MOVES
Motor Vehicle Emission Simulator

Effect of Driving Conditions on NO_x Emissions from 2010+ Heavy-duty Vehicles

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Scope

1. Variability in real-world duty cycles
2. Effect of exhaust temperature on NO_x emissions
3. Do we need a different modeling approach for SCR equipped vehicles?

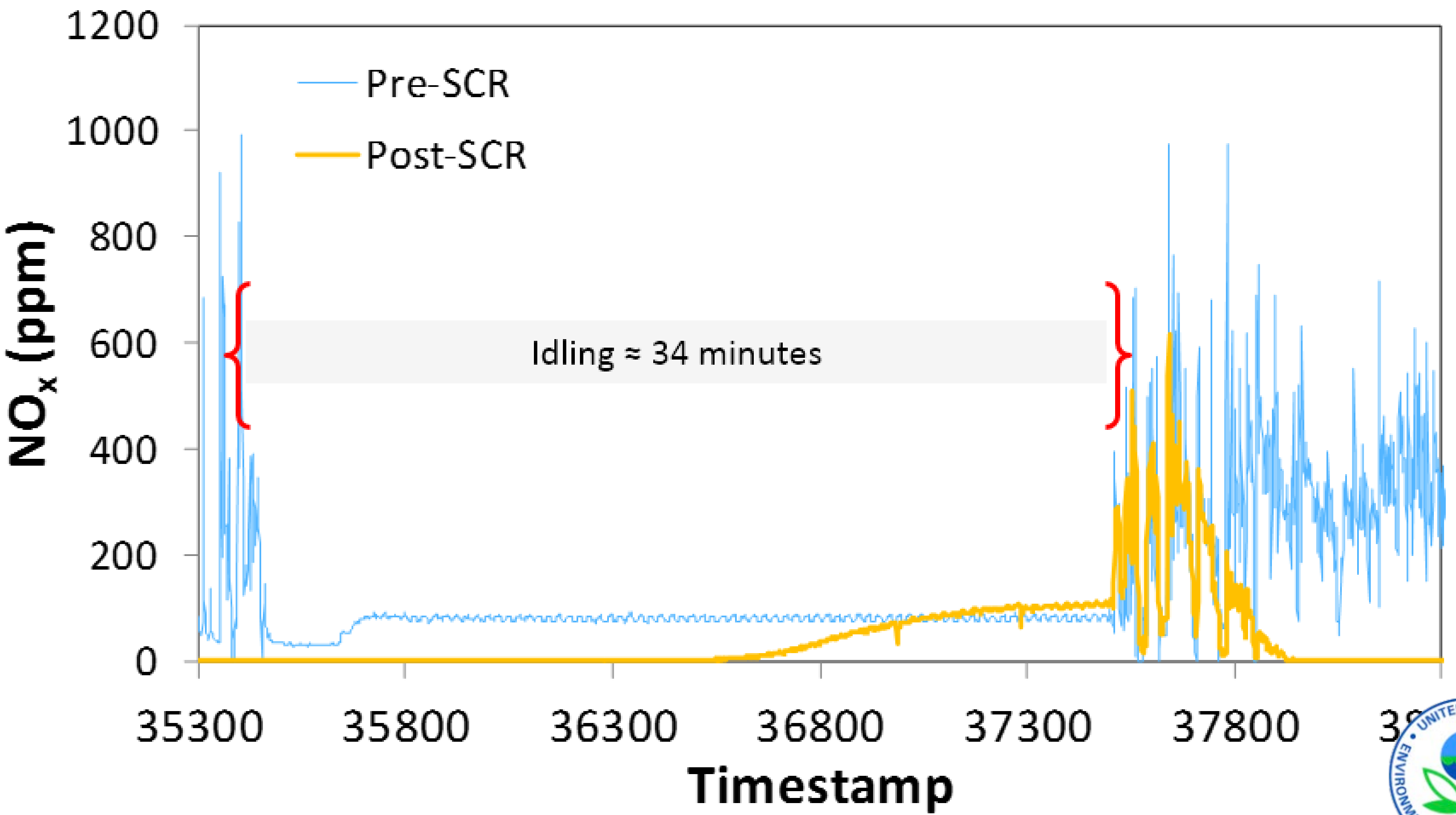
Motivation
MOVES2014a NO_x Data Sources

		Regulatory Class			
Data Source	**MYG**	**HHD**	**MHD**	**LHD**	**BUS**
ROVER and Consent Decree Testing	**1991-1997**	19	-	-	2
	1998	12	-	-	-
	1999-2002	78	30	-	25
	2003-2006	91	32	-	19
HDIU	**2003-2006**	40	25	15	-
	2007-2009	68	71	24	-
Houston Drayage	**1991-1997**	8	-	-	-
	1998	1	-	-	-
	1999-2002	10	-	-	-
	2003-2006	8	-	-	-

Table 2-2 (pg 16) , *Exhaust Emission Rates for Heavy-Duty On-road Vehicles in MOVES2014*, EPA-420-R-15-015a, November 2015
https://www3.epa.gov/otaq/models/moves/documents/420r15015a.pdf

Motivation
SCR Response Example 1

2010 MY, 13 liter, 450 hp, combination long-haul truck



Heavy-duty In-use Testing (HDIUT)

- Each year, US EPA selects some of the engine families with production volume ≥ 1,500 units
- Manufacturers find vehicles from fleets that have the selected engine family
- Tests are conducted under real-world conditions using 1065 certified instruments

