Evaluation of Transit Eco-driving in Rural, Suburban, and Urban Environments

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National Center for Sustainable Transportation

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Problem Statement

- About 43.5% of the total transit expenses are on operations and fuel cost is a significant portion
- Even 1% or 2% of fuel cost saving result in notable savings for operating costs
- Transit agencies are seeking solutions to reduce fuel use, which also reduces emissions
- In previous studies, eco-driving strategies can yield 2% to 27% fuel savings for transit fleets

Definition of eco-driving

- **Eco-driver training**: a feasible strategy to reduce fuel consumption and emissions of all kinds of vehicle types
- **Eco-driving techniques** (*Intelligent Energy Europe, 2011*)
  - Anticipate traffic
  - Maintain a steady speed
  - Limit engine loads
  - Limit high speeds
  - Avoid hard accelerations
  - Limit idling
  - Shift to the highest possible gear with low rpm
  - Check tire pressure regularly

Previous Research Findings

Source	Location	Vehicle Type	Methodology	Estimated benefits
Zarkadoula, et al. (2007)	Athens, Greece	Bus	Field measurement	**4.35%** reduction in fuel use per km
Wåhlberg (2007)	Uppsala, Sweden	Bus	Field measurement	**2%- 4%** fuel savings
Strömberg and Karlsson (2013)	Sweden	Bus	Field measurement	**6.8%** fuel savings
Carrese (2013)	City of Rome, Italy	Bus	Field measurement	Up to **27%** of fuel saving
Rolim, et al. (2014)	Portugal	Bus	Field measurement	Reduced travel time under undesired driving condition
Zheng and Zhang (2015)	Beijing, China	Bus	Simulation	Reduced Vehicle STP
Sullman, et al. (2015)	Helsinki, Finland.	Bus	Field measurement	**16.9%** fuel economy improvement
Xu, et al. (2017)	Atlanta, GA, USA	Bus	Field data and simulation	**5%** fuel saving for local transit, **7%** for express bus

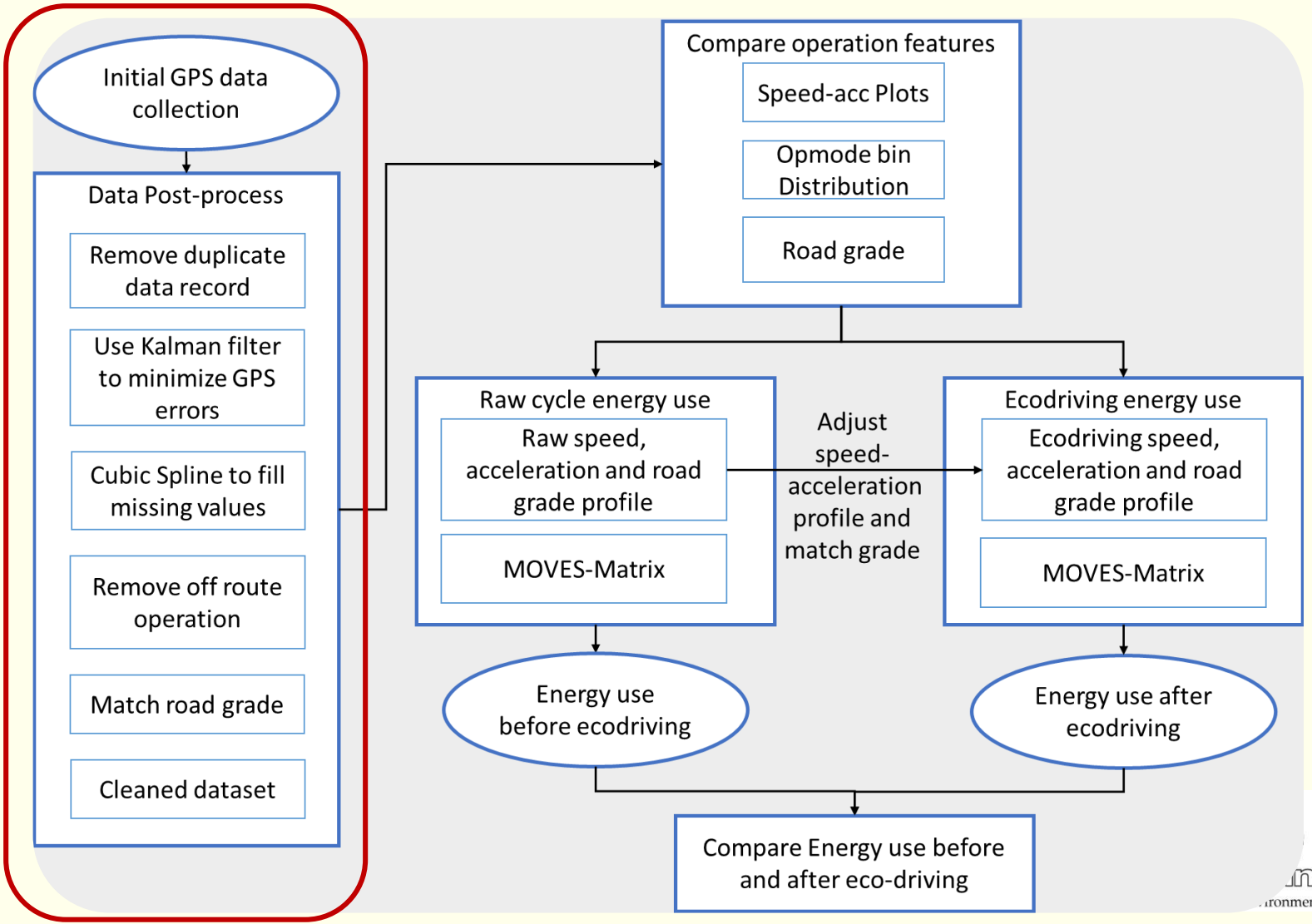
Research Gap

Study Area	• Most studies performed in urban areas • Need to analyze rural/suburban areas
Road Grade	• Flat terrain or constant grade • Need to consider instantaneous road grade
Local Context	• Most studies performed in European countries • Need to consider local fuel, meteorology, and operating conditions in U.S.

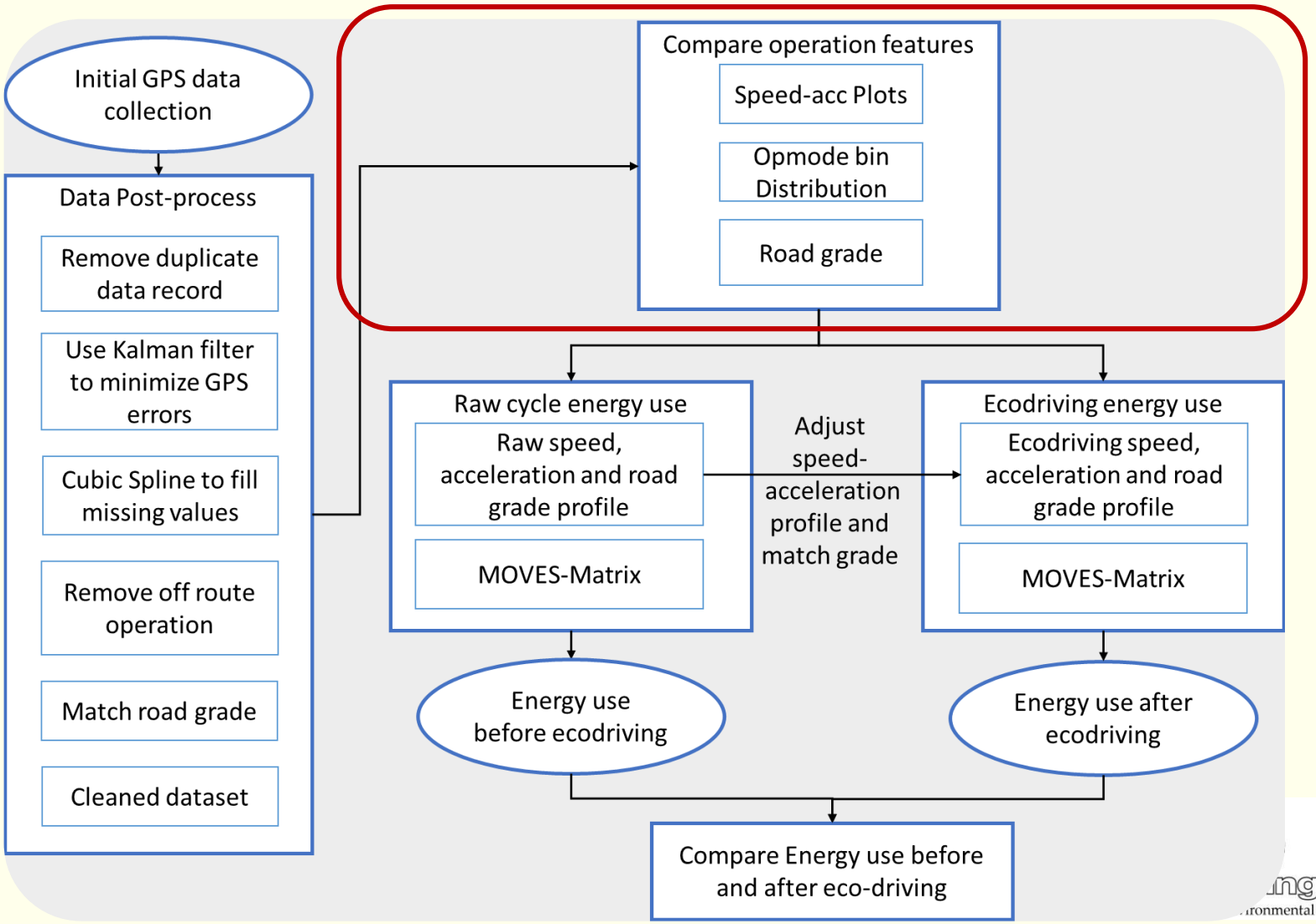
Research Goal

- **Assess the potential benefits of eco-driving for transit services in different areas**
  - **Urban, suburban, rural**
- **Examine the relationship between fuel saving and local transit service characteristics:**
  - **Travel speed**
  - **Road grade**
  - **Fuel type**
  - **Annual mileage**

