

Appendix B.

DRAFT

User Manual for Piedmont Passenger Train Fuel Use and Emission Estimator Software

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DISCLAIMER

The authors are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the North Carolina Department of Transportation or the Federal Highway Administration.

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1.0 INTRODUCTION

1.1 What is this Software?

This software is used to estimate trip and station-to-station segment based fuel use and emissions for Piedmont passenger trains. This software tool was developed based on data collected by the Mobile Air Pollutant Emissions Laboratory at North Carolina State University using Portable Emission Measurement Systems from 2013 to 2019 (1–5). The software tool is applicable to passenger trains with no more than 2 locomotives, no more than 6 passenger cars, and fueled with ultra-low sulfur diesel or 20% blend of biodiesel (B20), for speed limit of no more than 79 mph, for track grade within $\pm 2\%$, and for track curvature within 5 degrees.

1.2 Purpose

The purpose is to develop a planning-level software for estimating the fuel use and emissions of a typical Piedmont train operation based on second-by-second train speed, track grade, and track curvature to support analysis of the emissions and air quality impact of transportation improvement projects.

1.3 System Requirements

This software requires the following configurations:

- An computer running Microsoft Windows 10 and 11
- A Microsoft Excel 2016 and newer
- At least 300 Megabytes of free hard disk space

1.4 Copyright Notice

Microsoft Excel, Copyright © 2016, Microsoft Corporation. All Rights Reserved.

2.0 INTRODUCTION TO SOFTWARE WORKSHEET

2.1 Cover Page

This worksheet includes the name, authors, authors' affiliation, version number, release date, brief introduction, and key references for this software.

2.2 Input

This worksheet includes the only two required model inputs from users – a locomotive, consist, and fuel (LCF) ID and a train speed trajectory ID (Table 1). Users can confirm their selection of LCF ID and speed trajectory ID in Tables 2 and 3, respectively. Users can visualize the selected speed trajectory in Figure 1. A reference table for 12 LCF IDs (Table 4) is provided in this worksheet for users. A reference table for 45 train speed trajectory IDs (Table 5) is provided in this worksheet for users. This worksheet is also the user interface to run the software.

2.3 Output

This worksheet includes results based on running the software, including train information (Table 6), trip information (Table 7), as well as train activity (Table 8), total fuel use and emissions (Table 9, Figures 2-7 for fuel use, carbon dioxide [CO₂] emissions, carbon monoxide [CO] emissions, hydrocarbons [HC] emissions, nitrogen oxides [NO_x] emissions, and particulate matter [PM] emissions, respectively), distance-based fuel use and emission rates (Table 10, Figures 8-13 for fuel economy, CO₂ emission rates, CO emission rates, HC emission rates, NO_x emission rates, and PM emission rates, respectively), time-based fuel use and emission rates (Table 11, Figures 14-19 for fuel use rates, CO₂ emission rates, CO emission rates, HC emission rates, NO_x emission rates, and PM emission rates, respectively), and fuel-

based emission rates (Table 12, Figures 20-24 for CO₂ emission rates, CO emission rates, HC emission rates, NO_x emission rates, and PM emission rates, respectively) for each station-to-station segment and whole trip.

2.4 Diagnostics

This worksheet includes diagnostics for travel time, fuel use, and emissions for each pollutant species by sub-models based on running the software. Sub-models were developed based on engine load, such as locomotive power demand (LPD). There are four sub-models. Sub-models corresponding to negative, zero, and peak engine load include Sub-Model 1, Sub-Model 2, and Sub-Model 4, respectively. Sub-Model 3 accounts for all other engine loads.

Table UM-1 below show the definition of sub-models based on LPD.

Table UM-1. Locomotive Power Demand Sub-Model Definition

Sub-Model	Speed (v_t mph)	12-Second Backwards Moving Average Locomotive Power Demand ($LPD_{12,t}$ kW)
1	> 0	< 0
2	$= 0$	$= 0$
3	> 0	$0 < LPD_{12,t} < 2519$
4	> 0	≥ 2519

Notes: 1. v_t : locomotive speed at time t ;
2. $LPD_{12,t}$: 12-second backwards moving average locomotive power demand at time t .

The Diagnostics worksheet includes results for:

- Travel time, fuel use, and emissions for the whole trip for each sub-model (Table 13);
- Travel time for each station-to-station segment and whole trip for each mode in Sub-Model 3 (Table 14);
- Travel time for each station-to-station segment and whole trip for each sub-model (Table 15);

- Percent of travel time spent in each sub-model for each station-to-station segment and whole Trip (Table 16, Figure 25);
- Fuel use for each station-to-station segment and whole trip for each sub-model (Table 17);
- Percent of fuel use in each sub-model for each station-to-station segment and whole trip (Table 18, Figure 26);
- CO₂ emissions for each station-to-station segment and whole trip for each sub-model (Table 19);
- Percent of CO₂ emissions in each sub-model for each station-to-station segment and whole trip (Table 20, Figure 27);
- CO emissions for each station-to-station segment and whole trip for each sub-model (Table 21);
- Percent of CO emissions in each sub-model for each station-to-station segment and whole trip (Table 22, Figure 28);
- HC emissions for each station-to-station segment and whole trip for each sub-model (Table 23);
- Percent of HC emissions in each sub-model for each station-to-station segment and whole trip (Table 24, Figure 29);
- NO_x emissions for each station-to-station segment and whole trip for each sub-model (Table 25);
- Percent of NO_x emissions in each sub-model for each station-to-station segment and whole trip (Table 26, Figure 30);

- PM emissions for each station-to-station segment and whole trip for each sub-model (Table 27); and
- Percent of PM emissions in each sub-model for each station-to-station segment and whole trip (Table 28, Figure 31);

2.5 1 Hz LPD Estimation

This worksheet includes second-by-second train activity data and estimated LPD based on the selected train speed trajectory ID (Table 29). The train activity data include speed, acceleration, track grade, and track curvature. The estimated second-by-second LPD is estimated by based on resistive forces opposing train motion, including starting, journal, flange, drag, acceleration, grade, and curvature. The second-by-second 12-second backwards moving average LPD is also quantified.

2.6 Grade Curve Spec Elevation Data

This worksheet includes model default input data for track grade and curvature by quarter-mile segments (Table 30), train specification (Tables 31 and 32), and cumulative elevation gain for each station-to-station segment and whole trip (Table 33).

2.7 Sub-Model 1

This worksheet is the basis to quantify train fuel use and emission rates in Sub-Model 1. This worksheet default model default input data for train fuel use and emission rates for each LCF ID for Sub-Model 1 (Table 34).

2.8 Sub-Model 2

This worksheet is the basis to quantify train fuel use and emission rates in Sub-Model 2. This worksheet includes model default input data for train fuel use and emission rates for each LCF ID for Sub-Model 2 (Table 35).

2.9 Sub-Model 3 Regression

This worksheet is the basis to quantify Sub-Model 3 train fuel use and emission rates for LCFs and pollutants that were calibrated using quadratic regression models. This worksheet includes model default input data for Sub-Model 3 quadratic regression parameters to estimate fuel use rates for all LCF IDs (Table 36), CO₂ emission rates for all LCF IDs (Table 37), and NO_x emission rates for all LCF IDs except for LCF IDs 1 and 10 (Table 38).

2.10 Sub-Model 3 Modal

This worksheet is the basis to quantify Sub-Model 3 train fuel use and emission rates for LCFs and pollutants that were calibrated using modal models. This worksheet includes model default input data for Sub-Model 3 modal emission rates for CO for all LCF IDs (Table 39), for HC for all LCF IDs (Table 40), for PM for all LCF IDs (Table 41), and for NO_x for LCF IDs 1 and 10 (Table 42).

2.11 Sub-Model 4

This worksheet is the basis to quantify train fuel use and emission rates in Sub-Model 4. This worksheet includes default model input data for train fuel use and emission rates for each LCF ID for Sub-Model 4 (Table 43).

2.12 Trajectory Library

This worksheet includes second-by-second train activity data (e.g., speed, track grade, and track curvature) for all 45 speed trajectory IDs (Table 44). These activity data were collected and quantified based on over-the-rail measurements for Piedmont passenger trains between Raleigh and Charlotte.

3.0 DATA INPUT, RUNNING THE SOFTWARE, AND RESULTS OUTPUT

3.1 Data Input

In this section, users will learn how to enter data in the software. To enter input data, users need to go to the Input worksheet. Users only need to provide two inputs to the software, including a LCF ID and a train speed trajectory ID (Table 1).

Table 1. Model Inputs	
Please Select a Locomotive, Consist, and Fuel (LCF) ID	1
Please Select a Train Speed Trajectory ID	15

Please click this cell and select a LCF ID from the drop-down list. Please refer to Table 4 to review details regarding LCF options.

Please click this cell and select a Train Speed Trajectory ID from the drop-down list. Please refer to Table 5 to review details regarding speed trajectory options.

There are 12 LCF IDs. Table 4 in the Input worksheet shows a reference table for each LCF ID, including locomotive name, locomotive consist type, fuel type, blended after-treatment system used or not, number of passenger cars, train weight, and train length. Users can select a LCF ID from the drop-down list when clicking the cell.

Table 1. Model Inputs

Please Select a Locomotive, Consist, and Fuel (LCF) ID	1	Please click this cell and select a LCF ID from the drop-down list. Please refer to Table 4 to review details regarding LCF options.
Please Select a Train Speed Trajectory ID	15	Please click this cell and select a Train Speed Trajectory ID from the drop-down list. Please refer to Table 5 to review details regarding speed trajectory options.

There are 45 train speed trajectory IDs. Table 5 in the Input worksheet shows a reference table for each trajectory ID, including origin, destination, travel time, distance, and trip average speed. Users can select a speed trajectory ID from the drop-down list when clicking the cell.

Table 1. Model Inputs

Please Select a Locomotive, Consist, and Fuel (LCF) ID	1	Please click this cell and select a LCF ID from the drop-down list. Please refer to Table 4 to review details regarding LCF options.
Please Select a Train Speed Trajectory ID	15	Please click this cell and select a Train Speed Trajectory ID from the drop-down list. Please refer to Table 5 to review details regarding speed trajectory options.
Click Here to Run	Now several minutes to run the model	

Users can verify their selections for LCF ID and trajectory ID in Tables 2 and 3, respectively.

Table 2. Confirmation of User Input Selection for Locomotive, Consist, and Fuel (LCF) ID

LCF ID	Locomotive	Locomotive Consist Type	Fuel Type	Blended After-Treatment System	Number of Passenger Cars
1	NC1797	Single Locomotive	Ultra-Low Sulfur Diesel	No	3

Table 3. Confirmation of User Input Selection for Train Speed Trajectory ID

Speed Trajectory ID	Origin	Destination	Travel Time (min)	Distance (mile)	Average Speed (mph)
15	Raleigh	Charlotte	190	173	55

Users can also visualize the time series profile for the selected speed trajectory in the Input worksheet.