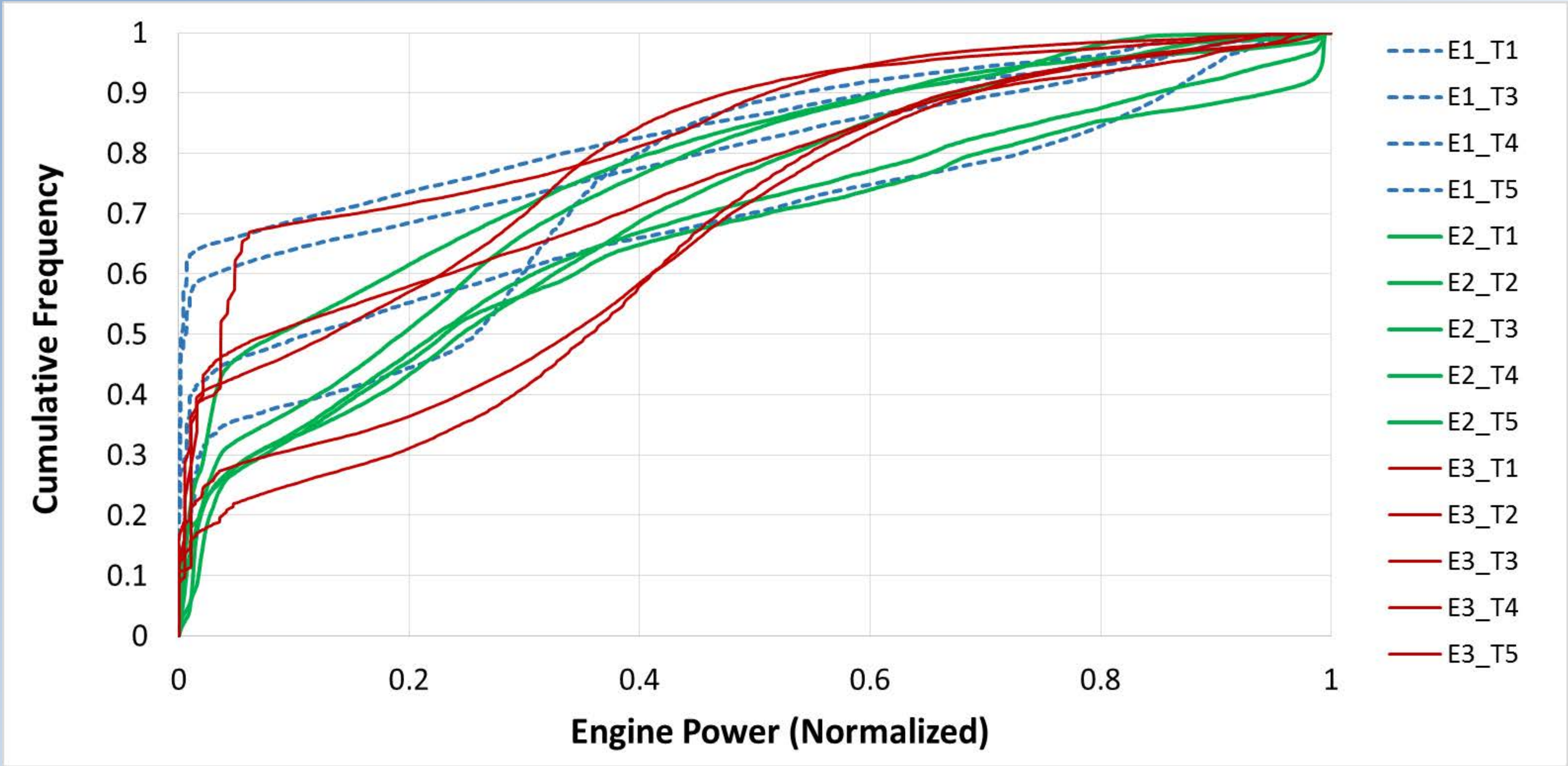
Relevant Regulation Citations:
— 40 CFR Part 86 Subpart T: Manufacturer-Run In-Use Testing Program for Heavy-Duty Diesel Engines.
— §86.007-11: Emission standards and supplemental requirements for 2007 and later model year diesel heavy-duty engines and vehicles.
— §86.1370-2007: Not-To-Exceed test procedures.
— §86.1901: What testing requirements apply to my engines that have gone into service?
— §1065.915: PEMS instruments.

Test Data Description

ID	Engine MY	Disp (L)	hp	Odo (10^3 mi)	Test Miles	Test Secs	Controls	Application
E1_T1	2010	15.0	475	246	266	23684	TC, CAC, EGR, DPF, SCR-U	Line Haul
E1_T3			475	268	330	30279		
E1_T4			475	261	153	27034		
E1_T5			475	324	258	39344		
E2_T1	2012	16.0	525	78	394	38039	TC, CAC, EGR, DPF, SCR-U, AMOX	Line Haul
E2_T2			575	127	253	31685		
E2_T3			525	153	322	39021		
E2_T4			525	107	317	33742		
E2_T5			525	166	393	36670		
E3_T1	2011	10.5	380	321	489	34241	TC, CAC, EGR, DPF	Delivery
E3_T2			400	205	190	23744		
E3_T3			380	206	325	34290		
E3_T4			400	131	191	35622		
E3_T5	2011	15.0	450	184	432	33474	TC, CAC, EGR, DPF	Delivery