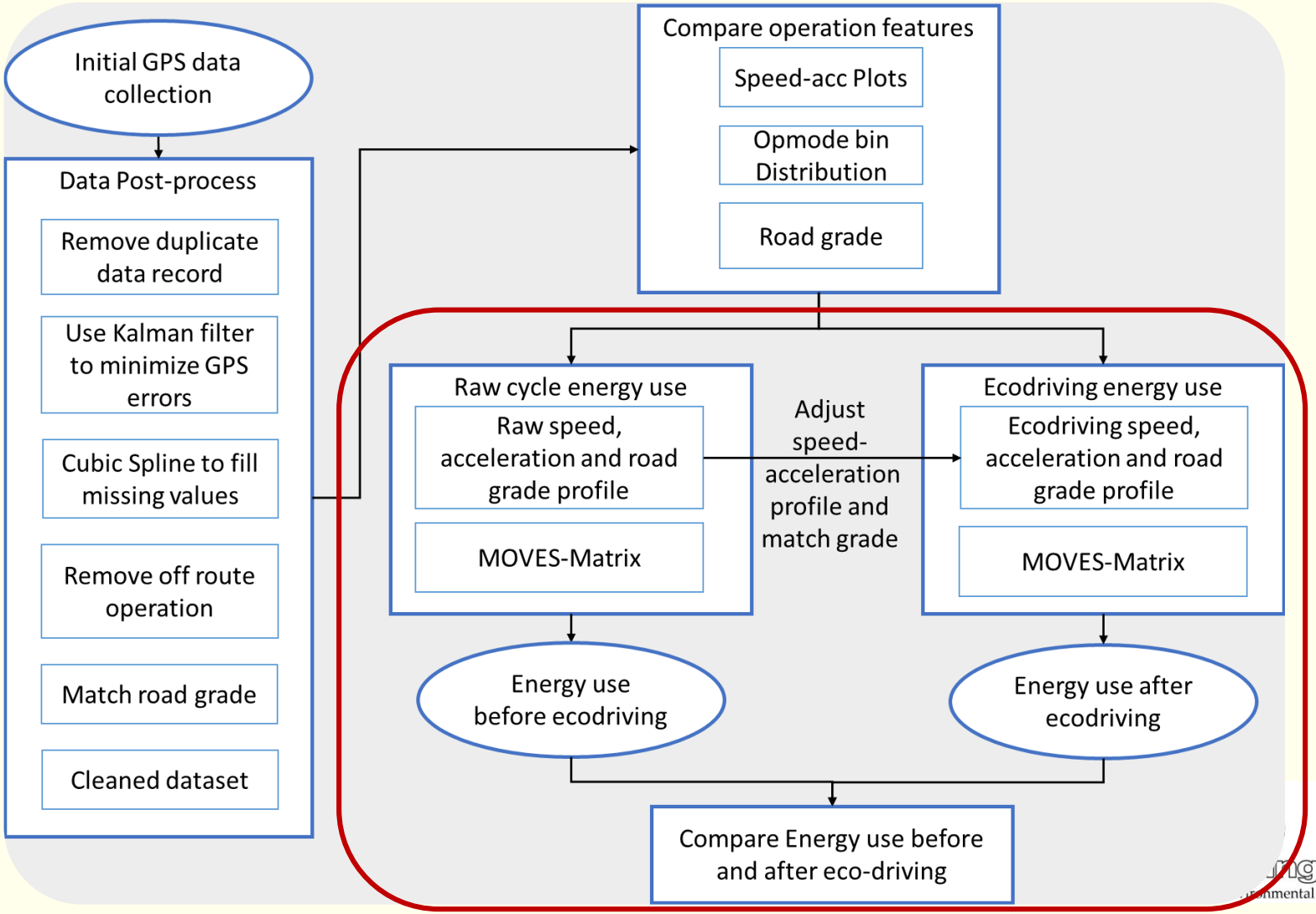
Methodology Overview



Methodology Overview

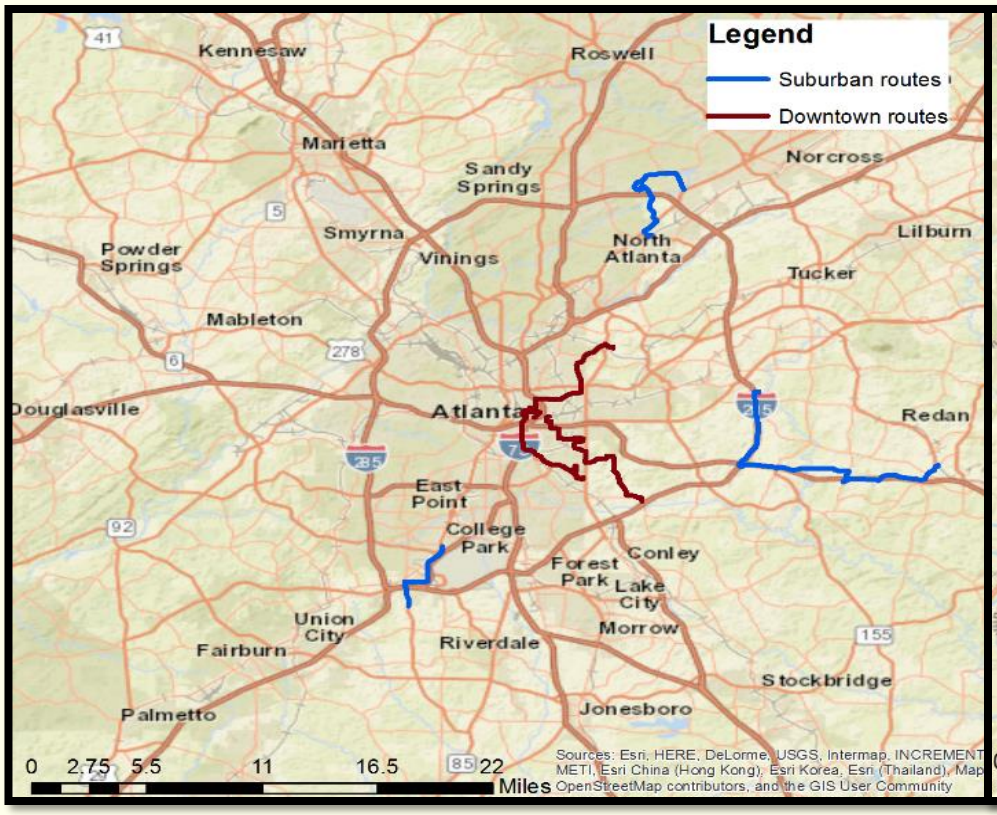


Methodology Overview

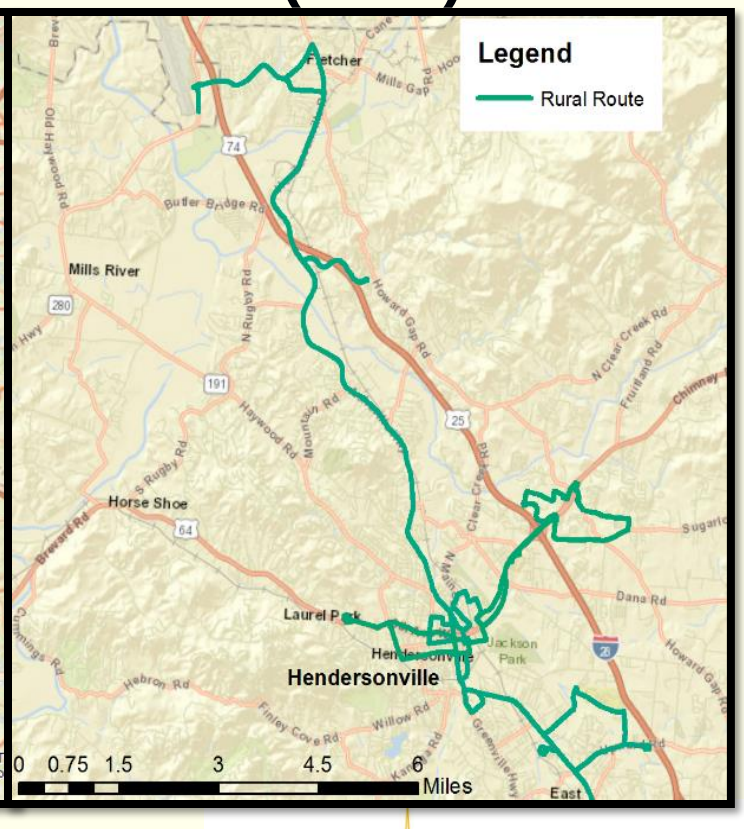


Vehicle Operations Data Collection

MARTA (urban + suburban)