Figure 1. Second-by-Second Speed Trajectory for Trajectory ID 15

3.2 Running the Software

In this section, users will learn how to run the software. To run the software, users need to go to the Input worksheet. After entering required input data (i.e., LCF ID and trajectory ID), users can single-click “Click Here to Run the Model” button to run the software. The button is located under Table 1 in the Input worksheet. Please allow 10 to 15 seconds processing time to run the software.

Please Select a Locomotive, Consist, and Fuel (LCF) ID	1	<div> <div>← Please click this cell and select a LCF ID from the drop-down list. Please refer to Table 4 to review details regarding LCF options.</div> <div>← Please click this cell and select a Train Speed Trajectory ID from the drop-down list. Please refer to Table 5 to review details regarding speed trajectory options.</div> </div>
Please Select a Train Speed Trajectory ID	15	
<div> <div>Click Here to Run the Model</div> <div>← Allow several minutes to run the model</div> </div>		

3.3 Results Output

In this section, users will learn how to review results for model outputs after the software run is completed. To review results for model outputs, users need to go to the Output worksheet. Tables 6 and 7 in the Output worksheet show the train and trip information, respectively, based on the user's selection.

Table 6. Train Information		Table 7. Trip Information	
Locomotive, Consist, and Fuel (LCF) ID	1	Trajectory ID	15
Locomotive	NC1797	Origin	Raleigh
Locomotive Consist Type	Single Locomotive	Destination	Charlotte
Fuel Type	Ultra-Low Sulfur Diesel	Travel Time (minute)	190
Blended After-Treatment System	No	Distance (mile)	173
Number of Baggage/Café and Passenger Cars	3	Average Speed (mph)	55
Train Weight (metric ton)	310		
Train Length (m)	100		

Table 8 in the Output worksheet quantifies train activities for each station-to-station segment and whole trip, including travel time, distance, maximum speed, average speed, average positive acceleration, average negative acceleration, idle duration at stations, idle duration during train operations, total idle duration, cumulative elevation gain, cumulative positive elevation gain, and cumulative negative elevation gain.

Table 8. Train Activity for Each Station-to-Station Segment and Whole Trip

Train Activity	Station-to-Station Segments								Whole Trip
	Raleigh-Cary	Cary-Durham	Durham-Burlington	Burlington-Greensboro	Greensboro-High Point	High Point-Salisbury	Salisbury-Kannapolis	Kannapolis-Charlotte	
Travel Time (minute)	13	19	39	20	15	32	15	27	190
Distance (mile)	8	18	33	21	15	34	16	27	173
Maximum Speed (mph)	78	82	77	80	79	81	79	81	82
Average Speed (mph)	40	56	52	63	63	64	64	60	55
Average Positive Acceleration (mph/s)	1.04	0.68	0.50	0.63	0.38	0.37	0.47	0.47	0.51
Average Negative Acceleration (mph/s)	-1.03	-0.95	-0.66	-0.75	-0.89	-0.68	-0.61	-0.63	-0.75
Idle duration at stations (minute) *	2	2	1	3	1	1	1	0	10
Idle duration during train operations (minute)	0	0	0	0	0	0	0	0	0
Total idle duration (minute)	2	2	1	3	1	1	1	0	11
Cumulative Elevation Gain (feet)	149	-111	271	154	83	-147	80	-100	365
Cumulative Positive Elevation Gain (feet)	314	470	1110	837	457	756	404	594	5093
Cumulative Negative Elevation Gain (feet)	-165	-581	-839	-683	-373	-903	-323	-695	-4729

*Note: Idle duration at stations refers to idling at Cary station for Raleigh-Cary, Durham station for Cary-Durham, Burlington station for Durham-Burlington, Greensboro station for Burlington-Greensboro, High Point station for Greensboro-High Point, Kannapolis station for Salisbury-Kannapolis, and Charlotte station for Kannapolis-Charlotte.

Table 9 in the Output worksheet quantifies total fuel use and emissions for CO₂, CO, HC, NO_x, and PM for each station-to-station segment and whole trip.

Table 9. Total Fuel Use and Emissions for Each Station-to-Station Segment and Whole Trip

Species (unit)	Station-to-Station Segments								Whole Trip
	Raleigh-Cary	Cary-Durham	Durham-Burlington	Burlington-Greensboro	Greensboro-High Point	High Point-Salisbury	Salisbury-Kannapolis	Kannapolis-Charlotte	
Fuel (gallon)	14	20	44	26	20	37	18	31	210
CO ₂ (kg)	137	197	440	262	203	370	179	308	2,106
CO (g)	197	303	670	394	311	572	256	494	3,259
HC (g)	702	1,003	2,054	1,097	774	1,695	846	1,320	9,868
NO _x (g)	4,111	5,603	12,180	6,945	5,122	10,094	5,239	7,932	7,383
PM (g)	26	42	98	61	51	86	37	76	478

Users can also visualize total fuel use and emissions for each station-to-station segment under Table 9. Figures 2 to 7 are station-to-station segment total fuel use and emissions of CO₂, CO, HC, NO_x, and PM, respectively, for a selected LCF ID and trajectory ID.

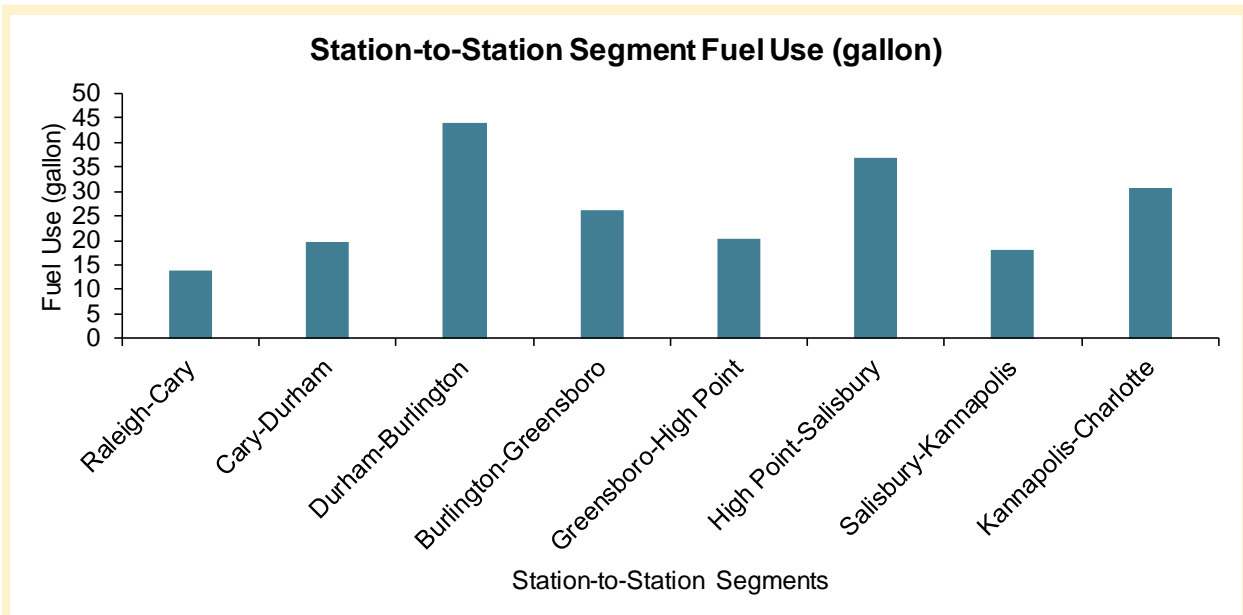


Figure 2. Station-to-Station Segment Total Fuel Use for LCF ID 1 and Trajectory ID 15

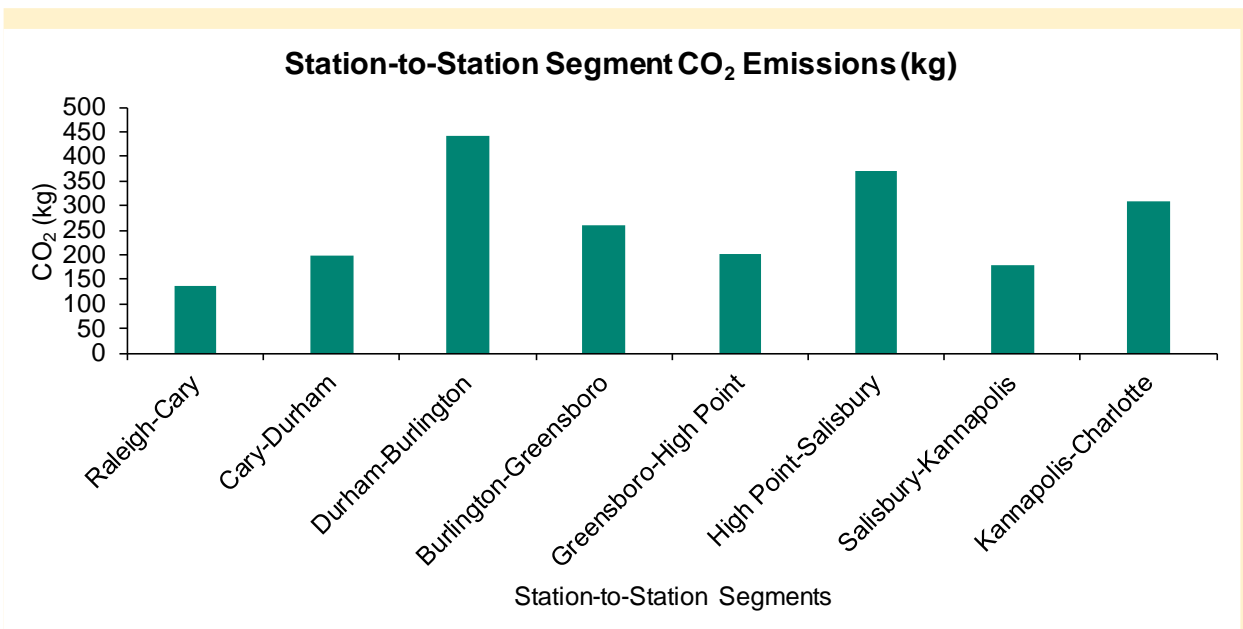


Figure 3. Station-to-Station Segment Total CO₂ Emissions for LCF ID 1 and Trajectory ID 15

