CALIFORNIA
AIR RESOURCES BOARD

Analyzing Real-World Engine Duty Cycles of Construction Equipment and Assessing the Need for a Low Load Cycle

November 3, 2021

Objectives

- Understand the real-world engine duty cycles of off-road construction equipment
  - Compare real-world engine duty cycles with the Nonroad Transient Cycle (NRTC)
  - Compare real-world engine duty cycles with the Low Load Application Cycle developed in research contract 18RD006[1]
- Assess the need for supplemental certification cycle development

[1] *"Off-Road Diesel Low-Emission Demo for Nitrogen (NOx), Particulate Matter (PM), and Toxics", https://ww3.arb.ca.gov/research/single-project.php?row_id=68119*

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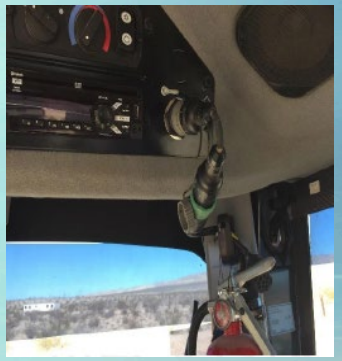
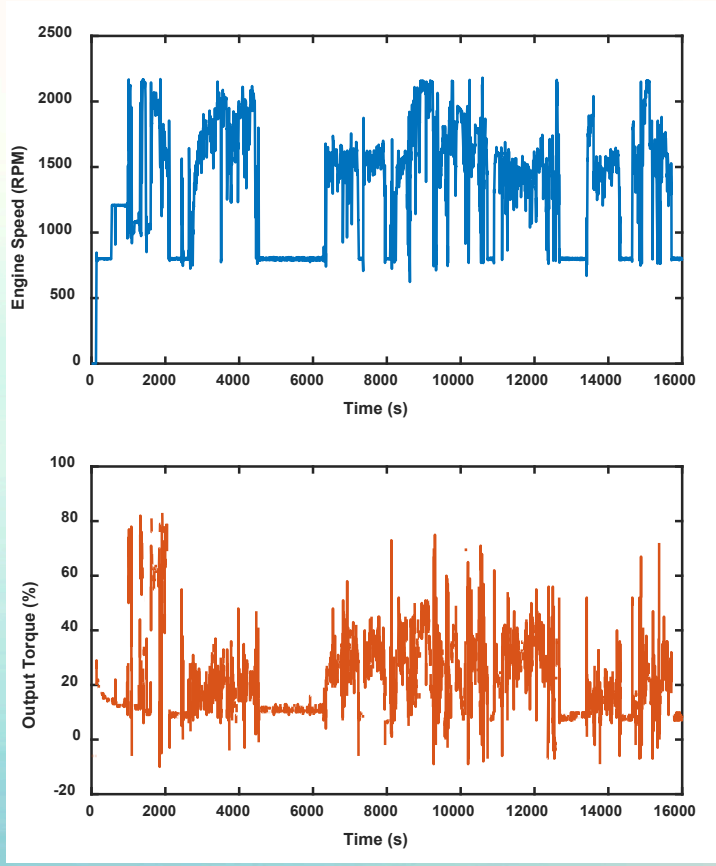
Real-World Activity Data Collection

- 35 pieces of construction equipment; 27 engines reported both actual & friction torques
- Tier 3 - Tier 4 engines, 2008 – 2018 model year
- The data covered major construction equipment types: loader, grader, backhoe, hauler, water truck, excavator, etc.
- 72 – 416 kW (96 – 558 hp)
- Real-world activity data were recorded at 1 Hz for at least 4 weeks for each engine



Normalized Engine Load

- Normalized engine load was used for the data analysis
- Assumed a reference torque value to calculate the engine output power
- Normalized all the calculated power values to the maximum
  - The assumed reference torque is canceled out