Apple Country Transit (rural)



Vehicle Fleet

MARTA

CNG

Diesel

Apple Country Transit

CNG

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Post-processing of On-road Data

1. **Remove duplicated data records:**
   Remove cycle data written twice on the server
2. **Kalman filter data smoothing:**
   Modify the erroneous GPS points
3. **Cubic spline to fill missing value:**
   Interpolate missing values (less than 5 seconds)
4. **Remove off-route operations:**
   Remove non-revenue operations and terminal idling
5. **Attach road grade:**
   Second-by-second road grade profile by route*

**Liu, Haobing, Hanyan Li, Michael Rodgers, Randall Guensler. (2018). Development of Road Grade Data Based On USGS Digital Elevation Model. 97th Annual Meeting of the Transportation Research Board. Washington, DC.*

Transit Service Statistics

Service	Downtown	Suburban	Rural
Agency	MARTA	MARTA	Apple Country Transit
Number of routes	3	3	3
Total distance (mile)	407.94	129.44	178.78
Total duration (h)	4774.95	2190.78	3574.96
Average speed (mph)	11.71	16.93	20.00
2.5th percentile grade (%)	-5.04	-4.29	-6.03
50th percentile grade (%)	0.36	0.00	-0.17
97.5th percentile grade (%)	4.99	7.71	6.02

Operation Patterns

- **Apply EPA's MOVES scaled tractive power (STP) to observed onroad activity**
- **STP is a function of speed, acceleration, and road grade**

$$STP = \left(\frac{A}{M}\right)V + \left(\frac{B}{M}\right)V^2 + \left(\frac{C}{M}\right)V^3 + \left(\frac{m}{M}\right)(a + g * sin\theta)V$$

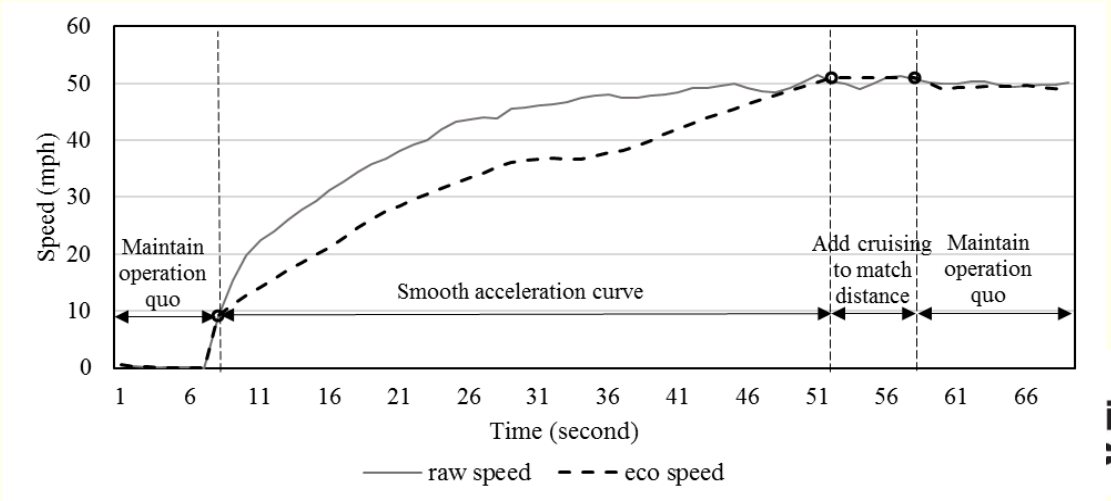
- **Using MOVES pre-2014 transit bus parameters**

Eco-driving strategy

- **Determine STP upper limit (STP_L)**
  - If current STP< STP_L, maintain operation quo
  - If current STP>= STP_L, adjust acceleration using until reach the top speed limit:

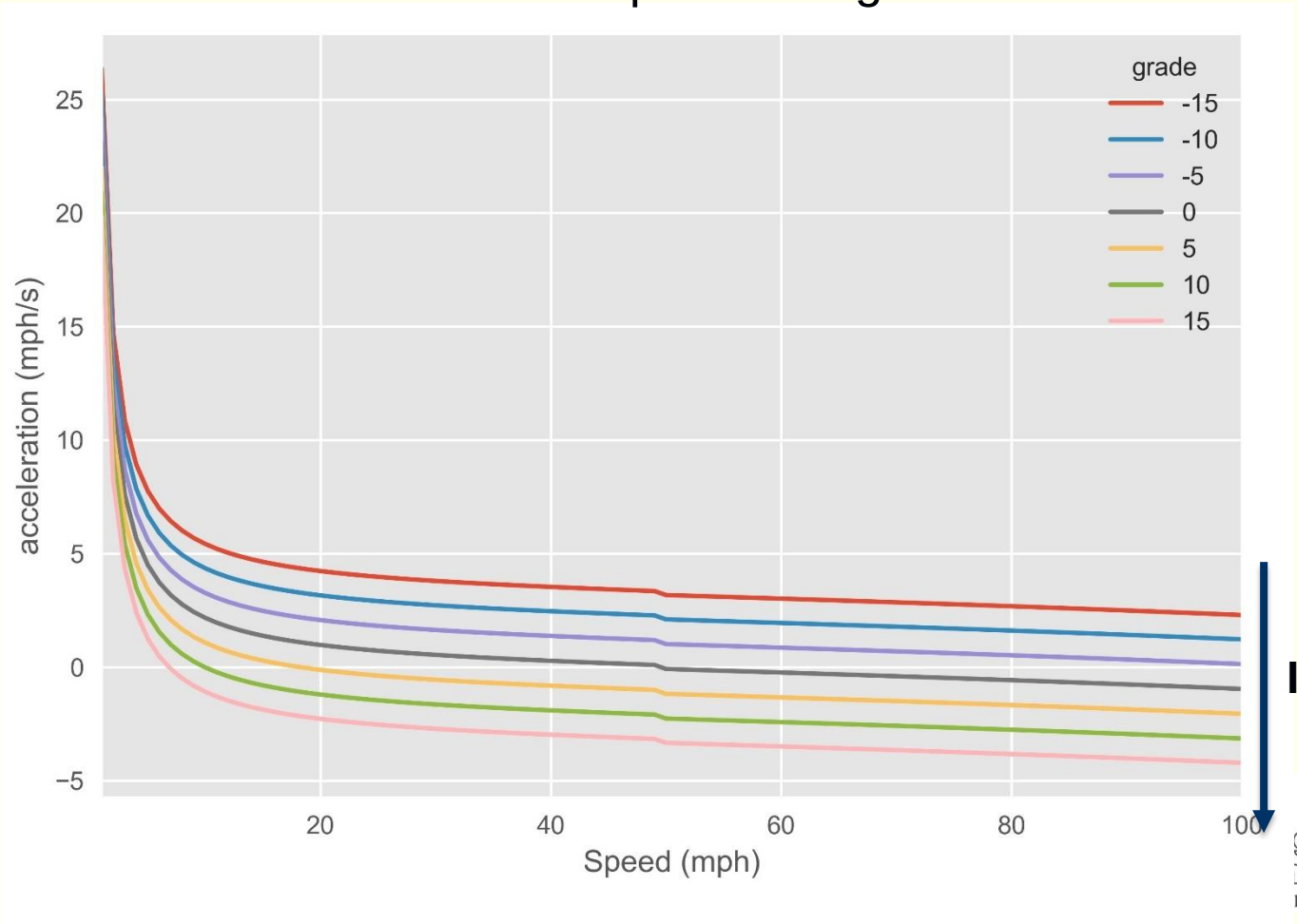
$$acc_L = \frac{STP_L * M}{mV} - g * sin\theta - \left(\frac{A}{m}\right) - \left(\frac{B}{m}\right)V - \left(\frac{C}{m}\right)V^2$$

- **Add additional cruising to match speed**



Eco-driving strategy – max acceleration

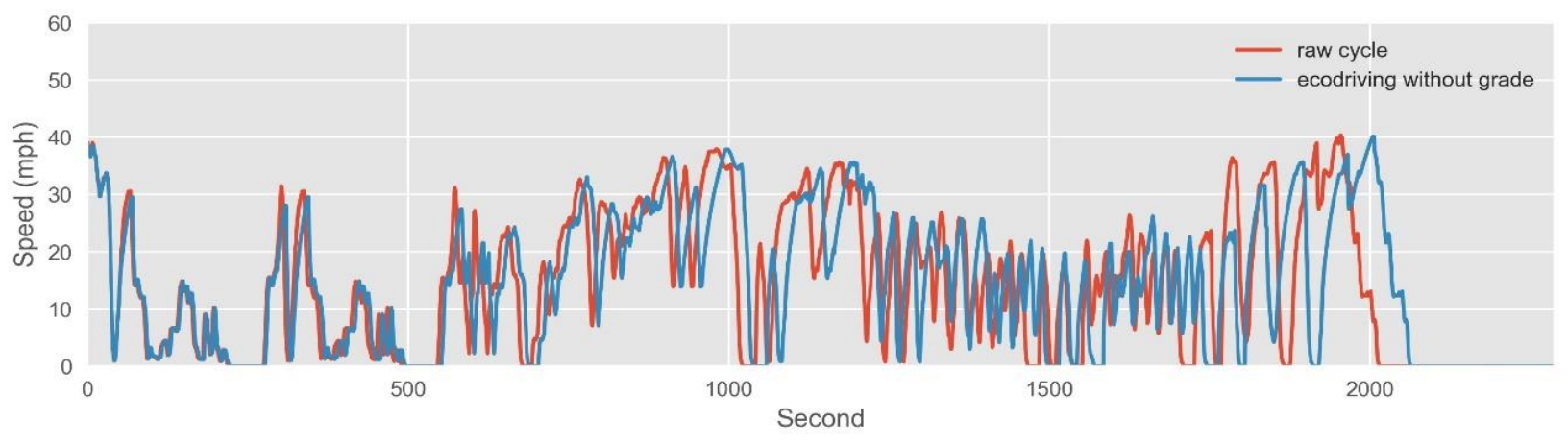
Maximum acceleration
under different speed and grade



