), and also provide **valuable diagnostics**.

Light-duty vehicles	Heavy-duty vehicles	Nonroad
SAE J1979	SAE J1979 &/or SAE J1939	SAE J1939 & OEM
Vehicle MY 1996+	Engine MY 2013+	Varies
Call / response, OEM broadcast	Broadcast and call/response	Many nonroad CANs are proprietary since EPA/CARB do not require a specific protocol or OBD connection

- Focus of this presentation is on HD, since LD data collection and analysis is relatively established, and HD includes both protocols

How do we open the "CAN"?

Old Way

New Types of Data Collection Tools

How do we open the “CAN”?

SAE J2534 Pass-Through Equipment
(Commercial Grade)

OBDII Interpreter
(Consumer Grade)

- Various types of hardware allow OBD access via laptop / software

Pigtails (Connector Converter)

- Accessing the CAN/ECM will require various connectors:
  - LDV/HDVs: SAE J1962
  - HDVs/Some Nonroad Equipment: SAE J1939 (Type1/2)
  - Most Nonroad Equipment: All Different Connectors

HDV J1939 to J1962

Caterpillar to J1962

Kubota to J1962

Harley Davidson to J1962

<u>CAN Access Points on Vehicles:</u>

- Under or near the steering wheel (LDVs)
- Different locations near the driver (HDVs, large NRs)
- Near the engine or driver seat (large NRs)
- Under the seat or near battery (smaller NRs and motorcycles)

SAE J1979 Protocol Highlights

- SAE J1979: Different modes used to collect different types of data
  - Mode $01, ***Live data***: Each parameter requested via parameter ID (PID)
  - Mode $02, ***Freeze Frame***: "Snapshot" of Mode $01 data when fault stored
  - Mode $03, ***Confirmed emissions fault codes*** / diagnostic trouble codes (DTCs),
  - Mode $04, ***Reset command***: erases all non-permanent emissions-related data
  - Mode $05, ***Oxygen sensor test results***: Useful for O2/mixture diagnostics
  - Mode $06, ***Onboard test results***: Also used for diagnostics, actual values for non-continuous monitors
  - Mode $07, ***Pending fault codes*** / DTCs: problem identified but hasn't occurred enough to move to Mode $03, won't command MIL
  - Mode $08, ***OBD system control***: bi-directional control for testing
  - Mode $09, ***Vehicle identification*** information: VIN, PCM info, etc.
  - Mode $0A, ***Permanent Emissions DTCs***: Cannot be cleared via Mode $04

SAE J1939 Protocol Highlights

- SAE J1939: Data provided “bundled”
  - Parameter Group Number (PGN) – Meaningful groupings of parameters, approximately 2400 SAE-defined unique PGNs
    - Suspect Parameter Number (SPN) – Individual parameters “grouped” within a PGN, approximately 6 SPNs per PGN, but that can vary from PGN to PGN
  - SPNs are generally unique (but are repeated in DM faults)
    - Approximately 24,000 SPNs, 8700 are reserved for OEMs, the remaining > 15,000 SPNs are system-specific
  - Identification, diagnostic, and operational data all provided as bundled PGNs/SPNs (rather than grouped by Service Modes as in J1979)

EPA Progress Made to Date

EPA has been refining CAN Data Gathering and Analysis Approaches

- Developed a deep understanding of J1939 and J1979 **(legislated) parameters and implementation strategies**;
    - Developed "medical record" (aka "snapshot") **J1939 Data fields (over 50 diagnostic messages, including operational cumulative data gathered in less than 2 minutes);**
    - Extensively gathered all data fields necessary for characterization of vehicle operation (100-200 fields on 1-Hz basis) **for understanding usage (activity) patterns;**
    - Learned how different OEMs store and broadcast data in different SAE protocols, areas and fields (SAE J1939/J1979, CAN1, CAN2, multiple controllers, etc.);

- **Resolved hardware issues** (specific OEM nuances, developed custom CAN adaptors, etc.), including nonroad;

- **Applied this knowledge** to multiple activity data gathering test programs including HDVs, and nonroad equipment (construction, agriculture and other small engines)