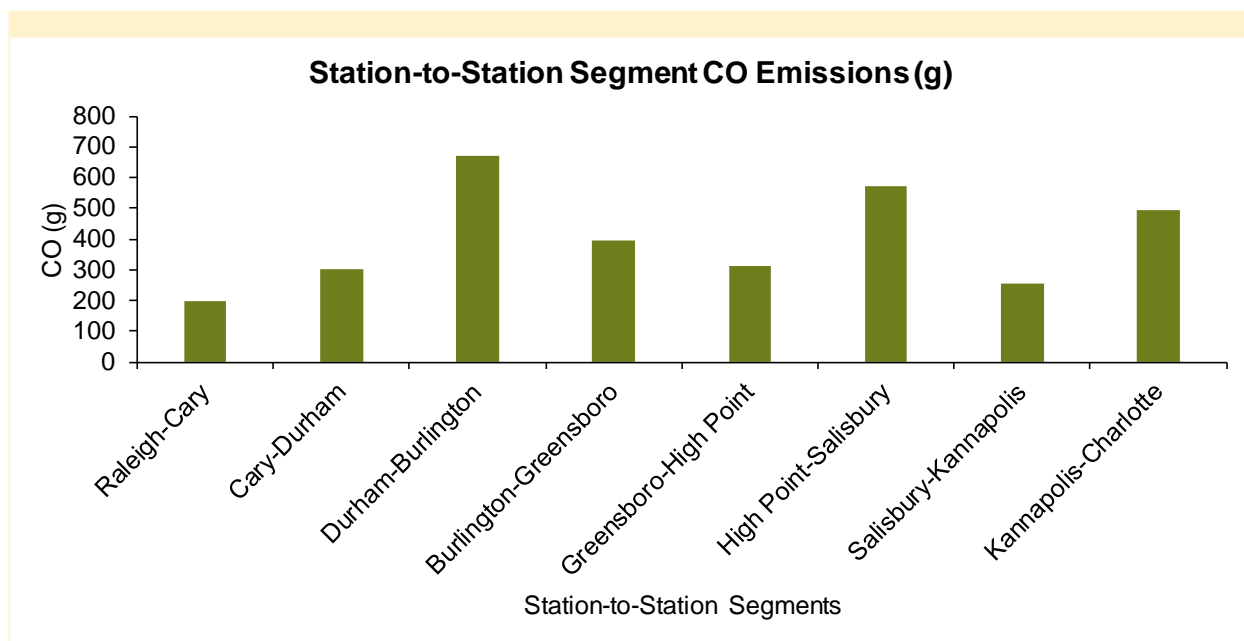


Figure 4. Station-to-Station Segment Total CO Emissions for LCF ID 1 and Trajectory ID 15

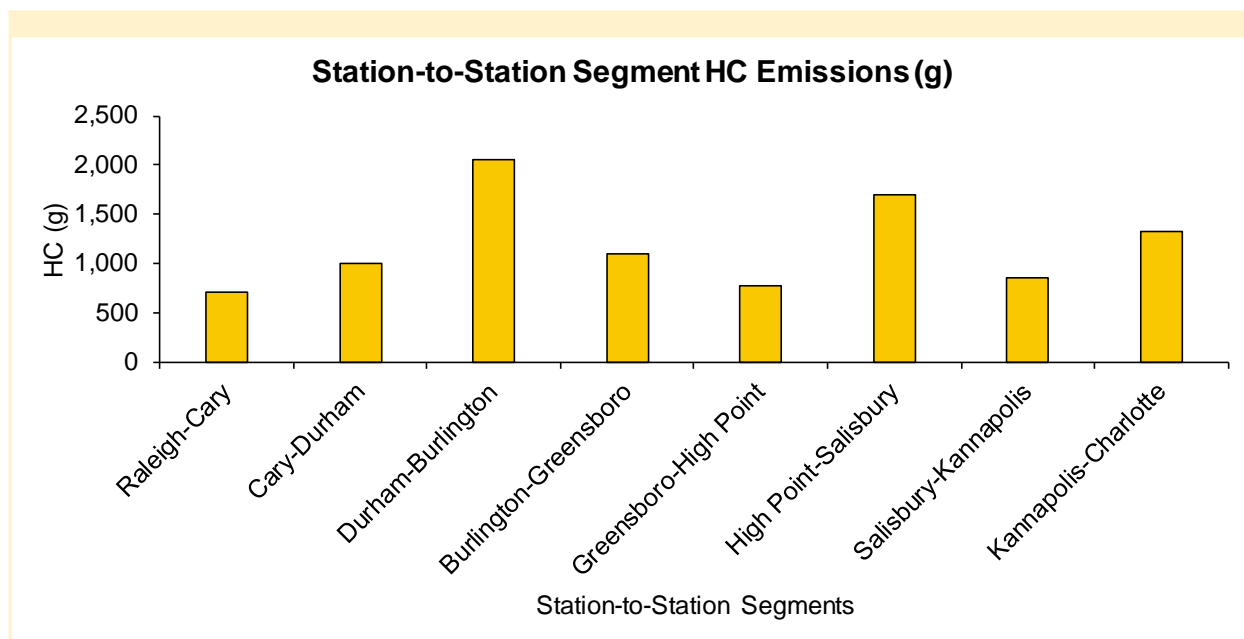


Figure 5. Station-to-Station Segment Total HC Emissions for LCF ID 1 and Trajectory ID 15

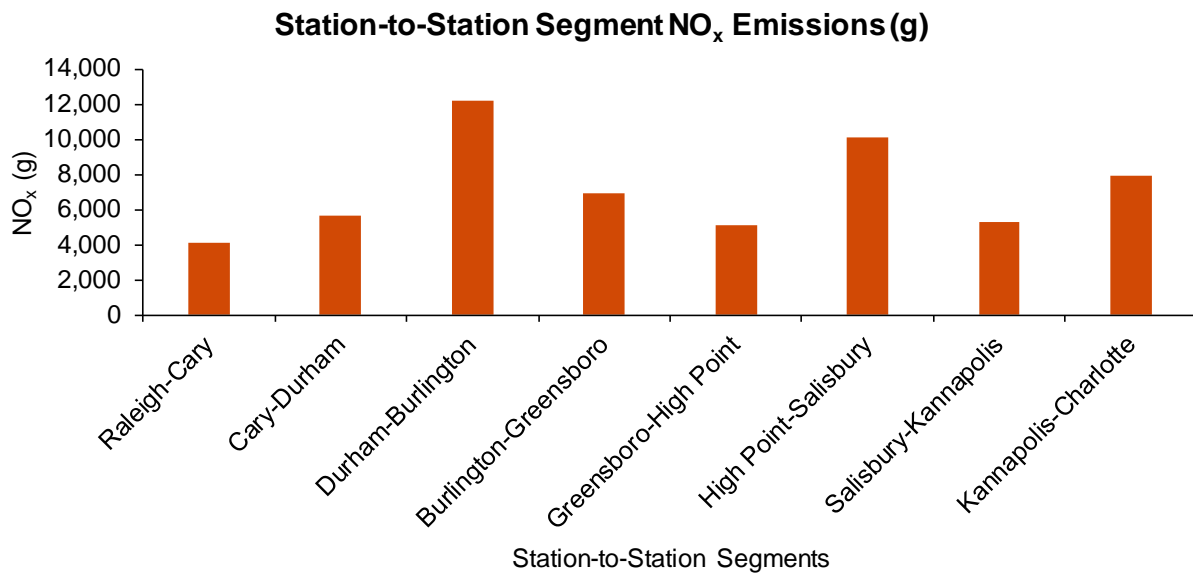


Figure 6. Station-to-Station Segment Total NO_x Emissions for LCF ID 1 and Trajectory ID 15

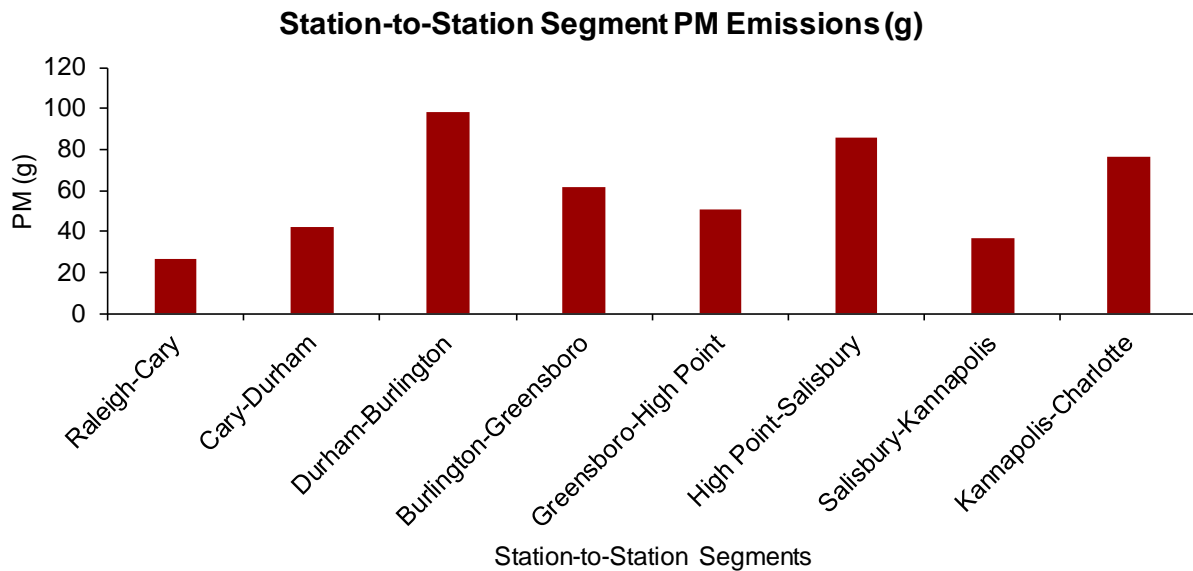


Figure 7. Station-to-Station Segment Total PM Emissions for LCF ID 1 and Trajectory ID 15

Table 10 in the Output worksheet quantifies fuel economy (mpg) as well as distance-based emission rates (e.g., g/mile) for CO₂, CO, HC, NO_x, and PM for each station-to-station segment and whole trip.

Table 10. Distance-based Segment Average Fuel Use and Emission Rates for Each Station-to-Station Segment and Whole Trip

Species (unit)	Station-to-Station Segments								Whole Trip
	Raleigh-Cary	Cary-Durham	Durham-Burlington	Burlington-Greensboro	Greensboro-High Point	High Point-Salisbury	Salisbury-Kannapolis	Kannapolis-Charlotte	
Fuel Economy (mpg)	0.6	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8
CO ₂ (kg/mile)	16.2	10.9	13.3	12.2	13.2	10.8	11.4	11.6	12.2
CO (g/mile)	23.2	16.8	20.2	18.4	20.2	16.7	16.3	18.6	18.8
HC (g/mile)	83.0	55.6	61.8	51.3	50.2	49.4	54.0	49.8	57.0
NO _x (g/mile)	486	311	366	325	332	294	334	299	43
PM (g/mile)	3.1	2.3	3.0	2.9	3.3	2.5	2.4	2.9	2.8

Users can also visualize fuel economy and distance-based emission rates for each station-to-station segment and whole trip under Table 10. Figures 8 to 13 are fuel economy and distance-based emission rates of CO₂, CO, HC, NO_x, and PM, respectively, for each station-to-station segment and whole trip for a selected LCF ID and trajectory ID.