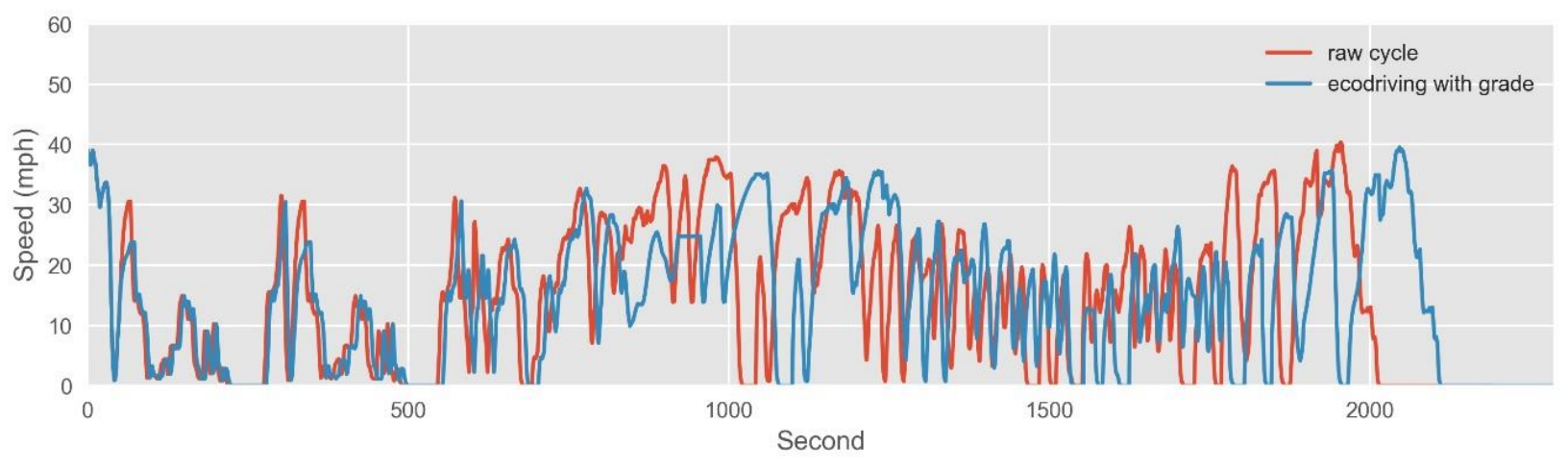
Increasing grade

Eco-driving Strategy – Cycle Comparison

Eco-driving without grade (STP_L = 6)



Eco-driving with grade (STP_L = 6)

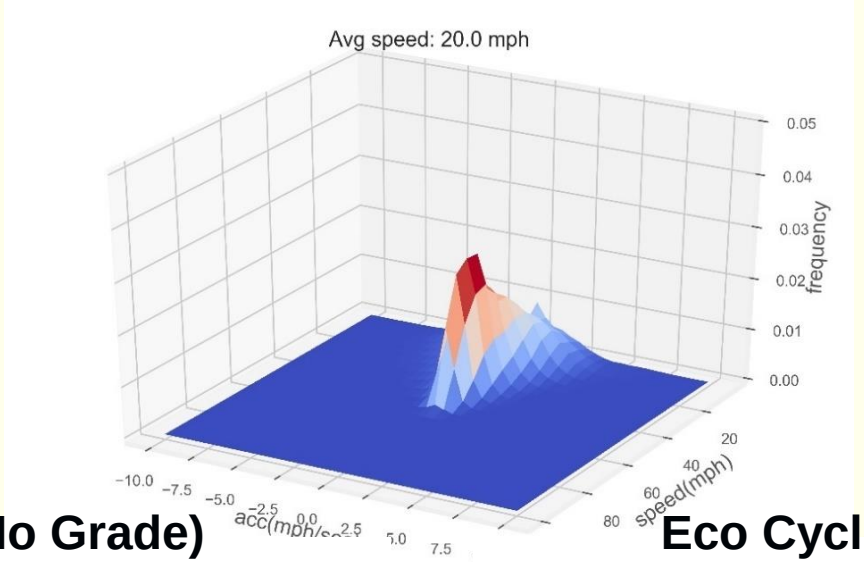


Performance Metrics

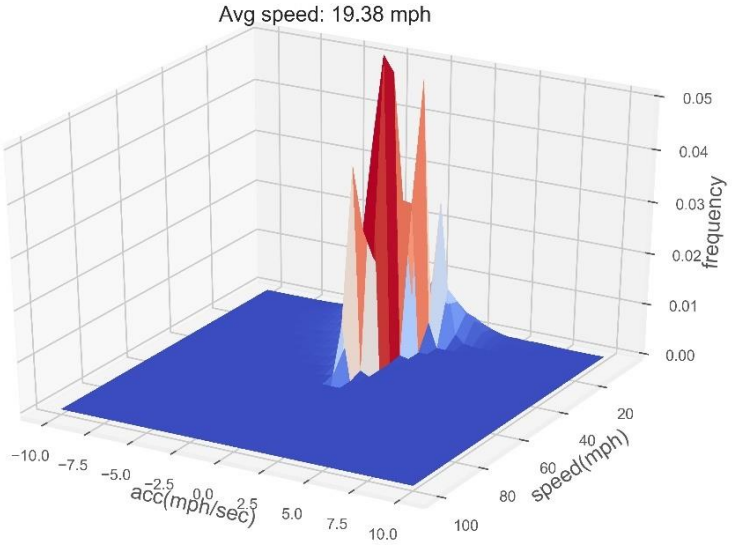
- **Speed-acceleration distribution:** idling truncated
- **Operating Mode (OpMode) bin distribution:** fraction of different operation condition, include idling, braking, different speed levels and power levels
- **Energy consumption:** energy consumption in MJ per mile for raw driving cycle and eco-driving cycle, CNG fuel and diesel fuel, with and without grade
- **On-time performance:** travel time after eco-driving compared to bus schedule
- **Cost:** total fuel cost saving and fuel cost saving per mile, based on 2017 summer local fuel cost.

Rural Speed-Acceleration Distribution

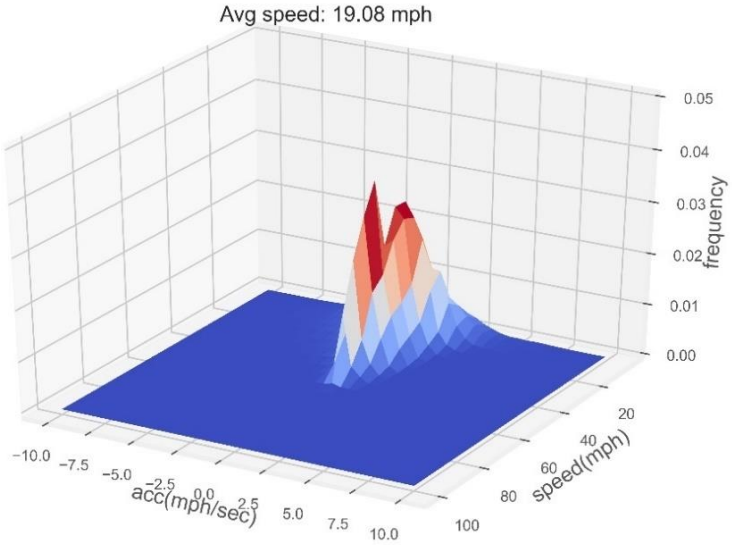
Raw Cycle



Eco Cycle (No Grade)

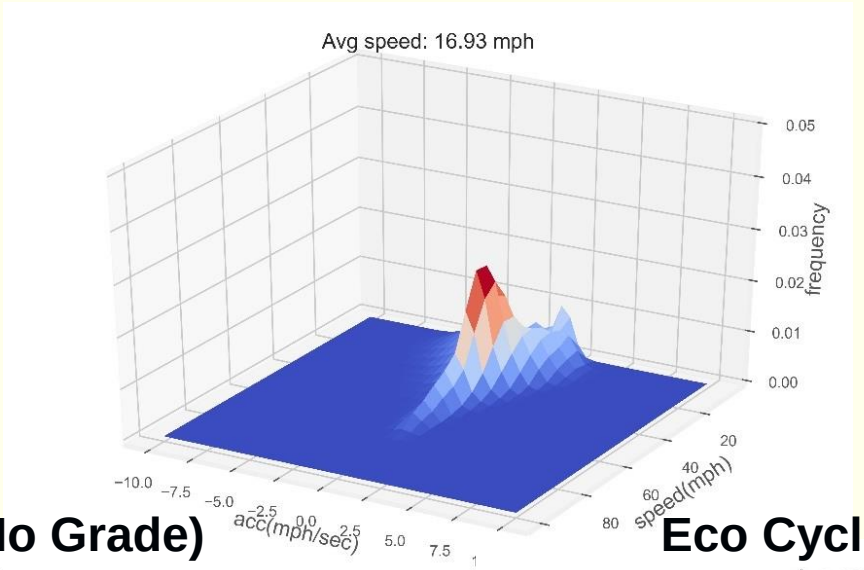


Eco Cycle (with Grade)