TC: Turbocharger | CAC: Charge Air Cooler | EGR: Exhaust Gas Recirculation | DOC: Diesel Oxidation Catalyst
DPF: Diesel Particulate Filter | SCR-U: Selective Catalytic Reduction using Urea | AMOX: Ammonia Oxidation Catalyst

Real-world Duty Cycles

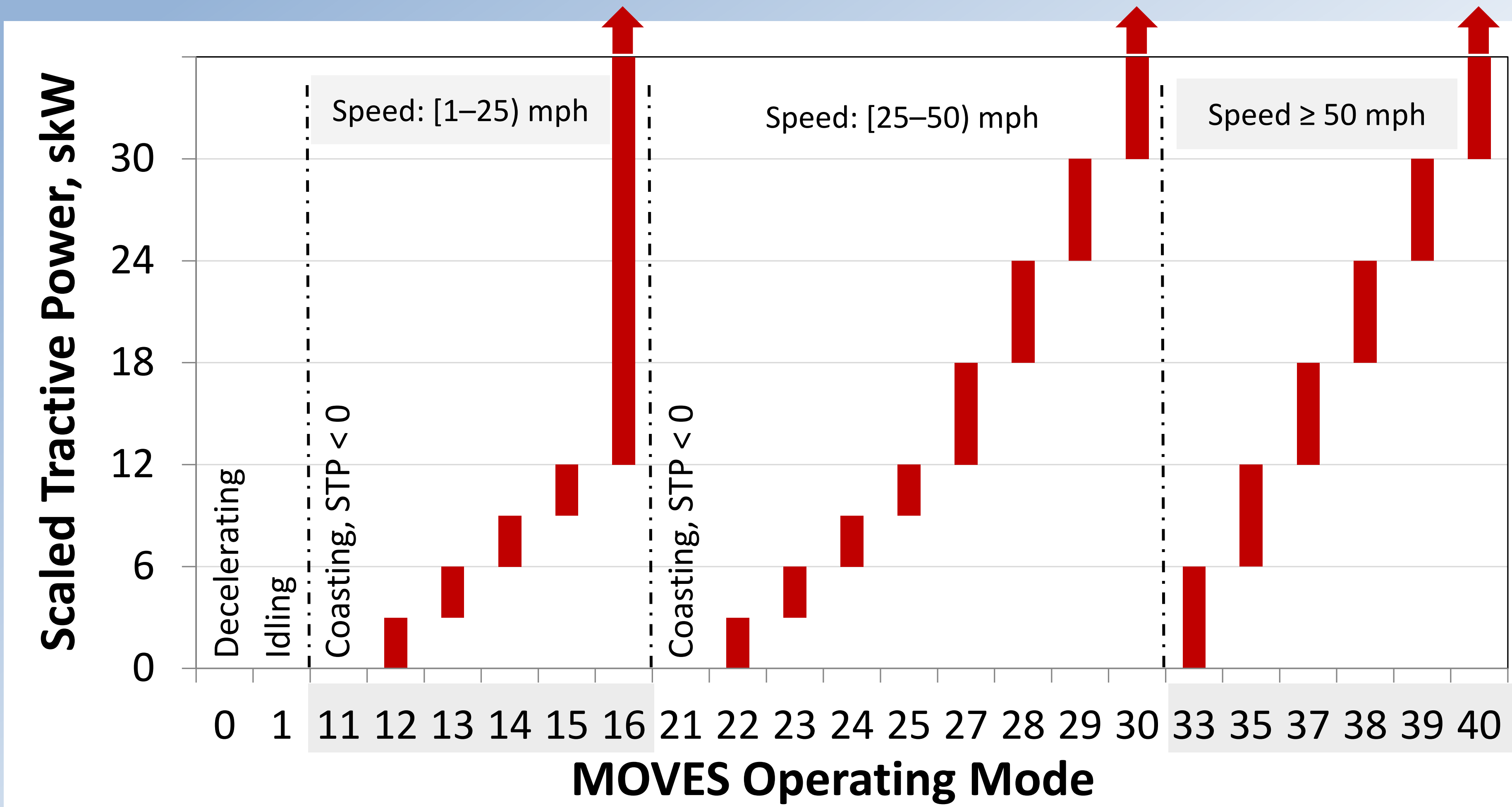


MOVES Scaled Tractive Power

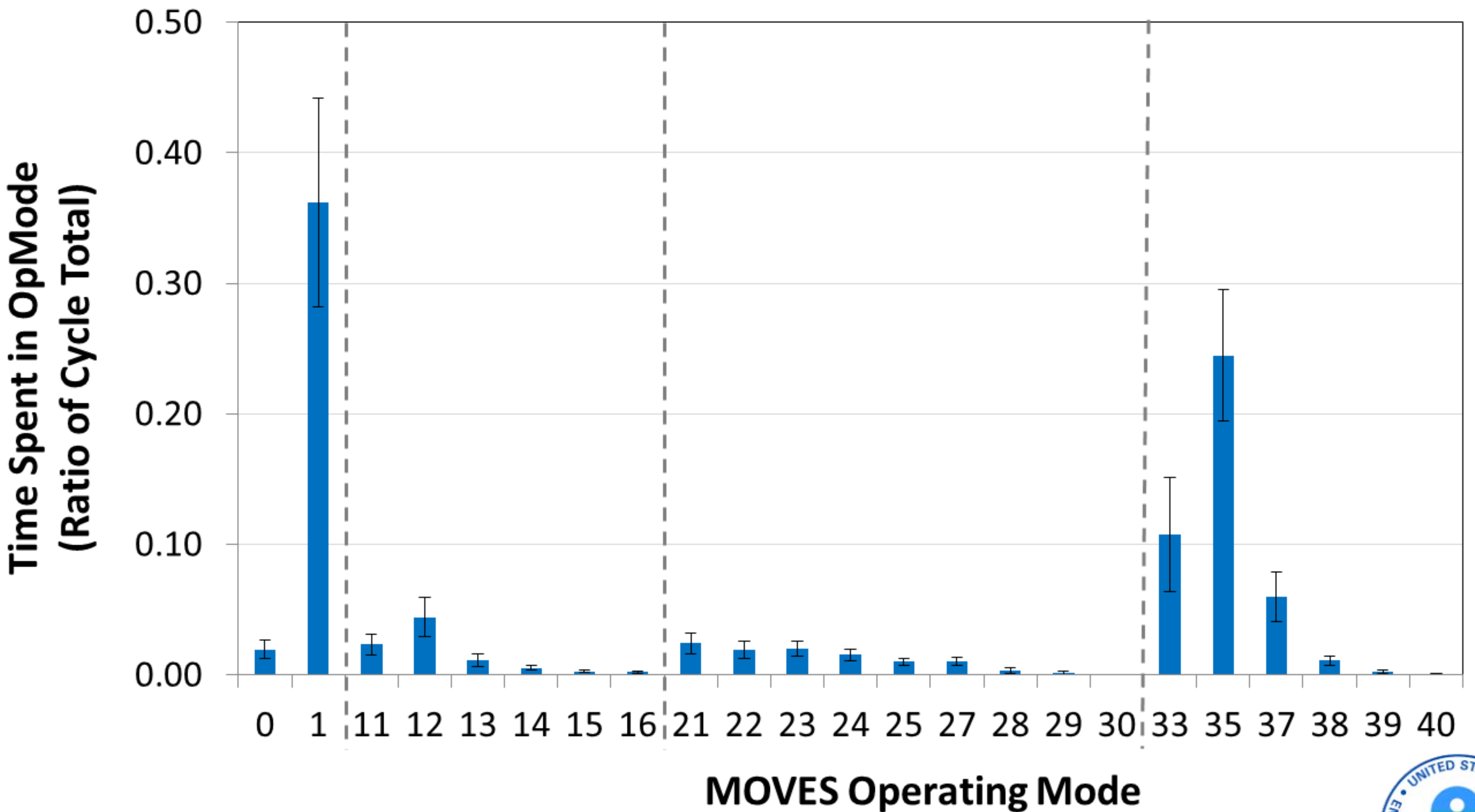
$$STP_t = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{f_{scale}}$$