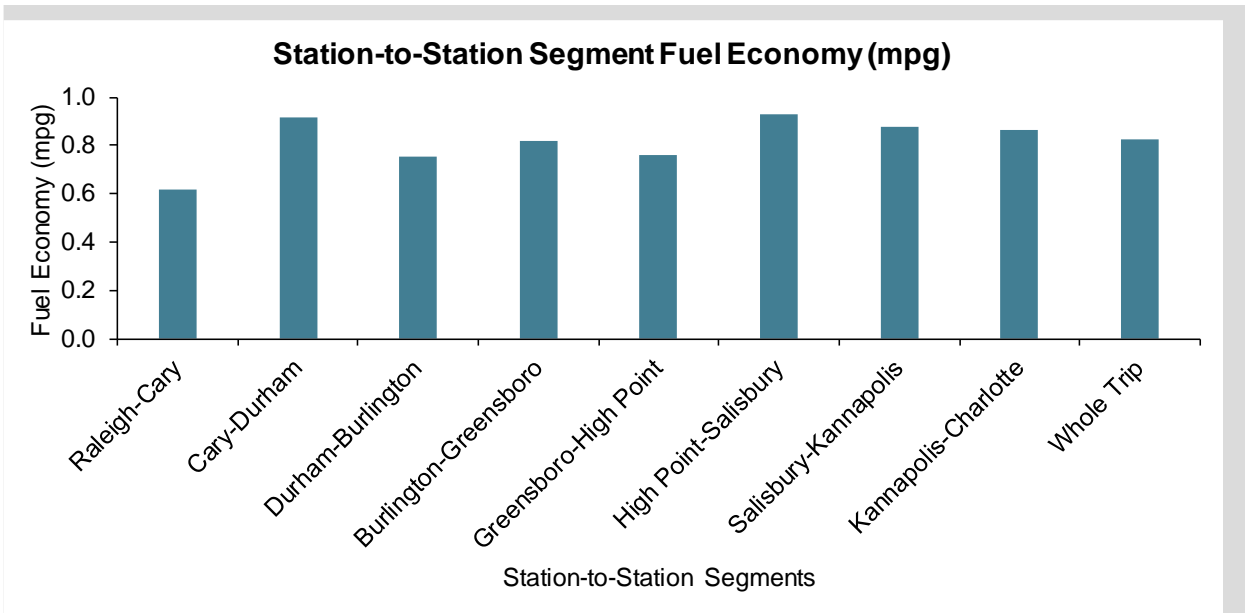


Figure 8. Station-to-Station Segment and Whole Trip Fuel Economy for LCF ID 1 and Trajectory ID 15

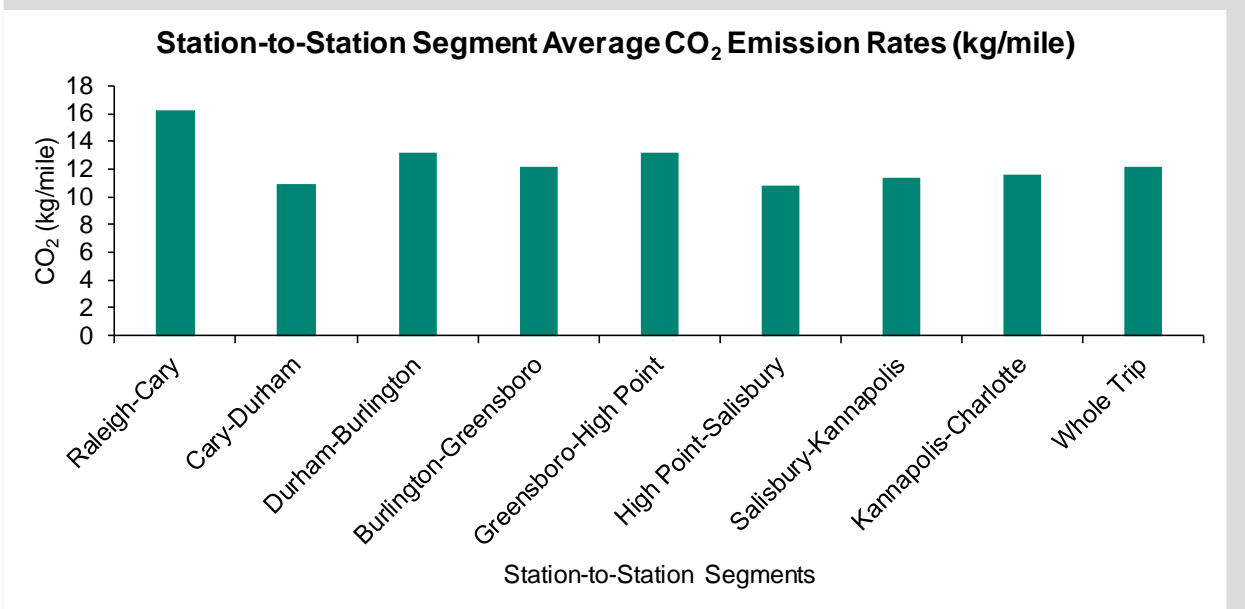


Figure 9. Distance-Based Station-to-Station Segment Average and Whole Trip Average CO₂ Emission Rates for LCF ID 1 and Trajectory ID 15

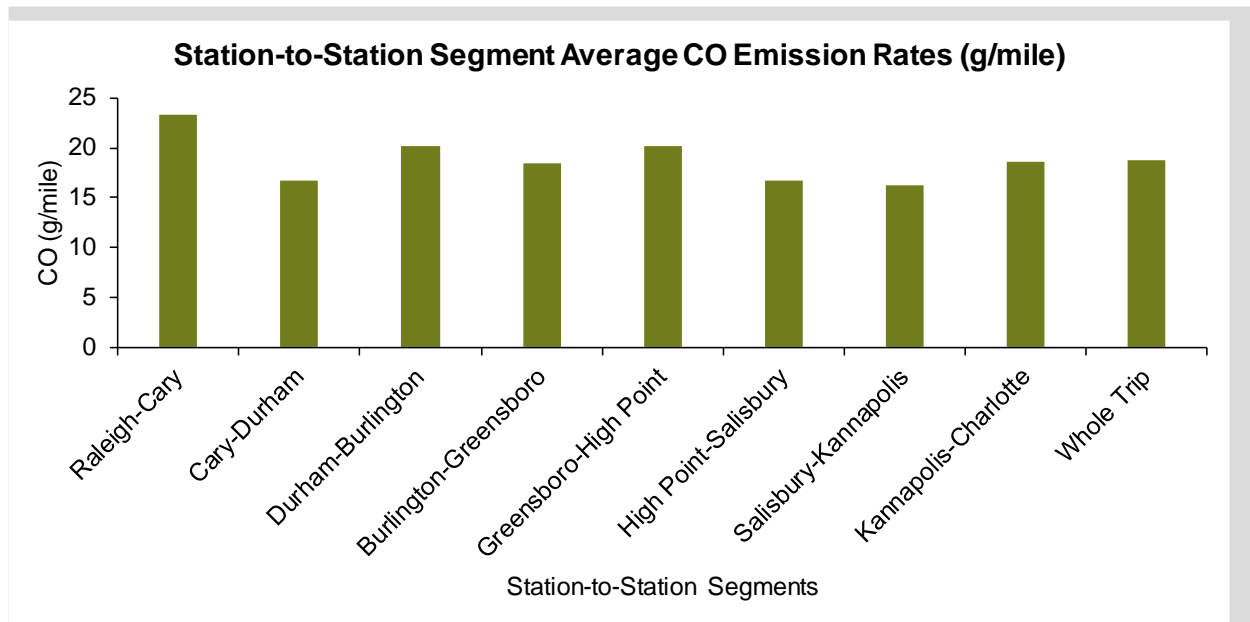


Figure 10. Distance-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for LCF ID 1 and Trajectory ID 15

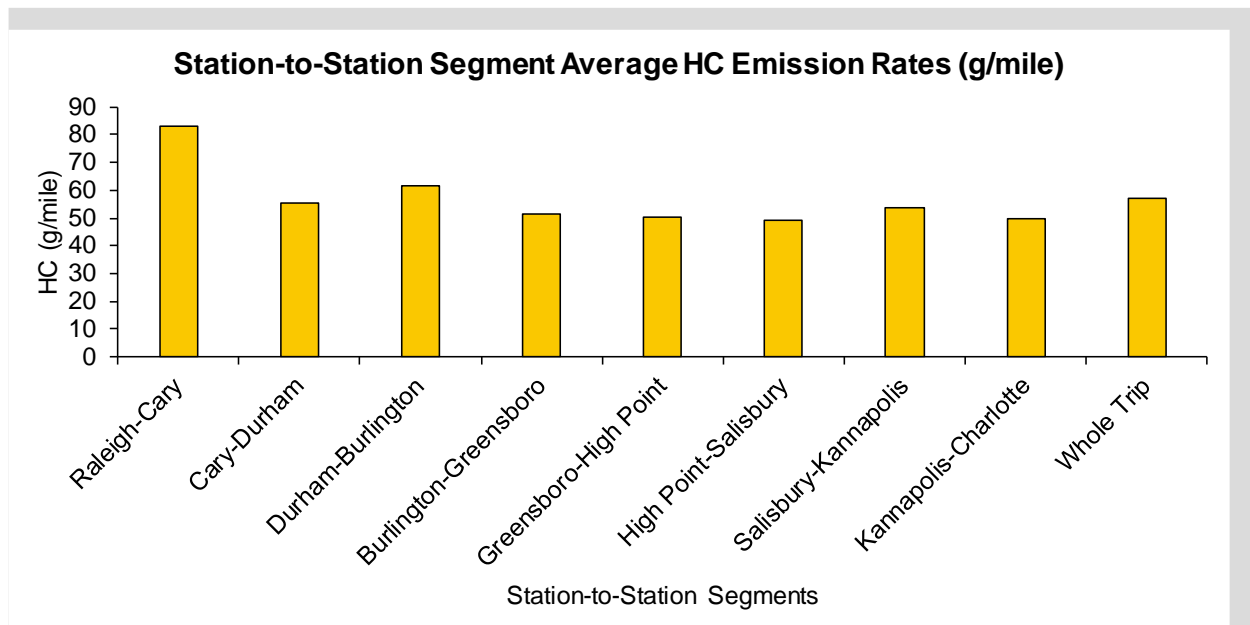


Figure 11. Distance-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for LCF ID 1 and Trajectory ID 15