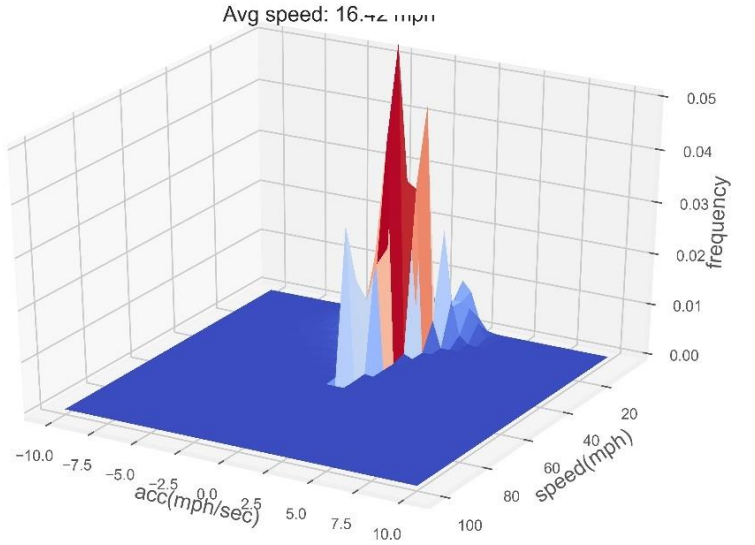


Suburban Speed-Acceleration Distribution

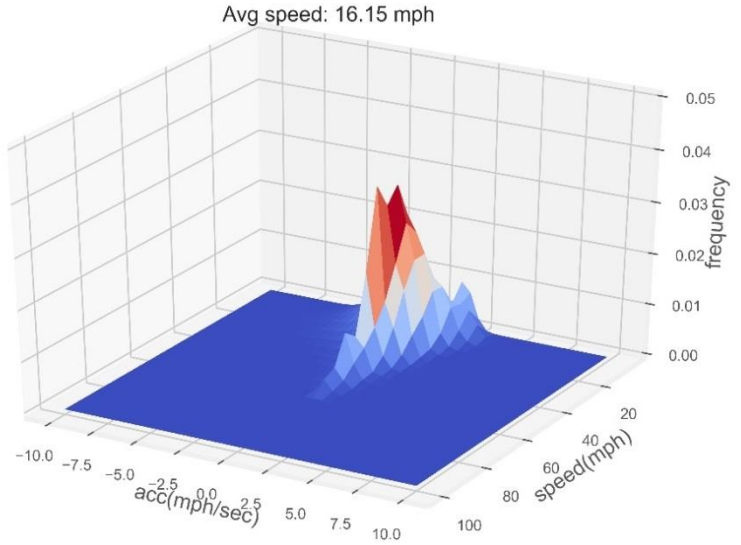
Raw Cycle



Eco Cycle (No Grade)

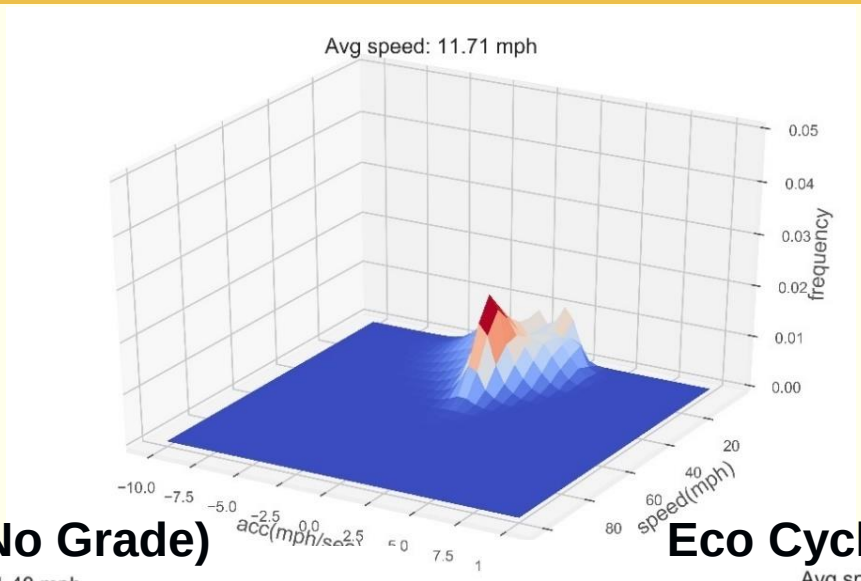


Eco Cycle (with Grade)

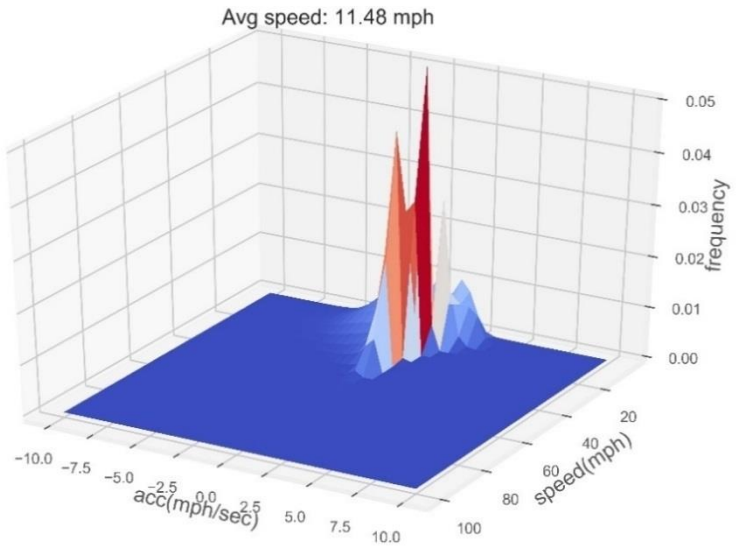


Urban Speed-Acceleration Distribution

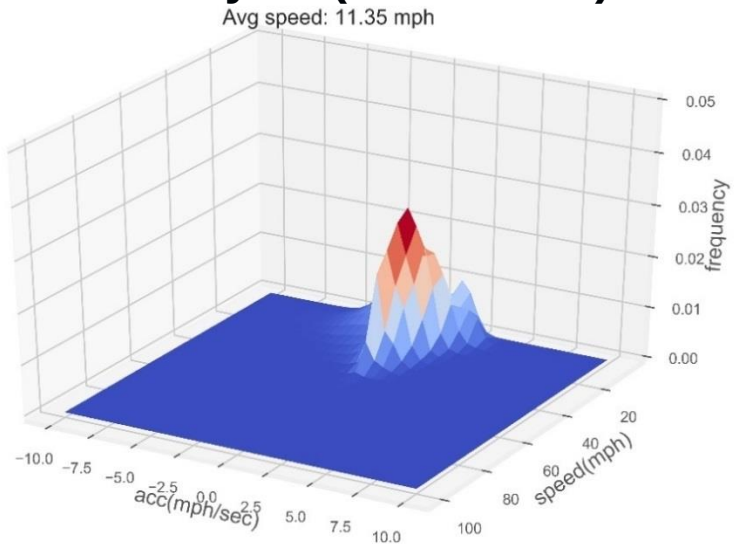
Raw Cycle



Eco Cycle (No Grade)

