Learning Surrogates for Diverse Vehicle Emission Models

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Motivation

- Emission modeling for transportation is crucial
- MOVES as the industry standard
  - Provided and enforced by EPA
  - Used by transportation offices and policy makers across the US.
  - Very comprehensive
- Emerging transportation strategies from advances in interconnectivity, decision-making systems, ML

MOVES
Motor Vehicle Emission Simulator

EPA United States Environmental Protection Agency

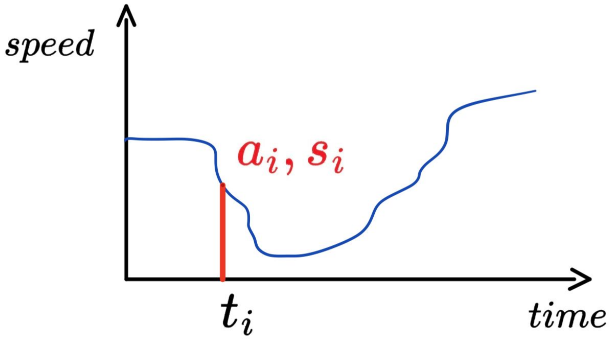
What is the issue with current models?

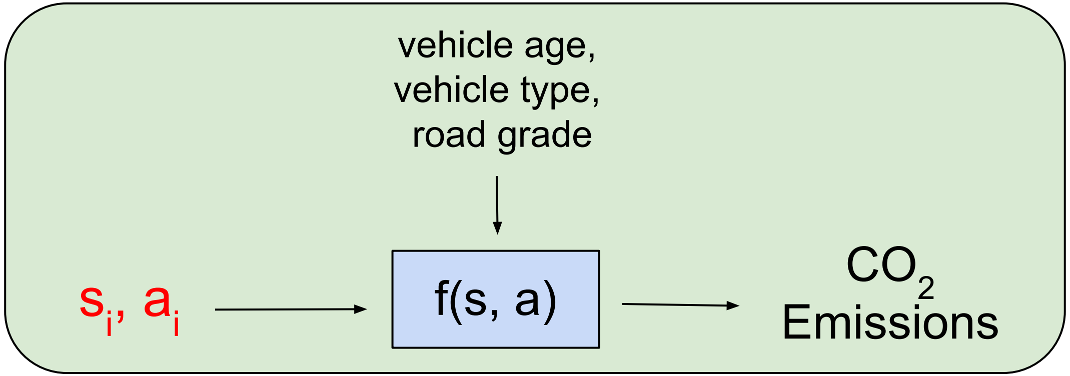
Lack of a model that is:

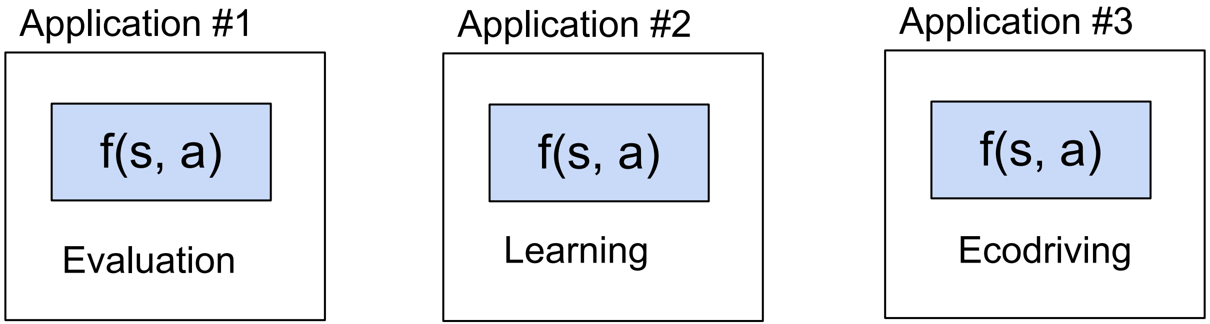
1. Diverse (breadth of inputs)
2. Instantaneous (second by second emissions)
3. Programmatic (ease of use and running time)