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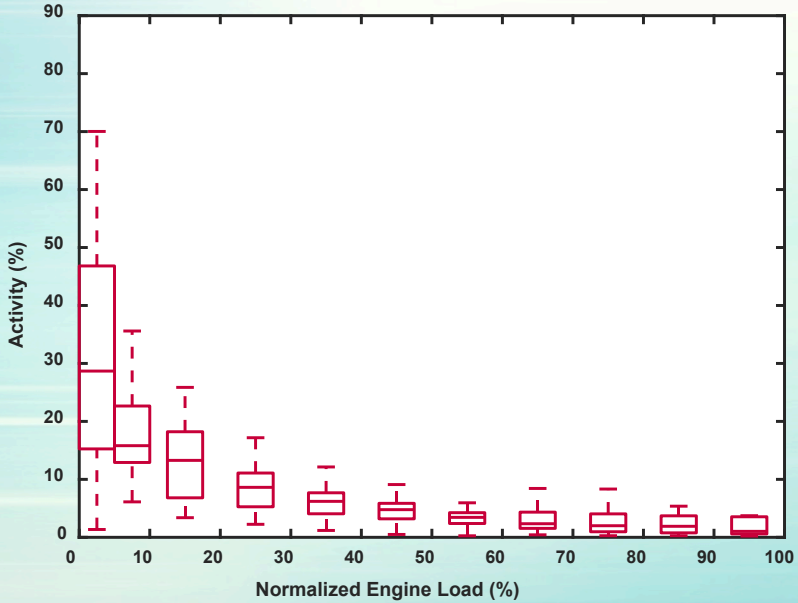
Distribution of Normalized Engine Load

All 27 engines



- Largest 1Hz activity dataset for construction equipment
- Instantaneous data were categorized into 11 engine load bins: 0 – 5%, 5 – 10%, 10 – 20%, 20 – 30%, …, 90 – 100%
- The y-axis shows the percent of time of engine activities
- Each box shows the distribution of activities of all 27 engines at the given bin
- 21 out of 27 engines had >50% of activity in low load bins (i.e., < 20% normalized engine load)

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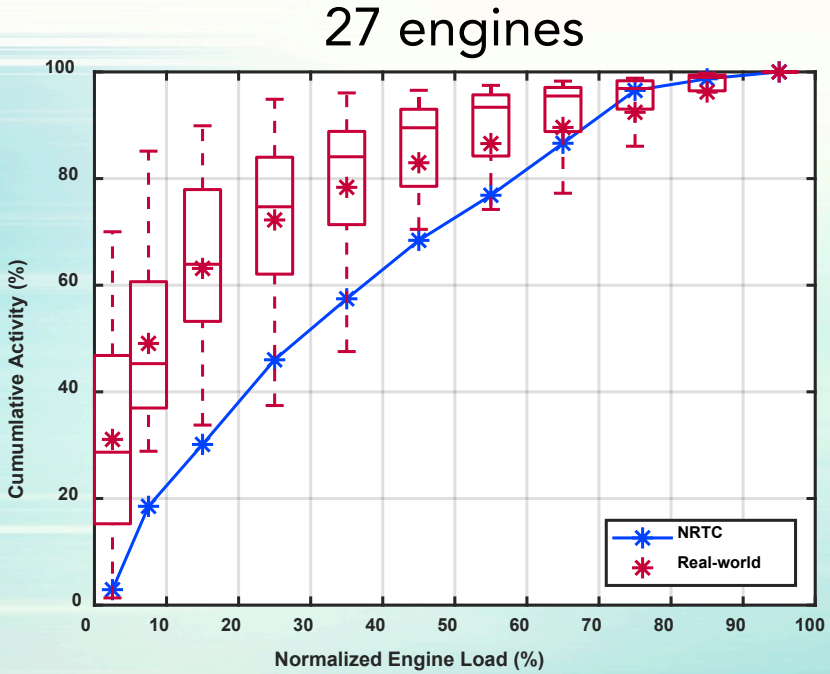
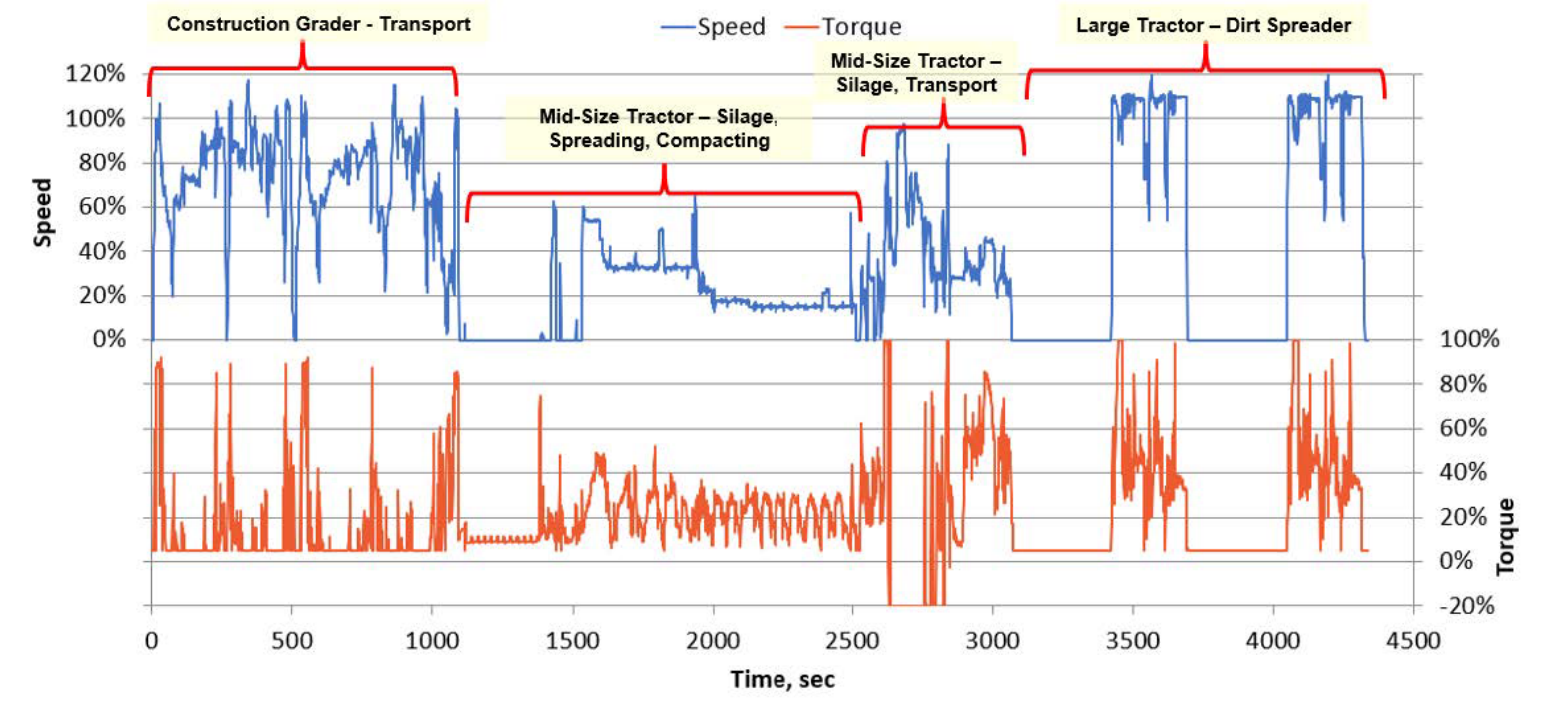
Real-World Data Comparison with NRTC