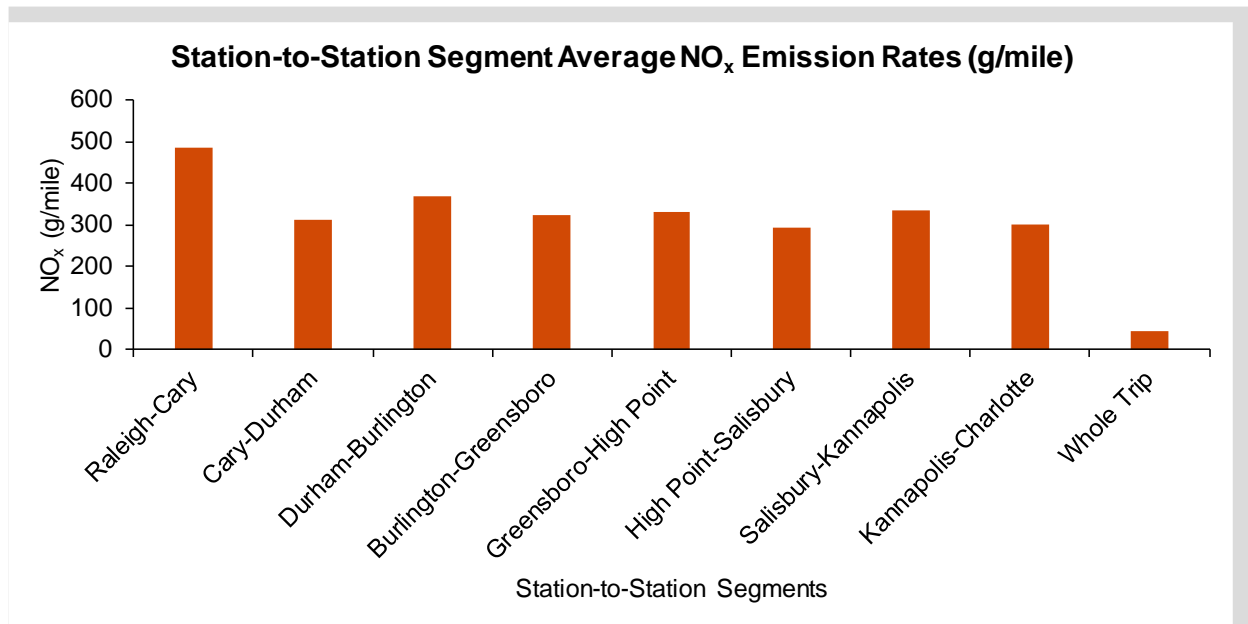


Figure 12. Distance-Based Station-to-Station Segment Average and Whole Trip Average NO_x Emission Rates for LCF ID 1 and Trajectory ID 15

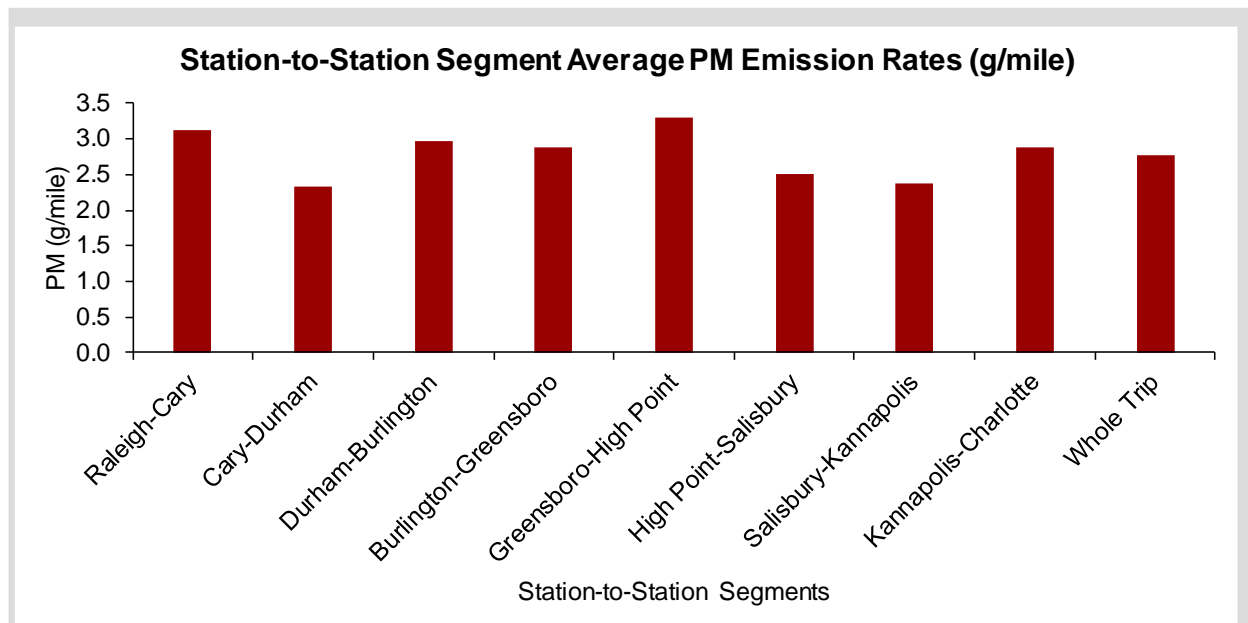


Figure 13. Distance-Based Station-to-Station Segment Average and Whole Trip Average PM Emission Rates for LCF ID 1 and Trajectory ID 15

Table 11 in the Output worksheet quantifies time-based fuel use and emission rates (e.g., g/s) for CO₂, CO, HC, NO_x, and PM for each station-to-station segment and whole trip.

Table 11. Time-based Segment Average Fuel Use and Emission Rates for Each Station-to-Station Segment and Whole Trip

Species (unit)	Station-to-Station Segments								Whole Trip
	Raleigh-Cary	Cary-Durham	Durham-Burlington	Burlington-Greensboro	Greensboro-High Point	High Point-Salisbury	Salisbury-Kannapolis	Kannapolis-Charlotte	
Fuel (g/s)	57	54	60	67	73	61	64	61	58
CO ₂ (g/s)	181	170	190	213	230	192	202	194	185
CO (mg/s)	259	260	289	320	352	296	288	310	286
HC (mg/s)	923	861	884	893	876	878	952	829	866
NO _x (mg/s)	5,402	4,814	5,243	5,651	5,800	5,230	5,893	4,983	648
PM (mg/s)	35	36	42	50	57	44	42	48	42

Users can also visualize time-based fuel use and emission rates for each station-to-station segment and whole trip under Table 11. Figures 14 to 19 are time-based fuel use and emission rates of CO₂, CO, HC, NO_x, and PM, respectively, for each station-to-station segment and whole trip for a selected LCF ID and trajectory ID.

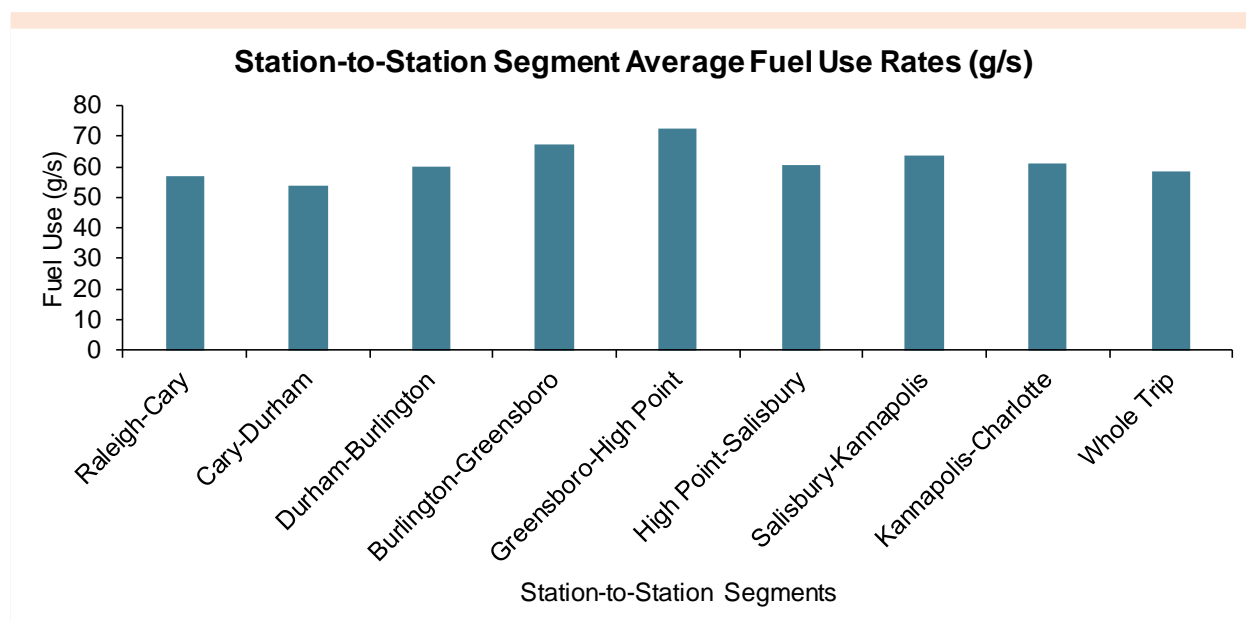


Figure 14. Time-Based Station-to-Station Segment Average and Whole Trip Average Fuel Use Rates for LCF ID 1 and Trajectory ID 15

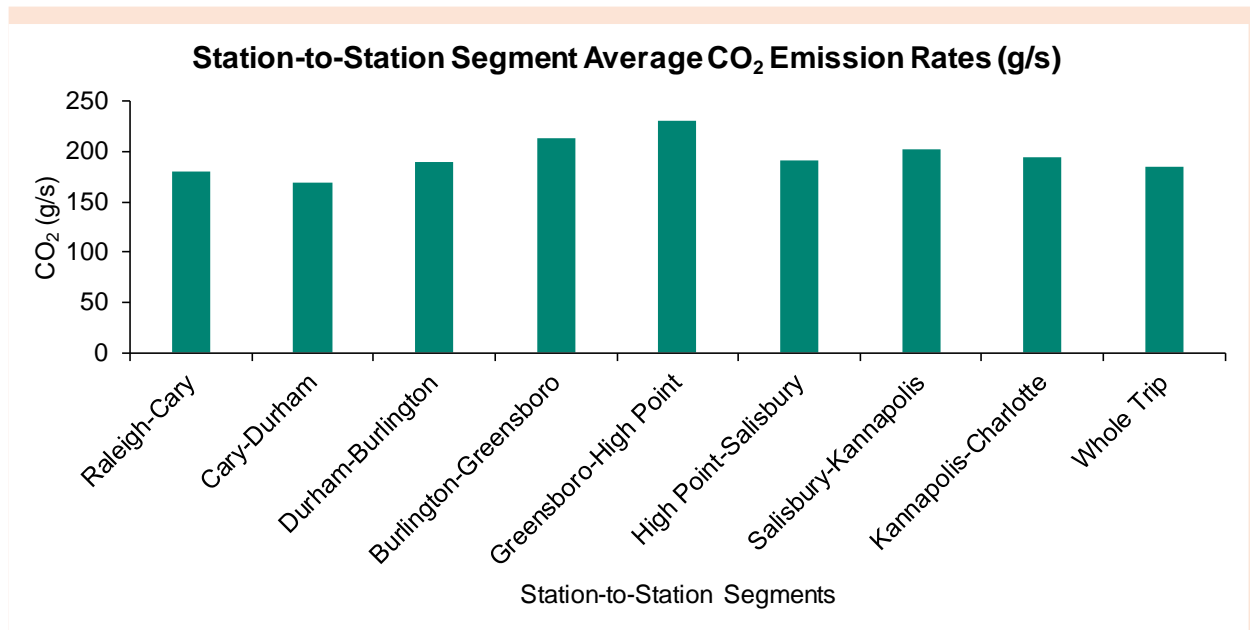


Figure 15. Time-Based Station-to-Station Segment Average and Whole Trip Average CO₂ Emission Rates for LCF ID 1 and Trajectory ID 15