Models \ Features	Fuel Variety	Road Grade	Vehicle Type	Vehicle Age	Instantaneous	Programmatic
MOVES [16]	✓	✓	✓	✓	x	x
FastSIM [3]	✓	✓	✓	✓	x	✓
HBEFA [8]	✓	✓	✓	✓	✓	x
PHEM [4]	*	✓	*	x	x	x
MOVESTAR [18]	x	x	*	x	✓	✓
Ours	✓	✓	✓	✓	✓	✓

Goal


speed
a_i, s_i
t_i
time


vehicle age,
vehicle type,
road grade
s_i, a_i
f(s, a)
CO_2
Emissions


Application #1
f(s, a)
Evaluation
Application #2
f(s, a)
Learning
Application #3
f(s, a)
Ecodriving

Objective: Calculate CO2 Emission of a given trajectory

Driving behavior
- Links
- Driving cycles

Specifications:
- Vehicle Type and Age
- Fuel type

Environment:
- City
- Time of Year
- Hour of the Day

MOVES
Motor Vehicle Emission Simulator

Output
- Emissions (mass/time)

MOVES is not suitable for some analyses

Roadway interventions
[strategies/technologies]

Impact Assessment tools

Infrastructure, technology, etc.

EV adoption

MOVES Motor Vehicle Emission Simulator

EPA

Industry Standard

Emerging Behavioral-based

Eco Driving

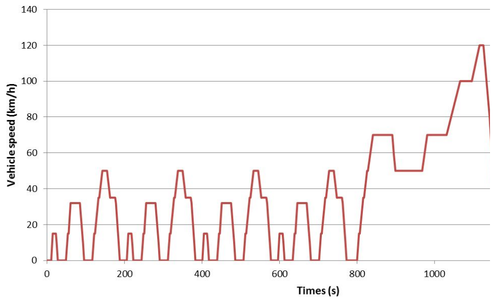
Lagrangian Congestion mitigation

???

Why - Extend and improve MOVES-model use

1) MOVES hard to use for behavioral analyses: Default driving cycle, cumbersome program

Driving Cycle



2) Retrospective approach

3) Other instantaneous and programmatic approaches lack diversity

Models \ Features	Fuel Variety	Road Grade	Vehicle Type	Vehicle Age	Instantaneous	Programmatic
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HBEFA [8]	✓	✓	✓	✓	✓	x
PHEM [4]	*	✓	*	x	x	x
MOVESTAR [18]	x	x	*	x	✓	✓
Ours	✓	✓	✓	✓	✓	✓

