

BATTERY AND HEATING DATA IN REAL DRIVING CYCLES

Predicting Battery State of Charge

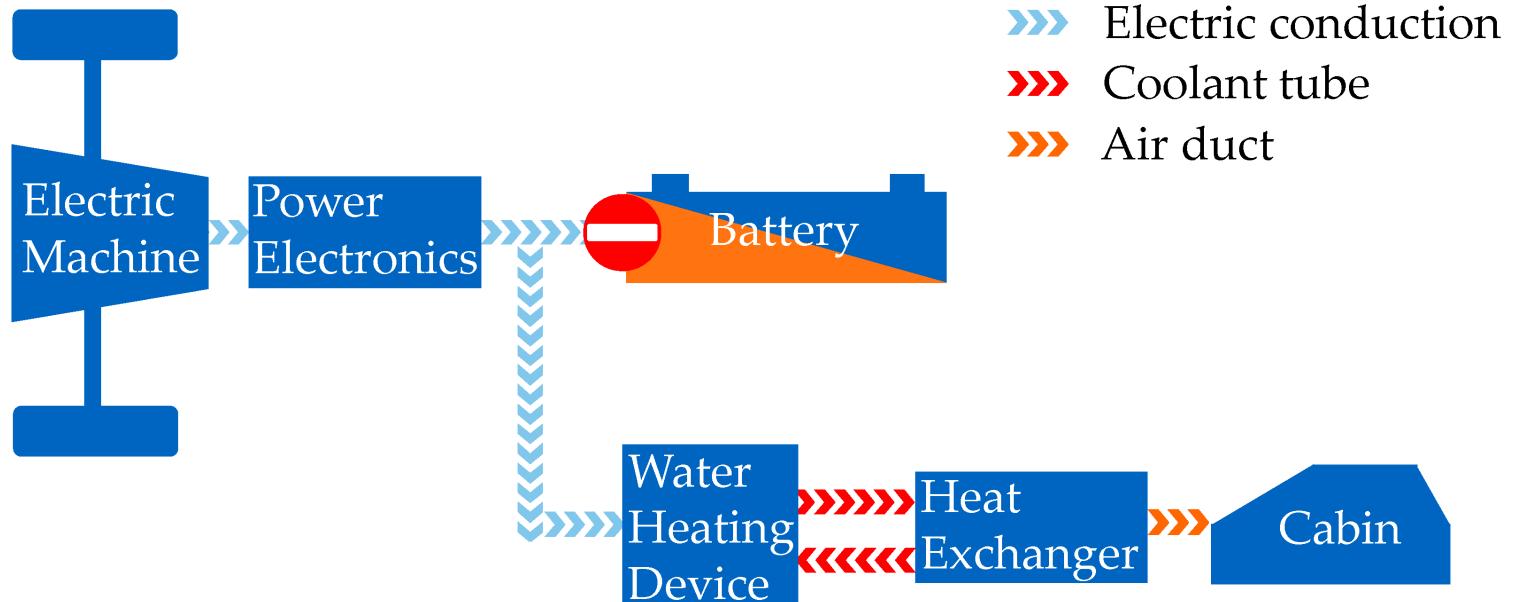
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Date: 22-12-2023

Business Understanding

Abstract:

- EV face significant loading fluctuation due to driving behavior
- Dynamic performance but constant Aux load
- Highest AUX consumption: eAC/PTC
- Eventually decrease range
- Using electro thermal recuperation (Regenerative Braking) enhanced the range and battery life
- Predict the **State of Charge for given drive profile**



Data Understanding

Vehicle Data:

- Model: BMW i3 60Ah
 - UBE: 18.8 kWh
 - Range: 115 km
 - Efficiency: 163 Wh/km
- Drive Profile:
 - 72 Real Drive trips
 - Each trip contains:
 - Environmental data (temperature, elevation, etc.)
 - Vehicle data (speed, throttle, etc.)
 - Battery data (voltage, current, temperature, SoC)
 - Heating circuit data (indoor temperature, heating power, etc.)
- Category:
 - **Category A: Summer** (Does not contain all measured data due to trouble with measurement system)
 - **Category B: Recorded in winter** and data is consistent



Data Understanding

Classification: Public

Vehicle Performance Metrics

Performance

Acceleration 0 - 100 km/h	7.2 sec
Top Speed	150 km/h
Electric Range	115 km

Total Power	125 kW (170 PS)
Total Torque	250 Nm
Drive	Rear

Battery

Nominal Capacity	21.6 kWh	Useable Capacity	18.8 kWh
Battery Type	Lithium-ion	Cathode Material	No Data
Number of Cells	No Data	Pack Configuration	No Data
Architecture	400 V	Nominal Voltage	No Data

Charging

Home / Destination

Charge Port	Type 2	Charge Time (0->115 km)	3 hours
Port Location	Right Side - Rear	Charge Speed	38 km/h
Charge Power	7.4 kW AC		

Fast Charging

Fastcharge Port	CCS	Fastcharge Time (12->92 km)	20 min
FC Port Location	Right Side - Rear	Fastcharge Speed	240 km/h
Fastcharge Power (max)	47 kW DC		

Plug & Charge

Plug & Charge Supported	No	Supported Protocol	-
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Energy Consumption

EVDB Real Range			
Range	115 km	CO2 Emissions	0 g/km
Vehicle Consumption	163 Wh/km	Vehicle Fuel Equivalent	1.8 l/100km
NEDC Ratings			
Range	190 km	CO2 Emissions	0 g/km
Rated Consumption	No Data	Rated Fuel Equivalent	No Data
Vehicle Consumption	99 Wh/km	Vehicle Fuel Equivalent	1.1 l/100km

Rated = official figures as published by manufacturer. Rated consumption and fuel equivalency figures include charging losses.
Vehicle = calculated battery energy consumption used by the vehicle for propulsion and on-board systems.

Real Energy Consumption

between 104 - 235 Wh/km

City - Cold Weather	163 Wh/km	City - Mild Weather	104 Wh/km
Highway - Cold Weather	235 Wh/km	Highway - Mild Weather	179 Wh/km
Combined - Cold Weather	188 Wh/km	Combined - Mild Weather	139 Wh/km

Indication of real-world energy use in several situations. Cold weather: 'worst-case' based on -10°C and use of heating. Mild weather: 'best-case' based on 23°C and no use of A/C. For 'Highway' figures a constant speed of 110 km/h is assumed. The energy use will depend on speed, style of driving, climate and route conditions.

Real Range

between 80 - 180 km

City - Cold Weather	115 km	City - Mild Weather	180 km
Highway - Cold Weather	80 km	Highway - Mild Weather	105 km
Combined - Cold Weather	100 km	Combined - Mild Weather	135 km

Indication of real-world range in several situations. Cold weather: 'worst-case' based on -10°C and use of heating. Mild weather: 'best-case' based on 23°C and no use of A/C. For 'Highway' figures a constant speed of 110 km/h is assumed. The actual range will depend on speed, style of driving, weather and route conditions.

Data Understanding

Classification: Public

Overview of Simulated data

- Data recorded in two different forms:
 - Simulated Data
 - Measured data
 - Data points of simulated data is highlighted
 - Two types of simulated data
 - CAN
 - LIN
 - Considering Standard CAN signal for trace study

Simulated Data

- Data Structure:
 - Size: 38221X42
 - Total Simulated Data: 24 (Both CAN and LIN)
 - Supporting Document:
 -  Standard CAN
 -  Standard LIN
 -  Merged CAN data
 - These data can be used to calculate the performance, range, system power, Energy Consumption, etc. using 1-D simulation / post-processing tool

Simulated CAN data

Simulated LIN data

Data Understanding

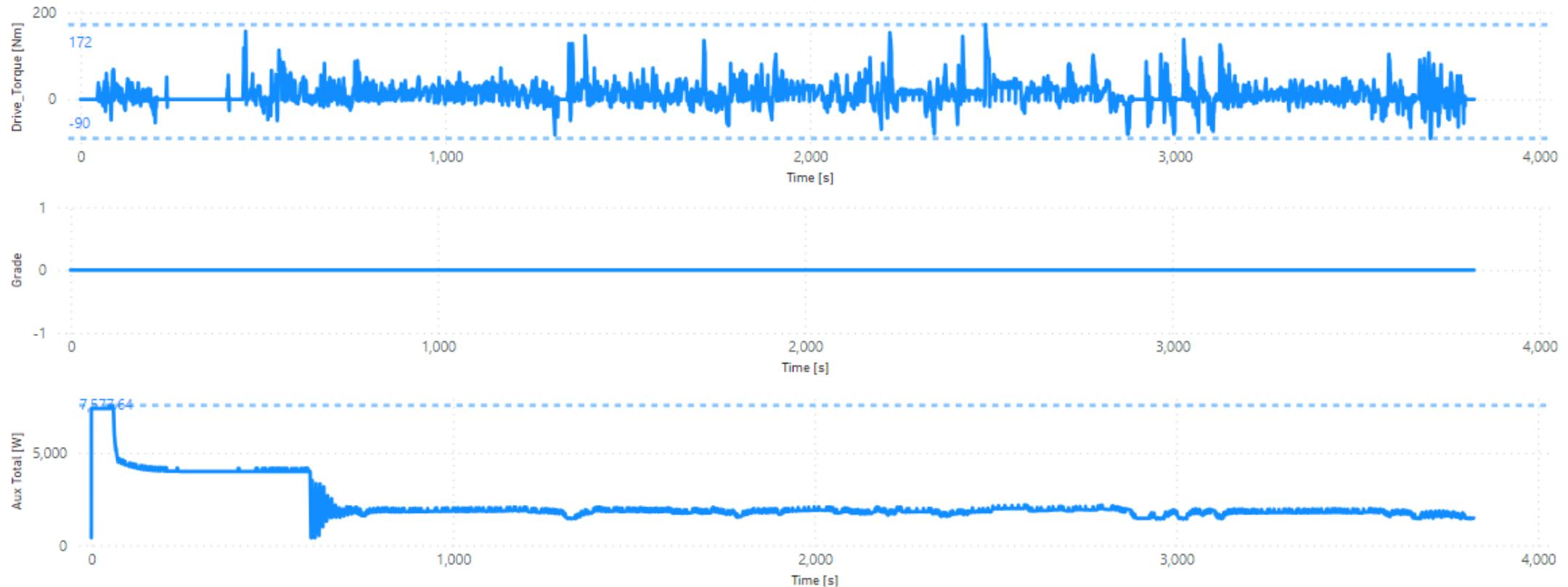
Classification: Public

0_standard CAN: Simulated data Trace (Interactive dash)

Data Understanding

Classification: Public

0_standard CAN: Simulated data Trace (Interactive dash)



< Filters

Data Understanding

Classification: Public

Measured data: Overview

Overview data set:

➤ Shape: 70 rows 14 columns

➤ Column data:

- Trip

- I. Trip A (Cat A)

- II. Trip B (Cat B)

- Date

- Route/Area

- I. Munich East

- II. Munich North

- III. Munich South

- IV. FTMRoute (2x)

- V. FTMRoute

- VI. FTMRoute reverse

- VII. Munich North + Fast Charging

- VIII. Munich Northeast

- IX. Highway

- Battery Temperature (Start) [°C]

- Battery Temperature (End) [°C]

- Weather

- I. Sunny

- II. Slightly cloudy

- III. Rainy

- IV. Cloudy

- V. Dark, Little rainy

- VI. Dark

- VII. Sunrise

- VIII. Sunset

- Battery State of Charge (Start)

- Battery State of Charge (End)

- SoC difference

- Ambient Temperature (Start) [°C]

- Target Cabin Temperature [°C]

- Distance [km]

- Duration [min]

- Fan

- I. Automatic, Level 1

Trip	Date	Route/Area	Weather	Battery Temperature (Start) [°C]	Battery Temperature (End) [°C]	Battery State of Charge (Start) [%]	Battery State of Charge (End) [%]	Ambient Temperature (Start) [°C]	Target Cabin Temperature [°C]	Distance [km]	Duration [min]	Fan	
TripA01	2025-05-25, 15-21-15	Munich East	Sunny	20.0	22.0	88.2%	86.8%	23.0	23.0	17.43	16.82	Automatic, Level 1	
TripA02	2025-05-25, 14-25-21	Munich East	Sunny	23.0	26.0	88.2%	87.5%	22.0	22.0	23.55	22.89	Automatic, Level 1	
TripA03	2025-05-25, 10-25-21	Munich East	Sunny	24.0	25.0	83.5%	75.7%	24.0	21.5	27.0	12.82	Automatic, Level 1	
TripA04	2025-05-25, 10-15-21	Munich East	Sunny	25.0	27.0	75.5%	66.7%	24.0	22.0	10.73	6.07	Automatic, Level 1	
TripA05	2025-05-25, 10-15-21	Munich East	Sunny	27.0	27.0	66.7%	65.0%	24.5	24.0	12.58	12.58	Automatic, Level 1	
TripA06	2025-07-01, 05-05-21	Munich North	Sunny	25.0	28.0	85.1%	81.7%	26.5	26.5	45.55	52.74	Automatic, Level 1	
TripA07	2025-07-01, 05-05-21	Munich North	Sunny	26.0	29.0	84.5%	80.2%	25.2	25.2	33.5	25.0	Automatic, Level 1	
TripA08	2025-07-01, 05-25-21	Munich East	Slightly cloudy	28.0	31.0	88.5%	86.5%	21.0	21.0	22.5	18.24	Automatic, Level 1	
TripA09	2025-07-01, 05-25-21	Munich East	Slightly cloudy	27.0	29.0	84.5%	81.7%	21.0	21.0	11.66	10.57	Automatic, Level 1	
TripA10	2025-07-01, 05-25-21	Munich East	Slightly cloudy	22.0	22.0	88.5%	86.5%	22.5	22.5	25.0	16.25	Automatic, Level 1	
TripA11	2025-07-01, 05-25-21	Munich East	Sunny	28.0	27.0	87.0%	75.8%	21.0	20.0	30.0	17.73	Automatic, Level 1	
TripA12	2025-07-01, 05-15-21	Munich East	Sunny	28.0	30.0	75.5%	64.3%	11.2%	28.5	25.0	18.65	21.31	Automatic, Level 1
TripA13	2025-07-01, 05-05-21	Munich East	Sunny	22.0	22.0	82.5%	82.5%	21.0	21.0	23.0	4.57	Automatic, Level 1	
TripA14	2025-07-01, 05-25-21	Munich East	Sunny	22.0	22.0	82.5%	79.4%	22.0	22.0	22.0	4.57	Automatic, Level 1	
TripA15	2025-07-01, 05-25-21	Munich East	Sunny	15.0	15.0	84.0%	84.0%	18.0	18.0	22.0	17.57	Automatic, Level 1	
TripA16	2025-07-01, 05-25-21	Munich East	Sunny	15.0	15.0	87.0%	87.0%	18.5	18.5	28.88	31.59	Automatic, Level 1	
TripA17	2025-07-01, 05-25-21	Munich East	Slightly cloudy	15.0	18.0	88.5%	77.8%	18.5	18.5	28.0	12.57	Automatic, Level 1	
TripA18	2025-07-01, 05-45-21	Munich East	Slightly cloudy	15.0	15.0	77.0%	77.0%	17.0	17.0	22.0	12.15	Automatic, Level 1	
TripA19	2025-07-01, 05-45-21	Munich East	Slightly cloudy	22.0	22.0	88.5%	80.4%	8.0	23.5	30.0	16.73	26.49	Automatic, Level 1
TripA20	2025-07-01, 05-07-21	Munich East	Slightly cloudy	17.0	17.0	77.0%	69.1%	14.0	14.0	28.0	11.62	Automatic, Level 1	
TripA21	2025-07-01, 05-15-21	Munich East	Sunny	18.0	20.0	81.0%	63.7%	17.0	22.5	22.0	14.32	33.95	Automatic, Level 1
TripA22	2025-07-01, 05-15-21	Munich East	Sunny	15.0	20.0	81.0%	78.0%	19.0	20.0	23.0	30.0	Automatic, Level 1	
TripA23	2025-07-01, 05-15-21	Munich East	Sunny	15.0	17.0	87.0%	87.0%	18.5	18.5	22.0	8.36	Automatic, Level 1	
TripA24	2025-07-01, 05-15-21	Munich East	Sunny	17.0	19.0	87.0%	74.4%	7.5%	18.0	21.0	11.77	8.87	Automatic, Level 1
TripA25	2025-07-01, 05-25-21	Munich East	Sunny	15.0	20.0	74.0%	85.2%	18.0	22.0	33.0	12.29	Automatic, Level 1	
TripA26	2025-07-01, 05-25-21	Munich East	Slightly cloudy	15.0	20.0	88.5%	78.8%	7.0	22.0	30.0	18.03	26.87	Automatic, Level 1
TripA27	2025-07-01, 05-35-21	Munich East	Sunny	15.0	15.0	87.0%	86.8%	11.7%	25.5	25.0	20.43	33.34	Automatic, Level 1
TripA28	2025-07-01, 05-35-21	Munich East	Slightly cloudy	15.0	20.0	78.5%	72.0%	3.5%	20.5	25.0	15.52	25.94	Automatic, Level 1
TripA29	2025-07-01, 05-35-21	Munich East	Sunny	22.0	22.0	87.0%	87.0%	18.0	20.0	23.0	22.0	Automatic, Level 1	
TripA30	2025-07-01, 05-35-21	Munich East	Sunny	22.0	23.0	88.5%	87.0%	18.0	22.0	23.0	15.52	22.0	Automatic, Level 1
TripA31	2025-07-01, 05-35-21	Munich East	Sunny	20.0	21.0	87.0%	82.5%	71.0%	23.5	28.0	5.58	18.89	Automatic, Level 1
TripA32	2025-07-01, 05-35-21	Munich East	Slightly cloudy	21.0	26.0	88.5%	53.5%	27.0%	20.0	27.5	37.21	27.87	Automatic, Level 1