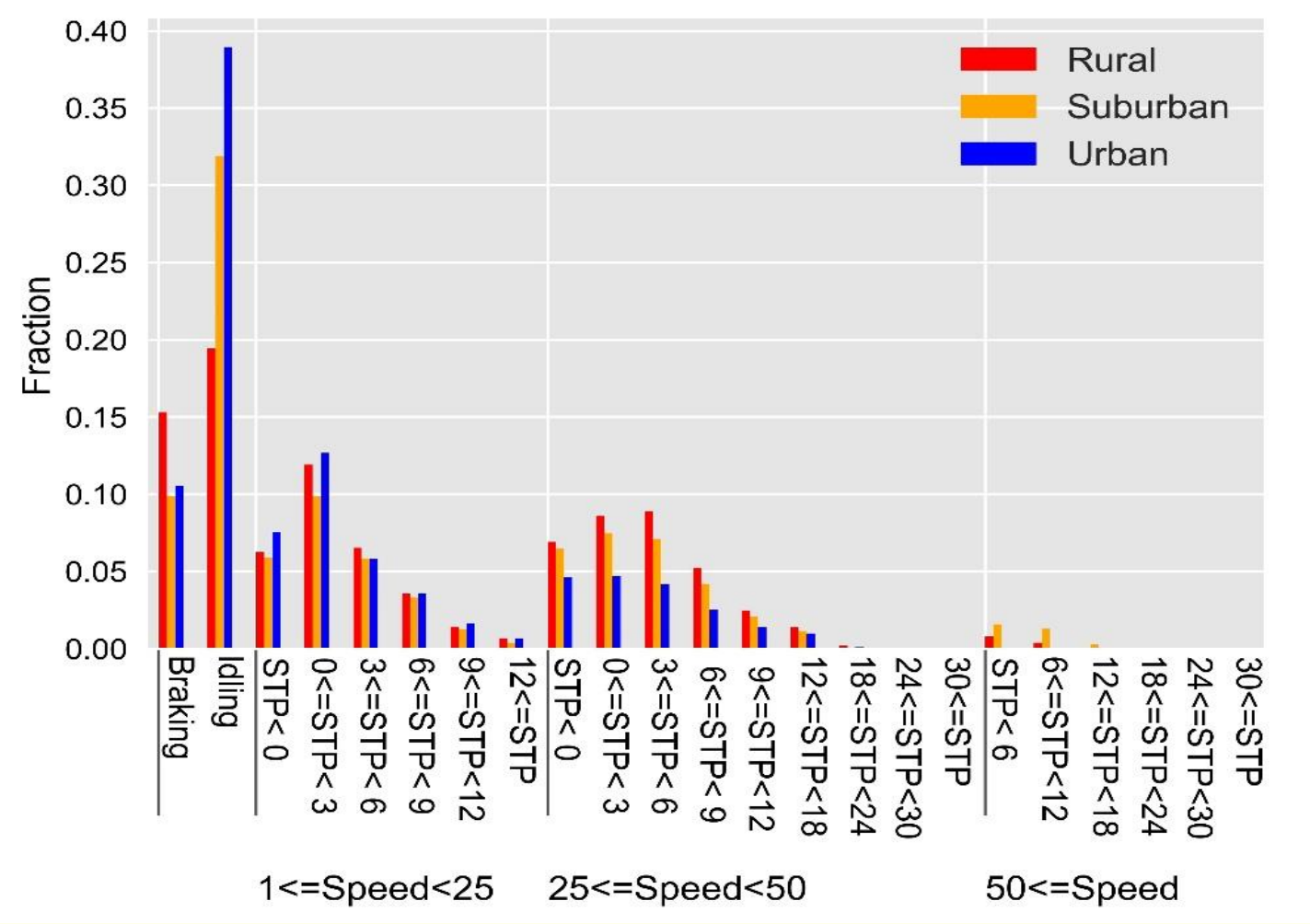


Eco Cycle (with Grade)



Raw Cycle (No Grade) OpMode Bin Distribution

- **Raw Cycle (No Grade)**



Eco Cycle (No Grade) OpMode Bin Distribution

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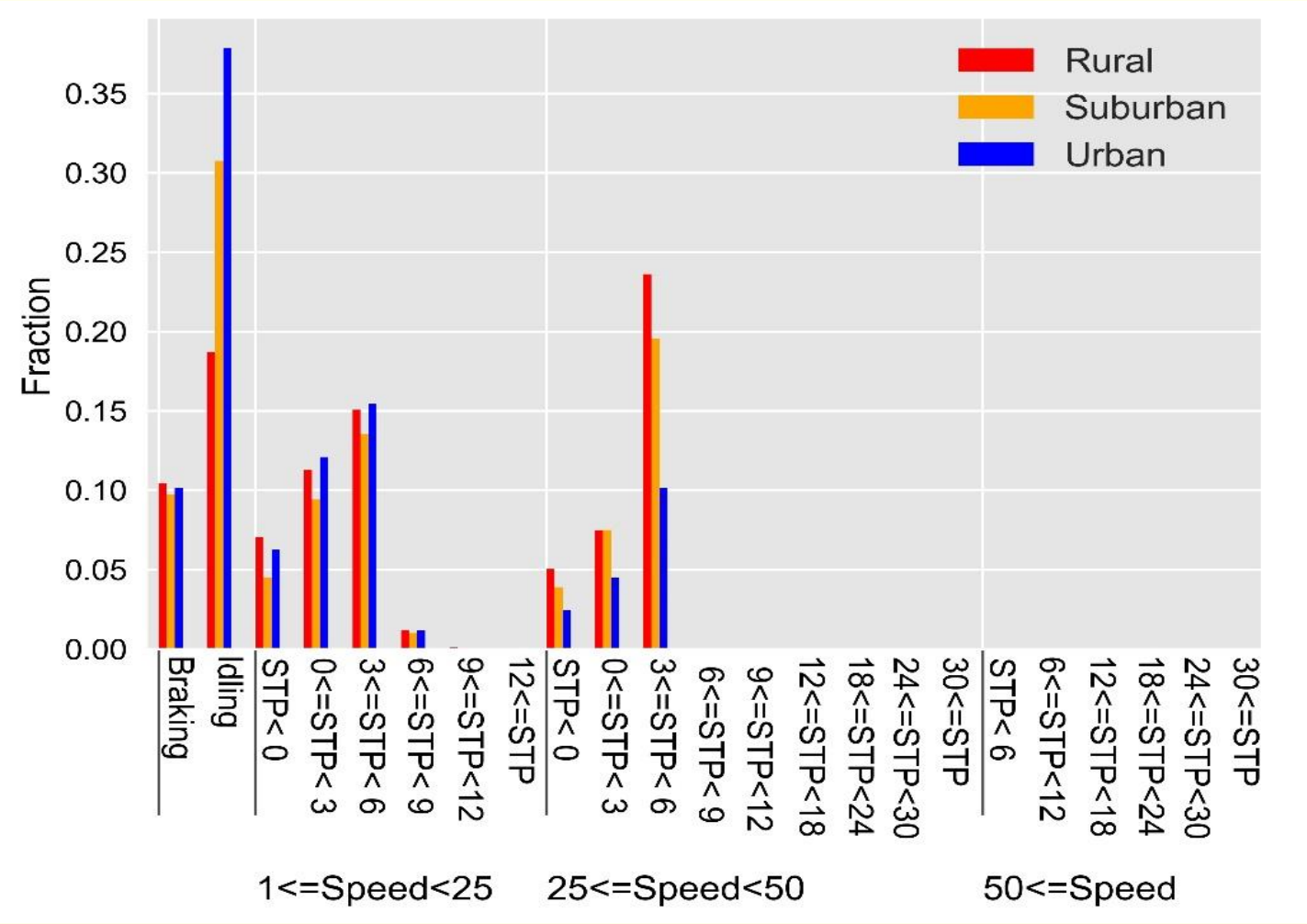
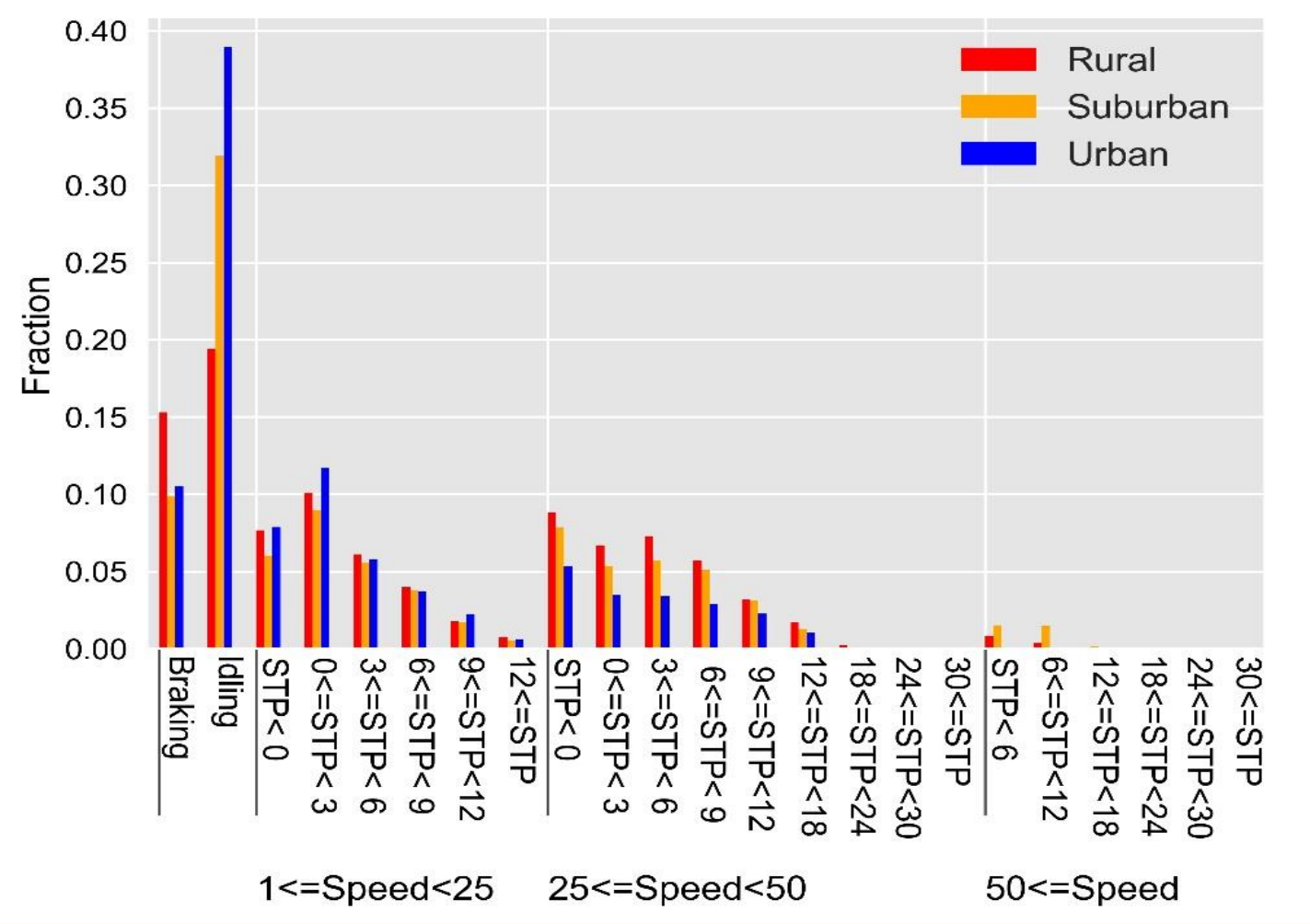