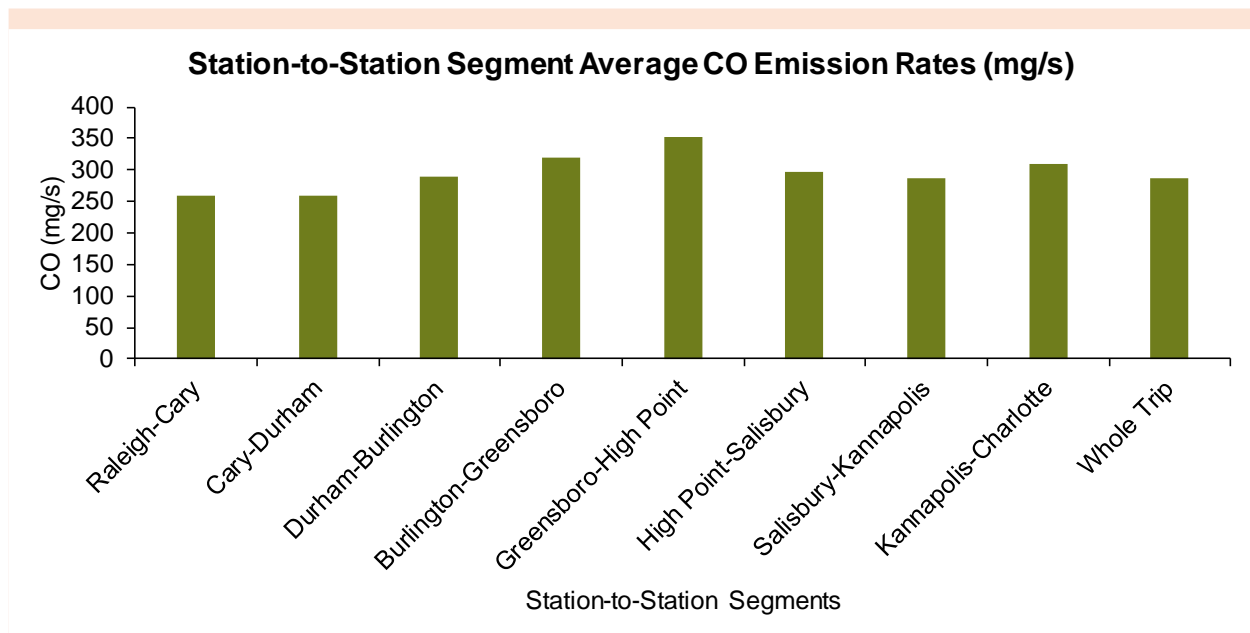


Figure 16. Time-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for LCF ID 1 and Trajectory ID 15

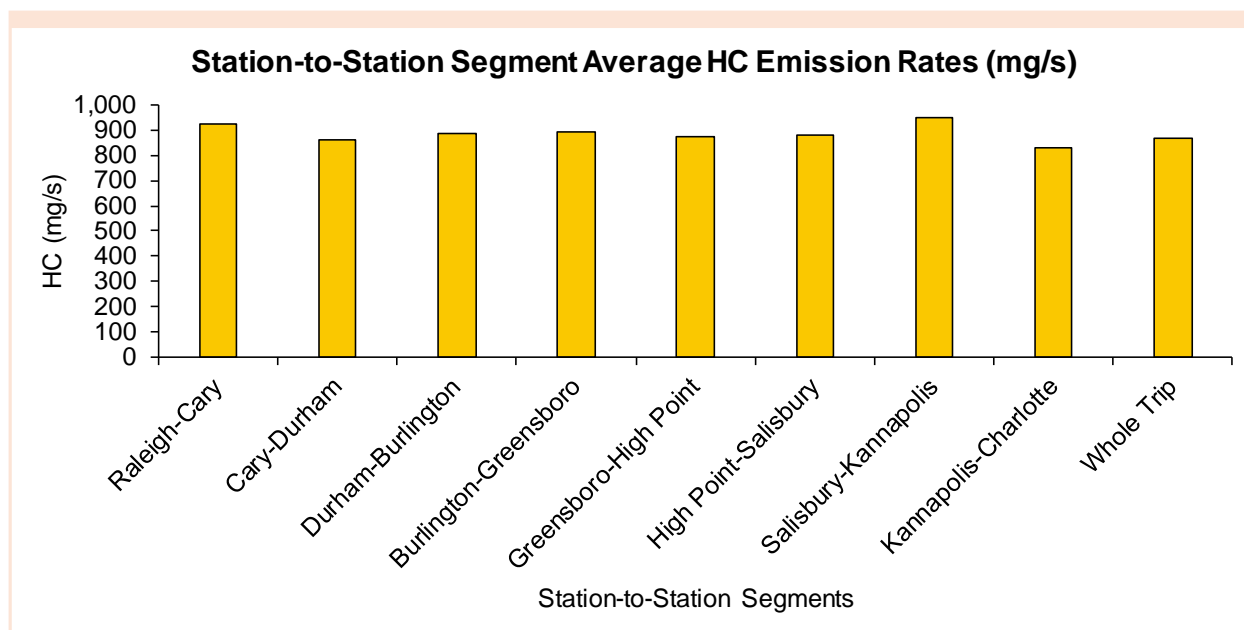


Figure 17. Time-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for LCF ID 1 and Trajectory ID 15

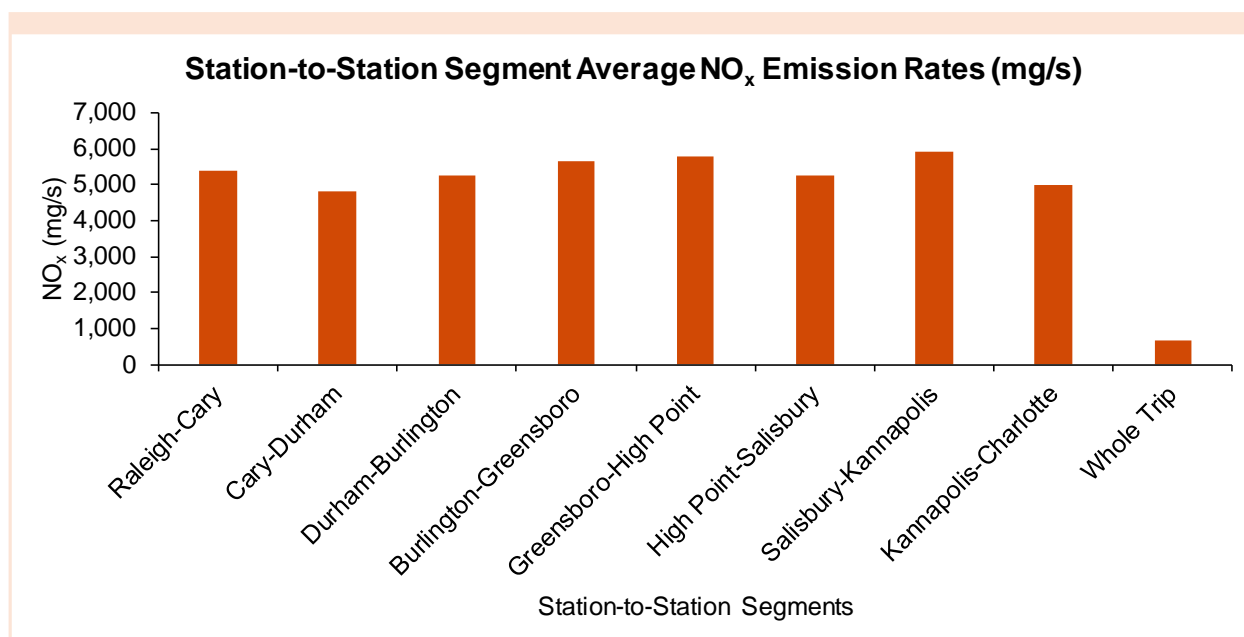


Figure 18. Time-Based Station-to-Station Segment Average and Whole Trip Average NO_x Emission Rates for LCF ID 1 and Trajectory ID 15

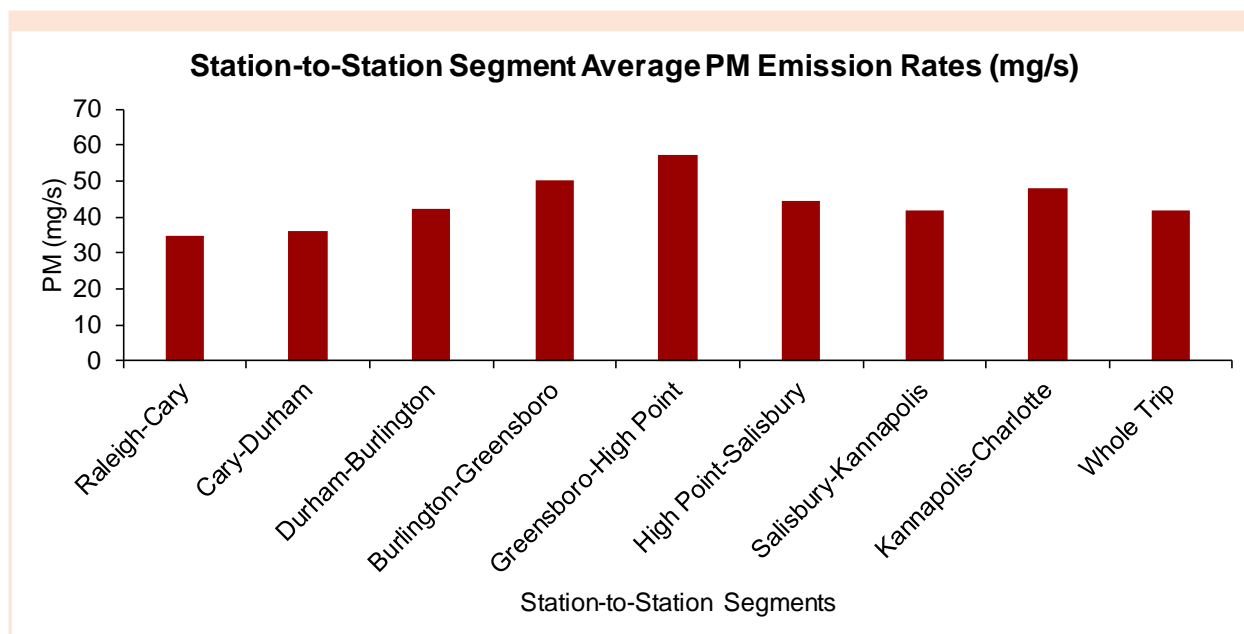


Figure 19. Time-Based Station-to-Station Segment Average and Whole Trip Average PM Emission Rates for LCF ID 1 and Trajectory ID 15

Table 12 in the Output worksheet quantifies fuel-based emission rates (e.g., g/gallon) for CO₂, CO, HC, NO_x, and PM for each station-to-station segment and whole trip.