Overview Dataset



Microsoft Excel
Worksheet

Data Understanding

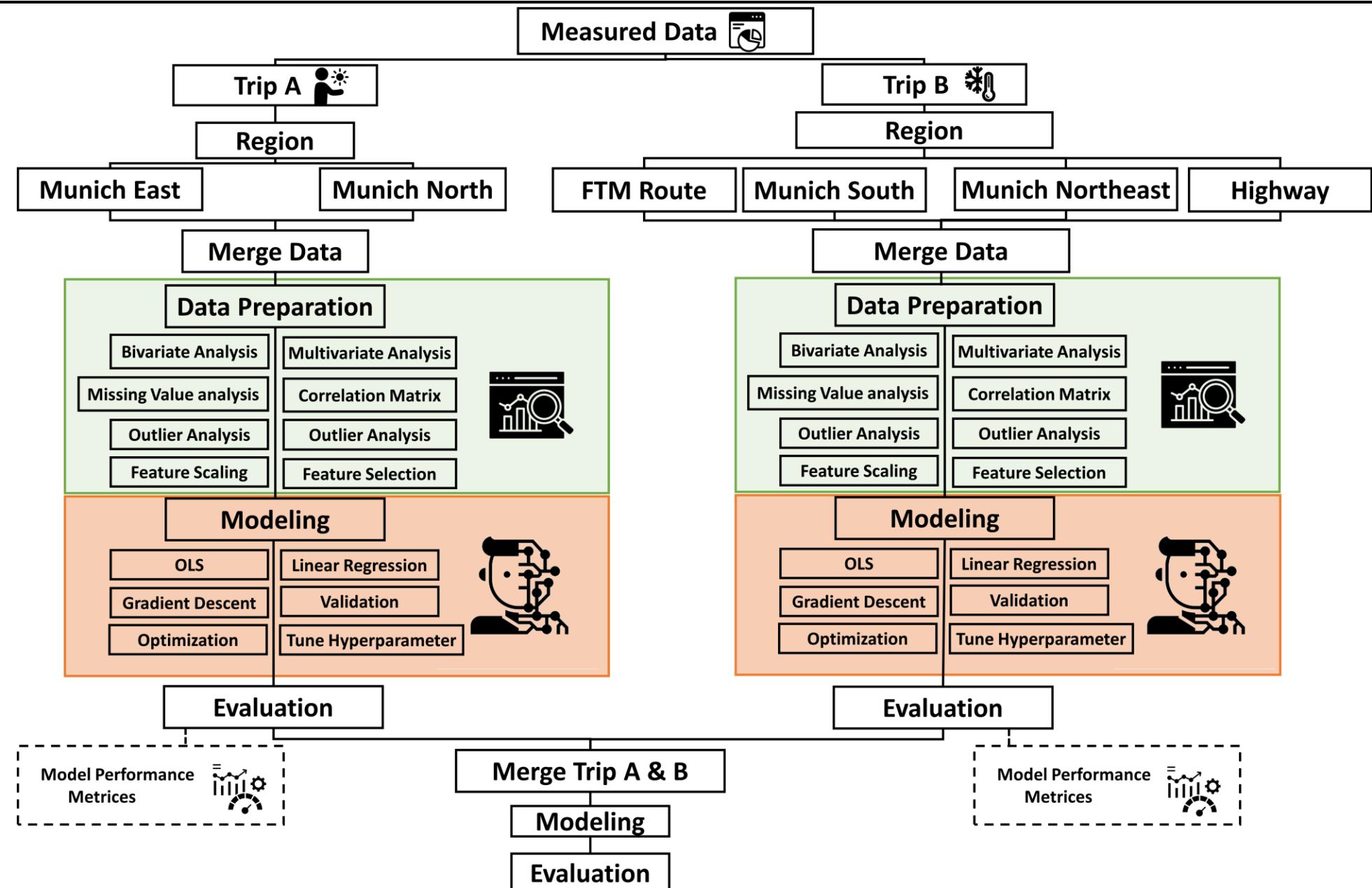
Classification: Public

Measured data: Overview

Data Understanding

Methodology

Classification: Public



Data Understanding

Classification: Public

Measured data: Trip A

- Category A (Trip A) – Summer
- Total Trips: 32
- Data:
 - Measured Data*
 - Simulated Data
- Process: CRISP-DM
- Model: Regression
- Data Size:
 - Rows: 467701
 - Columns: 28
- Feature: 28 features
- Target Variable: Battery State of Charge

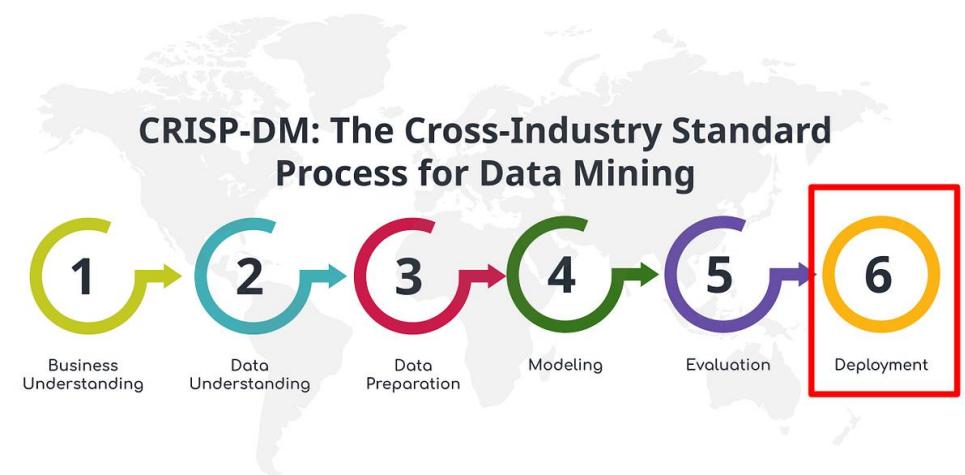
***Note:** Measured data considered for the developing model and prediction

	Time [s]	Velocity [km/h]	Elevation [m]	Throttle [%]	Motor Torque [Nm]	Longitudinal Acceleration [m/s^2]	Regenerative Braking Signal	Battery Voltage [V]	Battery Current [A]	Battery Temperature [°C]	Battery max. Temperature [°C]	displayed SoC [%]	min. SoC [%]	max. SoC [%]
0	0.000000	0.000000	574.000000	0.000000	0.000000	-0.030000	0.000000	391.400000	-2.200000	21	22.000000	100.000000	8	90.000000
1	0.100000	0.000000	574.000000	0.000000	0.000000	0.000000	0.000000	391.400000	-2.210000	21	22.000000	100.000000	8	90.000000
2	0.200000	0.000000	574.000000	0.000000	0.000000	-0.010000	0.000000	391.400000	-2.260000	21	22.000000	100.000000	8	90.000000
3	0.300000	0.000000	574.000000	0.000000	0.000000	-0.030000	0.000000	391.400000	-2.300000	21	22.000000	100.000000	8	90.000000
4	0.400000	0.000000	574.000000	0.000000	0.000000	-0.030000	0.000000	391.400000	-2.300000	21	22.000000	100.000000	8	90.000000
5	0.500000	0.000000	574.000000	0.000000	0.000000	-0.010000	0.000000	391.400000	-2.300000	21	22.000000	100.000000	8	90.000000
6	0.600000	0.000000	574.000000	0.000000	0.000000	-0.010000	0.000000	391.400000	-2.300000	21	22.000000	100.000000	8	90.000000
7	0.700000	0.000000	574.000000	0.000000	0.000000	-0.030000	0.000000	391.400000	-2.310000	21	22.000000	100.000000	8	90.000000
8	0.800000	0.000000	574.000000	0.000000	0.380000	-0.010000	0.000000	391.400000	-2.360000	21	22.000000	100.000000	8	90.000000
9	0.900000	0.000000	574.000000	0.000000	0.120000	-0.010000	0.000000	391.400000	-2.370000	21	22.000000	100.000000	8	90.000000

Trip_A.shape

(467701, 28)

```
Time [s]          float64  
Velocity [km/h]    float64  
Elevation [m]      float64  
Throttle [%]       float64  
Motor Torque [Nm]   float64  
Longitudinal Acceleration [m/s^2] float64  
Regenerative Braking Signal float64  
Battery Voltage [V] float64  
Battery Current [A] float64  
Battery Temperature [°C] int64  
max. Battery Temperature [°C] float64  
displayed SoC [%] float64  
min. SoC [%]        float64  
max. SoC [%]        float64  
Heating Power CAN [kW] float64  
Heating Power LIN [W] float64  
Requested Heating Power [W] float64  
AirCon Power [kW]    float64  
Heater Signal       int64  
Heater Voltage [V]   float64  
Heater Current [A]   float64  
Ambient Temperature [°C] float64  
Coolant Temperature Heatercore [°C] float64  
Requested Coolant Temperature [°C] float64  
Coolant Temperature Inlet [°C]    float64  
Heat Exchanger Temperature [°C]   float64  
Cabin Temperature Sensor [°C]    float64  
SOC [%]             float64
```



Data Understanding

Classification: Public

Measured data: Trip B

- Category A (Trip B) – Winter
- Total Trips: 38
- Data:
 - Measured Data*
 - Simulated Data
- Process: CRISP-DM
- Model: Regression
- Data Size:
 - Rows: 627092
 - Columns: 48
- Feature: 48 features
- Target Variable: Battery State of Charge

***Note:** Measured data considered for the developing model and prediction

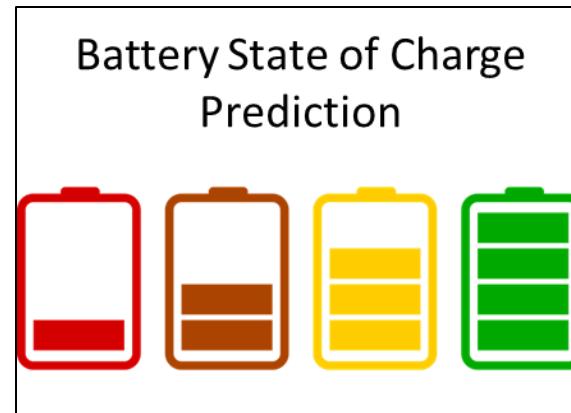
Time [s]	Velocity [km/h]	Elevation [m]	Throttle [%]	Motor Torque [Nm]	Longitudinal Acceleration [m/s^2]	Regenerative Braking Signal	Battery Voltage [V]	Battery Current [A]	Battery Temperature [°C]	max. Battery Temperature [°C]	displayed SoC [%]	min. SoC [%]	mz
0	0.000000	0.000000	449.000000	0.000000	0.000000	-0.329300	0	388.800000	-19.061280	7.000000	7	100.000000	8.000000
1	0.100000	0.000000	449.000000	0.000000	0.000000	-0.329300	0	388.800000	-19.061280	7.000000	7	100.000000	8.000000
2	0.200000	0.000000	449.000000	0.000000	0.000000	-0.358000	0	388.800000	-18.861270	7.000000	7	100.000000	8.000000
3	0.300000	0.000000	449.000000	0.000000	0.000000	-0.352350	0	388.800000	-18.690310	7.000000	7	100.000000	8.000000
4	0.400000	0.000000	449.000000	0.000000	0.000000	-0.343670	0	388.800000	-18.640310	7.000000	7	100.000000	8.000000
Temperature Defrost central right [°C]	Temperature Footwell Driver [°C]	Temperature Footwell Co-Driver [°C]	Temperature Feetvent Co-Driver [°C]	Temperature Feetvent Driver [°C]	Temperature Head Co-Driver [°C]	Temperature Head Driver [°C]	Temperature Vent right [°C]	Temperature Vent central right [°C]	Temperature Vent central left [°C]	Temperature Vent right [°C]	SoC [%]		
11.134510	9.301590	8.428780	7.730530	8.079650	12.531010	13.491110	10.261690	9.650720	9.650720	10.348970	86.100000		
11.134510	9.301590	8.428780	7.730530	8.079650	12.531010	13.491110	10.261690	9.650720	9.650720	10.348970	86.100000		
11.134510	9.301590	8.428780	7.730530	8.095950	12.531010	13.491110	10.261690	9.650720	9.650720	10.348970	86.100000		
11.134510	9.301590	8.434630	7.753940	8.130860	12.531010	13.491110	10.261690	9.650720	9.650720	10.348970	86.100000		
11.134510	9.301590	8.443360	7.788850	8.165770	12.531010	13.491110	10.261690	9.650720	9.650720	10.348970	86.100000		

Trip_B.shape

(627092, 48)

Time [s]
Velocity [km/h]
Elevation [m]
Throttle [%]
Motor Torque [Nm]
Longitudinal Acceleration [m/s^2]
Regenerative Braking Signal
Battery Voltage [V]
Battery Current [A]
Battery Temperature [°C]
max. Battery Temperature [°C]
displayed SoC [%]
min. SoC [%]
max. SoC [%]
Heating Power CAN [kW]
Heating Power LIN [W]
Requested Heating Power [W]
AirCon Power [kW]
Heater Signal
Heater Voltage [V]
Heater Current [A]
Ambient Temperature [°C]
Ambient Temperature Sensor [°C]
Coolant Temperature Heatercore [°C]

float64 Requested Coolant Temperature [°C]
float64 Coolant Temperature Inlet [°C]
float64 Coolant Volume Flow +500 [l/h]
float64 Heat Exchanger Temperature [°C]
float64 Cabin Temperature Sensor [°C]
float64 Temperature Coolant Heater Inlet [°C]
int64 Temperature Coolant Heater Outlet [°C]
float64 Temperature Heat Exchanger outlet [°C]
float64 Temperature Defrost lateral left [°C]
float64 Temperature Defrost lateral right [°C]
int64 Temperature Defrost central [°C]
float64 Temperature Defrost central left [°C]
float64 Temperature Defrost central right [°C]
float64 Temperature Footwell Driver [°C]
float64 Temperature Footwell Co-Driver [°C]
float64 Temperature Feetvent Co-Driver [°C]
float64 Temperature Feetvent Driver [°C]
float64 Temperature Head Co-Driver [°C]
int64 Temperature Head Driver [°C]
float64 Temperature Vent right [°C]
float64 Temperature Vent central right [°C]
float64 Temperature Vent central left [°C]
float64 Temperature Vent right [°C]
float64 SOC [%]



Data Preparation

Classification: Public

Measured data: Trip A overview

- Time [s]
 - Velocity [km/h]
 - Elevation [m]
 - Throttle [%]
 - Motor Torque [Nm]
 - Longitudinal Acceleration [m/s^2]
 - Regenerative Braking Signal
 - Battery Voltage [V]
 - Battery Current [A]
 - Battery Temperature [$^\circ C$]
 - max. Battery Temperature [$^\circ C$]
 - displayed SoC [%]
 - min. SoC [%]
 - max. SoC [%]
 - Heating Power CAN [kW]
 - Heating Power LIN [W]
 - Requested Heating Power [W]
 - AirCon Power [kW]
 - Heater Signal Heater Voltage [V]
 - Heater Current [A]
 - Ambient Temperature [$^\circ C$]
 - Coolant Temperature Heatercore [$^\circ C$]
 - Requested Coolant Temperature [$^\circ C$]
 - Coolant Temperature Inlet [$^\circ C$]
 - Heat Exchanger Temperature [$^\circ C$]
 - Cabin Temperature Sensor [$^\circ C$]
 - SoC [%]