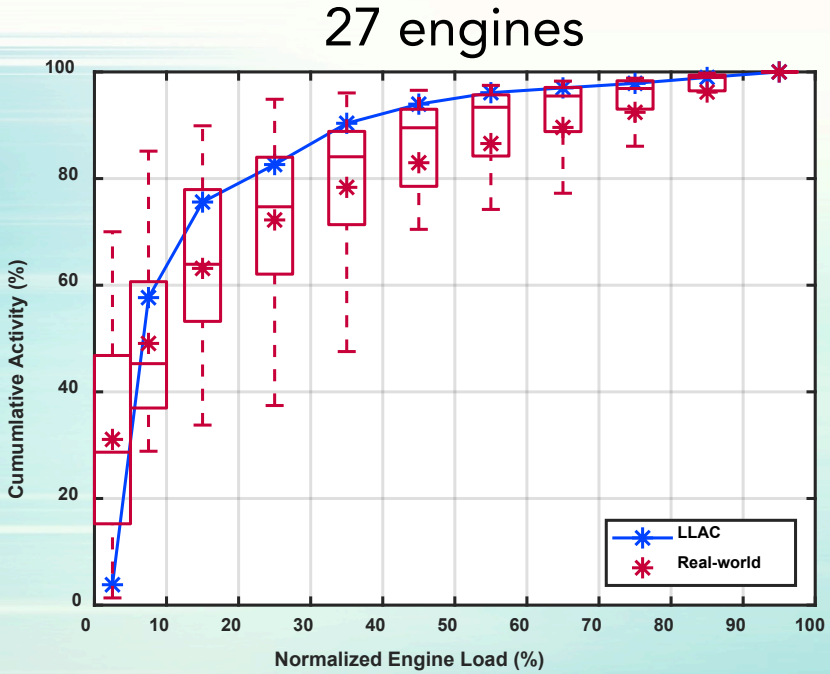
- Real-world data of most engines showed significantly more low load operations than the NRTC
  - On average, 63% of activity was below 20% engine load
- The data indicates NRTC does not sufficiently represent the low load conditions that occur in real-world duty cycles
- The average load of NRTC is ~37%, while the average load of the real-world data is ~19%