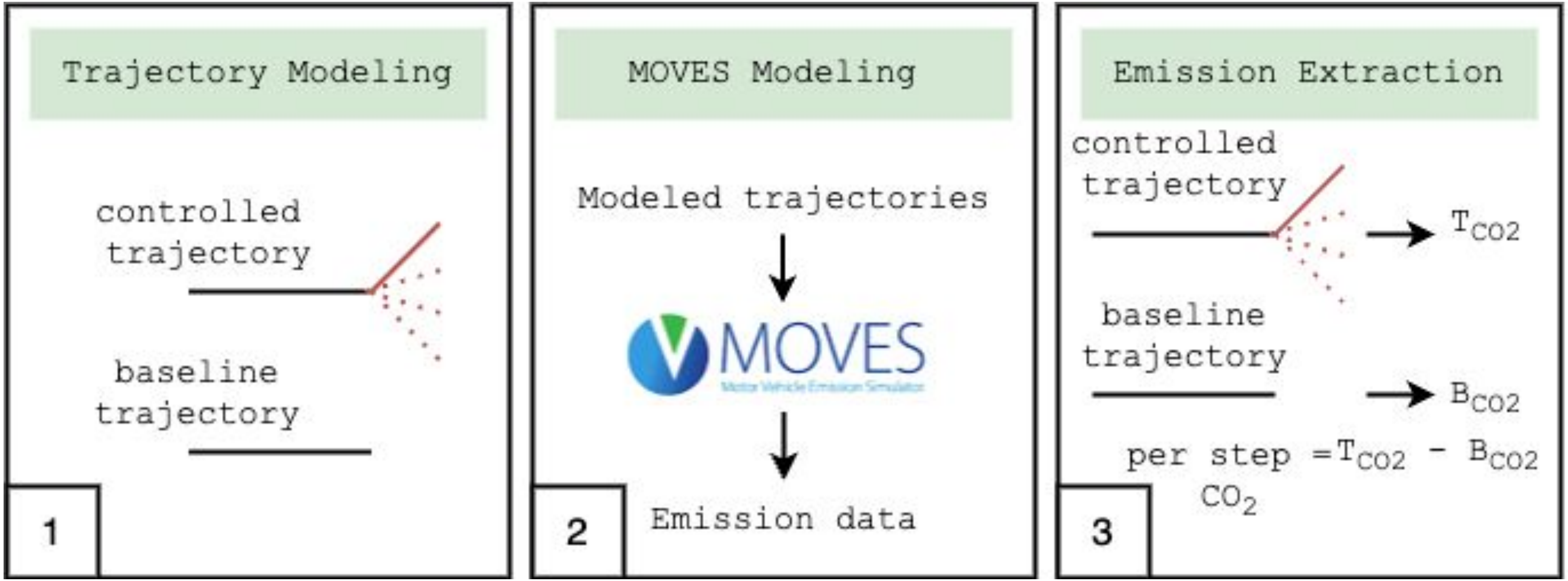
Contribution:

Diverse: fuel types, vehicle types, road grades, vehicle ages, and cities of interest.

Instantaneous: able to calculate the emissions for an action taken within a single time step

Lightway-programmatic: have an API or scripted-based queries and results can be returned quickly

Methodology: Reverse engineer MOVES



Fitting

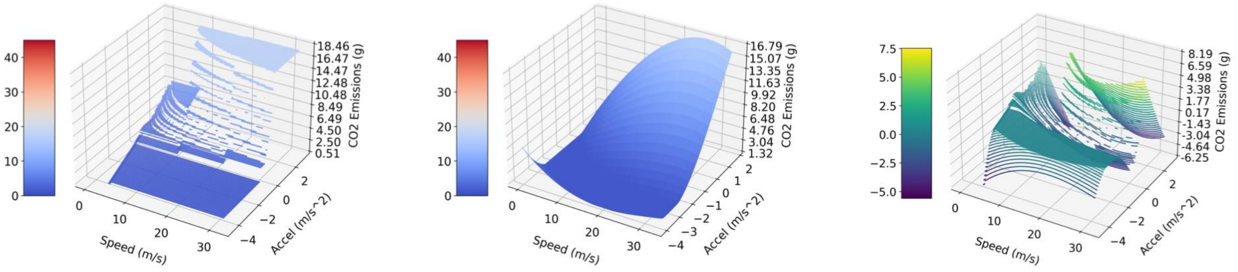
- Fit a third order two-variable polynomial