Data Preparation

Classification: Public

Measured data: Trip B overview

	Time [s]	Velocity [km/h]	Elevation [m]	Throttle [%]	Motor Torque [Nm]	Longitudinal Acceleration [m/s^2]	Regenerative Braking Signal	Battery Voltage [V]	Battery Current [A]	Battery Temperature [°C]	max. Battery Temperature [°C]	displayed SoC [%]	min. SoC [%]	max. SoC [%]	Heating Power CAN [kW]	Heating Power LIN [W]	Requested Heating Power [W]	AirCon Power [kW]	Heater Signal
count	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	596298.000000	596299.000000	596298.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000	627092.000000
mean	31354.550000	45.675707	514.248829	27.334257	11.725529	-0.010618	0.041397	371.546549	-18.716962	10.240713	10.897214	66.435341	7.999987	88.588724	1.612816	1646.893871	1663.103801	0.002967	1.000000
std	18102.601184	37.021488	47.472736	19.905289	34.092644	0.614530	0.199208	12.585229	49.465341	4.755280	4.968271	20.296813	0.010360	0.249298	1.776855	1729.015123	1712.964995	0.052023	0.000000
min	0.000000	0.000000	437.000000	0.000000	-88.000000	-9.030000	0.000000	301.800000	-404.380000	-1.000000	-1.000000	10.000000	0.000000	88.000000	0.000000	0.000000	0.000000	-0.170000	1.000000
25%	15677.275000	11.000000	481.000000	0.000000	0.000000	-0.240000	0.000000	363.900000	-36.050000	7.000000	8.000000	54.000000	8.000000	88.500000	0.960000	920.000000	920.000000	0.000000	1.000000
50%	31354.550000	43.000000	498.000000	33.000000	6.500000	-0.040000	0.000000	372.710000	-13.930000	10.000000	11.000000	68.000000	8.000000	88.500000	1.160000	1240.000000	1240.000000	0.000000	1.000000
75%	47031.825000	72.000000	530.000000	44.000000	23.000000	0.180000	0.000000	381.480000	-3.070000	13.000000	14.000000	82.000000	8.000000	88.500000	1.760000	1675.000000	1680.000000	0.000000	1.000000
max	62709.100000	152.000000	655.000000	135.000000	244.000000	4.460000	1.000000	394.190000	144.490000	22.000000	24.000000	100.000000	8.000000	89.000000	40.040000	38870.520000	38527.750000	2.000000	1.000000
Heater Voltage [V]	Heater Current [A]	Ambient Temperature [°C]	Ambient Temperature Sensor [°C]	Coolant Temperature Heatercore [°C]	Requested Coolant Temperature [°C]	Coolant Temperature Inlet [°C]	Coolant Volume Flow +500 [l/h]	Heat Exchanger Temperature [°C]	Cabin Temperature Sensor [°C]	Temperature Coolant Heater Inlet [°C]	Temperature Coolant Heater Outlet [°C]	Temperature Heat Exchanger Outlet [°C]	Temperature Defrost lateral left [°C]	Temperature Defrost lateral right [°C]	Temperature Defrost central [°C]	Temperature Defrost central left [°C]	Temperature Defrost central right [°C]	Temperature Footwell Driver [°C]	Temperature Footwell Co-Driver [°C]
627092.000000	627092.000000	627092.000000	622453.000000	627092.000000	627092.000000	598759.000000	627092.000000	627092.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000	622453.000000
384.100635	4.391395	5.522227	6.136288	50.402693	85.000000	49.439458	-15.715559	39.906324	22.164859	47.772016	50.538265	48.338588	29.769488	30.032027	33.688808	33.357948	31.561968	19.663228	23.534749
70.189615	4.495961	3.207609	3.460341	8.638719	0.000000	8.191617	81.257432	9.620340	4.414894	8.686438	9.032039	8.365544	5.592761	5.534259	6.531475	6.674065	7.490815	5.152778	5.743584
302.000000	0.000000	-3.500000	-3.440000	-1.000000	85.000000	-1.000000	-500.920000	5.000000	10.000000	-2.220000	-1.520000	-2.740000	-1.780000	-2.130000	-2.290000	-2.390000	-2.550000	-1.700000	-2.220000
366.000000	2.500000	3.500000	3.890000	48.000000	85.000000	47.000000	-0.230000	37.000000	21.840000	45.700000	47.470000	46.130000	28.120000	28.416270	30.950000	30.772870	30.160000	17.310000	22.130000
374.000000	3.250000	5.500000	5.800000	50.000000	85.000000	49.000000	-0.160000	40.500000	24.000000	47.650000	49.890000	48.050000	30.250000	30.420000	34.180000	34.060000	32.950000	20.600000	24.430000
383.100000	4.500000	8.000000	7.990000	53.000000	85.000000	52.000000	-0.150000	44.000000	24.840000	49.890000	52.420000	50.260000	32.610000	33.130000	36.580000	36.710000	35.400000	22.920000	26.590000
1023.000000	100.090000	14.000000	22.390000	80.530000	85.000000	67.000000	0.151870	65.050000	27.170000	67.780000	73.980000	68.570000	43.950000	43.080000	49.540000	49.360000	46.480000	30.600000	40.550000

Data Preparation

Classification: Public

Measured data – Trip A: Trace Manager



Filters

Data Preparation

Classification: Public

Measured data – Trip A: Missing Value Analysis

- Missing values identified
 - 5 variables has the missing values more than 60%

```
Trip_A.isnull().sum()
```

Time [s]
Velocity [km/h]
Elevation [m]
Throttle [%]
Motor Torque [Nm]
Longitudinal Acceleration [m/s^2]
Regenerative Braking Signal
Battery Voltage [V]
Battery Current [A]
Battery Temperature [°C]
max. Battery Temperature [°C]
displayed SoC [%]
min. SoC [%]
max. SoC [%]
Heating Power CAN [kW]
Heating Power LIN [W]
Requested Heating Power [W]
AirCon Power [kW]
Heater Signal
Heater Voltage [V]
Heater Current [A]
Ambient Temperature [°C]
Coolant Temperature Heatercore [°C]
Requested Coolant Temperature [°C]
Coolant Temperature Inlet [°C]
Heat Exchanger Temperature [°C]
Cabin Temperature Sensor [°C]
SoC [%]
dtype: int64



- Treated Missing values
 - Impute values for:
 - Requested Coolant Temp

Trip A.isnull(),sum()

Time [s]
Velocity [km/h]
Elevation [m]
Throttle [%]
Motor Torque [Nm]
Longitudinal Acceleration [m/s²]
Regenerative Braking Signal
Battery Voltage [V]
Battery Current [A]
Battery Temperature [°C]
max. Battery Temperature [°C]
displayed SoC [%]
min. SoC [%]
max. SoC [%]
Heating Power CAN [kW]
Requested Heating Power [W]
AirCon Power [kW]
Heater Signal
Ambient Temperature [°C]
Requested Coolant Temperature [°C]
Heat Exchanger Temperature [°C]
Cabin Temperature Sensor [°C]
SoC [%]
dtype: int64



- Treated Missing values
 - Imputed values for:
 - Requested Coolant Temp

Trip A.isnull().sum()

Time [s]
Velocity [km/h]
Elevation [m]
Throttle [%]
Motor Torque [Nm]
Longitudinal Acceleration [m/s²]
Regenerative Braking Signal
Battery Voltage [V]
Battery Current [A]
Battery Temperature [°C]
max. Battery Temperature [°C]
displayed SoC [%]
min. SoC [%]
max. SoC [%]
Heating Power CAN [kW]
Requested Heating Power [W]
AirCon Power [kW]
Heater Signal
Ambient Temperature [°C]
Requested Coolant Temperature [°C]
Heat Exchanger Temperature [°C]
Cabin Temperature Sensor [°C]
SoC [%]
dtype: int64

Data Preparation

Classification: Public

Measured data – Trip B: Missing Value Analysis

Time [s]	0
Velocity [km/h]	0
Elevation [m]	0
Throttle [%]	0
Motor Torque [Nm]	0
Longitudinal Acceleration [m/s^2]	0
Regenerative Braking Signal	0
Battery Voltage [V]	0
Battery Current [A]	0
Battery Temperature [°C]	0
max. Battery Temperature [°C]	0
displayed SoC [%]	30794
min. SoC [%]	30793
max. SoC [%]	30794
Heating Power CAN [kW]	0
Heating Power LIN [W]	0
Requested Heating Power [W]	0
AirCon Power [kW]	0
Heater Signal	0
Heater Voltage [V]	0
Heater Current [A]	0
Ambient Temperature [°C]	0
Ambient Temperature Sensor [°C]	4639
Coolant Temperature Heatercore [°C]	0
Requested Coolant Temperature [°C]	0
Coolant Temperature Inlet [°C]	0
Coolant Volume Flow +500 [l/h]	28333
Heat Exchanger Temperature [°C]	0
Cabin Temperature Sensor [°C]	0
Temperature Coolant Heater Inlet [°C]	4639
Temperature Coolant Heater Outlet [°C]	4639
Temperature Heat Exchanger Outlet [°C]	4639
Temperature Defrost lateral left [°C]	4639
Temperature Defrost lateral right [°C]	4639
Temperature Defrost central [°C]	4639
Temperature Defrost central left [°C]	4639
Temperature Defrost central right [°C]	4639
Temperature Footwell Driver [°C]	4639
Temperature Footwell Co-Driver [°C]	4639
Temperature Feetvent Co-Driver [°C]	4639
Temperature Feetvent Driver [°C]	4639
Temperature Head Co-Driver [°C]	4639
Temperature Head Driver [°C]	4639
Temperature Vent right [°C]	4639
Temperature Vent central right [°C]	4639
Temperature Vent central left [°C]	4639
Temperature Vent right [°C]	4639
SoC [%]	30793

- Missing values identified
→ Variable displayed SoC, min. SoC, max. SoC, SoC has the highest missing values
→ Identified missing values are less than 30%
→ Missing value imputation can be used
→ Imputed the variables using mean method
→ Data after imputation is highlighted in green



Time [s]	0
Velocity [km/h]	0
Elevation [m]	0
Throttle [%]	0
Motor Torque [Nm]	0
Longitudinal Acceleration [m/s^2]	0
Regenerative Braking Signal	0
Battery Voltage [V]	0
Battery Current [A]	0
Battery Temperature [°C]	0
max. Battery Temperature [°C]	0
displayed SoC [%]	0
min. SoC [%]	0
max. SoC [%]	0
Heating Power CAN [kW]	0
Heating Power LIN [W]	0
Requested Heating Power [W]	0
AirCon Power [kW]	0
Heater Signal	0
Heater Voltage [V]	0
Heater Current [A]	0
Ambient Temperature [°C]	0
Ambient Temperature Sensor [°C]	0
Coolant Temperature Heatercore [°C]	0
Requested Coolant Temperature [°C]	0
Coolant Temperature Inlet [°C]	0
Coolant Volume Flow +500 [l/h]	0
Heat Exchanger Temperature [°C]	0
Cabin Temperature Sensor [°C]	0
Temperature Coolant Heater Inlet [°C]	0
Temperature Coolant Heater Outlet [°C]	0
Temperature Heat Exchanger Outlet [°C]	0
Temperature Defrost lateral left [°C]	0
Temperature Defrost lateral right [°C]	0
Temperature Defrost central [°C]	0
Temperature Defrost central left [°C]	0
Temperature Defrost central right [°C]	0
Temperature Footwell Driver [°C]	0
Temperature Footwell Co-Driver [°C]	0
Temperature Feetvent Co-Driver [°C]	0
Temperature Feetvent Driver [°C]	0
Temperature Head Co-Driver [°C]	0
Temperature Head Driver [°C]	0
Temperature Vent right [°C]	0
Temperature Vent central right [°C]	0
Temperature Vent central left [°C]	0
Temperature Vent right [°C]	0
SoC [%]	0

Data Preparation

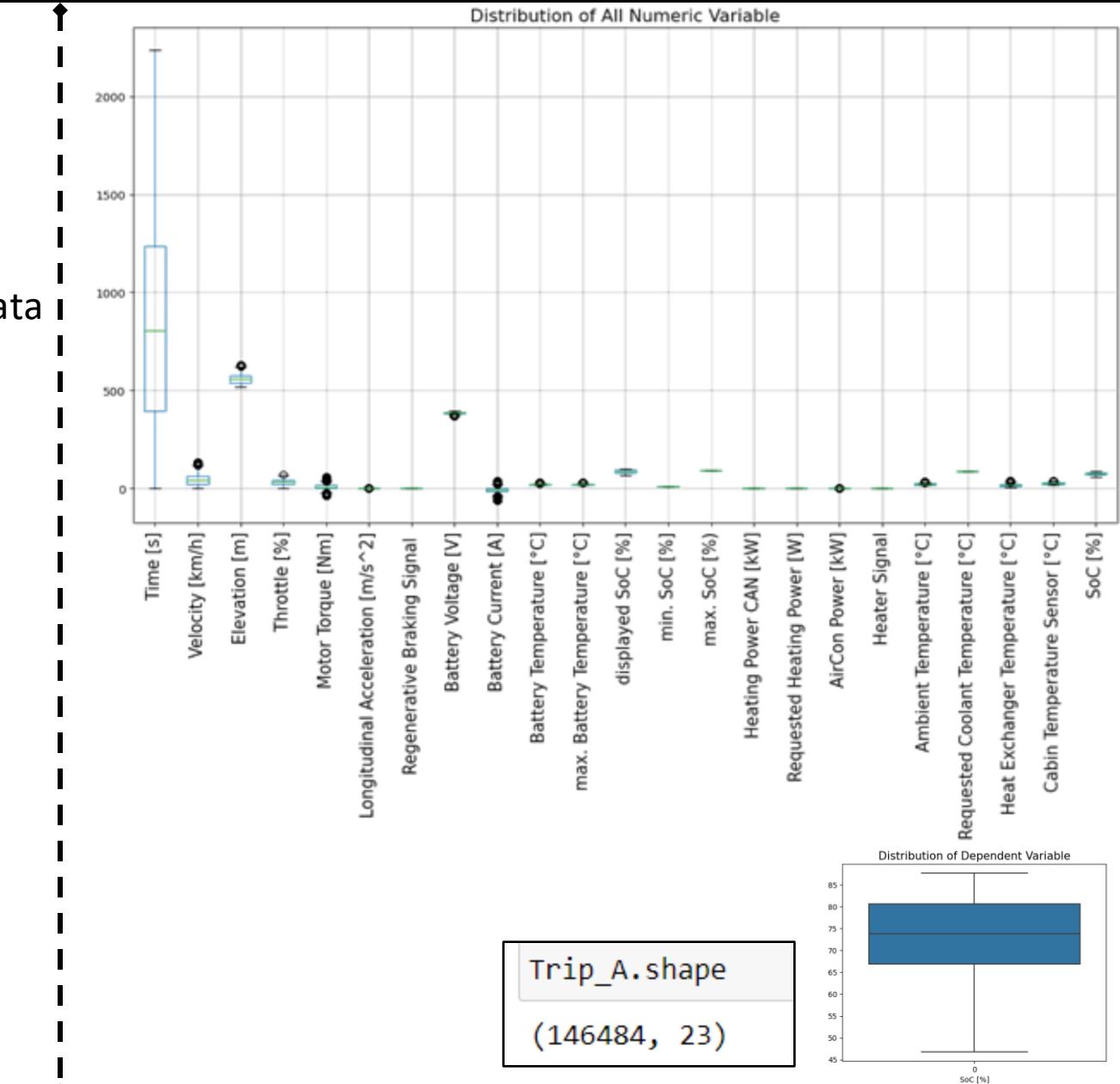
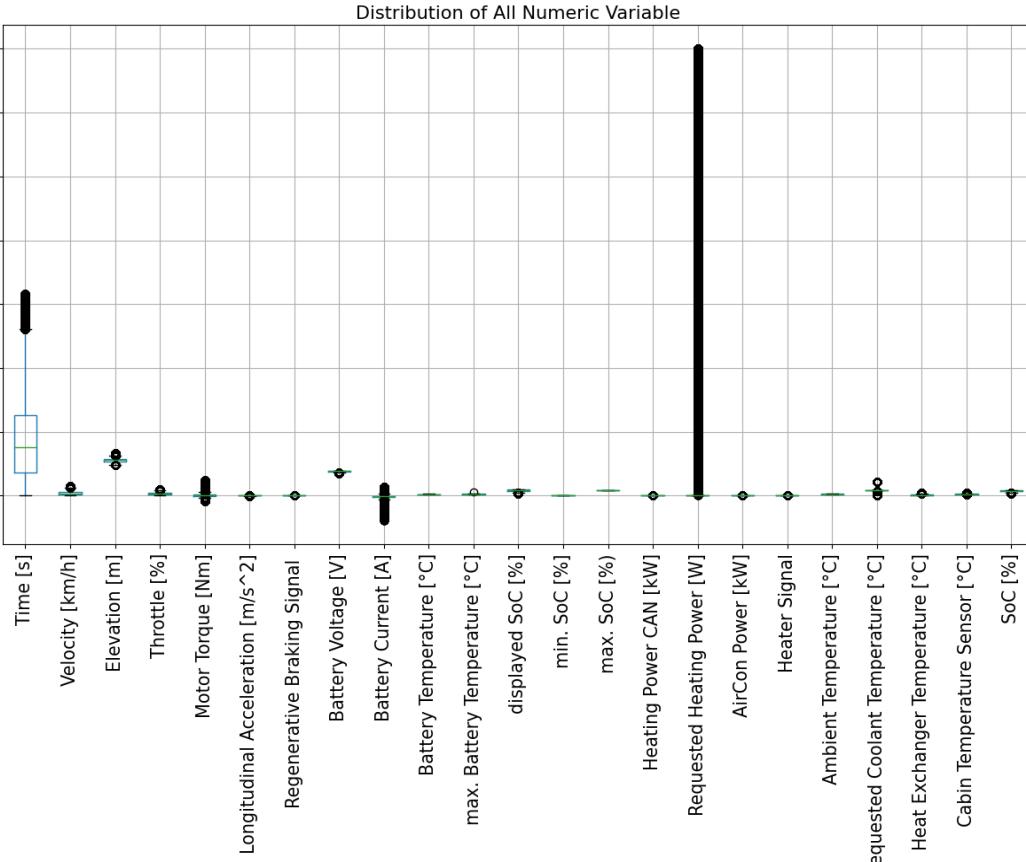
Classification: Public