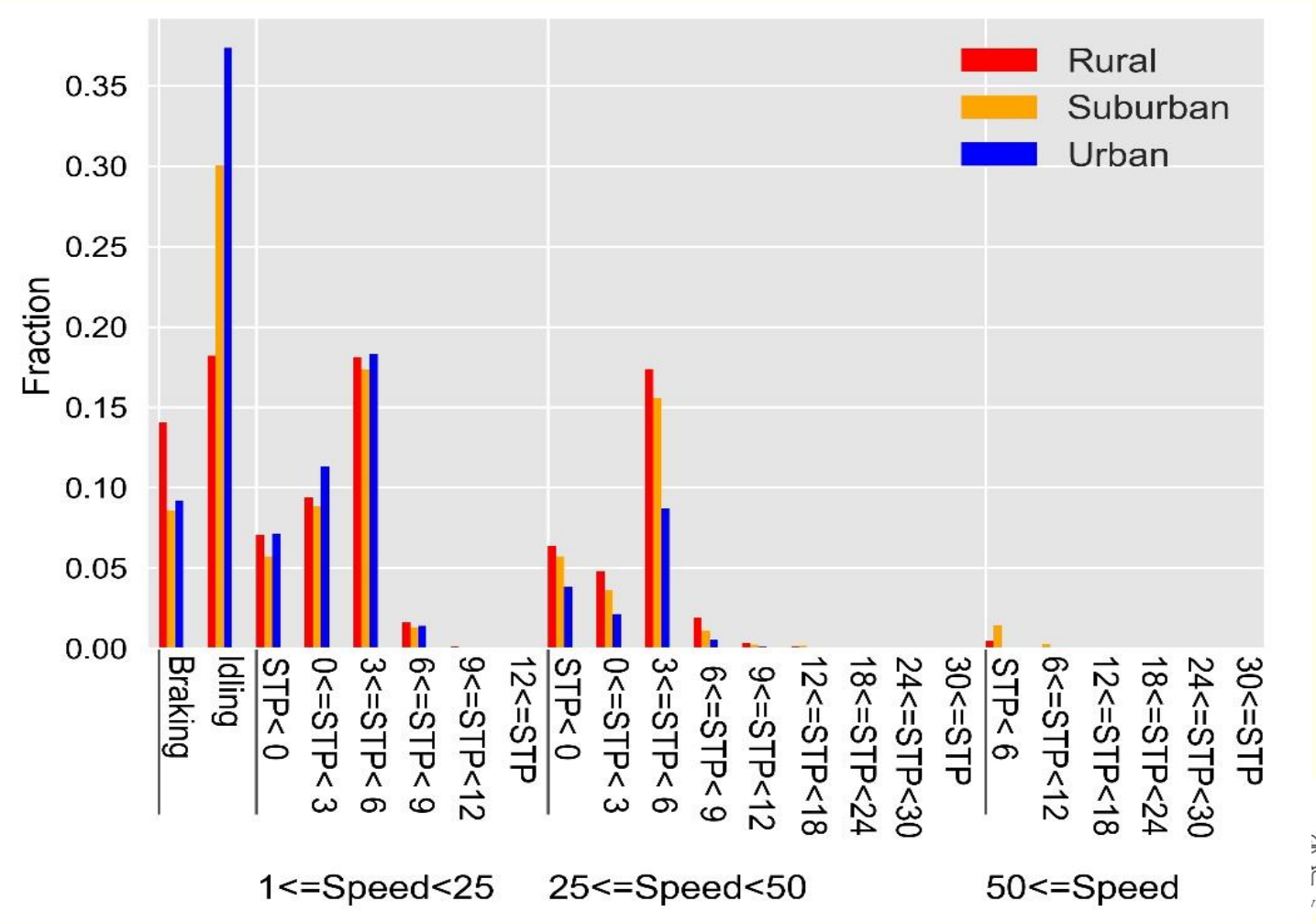
Raw Cycle (with Grade) OpMode Bin Distribution