- Utilized sklearn LinearRegression

- Also considered higher order polynomials and a neural network

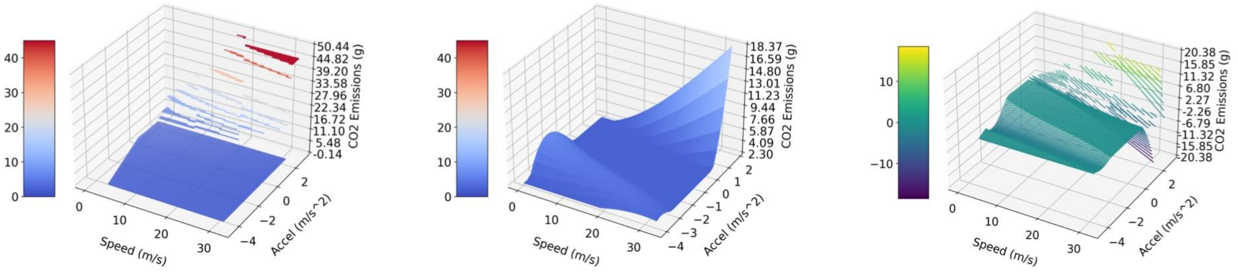
Emission Model (Passenger Car of Age 2 on 30% grade road)		
Speed (m/s)	Accel (m/s^2)	Emissions (g CO_2)
10	-4	1000.6
10	-2.5	1203.5
⋮	⋮	⋮
30	3.5	1788.2

$$F(v,a) = max\{I, c_0 + c_1 v + c_2 a + c_3 v^2 + c_4 va + c_5 a^2 + c_6 v^3 + c_7 (v^2) a + c_8 v (a^2) + c_9 a^3\}$$



(a) Ground truth emissions data (b) Fitted emission model (c) Function fitting error

Figure 3: An emission model with low error: 10 year-old Light Commercial Trucks on 0% road grade.



(a) Ground truth emissions data (b) Fitted emission model (c) Function fitting error

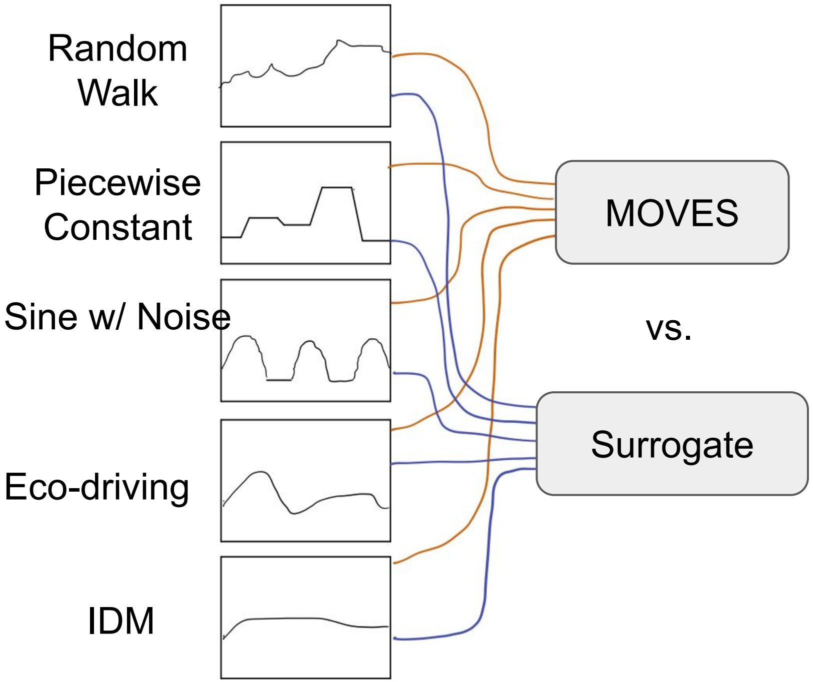
Figure 4: An emission model with high error: 6 year-old transit buses on -25% road grade