Measured data – Trip A: Outlier Analysis and Treatment

→ Outlier Identified on the following variables:

- Time [s]
- Battery Current [A]
- Motor Torque
- Requested Heating Power [W] (Upper Extreme)

→ Outliers are removed and reduced the skewness of the data



Data Preparation

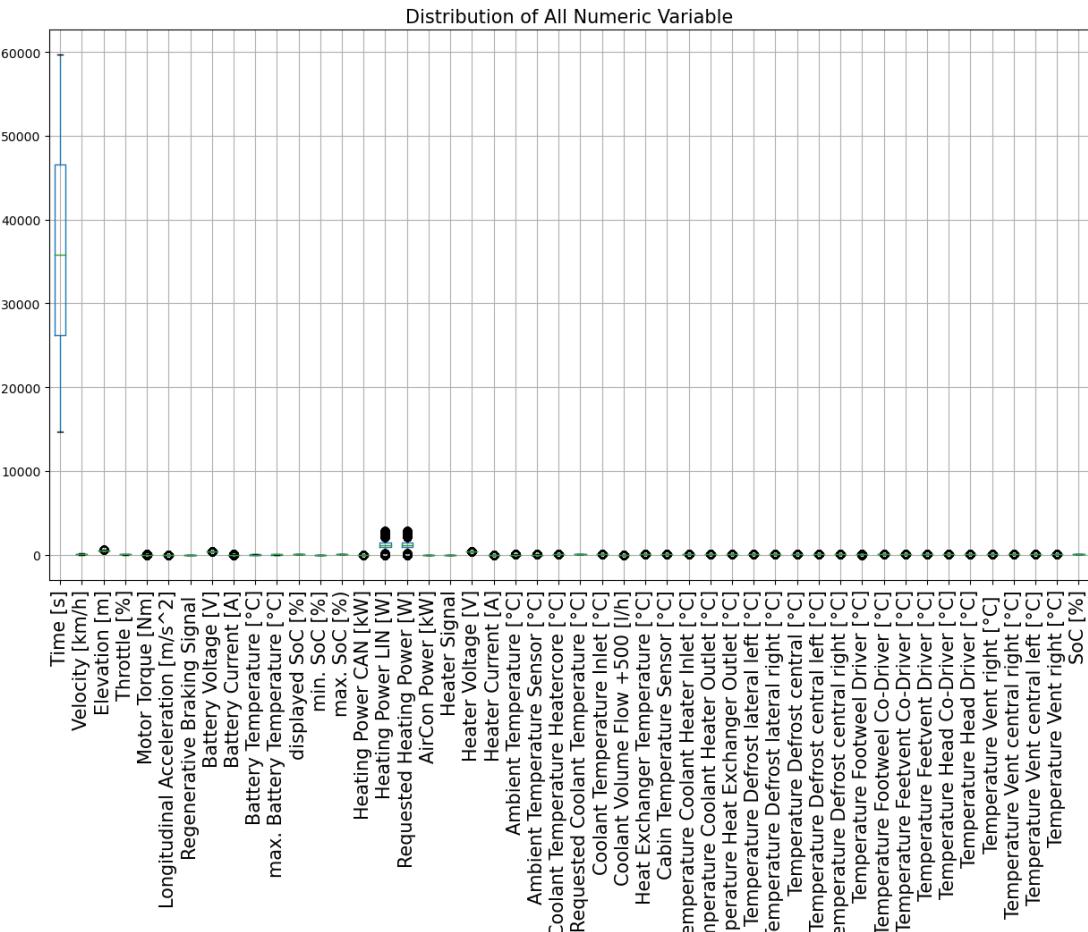
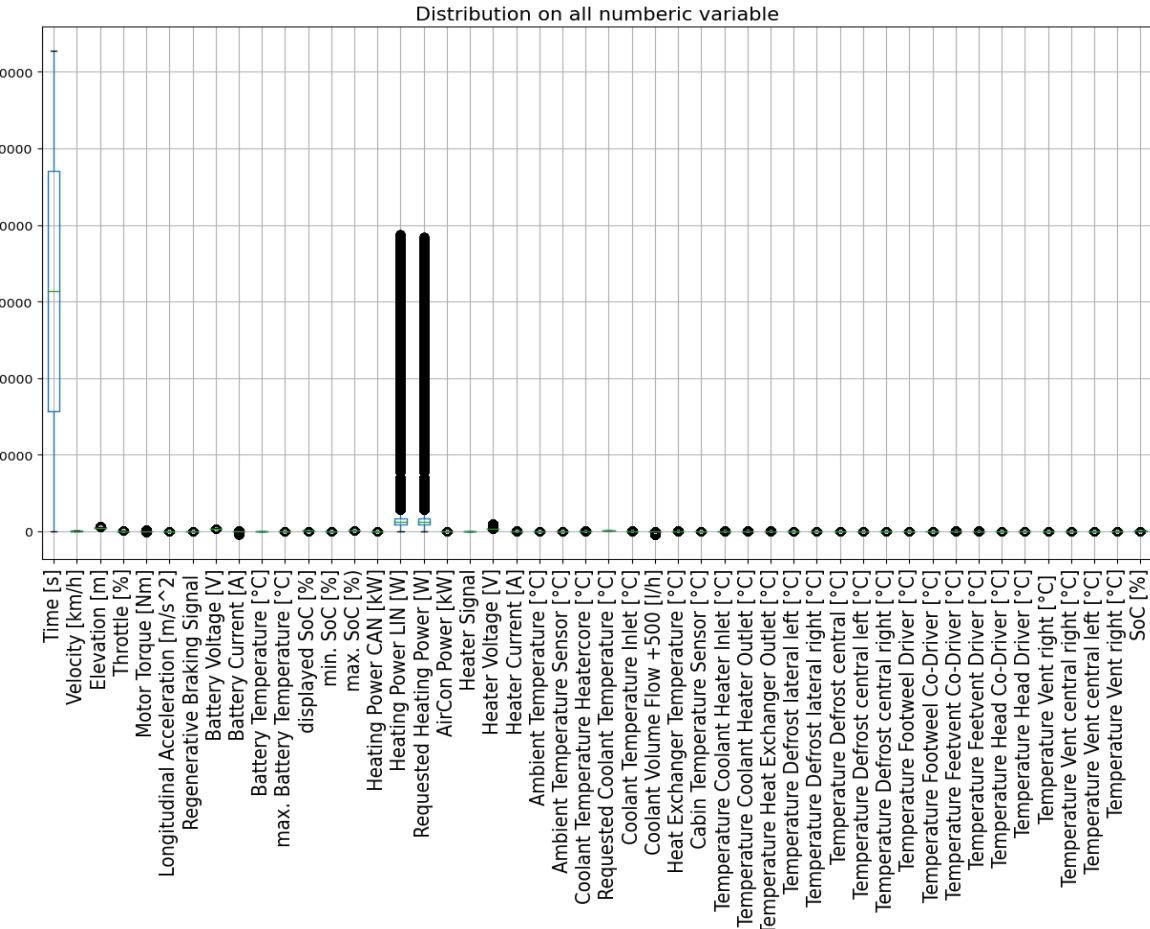
Classification: Public

Measured data – Trip A: Outlier Analysis and Treatment

→ Outlier Identified on the following variables:

- Heating Power LIN [W]
- Requested Heating Power [W] (Upper Extreme)

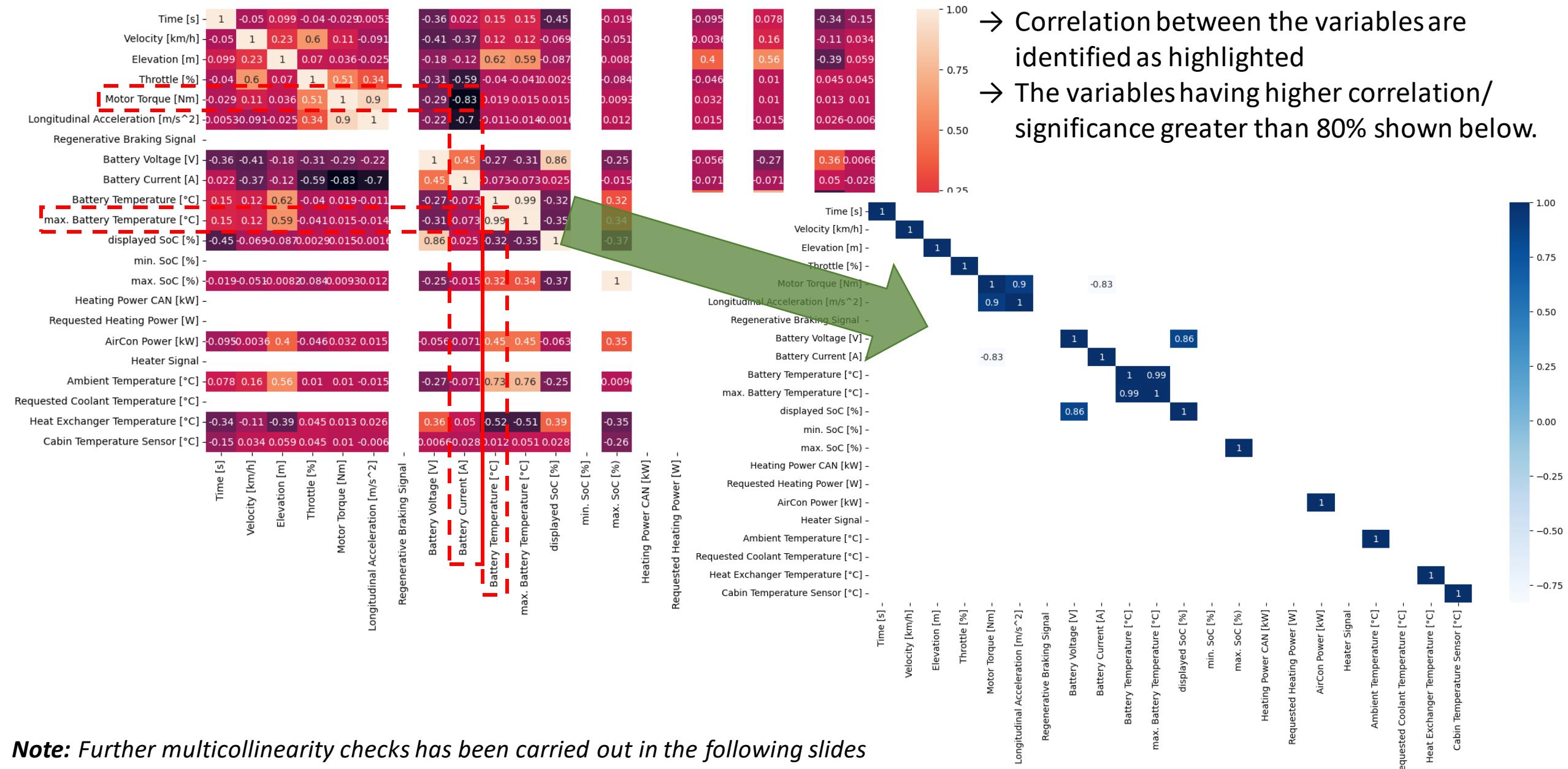
→ Outliers are treated and reduced the skewness of the data



Data Preparation

Classification: Public

Measured data – Trip A: Correlation Matrix



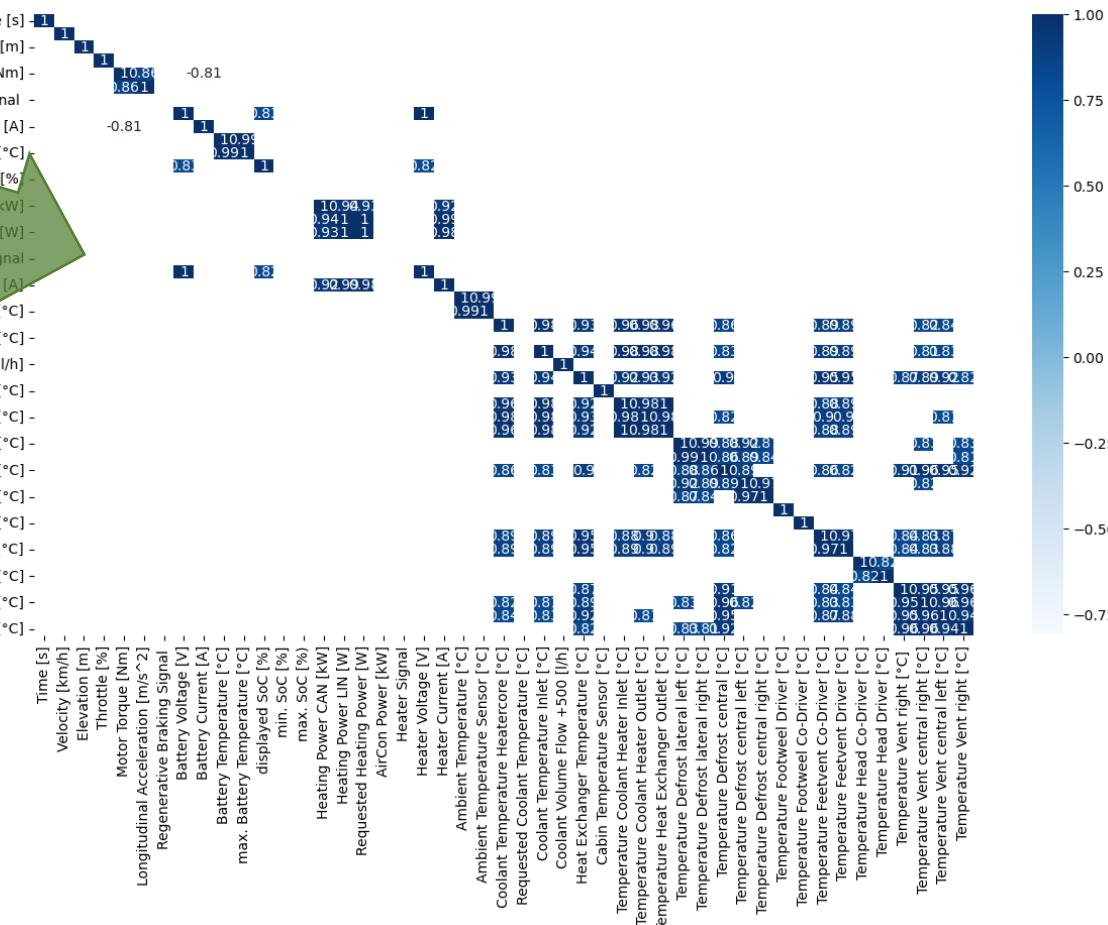
Note: Further multicollinearity checks has been carried out in the following slides

Data Preparation

Measured data – Trip B: Correlation Matrix

Classification: Public

- Correlation between the variables are identified
- The variables having higher correlation/significance greater than 80% shown below.



Note: Further multicollinearity checks has been carried out in the following slides

Data Modeling

Classification: Public

Measured data – Trip A: Model Summary

- Model OLS before multicollinearity check
 - Divided the data to training and testing with testing sample size of 20%
 - **Interpretation:** The **R-squared is 0.989** which means that the above model explains a 98% of the variation in the SoC%.
 - The Durbin-Watson test is used to check the autocorrelation between the residuals.
 - If the Durbin-Watson test statistic is near to **2: no autocorrelation**
 - If the Durbin-Watson test statistic is **between 0 and 2: positive autocorrelation**
 - If the Durbin-Watson test statistic is between **2 and 4: negative autocorrelation**
 - The summary output shows that the value of the test statistic is less than 2 (= 1.995) which means there is a **positive autocorrelation**.
 - The Jarque-Bera test is used to check the normality of the residuals. Here, the **p-value of the test is less than 0.05**; that implies the residuals are **not normally distributed**.
 - Also, the '**Cond. No' (4.27e+17)** represents the Condition Number (CN) that is used to check the multicollinearity.
 - **If CN < 100: no multicollinearity.** **If CN is between 100 and 1000: moderate multicollinearity** **If CN > 1000: severe multicollinearity**
 - Thus, model shows severe multicollinearity in the data.