Table 12. Fuel-based Segment Average Emission Rates for Each Station-to-Station Segment and Whole Trip

Species (unit)	Station-to-Station Segments								Whole Trip
	Raleigh-Cary	Cary-Durham	Durham-Burlington	Burlington-Greensboro	Greensboro-High Point	High Point-Salisbury	Salisbury-Kannapolis	Kannapolis-Charlotte	
CO ₂ (kg/gallon)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
CO (g/gallon)	14.3	15.4	15.2	15.1	15.3	15.5	14.3	16.1	15.5
HC (g/gallon)	51.1	50.8	46.7	42.0	38.2	45.9	47.2	42.9	46.9
NO _x (g/gallon)	299	284	277	266	253	273	292	258	35
PM (g/gallon)	1.9	2.1	2.2	2.4	2.5	2.3	2.1	2.5	2.3

Users can also visualize fuel-based emission rates for each station-to-station segment and whole trip under Table 12. Figures 20 to 24 are fuel-based emission rates of CO₂, CO, HC, NO_x,

and PM, respectively, for each station-to-station segment and whole trip for a selected LCF ID and trajectory ID.

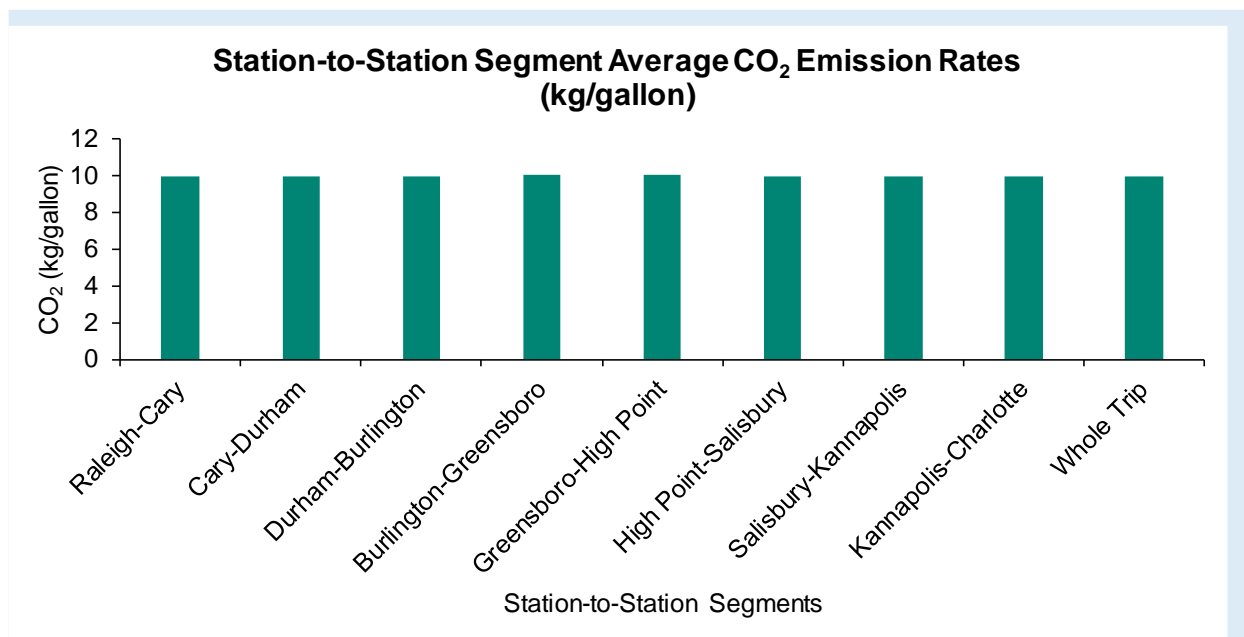


Figure 20. Fuel-Based Station-to-Station Segment Average and Whole Trip Average CO₂ Emission Rates for LCF ID 1 and Trajectory ID 15

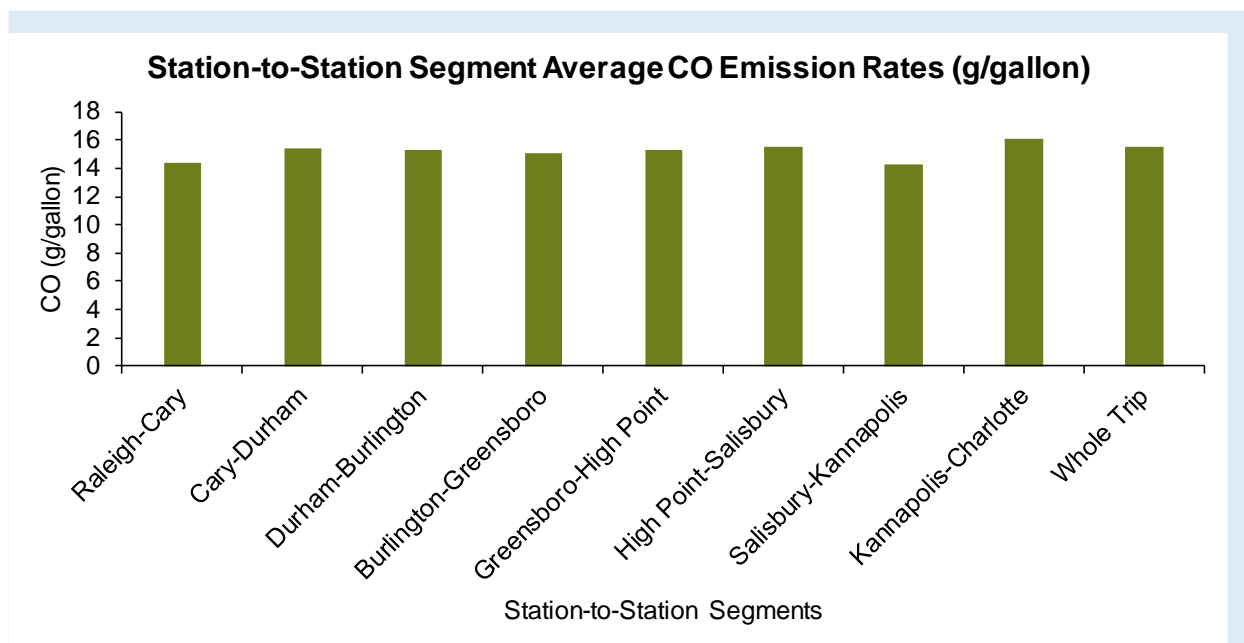


Figure 21. Fuel-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for LCF ID 1 and Trajectory ID 15

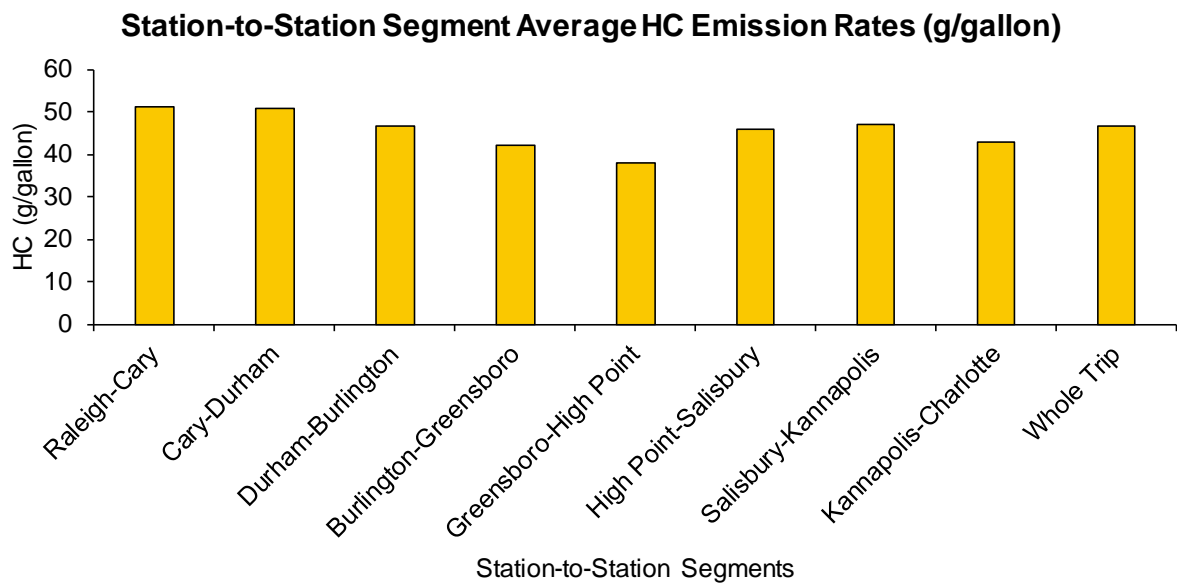


Figure 22. Fuel-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for LCF ID 1 and Trajectory ID 15