STP_t	=	scaled tractive power at time t, skW
A	=	rolling resistance coefficient [kW-s/m]
B	=	rotational resistance coefficient [$kW\text{-}s^2/m^2$]
C	=	aerodynamic drag coefficient [$kW\text{-}s^3/m^3$]
a_t	=	vehicle acceleration at time t [m/s^2]
m	=	vehicle mass [metric ton]
v_t	=	vehicle speed at time t [m/s]
f_{scale}	=	scaling factor, unitless

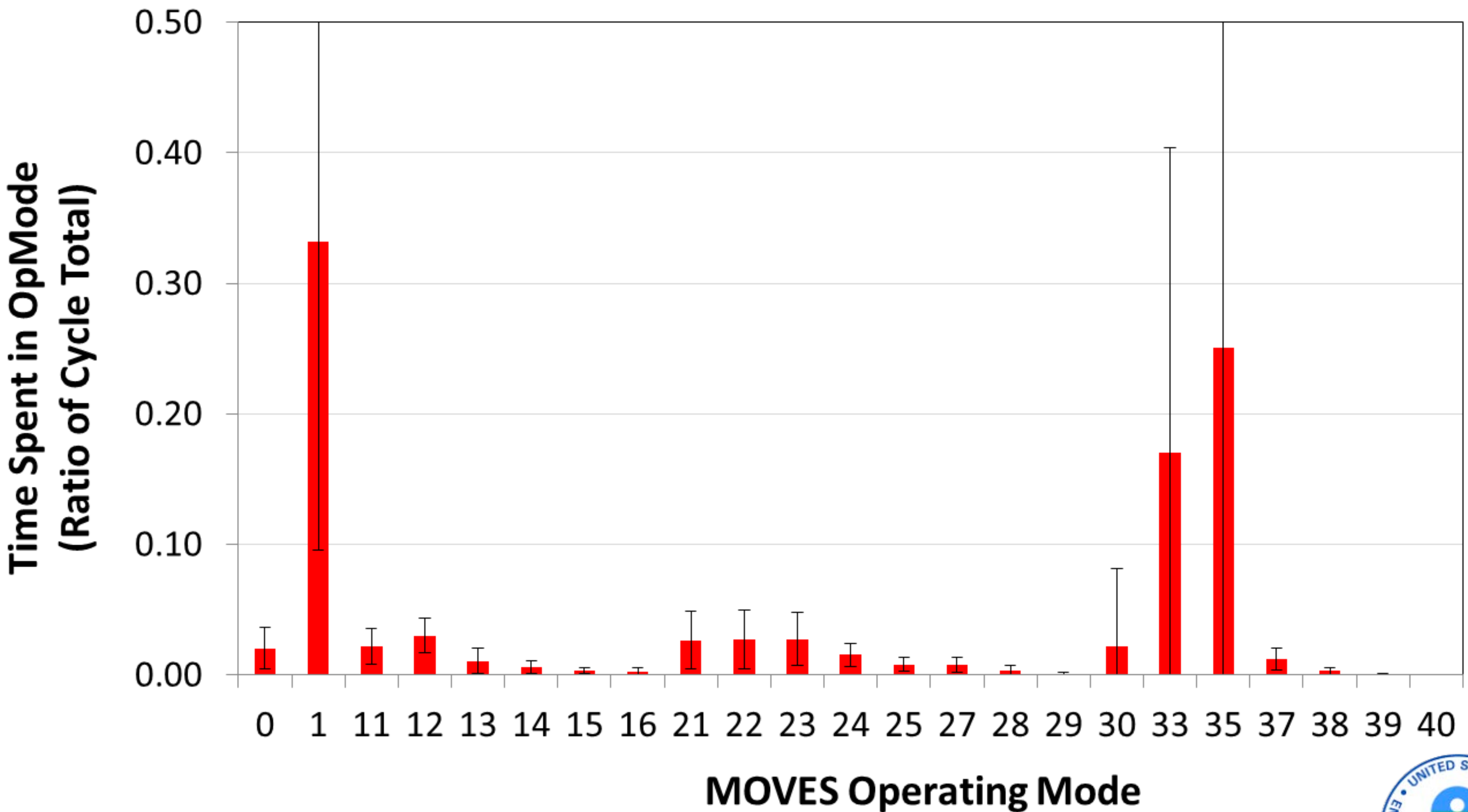
MOVES Operating Modes (OpMode)