OLS Regression Results						
Dep. Variable:	SoC [%]	R-squared (uncentered):	0.989			
Model:	OLS	Adj. R-squared (uncentered):	0.989			
Method:	Least Squares	F-statistic:	1.187e+06			
Date:	Wed, 27 Dec 2023	Prob (F-statistic):	0.00			
Time:	11:18:33	Log-Likelihood:	1.5274e+05			
No. Observations:	179710	AIC:	-3.054e+05			
Df Residuals:	179696	BIC:	-3.053e+05			
Df Model:	14					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975]
Time [s]	-0.0129	0.000	-43.235	0.000	-0.013	-0.012
Velocity [km/h]	-0.0222	0.000	-56.185	0.000	-0.023	-0.021
Elevation [m]	-0.0294	0.000	-106.636	0.000	-0.030	-0.029
Throttle [%]	0.0154	0.000	38.661	0.000	0.015	0.016
Motor Torque [Nm]	0.0031	0.001	4.176	0.000	0.002	0.005
Longitudinal Acceleration [m/s^2]	-0.0077	0.001	-12.030	0.000	-0.009	-0.000
Regenerative Braking Signal	2.968e-17	3.35e-19	88.527	0.000	2.9e-17	3.03e-17
Battery Current [A]	5.854e-05	0.000	0.118	0.906	-0.001	0.001
max. Battery Temperature [°C]	0.0655	0.000	135.114	0.000	0.065	0.066
displayed SoC [%]	0.9660	0.000	3291.344	0.000	0.965	0.967
min. SoC [%]	1.063e-17	1.22e-19	87.015	0.000	1.04e-17	1.09e-17
max. SoC [%]	-0.1049	0.000	-308.884	0.000	-0.106	-0.104
Heating Power CAN [kW]	-4.58e-17	4.43e-20	-1033.194	0.000	-4.59e-17	-4.57e-17
AirCon Power [kW]	0.0247	0.000	72.584	0.000	0.024	0.025
Ambient Temperature [°C]	-0.0195	0.000	-44.057	0.000	-0.020	-0.019
Heat Exchanger Temperature [°C]	-0.0509	0.000	-153.233	0.000	-0.052	-0.056
Cabin Temperature Sensor [°C]	0.0067	0.000	22.858	0.000	0.006	0.007
Omnibus:	818.816	Durbin-Watson:	1.995			
Prob(Omnibus):	0.000	Jarque-Bera (JB):	821.377			
Skew:	0.159	Prob(JB):	4.37e-179			
Kurtosis:	2.906	Cond. No.	4.27e+17			

Data Modeling

Classification: Public

Measured data – Trip B: Model Summary

- Model OLS before multicollinearity check
- Divided the data to training and testing with testing sample size of 20%
- **Interpretation:** The R-squared is 0.998 which means that the above model explains a 98% of the variation in the SoC%.
- The Durbin-Watson test is used to check the autocorrelation between the residuals.
 - If the Durbin-Watson test statistic is near to 2: no autocorrelation
 - If the Durbin-Watson test statistic is between 0 and 2: positive autocorrelation
 - If the Durbin-Watson test statistic is between 2 and 4: negative autocorrelation
- The summary output shows that the value of the test statistic is less than 2 (= 1.999) which means there is a **positive autocorrelation**.
- The Jarque-Bera test is used to check the normality of the residuals. Here, the **p-value of the test is less than 0.05**; that implies the residuals are **not normally distributed**.
- Also, the '**Cond. No**' (**1.37e+16**) represents the Condition Number (CN) that is used to check the multicollinearity.
- **If CN < 100: no multicollinearity.** If CN is between 100 and 1000: **moderate multicollinearity** If CN > 1000: **severe multicollinearity**
- Thus, model shows severe multicollinearity in the data.

OLS Regression Results							
Dep. Variable:	SoC [%]	R-squared (uncentered):	0.998	F-statistic:	1.923e+06	Prob (F-statistic):	
Model:	OLS	R-squared (uncentered):	0.998	Log-Likelihood:	3.0572e+05	AIC:	
Method:	Least Squares	F-statistic:	1.923e+06	BIC:	-6.114e+05	Prob (BIC):	
Date:	Tue, 16 Jan 2024	Prob (F-statistic):	0.00	K-Squared:	0.00	Prob (K-Squared):	
Time:	21:24:26	Log-Likelihood:	3.0572e+05	AIC:	-6.114e+05	Prob (AIC):	
No. Observations:	192248	BIC:	-6.109e+05	K-Squared:	0.00	Prob (K-Squared):	
Df Residuals:	192207	Covariance Type:	nonrobust	AIC:	-6.109e+05	Prob (AIC):	
Df Model:	41	std err	t	P> t	[0.025	0.975]	
coef	Time [s]	-0.0296	0.000	-147.988	0.000	-0.030	-0.029
Velocity [km/h]	0.0023	0.000	10.356	0.000	0.002	0.003	
Elevation [m]	-0.0025	0.000	-15.749	0.000	-0.003	-0.002	
Throttle [%]	0.0011	0.000	6.023	0.000	0.001	0.001	
Motor Torque [Nm]	-0.0008	0.000	-2.320	0.020	-0.001	-0.000	
Longitudinal Acceleration [m/s^2]	0.0007	0.000	13.272	0.000	0.003	0.004	
Regenerative Braking Signal	2.196e-16	1.37e-17	16.064	0.000	1.93e-16	2.46e-16	
Battery Voltage [V]	0.0512	0.003	15.079	0.000	0.045	0.058	
Battery Current [A]	-0.0141	0.000	-43.018	0.000	-0.015	-0.014	
Battery Temperature [°C]	0.0086	0.001	50.065	0.000	0.066	0.071	
max. Battery Temperature [°C]	-0.0889	0.001	-64.990	0.000	-0.092	-0.086	
displayed SoC [%]	0.9555	0.001	1712.338	0.000	0.954	0.957	
min. SoC [%]	-1.03e-16	3.38e-18	-30.453	0.000	-1.1e-16	-9.64e-17	
max. SoC [%]	-1.284e-16	4.15e-18	-30.980	0.000	-1.37e-16	-1.2e-16	
Heating Power CAN [kW]	0.0050	0.000	14.552	0.000	0.004	0.006	
Heating Power LTN [W]	-0.0212	0.002	-11.134	0.000	-0.025	-0.017	
Requested Heating Power [W]	0.0018	0.002	1.143	0.253	-0.001	0.005	
Coolant Flow [l/h]	-1.95e-16	2.1e-18	-30.200	0.000	-1.28e-16	-1.3e-16	
Water Signal	-5.25e-17	1.15e-18	16.675	0.000	-5.37e-17	-4.53e-17	
Heater Voltage [V]	0.0053	0.003	1.586	0.113	-0.001	0.012	
Heater Current [A]	-0.01	0.001	17.056	0.000	0.01	0.01	
Ambient Temperature [°C]	0.0133	0.001	14.963	0.000	0.012	0.015	
Ambient Temperature Sensor [°C]	-0.0060	0.001	-6.613	0.000	-0.008	-0.004	
Coolant Temperature Heatercore [°C]	-0.0021	0.001	-2.285	0.022	-0.004	-0.000	
Requested Coolant Temperature [°C]	7.885e-17	1.27e-18	62.167	0.000	7.64e-17	8.13e-17	
Coolant Temperature Inlet [°C]	-0.0034	0.001	-4.073	0.000	-0.005	-0.002	
Coolant Volume Flow +500 [l/h]	9.066e-05	0.000	0.759	0.448	-0.000	0.000	
Heat Exchanger Temperature [°C]	-0.0310	0.001	-41.690	0.000	-0.032	-0.030	
Cabin Temperature Sensor [°C]	0.0029	0.000	7.482	0.000	0.002	0.004	
Temperature Coolant Heater Inlet [°C]	0.0016	0.002	0.690	0.490	-0.003	0.006	
Temperature Coolant Heater Outlet [°C]	-0.0199	0.002	-8.146	0.000	-0.025	-0.015	
Temperature Heat Exchanger Outlet [°C]	0.0347	0.003	12.884	0.000	0.029	0.040	
Temperature Defrost lateral left [°C]	0.0096	0.002	5.621	0.000	0.006	0.013	
Temperature Defrost lateral right [°C]	-0.0151	0.001	-10.314	0.000	-0.018	-0.012	
Temperature Defrost central [°C]	-0.0138	0.001	-11.309	0.000	-0.016	-0.011	
Temperature Defrost central left [°C]	0.0395	0.002	23.939	0.000	0.036	0.043	
Temperature Defrost central right [°C]	-0.0368	0.001	-34.479	0.000	-0.039	-0.035	
Temperature Footwell Driver [°C]	-0.0089	0.000	-33.521	0.000	-0.009	-0.008	
Temperature Footwell Co-Driver [°C]	-0.0107	0.000	-38.421	0.000	-0.011	-0.010	
Temperature Feetvent Co-Driver [°C]	-0.0155	0.001	-22.710	0.000	-0.017	-0.014	
Temperature Feetvent Driver [°C]	0.0249	0.001	30.586	0.000	0.023	0.026	
Temperature Head Co-Driver [°C]	0.0220	0.000	76.411	0.000	0.021	0.023	
Temperature Head Driver [°C]	0.0133	0.000	53.737	0.000	0.013	0.014	
Temperature Vent right [°C]	0.0175	0.001	20.272	0.000	0.016	0.019	
Temperature Vent central right [°C]	0.0358	0.001	47.551	0.000	0.034	0.037	
Temperature Vent central left [°C]	0.0188	0.001	23.082	0.000	0.017	0.020	
Temperature Vent right [°C]	-0.0589	0.001	-72.787	0.000	-0.060	-0.057	
Omnibus:	23799.992	Durbin-Watson:	1.999				
Prob(Omnibus):	0.000	Jarque-Bera (JB):	82447.647				
Skew:	-0.618	Prob(JB):	0.00				
Kurtosis:	5.900	Cond. No.	1.37e+16				

Data Modeling

Classification: Public

Measured data – Trip A: Multicollinearity checks and treatment

Variance Influence Factor (VIF):

- Detect the presence of multicollinearity between the features.
- Variable 'max Batt Temp' has the highest VIF.
- NaN identified, drop NaN variables as they don't posses any information

VIF_Factor	Features
0	57.630461 max. Battery Temperature [°C]
1	52.864911 Battery Temperature [°C]
2	36.638178 Battery Voltage [V]
3	29.082883 displayed SoC [%]
4	9.733611 Battery Current [A]
5	9.141540 Motor Torque [Nm]
6	6.388500 Longitudinal Acceleration [m/s^2]
7	6.083667 Ambient Temperature [°C]
8	4.607141 Velocity [km/h]
9	3.051488 Heat Exchanger Temperature [°C]
10	2.691083 Cabin Temperature Sensor [°C]
11	2.572426 Throttle [%]
12	2.251638 Elevation [m]
13	2.240067 max. SoC [%]
14	1.965373 AirCon Power [kW]
15	1.580334 Time [s]
16	NaN Regenerative Braking Signal
17	NaN min. SoC [%]
18	NaN Heating Power CAN [kW]
19	NaN Requested Heating Power [W]
20	NaN Heater Signal
21	NaN Requested Coolant Temperature [°C]



VIF_Factor	Features
0	57.630461 max. Battery Temperature [°C]
1	52.864911 Battery Temperature [°C]
2	36.638178 Battery Voltage [V]
3	29.082883 displayed SoC [%]
4	9.733611 Battery Current [A]
5	9.141540 Motor Torque [Nm]
6	6.388500 Longitudinal Acceleration [m/s^2]
7	6.083667 Ambient Temperature [°C]
8	4.607141 Velocity [km/h]
9	3.051488 Heat Exchanger Temperature [°C]
10	2.691083 Cabin Temperature Sensor [°C]
11	2.572426 Throttle [%]
12	2.251638 Elevation [m]
13	2.240067 max. SoC [%]
14	1.965373 AirCon Power [kW]
15	1.580334 Time [s]



VIF_Factor	Features
1.563277	Time [s]
2.438903	Velocity [km/h]
2.006671	Elevation [m]
2.401399	Throttle [%]
9.135978	Motor Torque [Nm]
6.384733	Longitudinal Acceleration [m/s^2]
4.373085	Battery Current [A]
3.936285	Battery Temperature [°C]
1.789520	displayed SoC [%]
2.059415	max. SoC [%]
1.963481	AirCon Power [kW]
4.733217	Ambient Temperature [°C]
2.898119	Heat Exchanger Temperature [°C]
2.573276	Cabin Temperature Sensor [°C]

- Now, we have all the variables with VIF less than 10.
- So, we can conclude that there is no multicollinearity in the data.
- Below shown variable used to build the MLR model with significant variables.

Data Modeling

Classification: Public

Measured data – Trip B: Multicollinearity checks and treatment

VIF_Factor	Features
910.622989	Battery Voltage [V]
878.697754	Heater Voltage [V]
580.463584	Temperature Heat Exchanger Outlet [°C]
471.681184	Temperature Coolant Heater Outlet [°C]
424.509756	Temperature Coolant Heater Inlet [°C]
285.845339	Heating Power LIN [W]
229.463395	Temperature Defrost lateral left [°C]
214.516238	Temperature Defrost central left [°C]
197.818728	Requested Heating Power [W]
169.684385	Temperature Defrost lateral right [°C]
148.337428	Battery Temperature [°C]
147.793417	max. Battery Temperature [°C]
117.295703	Temperature Defrost central [°C]
89.846699	Temperature Defrost central right [°C]
65.664628	Ambient Temperature Sensor [°C]
64.895662	Coolant Temperature Heatercore [°C]
62.463226	Ambient Temperature [°C]
61.700422	Heater Current [A]
58.471181	Temperature Vent right [°C]
53.758325	Coolant Temperature Inlet [°C]
51.986093	Temperature Feetvent Driver [°C]
51.752816	Temperature Vent central left [°C]
51.411924	Temperature Vent right [°C]
44.726030	Temperature Vent central right [°C]
43.831876	Heat Exchanger Temperature [°C]
36.941150	Temperature Feetvent Co-Driver [°C]
24.555946	displayed SoC [%]
11.958563	Cabin Temperature Sensor [°C]
9.305117	Heating Power CAN [kW]
8.536059	Battery Current [A]
8.332505	Motor Torque [Nm]
6.532945	Temperature Head Co-Driver [°C]
6.126363	Temperature Footwell Co-Driver [°C]
6.018856	Longitudinal Acceleration [m/s²]
5.523354	Temperature Footwell Driver [°C]
4.860559	Temperature Head Driver [°C]
3.891853	Velocity [km/h]
3.164052	Time [s]
2.740260	Throttle [%]
2.064006	Elevation [m]
1.124309	Coolant Volume Flow +500 [l/h]
NaN	Regenerative Braking Signal
NaN	min. SoC [%]
NaN	max. SoC %
NaN	AirCon Power [kW]
NaN	Heater Signal
NaN	Requested Coolant Temperature [°C]



VIF_Factor	Features
910.622989	Battery Voltage [V]
878.697754	Heater Voltage [V]
580.463584	Temperature Heat Exchanger Outlet [°C]
471.681184	Temperature Coolant Heater Outlet [°C]
424.509756	Temperature Coolant Heater Inlet [°C]
285.845339	Heating Power LIN [W]
229.463395	Temperature Defrost lateral left [°C]
214.516238	Temperature Defrost central left [°C]
197.818728	Requested Heating Power [W]
169.684385	Temperature Defrost lateral right [°C]
148.337428	Battery Temperature [°C]
147.793417	max. Battery Temperature [°C]
117.295703	Temperature Defrost central [°C]
89.846699	Temperature Defrost central right [°C]
65.664628	Ambient Temperature Sensor [°C]
64.895662	Coolant Temperature Heatercore [°C]
62.463226	Ambient Temperature [°C]
61.700422	Heater Current [A]
58.471181	Temperature Vent right [°C]
53.758325	Coolant Temperature Inlet [°C]
51.986093	Temperature Feetvent Driver [°C]
51.752816	Temperature Vent central left [°C]
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44.726030	Temperature Vent central right [°C]
43.831876	Heat Exchanger Temperature [°C]
36.941150	Temperature Feetvent Co-Driver [°C]
24.555946	displayed SoC [%]
11.958563	Cabin Temperature Sensor [°C]
9.305117	Heating Power CAN [kW]
8.536059	Battery Current [A]
8.332505	Motor Torque [Nm]
6.532945	Temperature Head Co-Driver [°C]
6.126363	Temperature Footwell Co-Driver [°C]
6.018856	Longitudinal Acceleration [m/s²]
5.523354	Temperature Footwell Driver [°C]
4.860559	Temperature Head Driver [°C]
3.891853	Velocity [km/h]
3.164052	Time [s]
2.740260	Throttle [%]
2.064006	Elevation [m]
1.124309	Coolant Volume Flow +500 [l/h]

VIF_Factor	Features
2.504728	Time [s]
2.673488	Velocity [km/h]
1.723005	Elevation [m]
2.483297	Throttle [%]
8.192972	Motor Torque [Nm]
5.936116	Longitudinal Acceleration [m/s²]
4.599474	Battery Current [A]
3.600575	Battery Temperature [°C]
1.461052	displayed SoC [%]
6.630709	Heating Power CAN [kW]
7.371837	Heater Current [A]
2.725244	Ambient Temperature [°C]
6.124554	Coolant Temperature Inlet [°C]
1.119113	Coolant Volume Flow +500 [l/h]
5.810224	Cabin Temperature Sensor [°C]
6.233827	Temperature Defrost central right [°C]
4.175909	Temperature Footwell Driver [°C]
4.812029	Temperature Footwell Co-Driver [°C]
5.528231	Temperature Head Co-Driver [°C]
4.350087	Temperature Head Driver [°C]
5.486040	Temperature Vent right [°C]