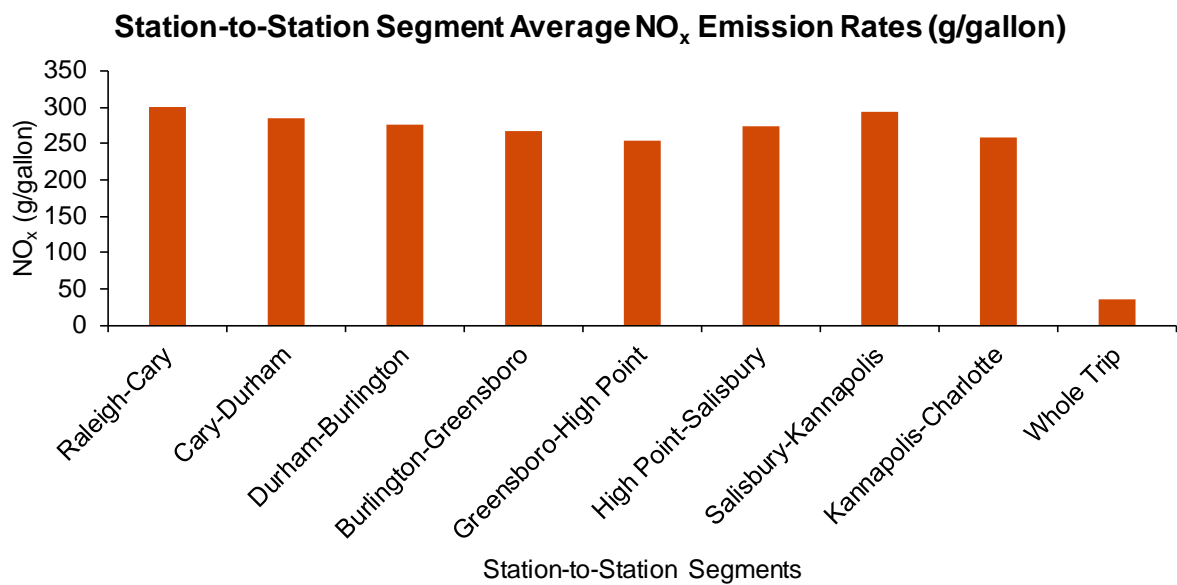
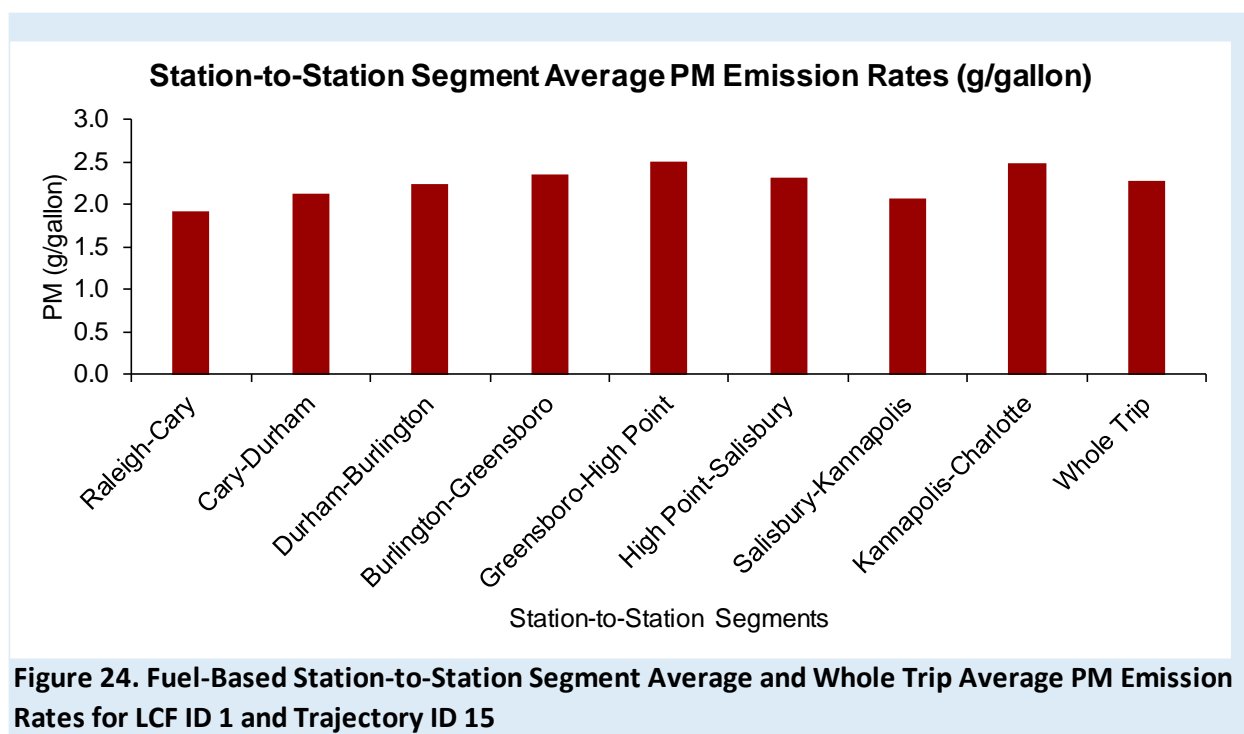


Figure 23. Fuel-Based Station-to-Station Segment Average and Whole Trip Average NO_x Emission Rates for LCF ID 1 and Trajectory ID 15



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APPENDIX A. LIST OF TABLES IN THE SOFTWARE

Table A-1. List of Tables in the Software

Worksheet	Table No.	Table Caption
Input	Table 1.	Model Inputs
Input	Table 2.	Confirmation of User Input Selection for Locomotive, Consist, and Fuel (LCF) ID
Input	Table 3.	Confirmation of User Input Selection for Train Speed Trajectory ID
Input	Table 4.	Reference Table for Locomotive, Consist, and Fuel (LCF) ID
Input	Table 5.	Reference Table for Train Speed Trajectory ID
Output	Table 6.	Train Information
Output	Table 7.	Trip Information
Output	Table 8.	Train Activity for Each Station-to-Station Segment and Whole Trip
Output	Table 9.	Total Fuel Use and Emissions for Each Station-to-Station Segment and Whole Trip
Output	Table 10.	Distance-based Segment Average Fuel Use and Emission Rates for Each Station-to-Station Segment and Whole Trip

Continued on next page.

Table A-1. Continued.

Worksheet	Table No.	Table Content
Output	Table 11.	Time-based Segment Average Fuel Use and Emission Rates for Each Station-to-Station Segment and Whole Trip
Output	Table 12.	Fuel-based Segment Average Emission Rates for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 13.	Travel Time, Fuel Use, and Emissions for the Whole Trip for Each Sub-Model
Diagnostics	Table 14.	Sub-Model 3 Travel Time (seconds) for Each Station-to-Station Segment and Whole Trip for Each Mode
Diagnostics	Table 15.	Travel Time (seconds) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 16.	Percent of Travel Time Spent in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 17.	Fuel Use (kg) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 18.	Percent of Fuel Use in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 19.	CO ₂ Emissions (kg) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model

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Table A-1. Continued.

Worksheet	Table No.	Table Content
Diagnostics	Table 20.	Percent of CO ₂ Emissions in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 21.	CO Emissions (g) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 22.	Percent of CO Emissions in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 23.	HC Emissions (g) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 24.	Percent of HC Emissions in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 25.	NO _x Emissions (g) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 26.	Percent of NO _x Emissions in Each Sub-Model for Each Station-to-Station Segment and Whole Trip
Diagnostics	Table 27.	PM Emissions (g) for Each Station-to-Station Segment and Whole Trip for Each Sub-Model
Diagnostics	Table 28.	Percent of PM Emissions in Each Sub-Model for Each Station-to-Station Segment and Whole Trip

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Table A-1. Continued.

Worksheet	Table No.	Table Content
1 Hz LPD Estimation	Table 29.	Second-by-Second Train Activity Data and Estimated Locomotive Power Demand (LPD) based on the Selected Speed Trajectory ID
Grade Curve Spec Elevation Data	Table 30.	Track Grade and Curvature for Quarter-Mile Segments
Grade Curve Spec Elevation Data	Table 31.	Train Specification Data
Grade Curve Spec Elevation Data	Table 32.	Train Specification Data Imputed Based on Model Inputs
Grade Curve Spec Elevation Data	Table 33.	Cumulative Elevation Gains for Each Station-to-Station Segment and Whole Trip
Sub-Model 1	Table 34.	Sub-Model 1 Fuel Use and Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Sub-Model 2	Table 35.	Sub-Model 2 Fuel Use and Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Sub-Model 3 Regression	Table 36.	Sub-Model 3 Regression Parameters for Estimating Fuel Use Rates

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Table A-1. Continued.

Worksheet	Table No.	Table Content
Sub-Model 3 Regression	Table 37.	Sub-Model 3 Regression Parameters for Estimating CO ₂ Emission Rates
Sub-Model 3 Regression	Table 38.	Sub-Model 3 Regression Parameters for Estimating NO _x Emission Rates
Sub-Model 3 Modal	Table 39.	Sub-Model 3 Modal CO Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Sub-Model 3 Modal	Table 40.	Sub-Model 3 Modal HC Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Sub-Model 3 Modal	Table 41.	Sub-Model 3 Modal PM Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Sub-Model 3 Modal	Table 42.	Sub-Model 3 Modal NO _x Emission Rates for Locomotive, Consist, and Fuel (LCF) ID 1 and 10
Sub-Model 4	Table 43.	Sub-Model 4 Fuel Use and Emission Rates for Each Locomotive, Consist, and Fuel (LCF) ID
Trajectory Library	Table 44.	Second-by-Second Train Activity Data for All Speed Trajectory IDs

APPENDIX B. LIST OF FIGURES IN THE SOFTWARE

Table B-1. List of Figures in the Software

Worksheet	Figure No.	Figure Caption
Input	Figure 1.	Second-by-Second Speed Trajectory for the User-Selected Trajectory ID
Output	Figure 2.	Station-to-Station Segment Total Fuel Use for the User-Selected LCF ID and Trajectory ID
Output	Figure 3.	Station-to-Station Segment Total CO ₂ Emissions for the User-Selected LCF ID and Trajectory ID
Output	Figure 4.	Station-to-Station Segment Total CO Emissions for the User-Selected LCF ID and Trajectory ID
Output	Figure 5.	Station-to-Station Segment Total HC Emissions for the User-Selected LCF ID and Trajectory ID
Output	Figure 6.	Station-to-Station Segment Total NO _x Emissions for the User-Selected LCF ID and Trajectory ID
Output	Figure 7.	Station-to-Station Segment Total PM Emissions for the User-Selected LCF ID and Trajectory ID
Output	Figure 8.	Station-to-Station Segment and Whole Trip Fuel Economy for the User-Selected LCF ID and Trajectory ID

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Table B-1. Continued.

Worksheet	Figure No.	Figure Caption
Output	Figure 9.	Distance-Based Station-to-Station Segment Average and Whole Trip Average CO ₂ Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 10.	Distance-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 11.	Distance-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 12.	Distance-Based Station-to-Station Segment Average and Whole Trip Average NO _x Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 13.	Distance-Based Station-to-Station Segment Average and Whole Trip Average PM Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 14.	Time-Based Station-to-Station Segment Average and Whole Trip Average Fuel Use Rates for the User-Selected LCF ID and Trajectory ID

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Table B-1. Continued.

Worksheet	Figure No.	Figure Caption
Output	Figure 15.	Time-Based Station-to-Station Segment Average and Whole Trip Average CO ₂ Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 16.	Time-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 17.	Time-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 18.	Time-Based Station-to-Station Segment Average and Whole Trip Average NO _x Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 19.	Time-Based Station-to-Station Segment Average and Whole Trip Average PM Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 20.	Fuel-Based Station-to-Station Segment Average and Whole Trip Average CO ₂ Emission Rates for the User-Selected LCF ID and Trajectory ID

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Table B-1. Continued.

Worksheet	Figure No.	Figure Caption
Output	Figure 21.	Fuel-Based Station-to-Station Segment Average and Whole Trip Average CO Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 22.	Fuel-Based Station-to-Station Segment Average and Whole Trip Average HC Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 23.	Fuel-Based Station-to-Station Segment Average and Whole Trip Average NO _x Emission Rates for the User-Selected LCF ID and Trajectory ID
Output	Figure 24.	Fuel-Based Station-to-Station Segment Average and Whole Trip Average PM Emission Rates for the User-Selected LCF ID and Trajectory ID
Diagnostics	Figure 25.	Percent of Travel Time Spent by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID
Diagnostics	Figure 26.	Percent of Fuel Consumption by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID

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Table B-1. Continued.

Worksheet	Figure No.	Figure Caption
Diagnostics	Figure 27.	Percent of CO ₂ Emissions by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID
Diagnostics	Figure 28.	Percent of CO Emissions by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID
Diagnostics	Figure 29.	Percent of HC Emissions by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID
Diagnostics	Figure 30.	Percent of NO _x Emissions by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID
Diagnostics	Figure 31.	Percent of PM Emissions by Sub-Models and by Station-to-Station Segments and Whole Trip for the User-Selected Trajectory ID