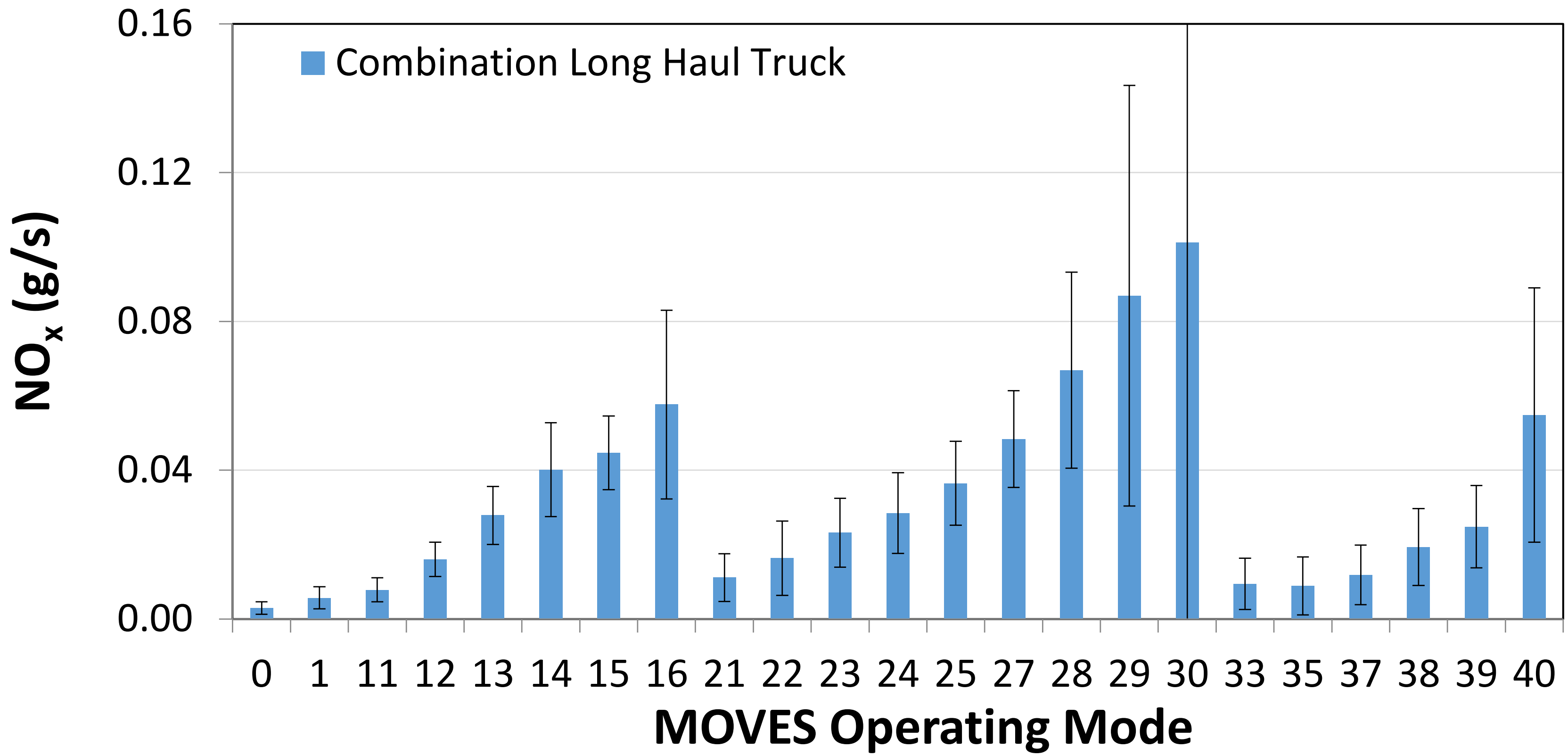
Variability in OpMode Time Distribution: Line-haul