Variance Influence Factor (VIF):

- Detect the presence of multicollinearity between the features.
- Variable 'Battery Voltage' has the highest VIF.
- NaN identified, drop NaN variables as they don't possess any information
- Now, we have all the variables with VIF less than 10.
- So, we can conclude that there is no multicollinearity in the data.
- Only above features will be considered for modeling

Data Modeling

Classification: Public

Measured data – Trip B: Model with significant variables

Before collinearity treatment

OLS Regression Results											
Dep. Variable:	SoC [%]	R-squared (uncentered):	0.998								
Model:	OLS	Adj. R-squared (uncentered):	0.998								
Method:	Least Squares	F-statistic:	1.923e+06								
Date:	Tue, 16 Jan 2024	Prob (F-statistic):	0.00								
Time:	21:24:26	Log-Likelihood:	3.0572e+05								
No. Observations:	192248	AIC:	-6.114e+05								
Df Residuals:	192207	BIC:	-6.109e+05								
Df Model:	41										
Covariance Type:	nonrobust										
	coef	std err	t	P> t	[0.025	0.975]					
Time [s]	-0.0296	0.000	-147.988	0.000	-0.030	-0.029					
Velocity [km/h]	0.0023	0.000	10.356	0.000	0.002	0.003					
Elevation [m]	-0.0025	0.000	-15.749	0.000	-0.003	-0.002					
Throttle [%]	0.0011	0.000	6.023	0.000	0.001	0.001					
Motor Torque [Nm]	-0.0008	0.000	-2.320	0.020	-0.001	-0.000					
Longitudinal Acceleration [m/s^2]	0.0037	0.000	13.272	0.000	0.003	0.004					
Regenerative Braking Signal	2.196e-16	1.37e-17	16.064	0.000	1.93e-16	2.46e-16					
Battery Voltage [V]	0.0512	0.003	15.079	0.000	0.045	0.058					
Battery Current [A]	-0.0141	0.000	-43.018	0.000	-0.015	-0.014					
Battery Temperature [°C]	0.0686	0.001	59.065	0.000	0.066	0.071					
max. Battery Temperature [°C]	-0.0889	0.001	-64.990	0.000	-0.092	-0.086					
displayed SoC [%]	0.9555	0.001	1712.338	0.000	0.954	0.957					
min. SoC [%]	-1.03e-16	3.38e-18	-36.453	0.000	-1.1e-16	-0.94e-17					
max. SoC [%]	-1.284e-16	4.15e-18	-30.980	0.000	-1.37e-16	-1.2e-16					
Heating Power CAN [kW]	0.0050	0.000	14.552	0.000	0.004	0.006					
Heating Power LIN [W]	-0.0212	0.002	-11.134	0.000	-0.025	-0.017					
Requested Heating Power [W]	0.0018	0.002	1.143	0.253	-0.001	0.005					
AirCon Power [kW]	1.329e-16	2.54e-18	52.263	0.000	1.28e-16	1.38e-16					
Heater Signal	-5.251e-17	3.15e-18	-16.675	0.000	-5.87e-17	-4.63e-17					
Heater Voltage [V]	0.0053	0.003	1.586	0.113	-0.001	0.012					
Heater Current [A]	0.0151	0.001	17.030	0.000	0.013	0.017					
Ambient Temperature [°C]	0.0133	0.001	14.963	0.000	0.012	0.015					
Ambient Temperature Sensor [°C]	-0.0060	0.001	-6.613	0.000	-0.008	-0.004					
Coolant Temperature Heatercore [°C]	-0.0021	0.001	-2.285	0.022	-0.004	-0.000					
Requested Coolant Temperature [°C]	7.885e-17	1.27e-18	62.167	0.000	7.64e-17	8.13e-17					
Coolant Temperature Inlet [°C]	-0.0034	0.001	-4.073	0.000	-0.005	-0.002					
Coolant Volume Flow +500 [l/h]	9.066e-05	0.000	0.759	0.448	-0.000	0.000					
Heat Exchanger Temperature [°C]	-0.0310	0.001	-41.690	0.000	-0.032	-0.030					
Cabin Temperature Sensor [°C]	0.0029	0.000	7.482	0.000	0.002	0.004					
Temperature Coolant Heater Inlet [°C]	0.0016	0.002	0.698	0.490	-0.003	0.006					
Temperature Coolant Heater Outlet [°C]	-0.0199	0.002	-8.146	0.000	-0.025	-0.015					
Temperature Heat Exchanger Outlet [°C]	0.0347	0.003	12.804	0.000	0.029	0.040					
Temperature Defrost lateral left [°C]	0.0096	0.002	5.621	0.000	0.006	0.013					
Temperature Defrost lateral right [°C]	-0.0151	0.001	-10.314	0.000	-0.018	-0.012					
Temperature Defrost central [°C]	-0.0138	0.001	-11.309	0.000	-0.016	-0.011					
Temperature Defrost central left [°C]	0.0395	0.002	23.939	0.000	0.036	0.043					
Temperature Defrost central right [°C]	-0.0368	0.001	-34.479	0.000	-0.039	-0.035					
Temperature Footwell Driver [°C]	-0.0089	0.000	-33.521	0.000	-0.009	-0.008					
Temperature Footwell Co-Driver [°C]	-0.0107	0.000	-38.421	0.000	-0.011	-0.010					
Temperature Feetvent Co-Driver [°C]	-0.0155	0.001	-22.710	0.000	-0.017	-0.014					
Temperature Feetvent Driver [°C]	0.0249	0.001	30.586	0.000	0.023	0.026					
Temperature Head Co-Driver [°C]	0.0220	0.000	76.411	0.000	0.021	0.023					
Temperature Head Driver [°C]	0.0133	0.000	53.737	0.000	0.013	0.014					
Temperature Vent right [°C]	0.0175	0.001	20.272	0.000	0.016	0.019					
Temperature Vent central right [°C]	0.0358	0.001	47.551	0.000	0.034	0.037					
Temperature Vent central left [°C]	0.0188	0.001	23.082	0.000	0.017	0.020					
Temperature Vent right [°C]	-0.0599	0.001	77.727	0.000	-0.060	-0.057					

Omnibus:	23799.992	Durbin-Watson:	1.999
Prob(Omnibus):	0.000	Jarque-Bera (JB):	82447.847
Skew:	-0.618	Prob(JB):	0.00
Kurtosis:	5.960	Cond. No.	1.37e+16

After collinearity treatment

OLS Regression Results											
Dep. Variable:	SoC [%]	R-squared (uncentered):	0.997								
Model:	OLS	Adj. R-squared (uncentered):	0.997								
Method:	Least Squares	F-statistic:	3.357e+06								
Date:	Tue, 16 Jan 2024	Prob (F-statistic):	0.00								
Time:	21:32:54	Log-Likelihood:	2.9490e+05								
No. Observations:	192248	AIC:	-5.898e+05								
Df Residuals:	192227	BIC:	-5.895e+05								
Df Model:	21										
Covariance Type:	nonrobust										
	coef	std err	t	P> t	[0.025	0.975]					
Time [s]	-0.0263	0.000	-139.576	0.000	-0.027	-0.026					
Velocity [km/h]	-0.0048	0.000	-24.851	0.000	-0.005	-0.004					
Elevation [m]	-0.0076	0.000	-48.581	0.000	-0.008	-0.007					
Throttle [%]	0.0011	0.000	5.712	0.000	0.001	0.001					
Motor Torque [Nm]	0.0008	0.000	2.445	0.014	0.000	0.002					
Longitudinal Acceleration [m/s^2]	0.0048	0.000	16.489	0.000	0.004	0.005					
Battery Current [A]	0.0048	0.000	18.921	0.000	0.004	0.005					
Battery Temperature [°C]	-0.0125	0.000	-55.303	0.000	-0.013	-0.012					
displayed SoC [%]	0.9982	0.000	6945.493	0.000	0.998	0.998					
Heating Power CAN [kW]	0.0020	0.000	6.428	0.000	0.001	0.003					
Heater Current [A]	-0.0061	0.000	-18.781	0.000	-0.007	-0.005					
Ambient Temperature [°C]	0.0093	0.000	47.463	0.000	0.009	0.010					
Coolant Temperature Inlet [°C]	0.0056	0.000	18.970	0.000	0.005	0.006					
Coolant Volume Flow +500 [l/h]	0.0002	0.000	1.561	0.119	-5.02e-05	0.000					
Cabin Temperature Sensor [°C]	-0.0146	0.000	-51.087	0.000	-0.015	-0.014					
Temperature Defrost central right [°C]	-0.0142	0.000	-47.818	0.000	-0.015	-0.014					
Temperature Footwell Driver [°C]	-0.0070	0.000	-28.953	0.000	-0.008	-0.007					
Temperature Footwell Co-Driver [°C]	-0.0161	0.000	-61.634	0.000	-0.017	-0.016					
Temperature Head Co-Driver [°C]	0.0259	0.000	92.440	0.000	0.025	0.026					
Temperature Head Driver [°C]	0.0157	0.000	63.198	0.000	0.015	0.016					
Temperature Vent right [°C]	-0.0125	0.000	-44.751	0.000	-0.013	-0.012					
Omnibus:	19054.357	Durbin-Watson:	2.006								
Prob(Omnibus):	0.000	Jarque-Bera (JB):	57929.629								
Skew:	-0.527	Prob(JB):	0.00								
Kurtosis:	5.474	Cond. No.	8.90								

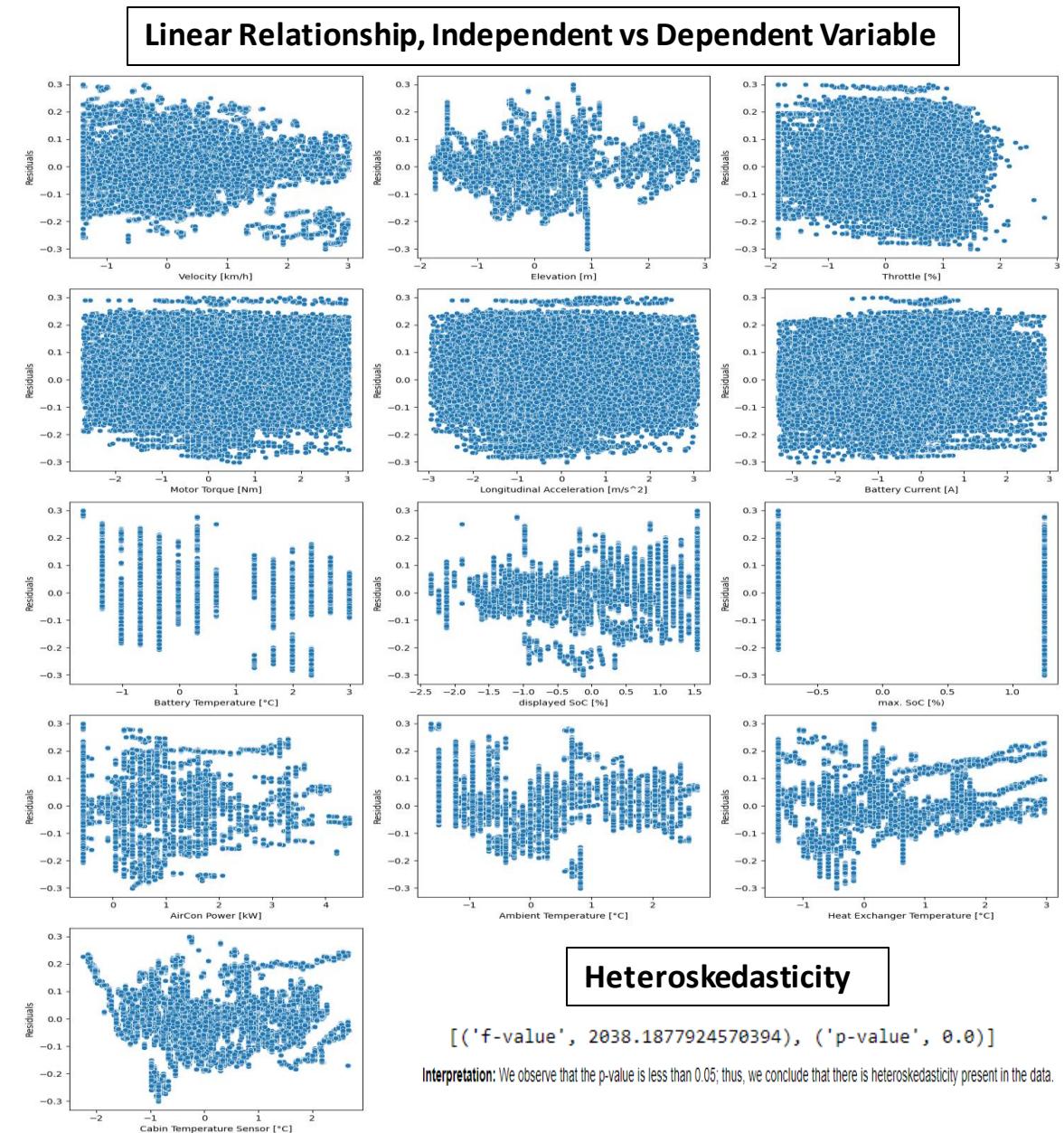
Note:

- ✓ Value of test statistic is near to 2: no autocorrelation
- ✓ Cond. No. < 100, No Multi collinearity
- ✓ JB < 0.05, data not normally distribution

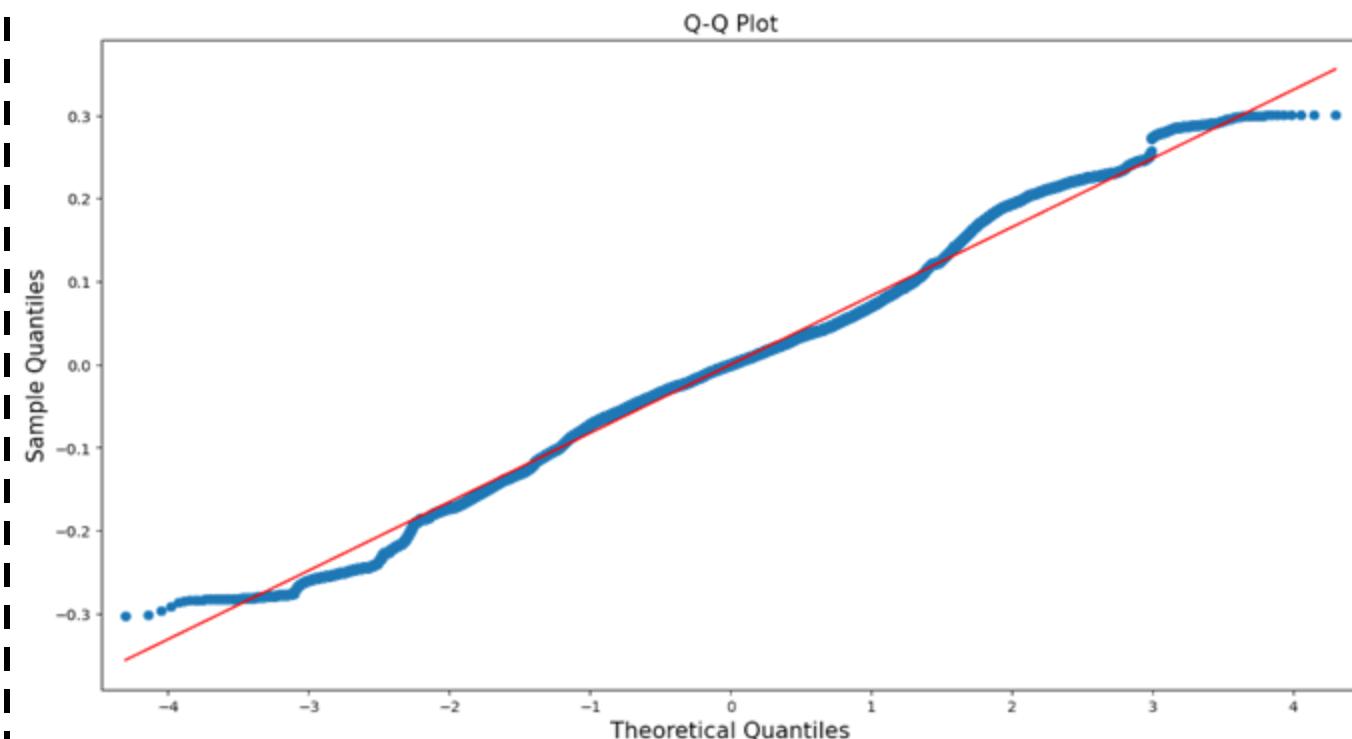
Data Modeling

Classification: Public

Measured data – Trip A: Multicollinearity Test After Model Build-up



Tests for Normality



Shapiro Wilk Test

The Shapiro Wilk test is used to check the normality of the residuals. The test hypothesis is given as:

H₀: Residuals are normally distributed

H1: Residuals are not normally distributed

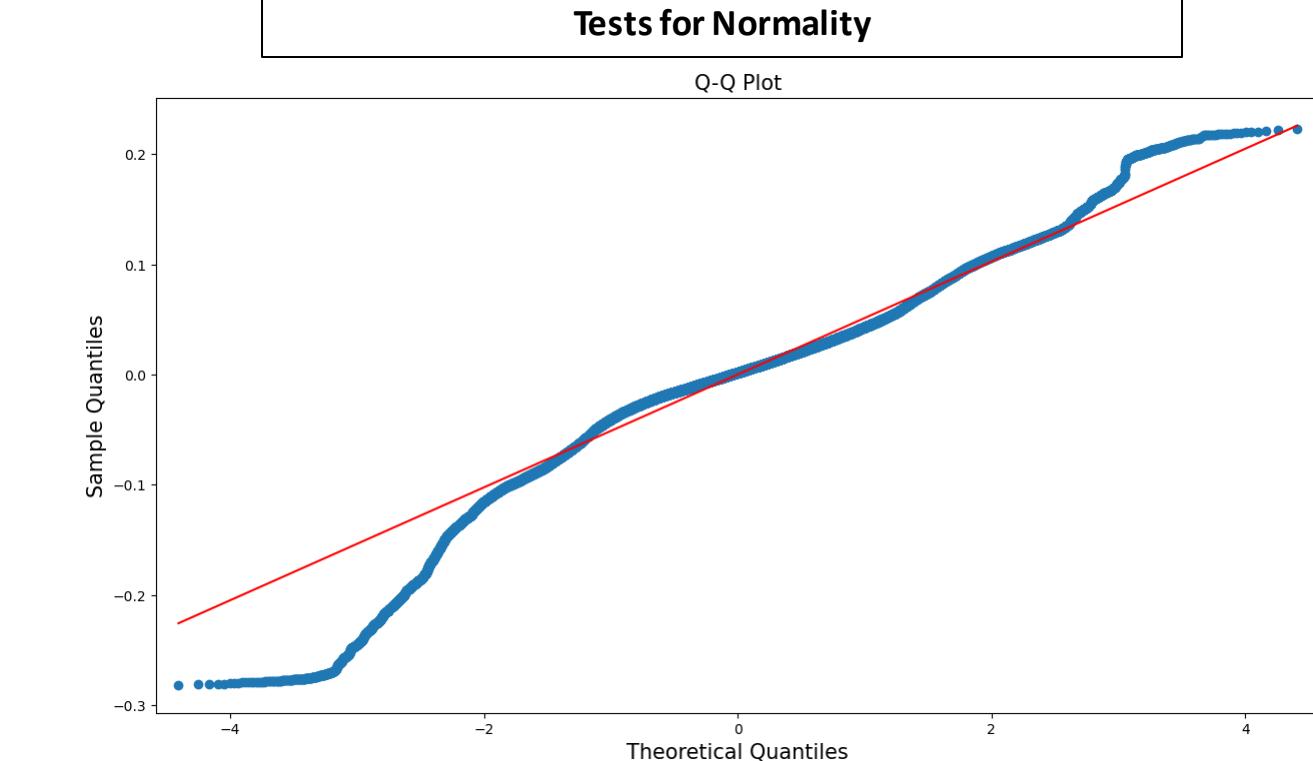
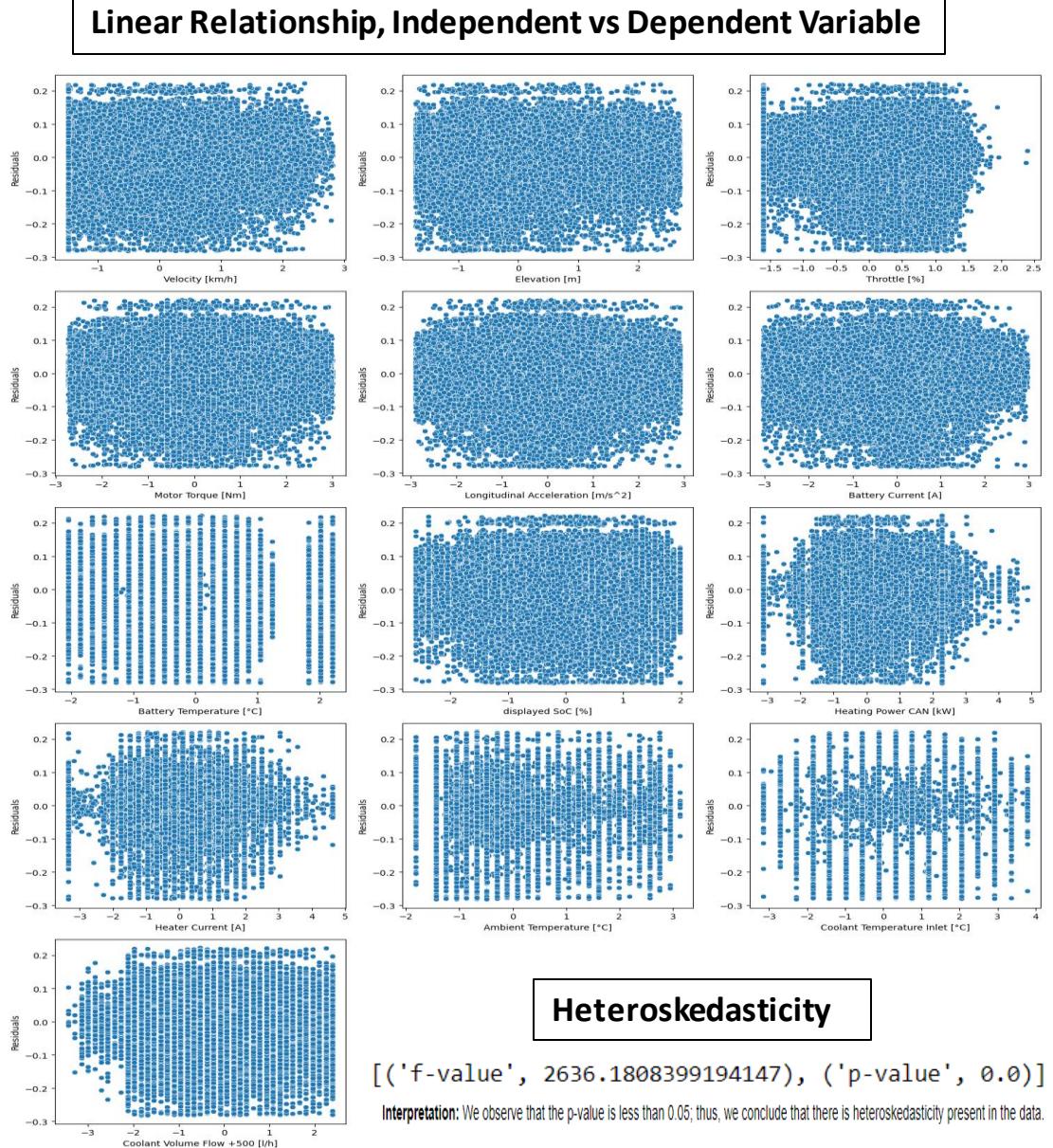
Test Statistic: 0.9870815873146057
P-Value: 0.9

Interpretation: P-Value is less than 0.05 (0.0), thus it reject null hypothesis. The residuals of the target variable are not normally distributed

Data Modeling

Classification: Public

Measured data – Trip B: Multicollinearity Test After Model Build-up



The Shapiro Wilk test is used to check the normality of the residuals. The test hypothesis is given as:

H0: Residuals are normally distributed

H1: Residuals are not normally distributed



Test Statistic: 0.9636120796203613

P-Value: 0.0

Interpretation: P-Value is less than 0.05 (0.0), thus it rejects the null hypothesis. The residuals of the target variable are not normally distributed.

Data Pre-Processing

Classification: Public

Measured data – Trip A: Feature Selection

Forward Feature Selection

- ✓ Type: Forward
- ✓ No of feature: 12
- ✓ Scoring: $R^2 = 0.993062$

Forward Feature Selection

- ✓ Type: Forward
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.9930651$

Backward Feature Selection

- ✓ Type: Backward
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.9930651$

Recursive Feature Selection

- ✓ Type: Linear Regression recursive
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.9930657$

Selected Feature	Selected Feature	Selected Feature	Selected Feature
Time [s]	Time [s]	Time [s]	Time [s]
Velocity [km/h]	Velocity [km/h]	Velocity [km/h]	Velocity [km/h]
Elevation [m]	Elevation [m]	Elevation [m]	Elevation [m]
Throttle [%]	Throttle [%]	Throttle [%]	Throttle [%]
Battery Current [A]	Battery Current [A]	Battery Current [A]	Battery Current [A]
Battery Temperature [°C]	Battery Temperature [°C]	Battery Temperature [°C]	Battery Temperature [°C]
displayed SoC [%]	displayed SoC [%]	displayed SoC [%]	displayed SoC [%]
max. SoC [%]	max. SoC [%]	max. SoC [%]	max. SoC [%]
AirCon Power [kW]	AirCon Power [kW]	AirCon Power [kW]	AirCon Power [kW]
Ambient Temperature [°C]	Ambient Temperature [°C]	Ambient Temperature [°C]	Ambient Temperature [°C]
Heat Exchanger Temperature [°C]			
Cabin Temperature Sensor [°C]			
Note:	Motor Torque [Nm]	Motor Torque [Nm]	Motor Torque [Nm]
	Long Acceleration [m/s^2]	Long Acceleration [m/s^2]	Long Acceleration [m/s^2]

Note:

- ✓ Shows similar R2 value
- ✓ 14 variable selected for further modeling and evaluation

Data Pre-Processing

Measured data – Trip B: Feature Selection

Classification: Public

Forward Feature Selection

- ✓ Type: Forward
- ✓ No of feature: 12
- ✓ Scoring: $R^2 = 0.99723$

Selected Feature
Time [s]
Velocity [km/h]
Elevation [m]
Temperature Defrost central right [°C]
Temperature Footwell Co-Driver [°C]
Battery Temperature [°C]
displayed SoC [%]
Temperature Head Co-Driver [°C]
Temperature Head Driver [°C]
Ambient Temperature [°C]
Heat Exchanger Temperature [°C]
Temperature Vent right [°C]



Forward Feature Selection

- ✓ Type: Forward
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.99727$

Backward Feature Selection

- ✓ Type: Backward
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.99727$

Recursive Feature Selection

- ✓ Type: Linear Regression recursive
- ✓ No of feature: Best
- ✓ Scoring: $R^2 = 0.99727$

Selected Feature
Time [s]
Velocity [km/h]
Elevation [m]
Throttle [%]
Motor Torque [Nm]
Longitudinal Acceleration [m/s ²]
Battery Current [A]
Battery Temperature [°C]
displayed SoC [%]
Heating Power CAN [kW]
Heater Current [A]

Selected Feature
Coolant Volume Flow +500 [l/h]
Coolant Temperature Inlet [°C]
Cabin Temperature Sensor [°C]
Temperature Defrost central right [°C]
Temperature Footwell Driver [°C]
Temperature Footwell Co-Driver [°C]
Temperature Head Co-Driver [°C]
Temperature Head Driver [°C]
Temperature Vent right [°C]
Ambient Temperature [°C]

Note:

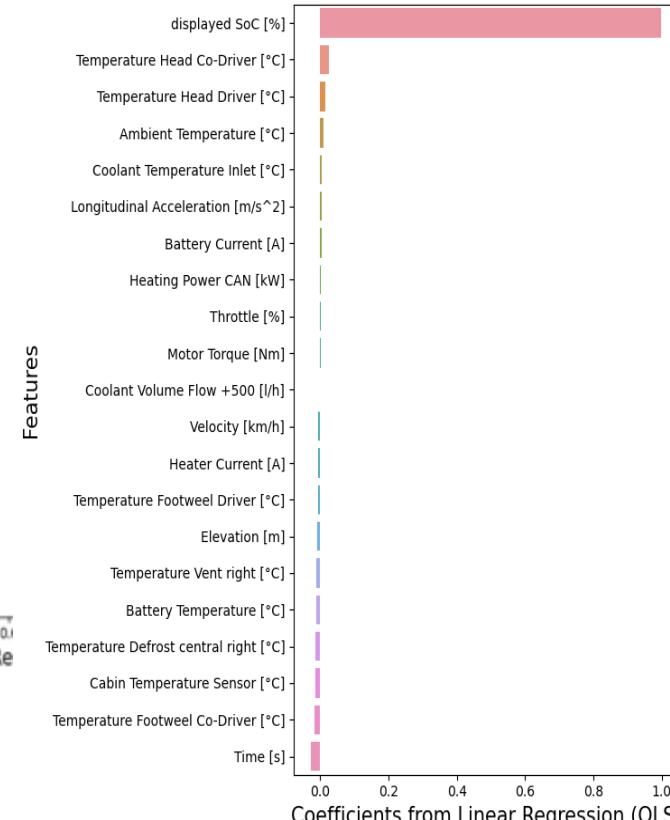
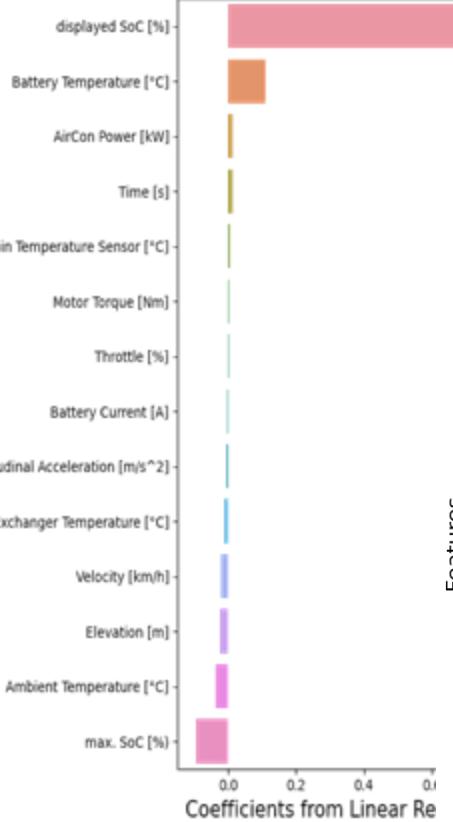
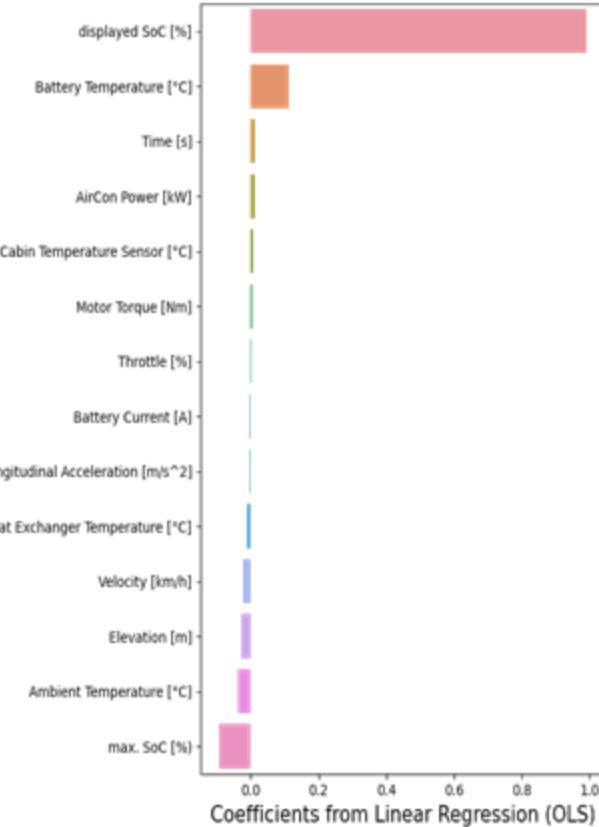
- ✓ Shows similar R2 value
- ✓ 21 variable selected for further modeling and evaluation

Data Evaluation

Classification: Public

Measured data: Trip A and B – Coefficient of OLS vs Gradient Descent

Trip-A



Trip-B



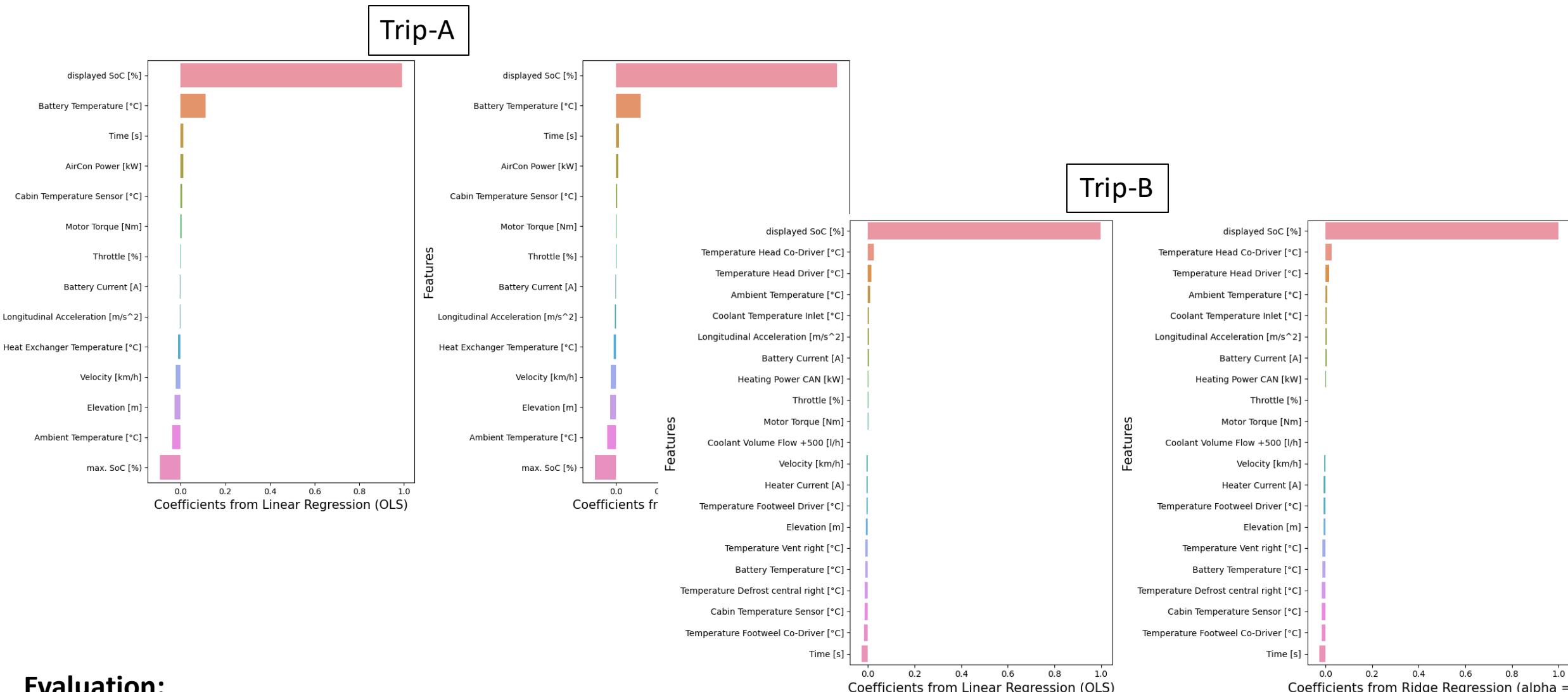
Evaluation:

- ✓ On average, the model's predictions are relatively close to the actual values, with an average RMSE of 0.0624.