- **Raw Cycle (with Grade)**



Eco Cycle (with Grade) OpMode Bin Distribution

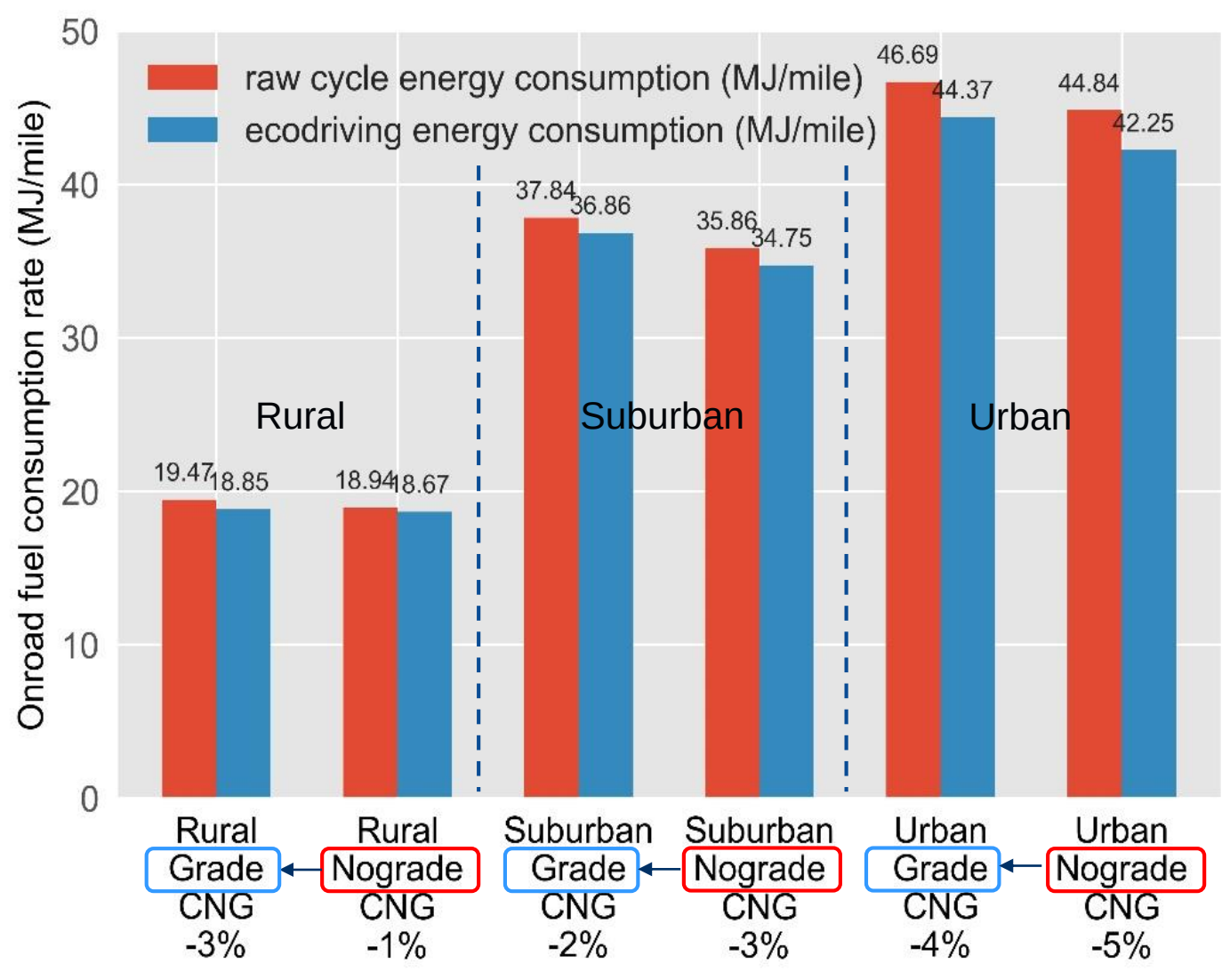
- **Eco Cycle (with Grade)**



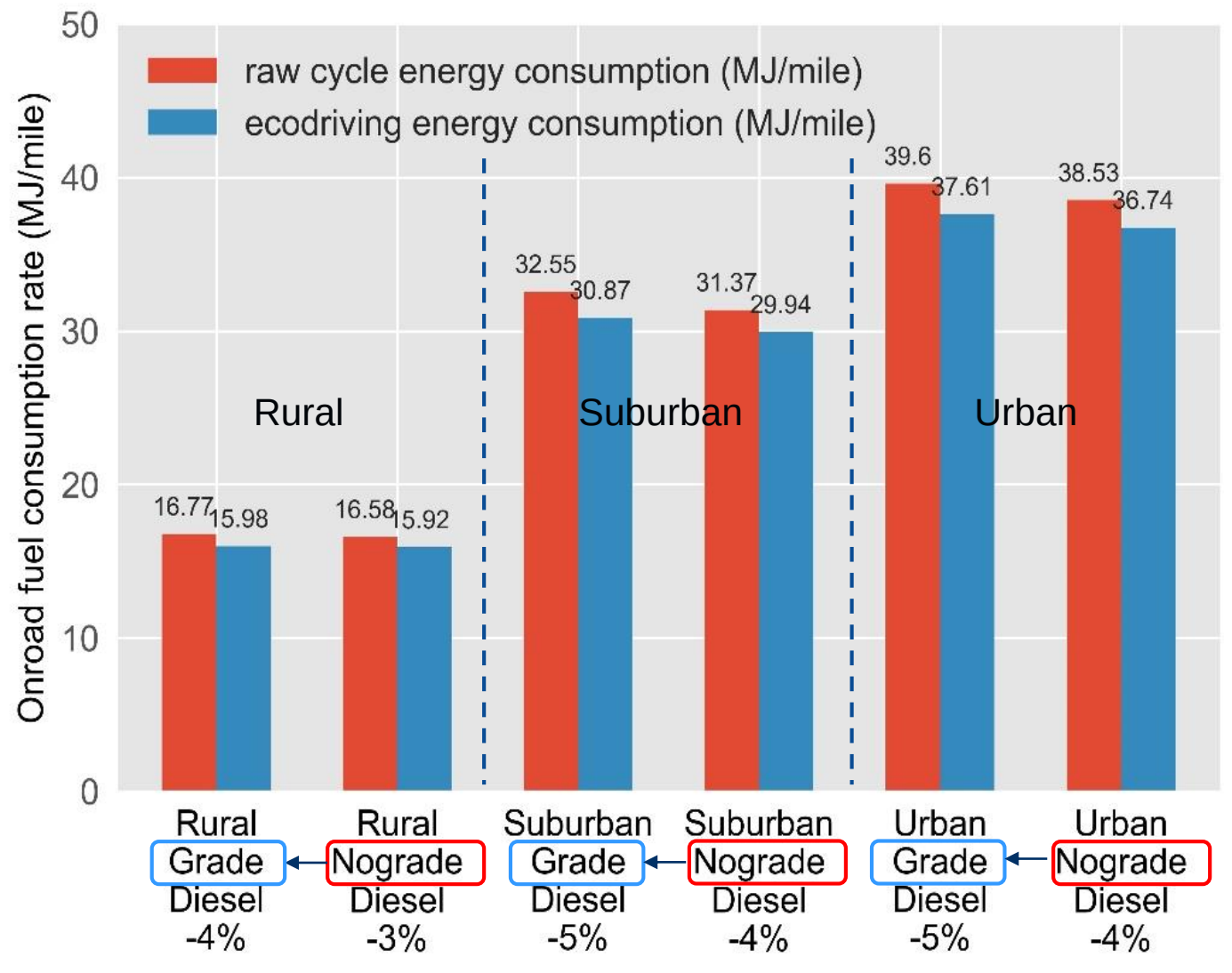
Energy Consumption Model Input Data

ITEM	MARTA	APPLE COUNTRY
County	Fulton, GA	Henderson, NC
Calendar year	2017	2017
Season	Summer	Summer
Temperature	85	85
Humidity	65	65
Fuel	Diesel CNG	Diesel CNG
IM program	MOVES default	MOVES default (no IM)
Vehicle type	Transit bus (42)	Transit bus (42), scaled by real world fuel economy
Model year	2011	2011
Cycle	• MARTA CYCLE • ECO CYCLE	• RURAL CYCLE • ECO CYCLE
Grade	• Real-world grade • No grade	• Real-world grade • No grade
Road type	Local	Local

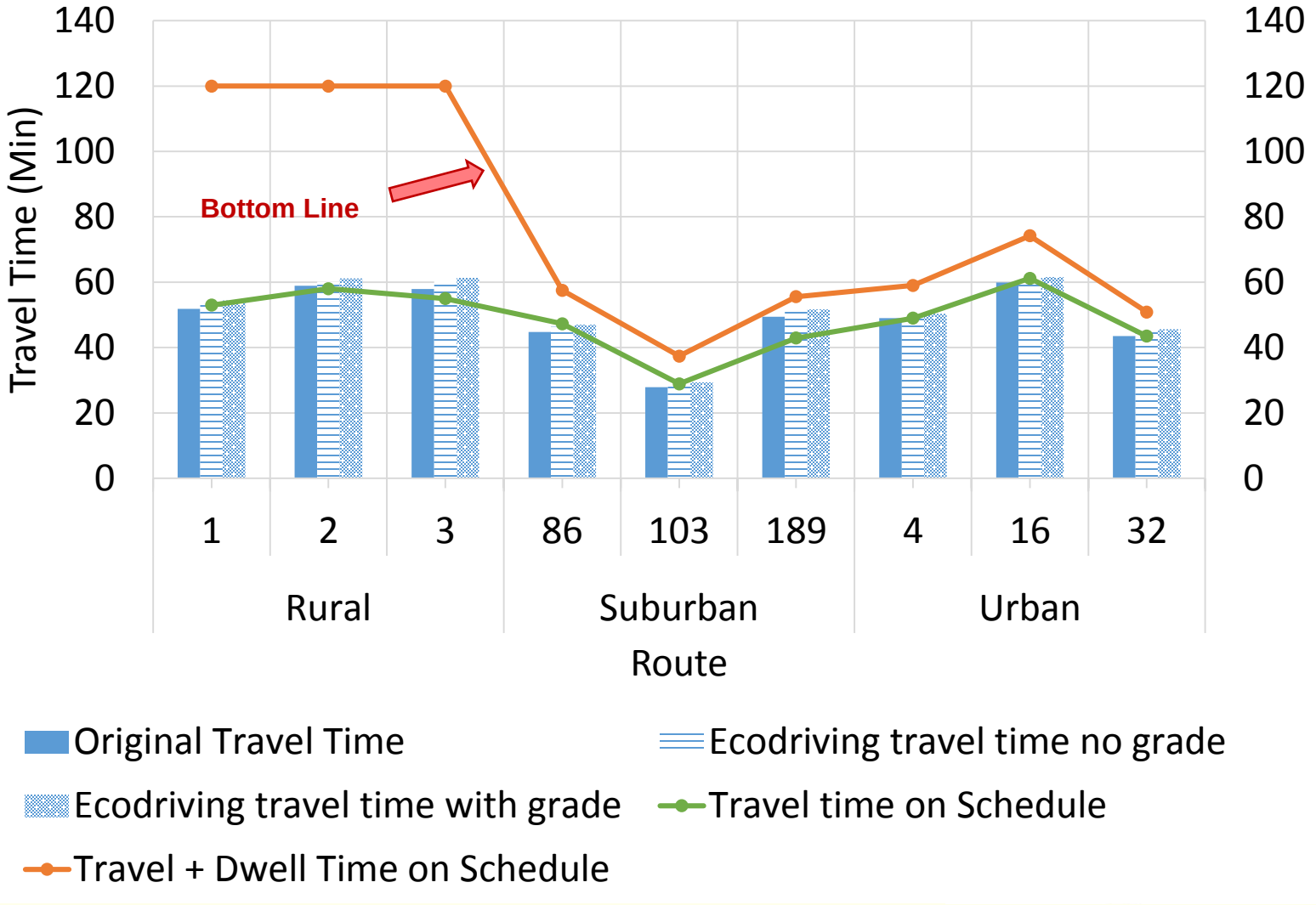
Energy Consumption (CNG)



Energy Consumption (Diesel)



On-schedule Check



Fuel Savings for Diesel

Diesel			
Service	Rural	Suburban	Urban
Annual mileage	163,373	981,856	730,005
Before Fuel rate (Mile/GGE)	7.3	3.8	3.1
Before fuel usage (DGE)	19,686	229,601	207,688
After Fuel rate (Mile/GGE)	7.7	4.0	3.3
After fuel usage (DGE)	18,759	217,702	197,237
Fuel saving (DGE)	927	11,899	10,451
Unit price ($/DGE)	2.1	2.3	2.3
Cost saving ($)	$1,946	$27,367	$24,037
Unit saving ($/Mile)	$0.012	$0.028	$0.033

Fuel Savings for CNG

CNG			
Service	Rural	Suburban	Urban
Annual mileage	163,373	981,856	730,005
Before Fuel rate (Mile/GGE)	6.3	3.2	2.6
Before fuel usage (GGE)	25,971	303,298	278,241
After Fuel rate (Mile/GGE)	6.5	3.3	2.8
After fuel usage (GGE)	25,140	295,434	264,402
Fuel saving (GGE)	830	7,864	13,840
Unit price ($/GGE)	2.1	2.4	2.4
Cost saving ($)	$1,741	$18,874	$33,215
Unit saving ($/Mile)	$0.011	$0.019	$0.045

Conclusions

- Eco-driving cycles provide different benefits:
  - CNG: 1-5% saving with grade, 2-4% without grade
  - Diesel: 4-5% saving with grade, 3-4% without grade
- The energy saving and cost saving results vary by service type and road grade conditions
- Overall, the eco-driving strategy can help reduce fuel use by 1% to 5% for these transit agencies
  - $0.011 to $0.045 savings in operating cost per mile
- Eco-driving can help agencies reduce fuel use, but the magnitude of the savings depends on local conditions

Future Work

- Assess routes that include highway operations
- Additional service parameters, such as signal timing, passenger load and drivers' acceptance to eco-driving guidance, should be incorporated
- Field studies are needed with ecodriving intervention to assess the variance in eco-driving benefits across vehicles and drivers
  - Proposals submitted to MARTA and Tech Trolley

THANK YOU!