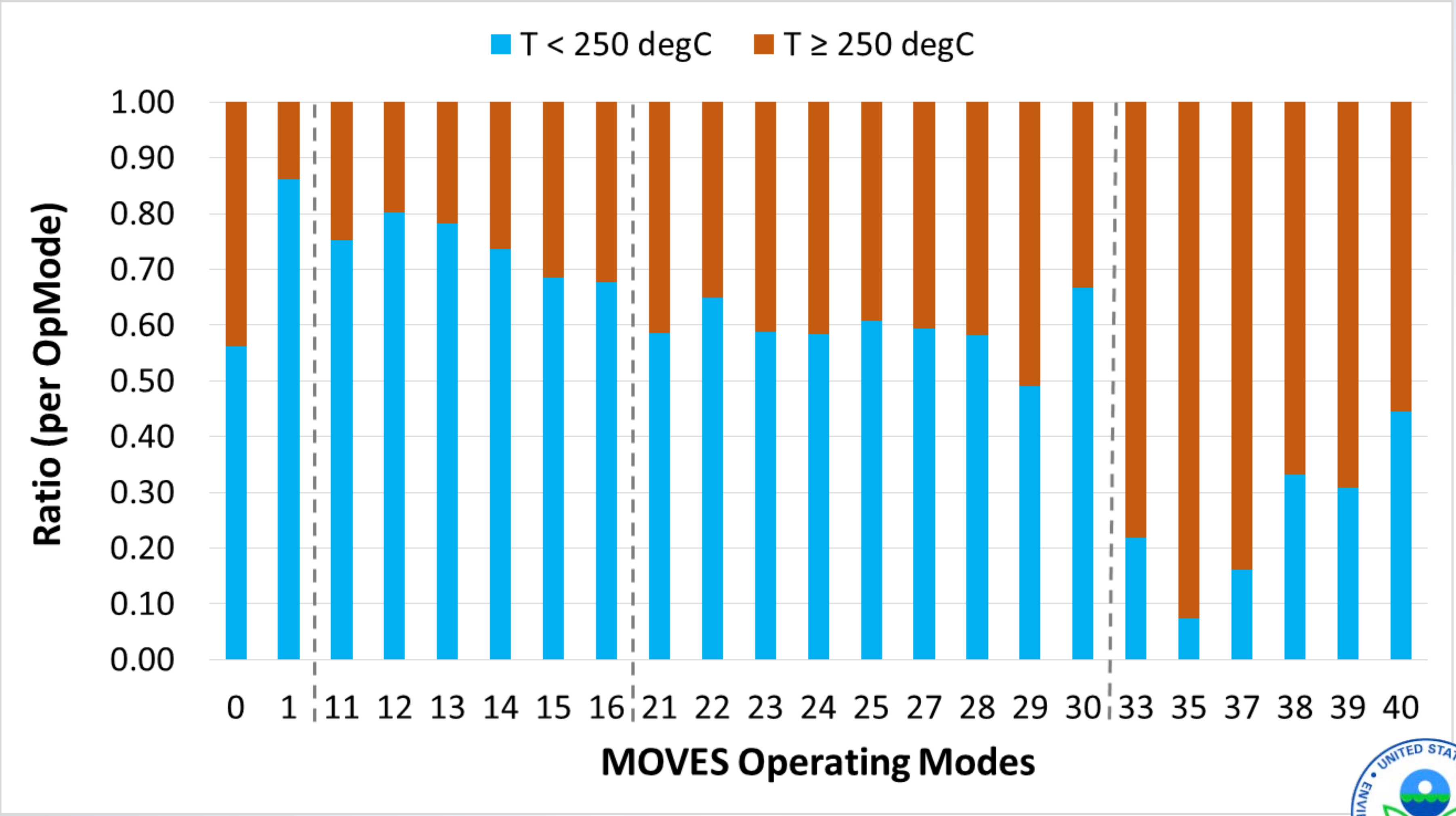
Variability in OpMode Time Distribution: Delivery