- Developing mini-PEMS to validate ECM data and quickly characterize emissions

Data Fields that can be Used

A) Vehicle Status Data (aka "medical record")

Diagnostic Messages

Engine/Emission Lamp Status

Maintenance Records

B) Vehicle Usage Data: Overall

C) Vehicle Usage Data: Second-by-second

D)

Maintained

Mal-Maintenance

Tampered

Modeling Local Usage Patterns

A) Vehicle Status Data - Readiness

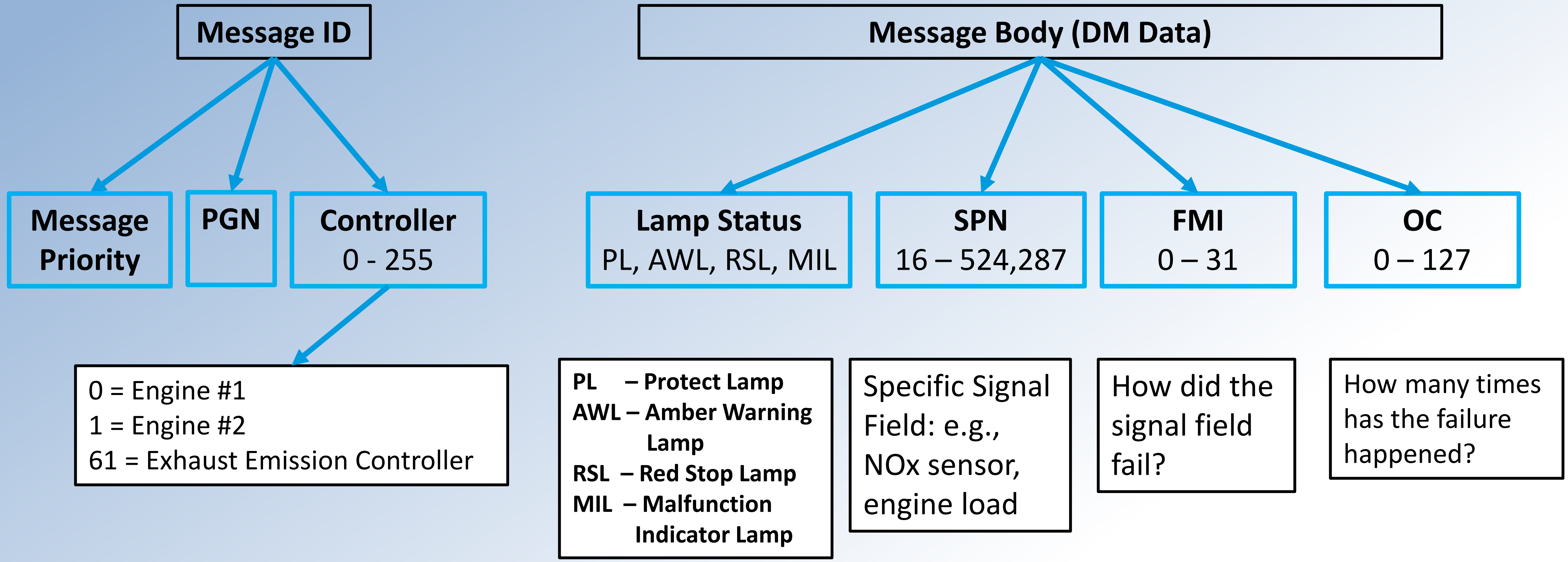
- Monitors tell whether vehicle's self-testing has completed
- Monitors similar (but not identical) between J1939 and J1979
  - Status since last reset (not supported, ready, or not ready)
  - Status since trip start (not supported, enabled, not enabled)
  - Cumulative operation (distance (km), time (s) , warm-ups(counts)) since last reset

Monitors (CI)	Monitors (CI), contd.
Comprehensive Component (continuous)	Evaporative emissions control system
Fuel system (continuous)	Catalyst / heated catalyst
Misfire (continuous)	NMHC catalyst
Exhaust Gas Recirculation / Variable Valve Timing	NOx converting catalyst and/or NOx adsorber
O2 sensor / exhaust gas sensor and heater	Diesel particulate filter
A/C system refrigerant	Boost pressure control system
Secondary air system	Cold start aid system