Validation

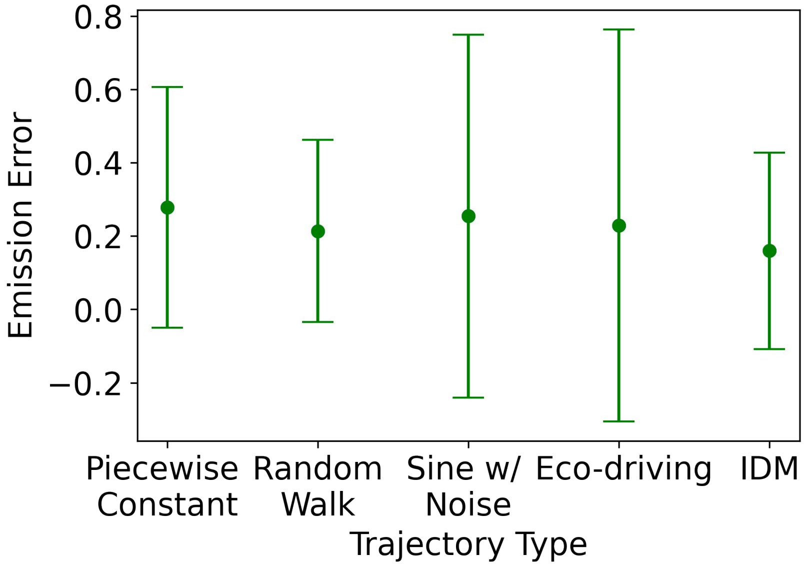
1. Created ~1000 drive cycles

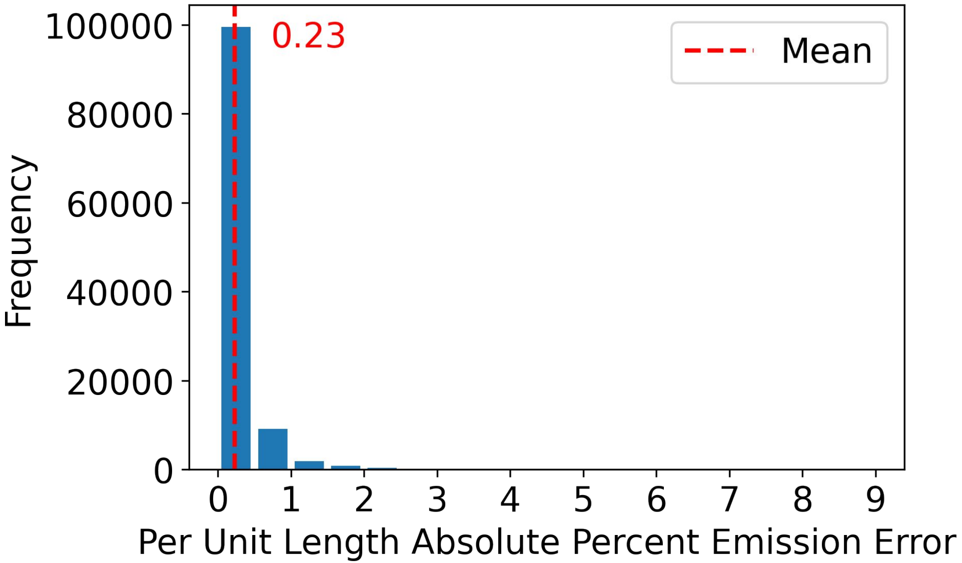
2. Calculated emissions of all 1000 drive cycles using MOVES (ground truth)

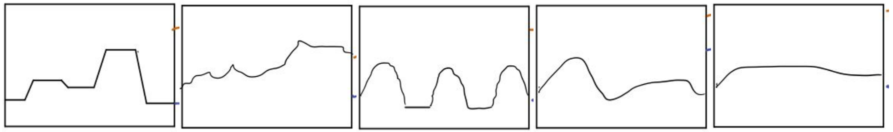
3. For each drive cycle, ran each inst. model on the drive cycle and summed up the second by second instantaneous emissions



Validation: Error







Outcomes

- Created a set of 1100 models encompassing:
    - 5 vehicle types
    - 20 vehicle ages
    - 11 road grades
- Models with second-by-second emission output: f(s,a)
- API - Programmatic format
    - A python script: choosing model + passing in a speed and acceleration value

Diverse

Instantaneous

Programmatic