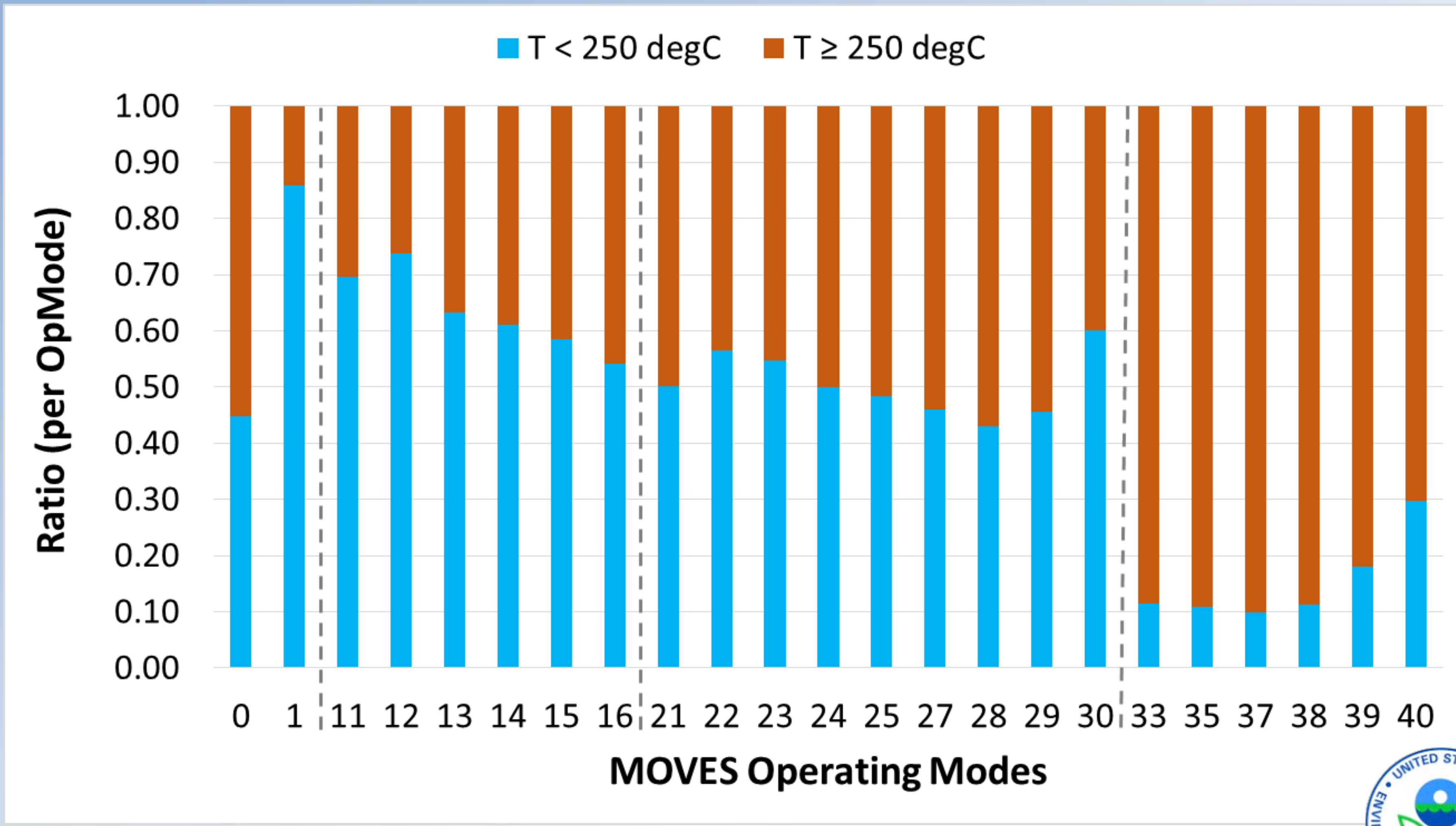
Variability in OpMode NO_x Emission Rates