A) Vehicle Status Data – Fault Reporting

SAE J1979 DTCs	SAE J1939 DMs
Fault codes are provided as stand-alone diagnostic trouble codes (DTCs) defined in SAE 2012DA	Fault codes a provided grouped in diagnostic messages (DMs)
Example: **P0400**: **1st digit = DTC type** **P**=powertrain, B=body, C=chassis, U=network **2nd digit = SAE/OEM** P**0**xxx/P2xxx/P34xxx -P39xxx are all SAE DTCs **3rd digit = system** (1 = Fuel & Air Metering, 2 = Fuel Control, 3 = Ign / Misfire, **4** = Aux Emission Controls, etc.) **4th - 5th digit = code defn.** (P04**00**=EGR Flow Malfunction)	Diagnostic messages contain MIL status (and other lamps), suspect parameter number (SPN), failure mode identifier (FMI), and occurrence count (OC).
	SPN: The SPNs used to report faults are the same SPN designation as the live operating parameters also reported (typically broadcast) by SAE J1939DA FMI: Designates the type of failure (i.e., voltage above normal, abnormal rate of change, data error, etc.) OC: Count of the number of times the failure has been identified

A) DM “Fault Code” Structure - SAE J1939



PGN = Parameter Group Number (“bundled” data)
SPN = Suspect Parameter Number (subset of PGN)

FMI = Failure Mode Identifier
OC = Occurrence Count

A) Diagnostic Information – Fault Code Types

Fault Status	Fault Type	SAE J1979 Mode	SAE J1939 DM / PGN
Active	All	N/A	DM1 / 65226
Active	Emissions-Only	Mode $03	DM12 / 65236
Pending	All	N/A	DM27 / 64898
Pending	Emissions-Only	Mode $07	DM6 / 65231
Historical	All	N/A	DM2 / 65227
Historical	Emissions-Only	N/A	DM23 / 64949
Permanent	Emissions-Only	Mode $0A	DM28 / 64896

Note:
- Only **emission-related permanent DTCs** cannot be cleared. All other DTC codes can be "cleared".
- Can help with profiling fleet on a longitudinal basis for emission-related issues when "snap-shot" data taken

B) Vehicle Usage Data: Overall

- By taking a quick "snap-shot" (< 2 minutes), we can gather cumulative vehicle usage patterns that can be used for modeling vehicles on a longitudinal basis.

Parameter	Example J1979 parameter	Example J1939 PGN / SPN	Units
Lifetime **Idle Run Time**	PID 7F, Info Type ID (ITID) 46	64252 / 12737	seconds
Lifetime **Vehicle Fuel Consumption**	ITID 17	64252 / 12732 64777 / 5054	liters
Lifetime **Urban Speed Run Time**	ITID 46	64252 / 12736	seconds
Total **Vehicle** / **Engine Run Time**	PID 7F, ITID 16 (engine, hours)	65255 / 246 (vehicle, seconds)	Hours / seconds
Average **Distance Between** Active **DPF Regenerations**	PID 8B	64920 / 5827	km
Lifetime **NOx tailpipe output** (by bin)	ITID 6E	64267 / multiple	g / kg
Lifetime **Vehicle Distance**	ITID 17	64252 / 12731	m

C) Vehicle Usage Data: Second-by-second

More detailed activity/engine load usage data to help with local and national modeling

Parameters	J1979 PID	J1939 PGN/SPN	Units
Engine speed	0C	61444 / 190	RPM
Vehicle Speed	0D	65265 / 84	Km/hr
Aftertreatment 1 **Outlet NOx**	83	61455 / 3226	PPM
Aftertreatment 1 **SCR Outlet Temp**	78	64830 / 4363	°C
EGR Mass Flow Rate	B0	61450 / 2659	Kg/hr
Aftertreatment 1 **DPF Pressure Delta**	7A	64946 / 3251	kPa
Reference Torque	63	65251 / 544	Nm
Engine Load	04, 43	61443 / 92	%
% Torque	64	65251 / multiple	%
DPF Regeneration Status (passive/active)	8B	64892 / 3699,3700	Yes/No

Note: There are more engine/vehicle parameters that can be record based on your research questions.