Low Load Application Cycle (LLAC)



"Off-Road Diesel Low-Emission Demo for Nitrogen (NOx), Particulate Matter (PM), and Toxics,"
https://ww3.arb.ca.gov/research/single-project.php?row_id=68119

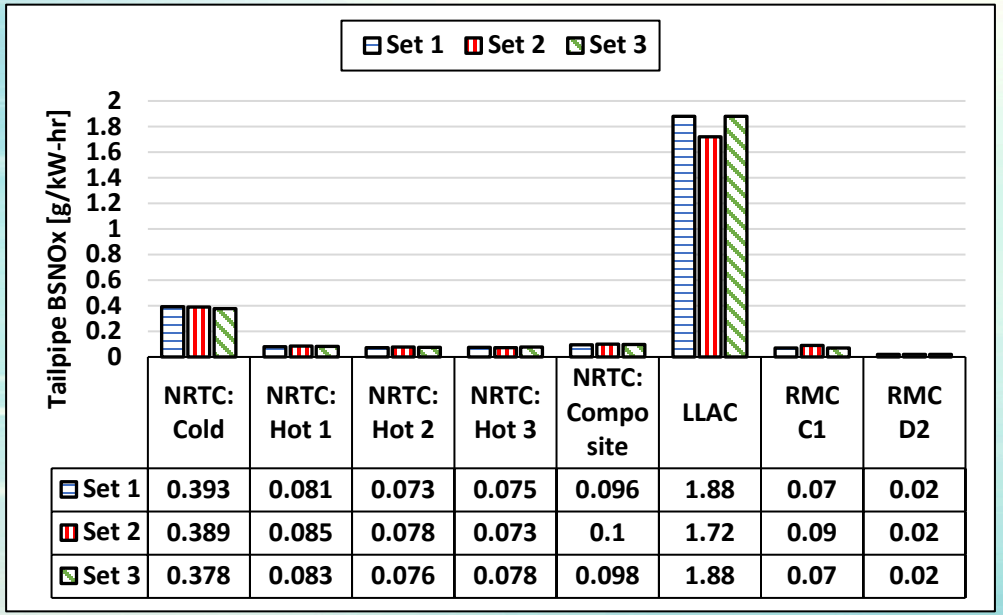
Real-World Data Comparison with LLAC



- The average load of LLAC is ~15% of the maximum power
  - Average load of NRTC is ~37%
  - Average load of the real-world data is ~19%
- The LLAC better captures real-world low load operations than the NRTC

Emission Implications

John Deere 6.8L Engine, SCR+DPF, Baseline
Individual Tailpipe NOx Results - SwRI



	NRTC: Cold	NRTC: Hot 1	NRTC: Hot 2	NRTC: Hot 3	NRTC: Composite	LLAC	RMC C1	RMC D2
Set 1	0.393	0.081	0.073	0.075	0.096	1.88	0.07	0.02
Set 2	0.389	0.085	0.078	0.073	0.1	1.72	0.09	0.02
Set 3	0.378	0.083	0.076	0.078	0.098	1.88	0.07	0.02

- A 6.8L John Deere engine was tested over different cycles in research contract 18RD006
- NOx emissions over the LLAC could be several times higher than the standard
- Compliance over the NRTC might not adequately control low load emissions in the real world
- Developing a certification LLC for off-road engines could be beneficial

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Conclusions & Next Steps

- Real-world data indicates that low load operations represent a significant portion of activity for off-road engines
- Current NRTC does not sufficiently represent the low load conditions that occur in real-world duty cycles
- The LLAC developed in research contract 18RD006 more closely represents real-world low load operations
- A certification LLC is critical for controlling real-world emissions
- The Low NOx demonstration engine had significantly higher emissions over the LLAC than over current certification cycles
- Next steps
  - Gather and analyze additional activity data from construction and agricultural equipment