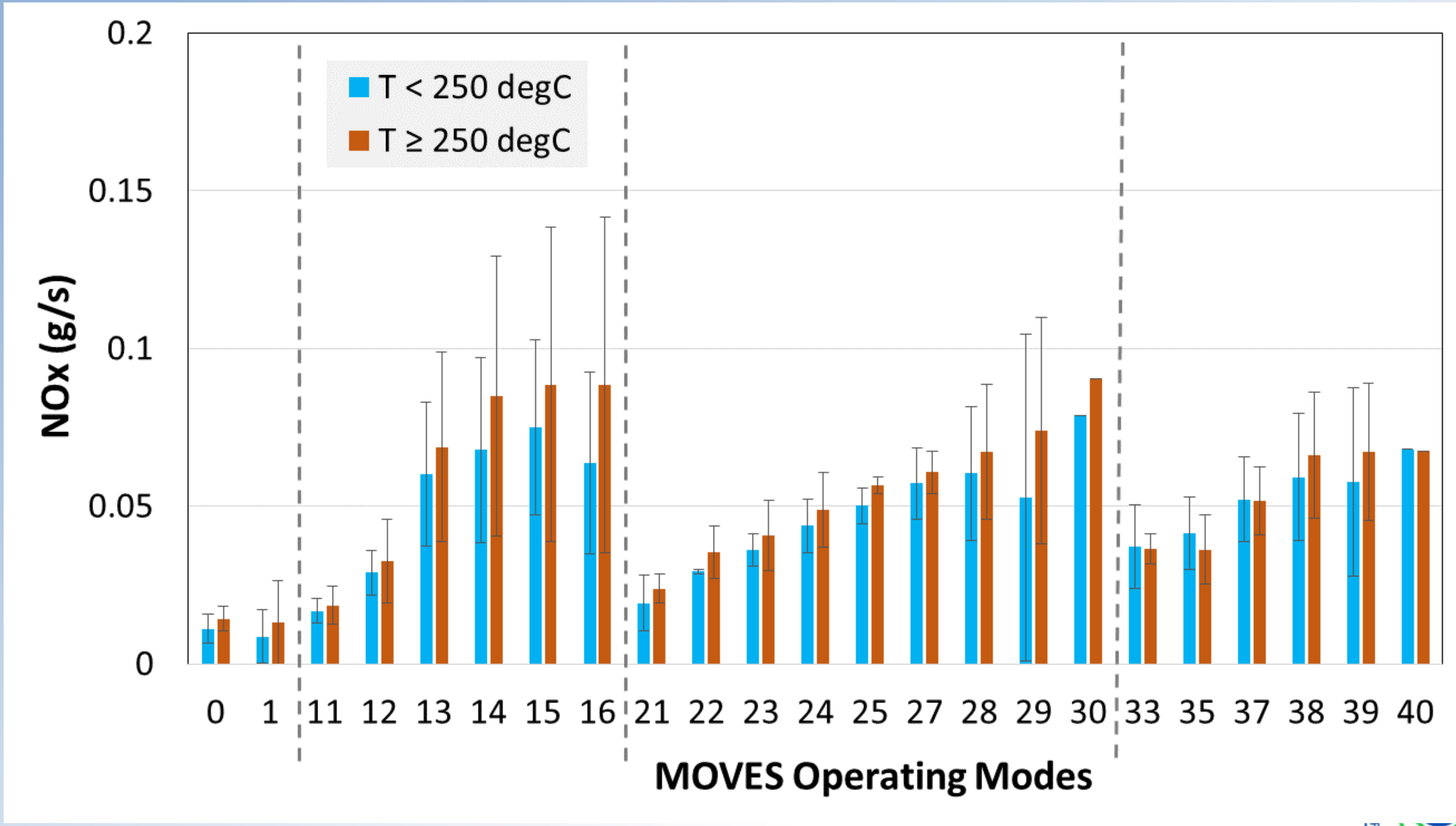
OpMode Time Ratio: Trucks with*out* SCR



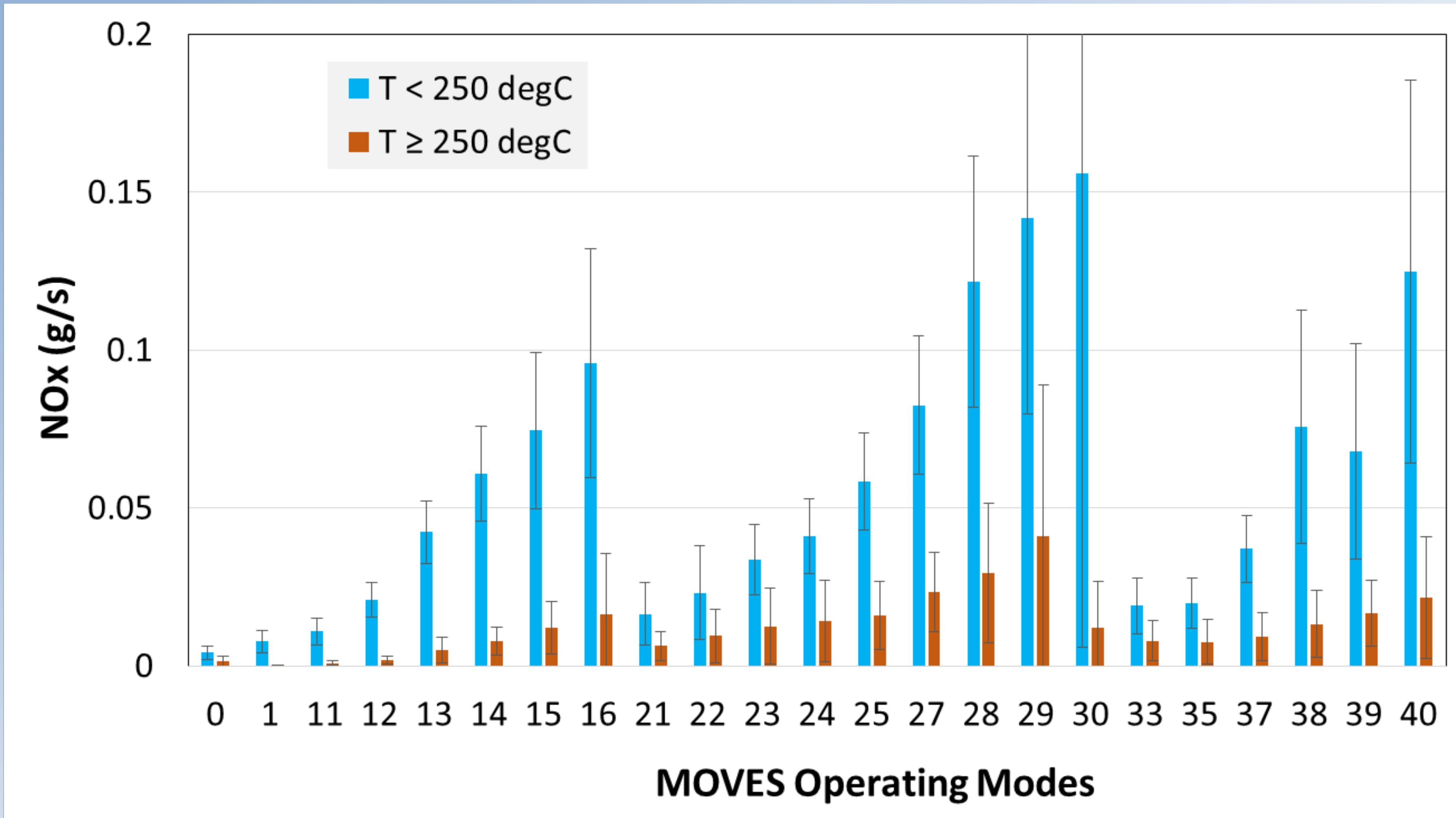
OpMode Time Ratio: Trucks with SCR



Exhaust Temperature Effect: Trucks with*out* SCR



Exhaust Temperature Effect: Trucks with SCR



Cycle Total Contribution: Trucks with SCR

	Contribution (Ratio)	
	Time	NO_x
T < 250 degC	0.49	0.65
T ≥ 250 degC	0.51	0.35

Conclusions

- MOVES OpModes continue to represent intra-cycle variability
- For trucks with SCR, exhaust temperature affects NO_x emission rates across all OpModes
- Representativeness of duty cycles *could* be evaluated based on engine power demand and after-treatment temperature distribution

Future Work

- Increase vehicle sample size from HDIUT data
- Seek data from other studies. Volunteers?
- Analyze temperature cut-off sensitivity
- Conduct modal analysis for effect of vehicle state in previous seconds on NO_x emissions in current second

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Extra Slides

Aftertreatment Temperature Real-world Example