D) Tampering Detection Strategies

- Alteration of powertrain, emission control components, and/or OBD system from as-certified configuration (can include reflash, deletes, emulators)
- Evaluation of "static" ("snapshot") and "live" data can reveal tampering:
  - Incorrect vehicle identifiers, calibration IDs, calibration verification numbers, engine family, etc. can indicate reflash
  - "Fingerprint" patterns of supported monitors, responding controllers, etc.
    Unsupported monitors can mask tampered or deleted systems
  - Readiness evaluation (including continuous monitors and comparing with cumulative histories since reset)
  - Review of reported cumulative aftertreatment activity and statistics can reveal disabled systems
  - Review of **live data** temperatures, pressures, concentrations, urea volume, etc. (looking for ranges, static values, etc., can indicate emulators and reflashes)
- EPA is developing new tools to **quickly (< 2 minutes)** identify tampering, using both "static" and "live" data.

Collaborative Test programs Using Tools to Access the CAN

- **<u>Agriculture Nonroad Activity Study by CARB</u>** – **Ongoing**
  - EPA is supporting data logging on over 240 pieces of equipment through contract and a Cooperative Research & Development Agreement (CRADA) with University of California-Riverside

- **<u>Construction Equipment Studies</u>** - **Ongoing**
  - EPA is supporting data logging:
  - South Coast Air Quality Management District (SCAQMD) 200 vehicle study through University of California-Riverside
    - Off-Road Construction by CARB – 100 vehicle study

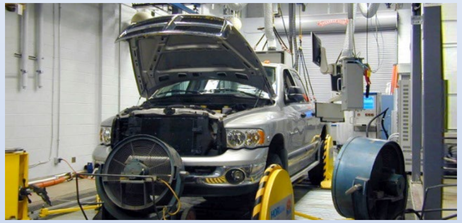
- **<u>Heavy-Duty Vehicles (HDVs) Emissions and Activity Study</u>** - **Completed**
  - EPA worked with UCR, CE-CERT on gathering activity data on 200 HDVs to get a better understanding usage patterns.

- EPA has supported <u>many test programs over the past 15 years</u> to gather real-world activity and emissions data using data loggers (PAMS) and PEMS for both on-highway and nonroad equipment to improve local and national modeling

Suite of Tools to Measure Activity and Emissions

Equipment Only Costs:

Laboratory Testing:
Chassis and/or Engine Dynamometer



~$3,000,000+

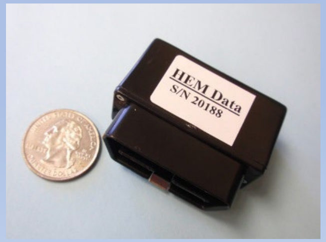
Portable Emissions Measurement Systems (PEMS) - Real World

~$200,000-$300,000

Screening Tools: mini-PEMS
Real World

~$30,000-$100,000

Portable Activity Measurement Systems (PAMS) – Real World



~$600 -$1,000

Conclusions

- Numerous data fields are available within the CAN that can be used to characterize and model local and national activity both in an aggregated and 1-Hz data rate;

- These usage patterns can help better define and reduce local emissions, and determine what new technologies will work for specific usage pattern in the real-world;

- EPA is working on methodologies to quickly find tampered and/or mal-maintained HDVs using the "snap-shot" methodology;

- EPA will continue to work on developing new "tools" to better understand the **real-world activity and emissions patterns of mobile sources;**

- EPA is looking for partnerships to continue and expand these efforts.

Additional Resources

The following resources provide additional information on acquiring CAN data from both heavy-duty and light-duty vehicles

- Walter, Richard, and Eric Walter. *Data Acquisition from HD Vehicles Using J1939 CAN Bus*, SAE International, 2016, SAE Order Number R-446, http://dx.doi.org/10.4271/R-446

- Walter, Richard, and Eric Walter. *Data Acquisition from Light-Duty Vehicles Using OBD and CAN*, SAE International, 2019, SAE Order Number R-458, http://dx.doi.org/10.4271/R-458

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Thank You

Questions?