Data Evaluation

Classification: Public

Measured data: Trip A and B – Coefficient of OLS vs Ridge Regression (alpha = 2)



Evaluation:

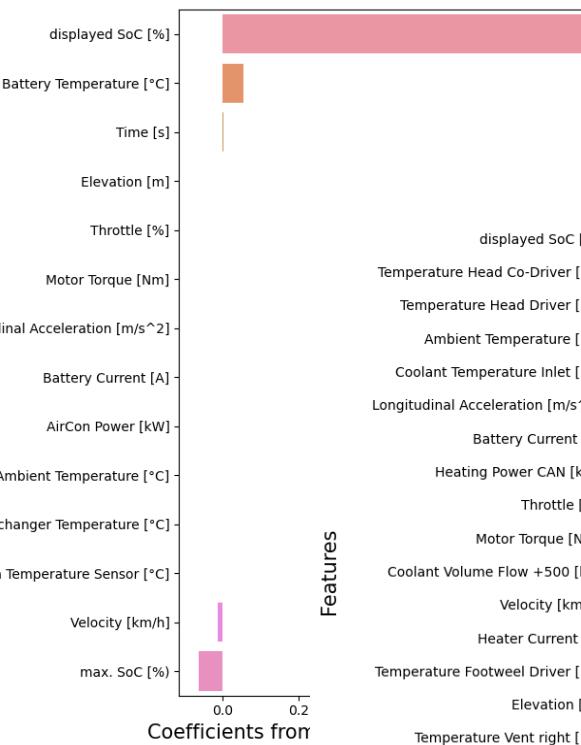
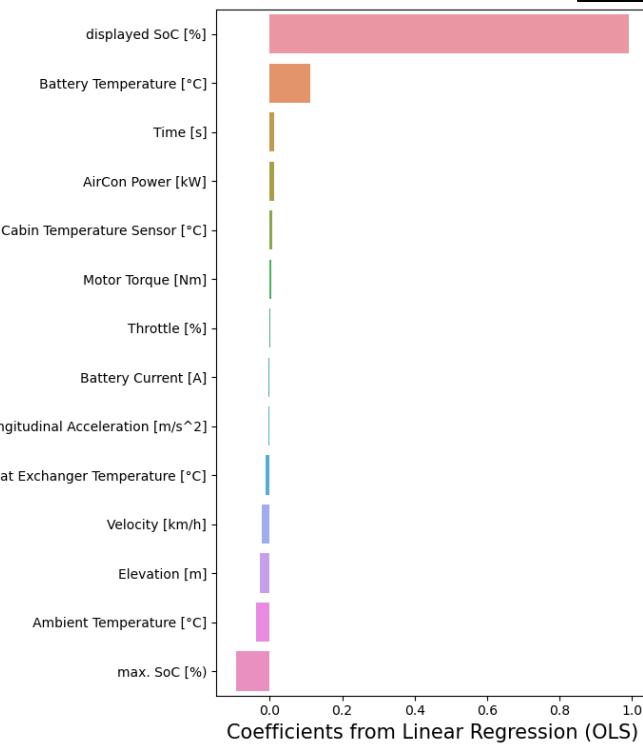
- ✓ On average, the model's predictions are relatively close to the actual values, with an average RMSE of 0.0624.

Data Evaluation

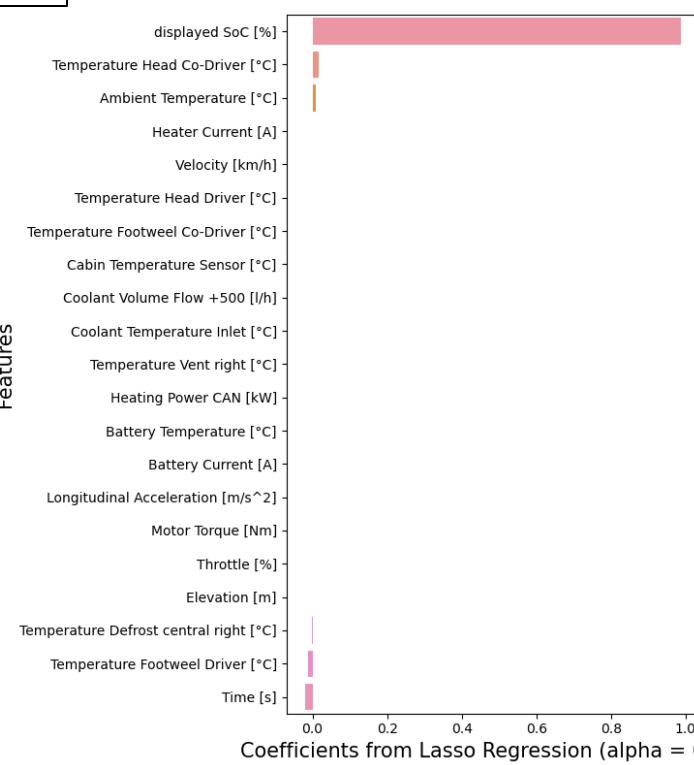
Classification: Public

Measured data: Trip A – Coefficient of OLS vs Lasso Regression (alpha=0.01)

Trip-A



Trip-B



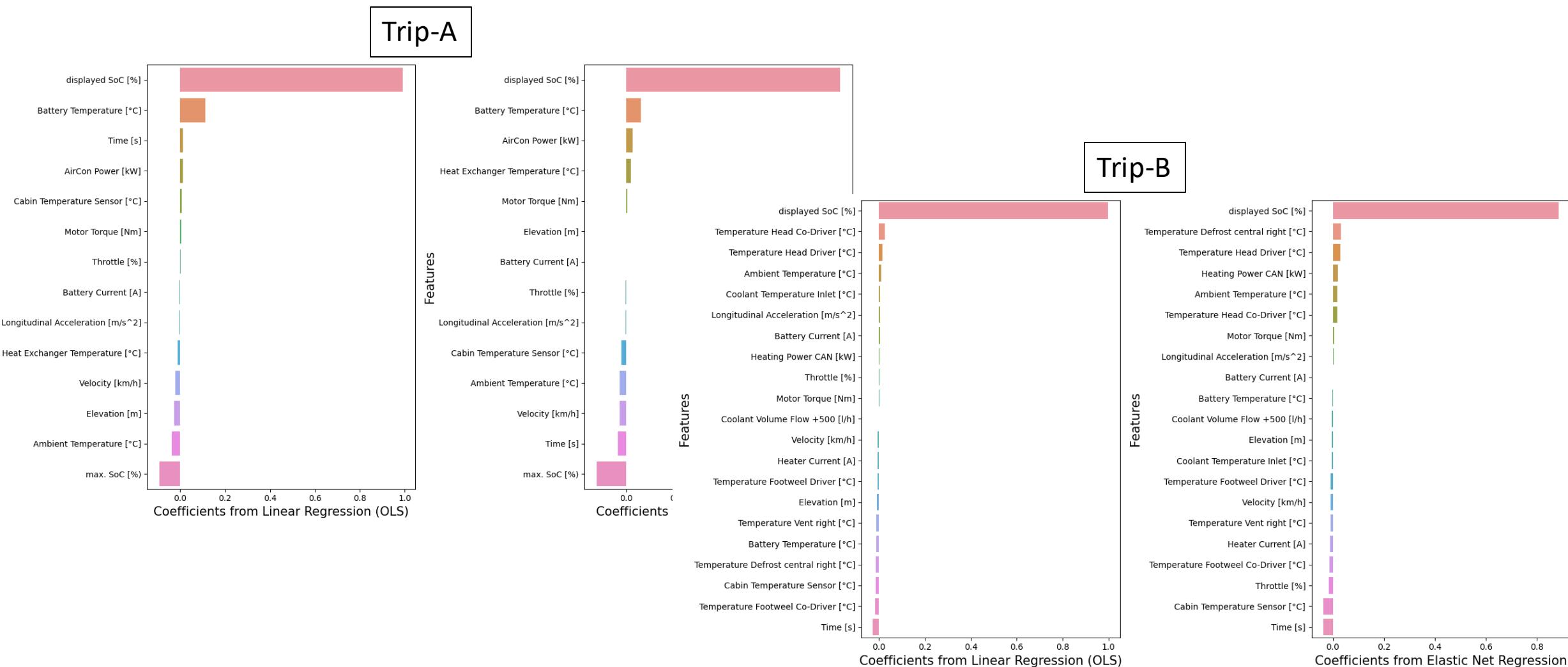
Evaluation:

- ✓ On average, the model's predictions are relatively close to the actual values, with an average RMSE of 0.0624.

Data Evaluation

Classification: Public

Measured data: Trip A – Coefficient of OLS vs Gradient Descent



Evaluation:

- ✓ On average, the model's predictions are relatively close to the actual values, with an average RMSE of 0.0624.

Data Evaluation

Classification: Public

Measured data: Trip A – Performance metrics

Model Name	R-squared	Adj. R-Square	MSE	RMSE	MAE	MAPE
MLR Full Model (OLS)	0.989	0.989	NA	NA	NA	NA
MLR with significant variable	0.993	0.993	0.0624	0.0833	0.0624	40.408
MLR model using Gradient Descent	0.993	0.993	0.0625	0.0834	0.0625	40.409
Cross Validation						
Validation Method	Minimum score obtained	Maximum score obtained	Average score obtained			
K-fold cross Validation	0.993	0.9932	0.9931			
K-fold cross Validation (using cross_val_score)	0.993	0.9932	0.9931			
	Minimum RMSE obtained	Maximum RMSE obtained	Average RMSE obtained			
Leave One Out Cross Validation (LOOCV)	0.0	0.3024	0.0624			

Evaluation:

- ✓ On average, the model's predictions are relatively close to the actual values, with an average RMSE of 0.0624.
- ✓ However, there are cases where the model performed exceptionally well (0.0 RMSE) and some cases where it had larger errors (0.3024 RMSE).
- ✓ Overall, it suggests that the model's performance is reasonably good
- ✓ Tuning and Optimization to be carried out to check availability of over fitting

Data Evaluation

Classification: Public

Measured data: Trip A – Performance metrics summary

Model Name	Alpha (Wherever Required)	I1-ratio	R-Squared	Adj. R-Squared	Test_RMSE	Test_MAPE
Linear Regression	-	-	0.993	0.993	0.0833	40.408
Linear Regression (using SGD)	-	-	0.993	0.993	0.0834	40.409
Ridge Regression (with alpha = 1)		1-	0.993108	0.99310747	0.0833	39.86
Ridge Regression (with alpha = 2)		2-	0.993108	0.369803	0.0833	39.8643
Lasso Regression	0.01-		0.9931	0.9931	0.092	80.2718
Elastic Net Regression	0.1	0.01	0.9931	0.993107	0.1364	81.057
Ridge Regression (using GridSearchCV)	0.1-		0.993108	0.993107	0.0833	39.8561
Lasso Regression (using GridSearchCV)	1.00E-15-		0.993108	0.993107	0.0833	39.8557
Elastic Net Regression (using GridSearchCV)	0.0001	0.0001	0.993108	0.993107	0.0833	39.9063



Model Name	Alpha (Wherever Required)	I1-ratio	R-Squared	Adj. R-Squared	Test_RMSE	Test_MAPE
Lasso Regression (using GridSearchCV)	1.00E-15-		0.993108	0.993107	0.0833	39.8557
Ridge Regression (using GridSearchCV)	0.1-		0.993108	0.993107	0.0833	39.8561
Ridge Regression (with alpha = 1)	1-		0.993108	0.993107473	0.0833	39.86
Ridge Regression (with alpha = 2)	2-		0.993108	0.369803	0.0833	39.8643
Elastic Net Regression (using GridSearchCV)	0.0001	0.0001	0.993108	0.993107	0.0833	39.9063
Linear Regression	-	-	0.993	0.993	0.0833	40.408
Linear Regression (using SGD)	-	-	0.993	0.993	0.0834	40.409
Lasso Regression	0.01-		0.9931	0.9931	0.092	80.2718
Elastic Net Regression	0.1	0.01	0.9931	0.993107	0.1364	81.057

Evaluation:

- ✓ Performance metrics for all model has been listed and sorted the model with lowest RMSE and MAPE.
- ✓ We can see that `Lasso Regression (using GridSearchCV)` has the lowest test RMSE. Here, Lasso regression with `alpha = 1.00E-15` seems to deal with the problem of overfitting efficiently.

Data Evaluation

Classification: Public

Measured data: Trip B – Performance metrics summary

Model Name	Alpha (Wherever Required)	I1-ratio	R-Squared	Adj. R-Squared	Test RMSE	Test MAPE
Linear Regression	-	-	0.997288	0.997287	0.052400	19.925822
Linear Regression (using SGD)	-	-	0.997277	0.997277	0.052500	20.174669
Ridge Regression (with alpha = 1)	1	-	0.997288	0.997287	0.052400	19.925425
Ridge Regression (with alpha = 2)	2	-	0.997288	0.997287	0.052400	19.925028
Lasso Regression	0.01	-	0.996290	0.996289	0.061500	25.221804
Elastic Net Regression	0.1	0.01	0.987751	0.987750	0.110900	32.474924
Ridge Regression (using GridSearchCV)	0.100000	-	0.997288	0.997287	0.052400	19.925782
Lasso Regression (using GridSearchCV)	0.000000	-	0.997288	0.997287	0.052400	19.925833
Elastic Net Regression (using GridSearchCV)	0.000100	0.010000	0.997288	0.997287	0.052400	19.919453



Model Name	Alpha (Wherever Required)	I1-ratio	R-Squared	Adj. R-Squared	Test RMSE	Test MAPE
Linear Regression	-	-	0.997288	0.997287	0.052400	19.925822
Ridge Regression (with alpha = 1)	1	-	0.997288	0.997287	0.052400	19.925425
Ridge Regression (with alpha = 2)	2	-	0.997288	0.997287	0.052400	19.925028
Ridge Regression (using GridSearchCV)	0.100000	-	0.997288	0.997287	0.052400	19.925782
Lasso Regression (using GridSearchCV)	0.000000	-	0.997288	0.997287	0.052400	19.925833
Elastic Net Regression (using GridSearchCV)	0.000100	0.010000	0.997288	0.997287	0.052400	19.919453
Linear Regression (using SGD)	-	-	0.997277	0.997277	0.052500	20.174669
Lasso Regression	0.01	-	0.996290	0.996289	0.061500	25.221804
Elastic Net Regression	0.1	0.01	0.987751	0.987750	0.110900	32.474924

Evaluation:

- ✓ Performance metrics for all model has been listed and sorted the model with lowest RMSE and MAPE.
- ✓ We can see that Elastic Net regression with alpha = 0.000100 has the least Test RMSE and Test MAPE. Here, Elastic Net regression with alpha = 2 seems to deal with the problem of overfitting efficiently.

Thank you for your time and consideration