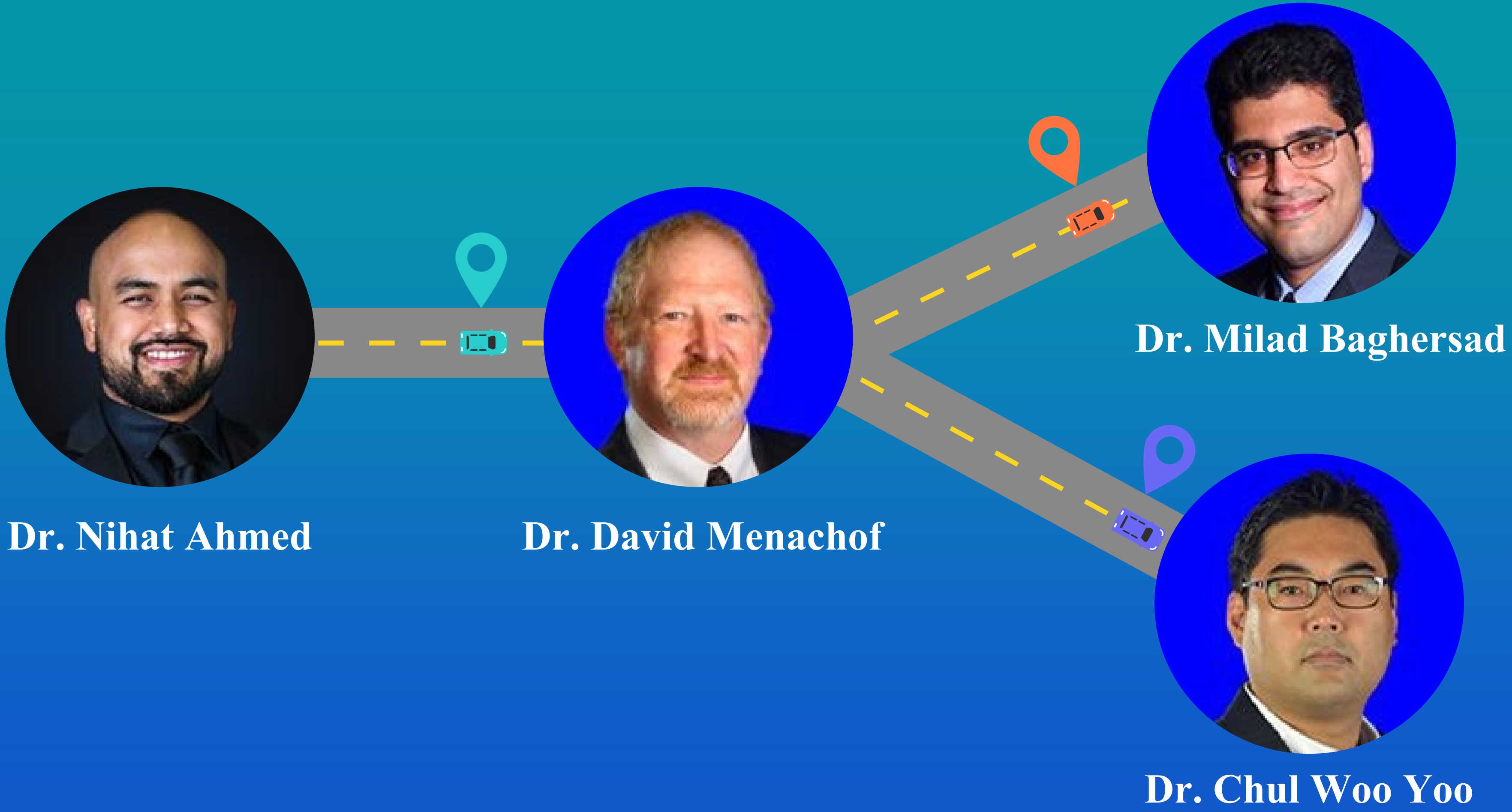
Optimal Charging Station Locations: Infrastructure For Fully Electric Semi-Trucks in the U.S.A.

Our Research Focus on the

Optimal Charging Station Locations

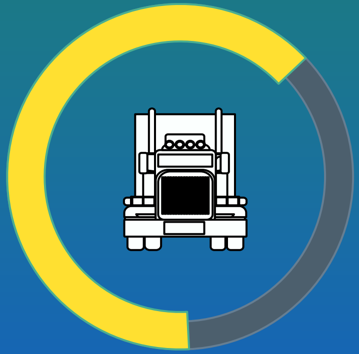
Infrastructure For Fully Electric Semi-Trucks in the U.S.A.


Dr. Nihat Ahmed
Dr. David Menachof
Dr. Milad Baghersad
Dr. Chul Woo Yoo

Why This Study?

- According to the Federal Highway Administration, long-distance trucks travel upwards of 100,000 miles a year. Truck drivers drive an estimated total of 140 billion miles every year.
- Historically Majority of semi-trucks are diesel powered, and some being gasoline powered.
- With fully Electric Semi-trucks entering the market, the major challenge is the electric charging infrastructure in the U.S. roadways.
- There has been numerous studies and academic research on Electronic Vehicle and Charging infrastructure, but majority focused on passenger EVs only.
- There is scholarly research on electric trucks, but on ‘last mile’ only, therefore shorter distance, not focused on long hauls.

U.S. Government Policy



65%

Freight trucks

$5 billion

White house passed a bill this June 2022, the Bipartisan Infrastructure Law includes $5 billion in funding for states with a goal to build a national charging network.
*Triggered investment of over $100 billion from private companies

Source

GHG

On March 28, 2022, EPA published a proposed rule that would set new, more stringent standards to reduce pollution from heavy-duty vehicles and engines starting in model year 2027.

Source

FRLM

OD

Optimal locations of U.S. fast charging stations for long -distance trip completion by battery electric vehicles

This paper uses U.S. long distance travel data to place charging stations with the objective of maximizing long-distance trip completions.

He et al (2019)

+

Location optimisation method for fast - charging stations along national roads

In this paper, an arc-based location optimisation method realized by using a GIS is presented, to achieve even coverage with the minimum number of fast-charging stations along the roads.

Csiszár et al (2020)

→

Optimal Charging Station Locations: Infrastructure For Fully Electric Semi - Trucks in the U.S.A.

Our study is based on both these papers. They are both looking at FRLM and OD model.

Our framework is to use the **existing locations** and analyze the **feasibility** of the OD routes.

Our Study

Literature Gap & Our Contribution

EV: Breckle (2022), Iwan (2021), and Bandeira (2019)

GAP

A significant amount of literature has been completed regarding EVs and charging infrastructure locations. However, they have all been focusing on passenger EVs, and ‘last mile’ short distance vans/trucks. There is a gap on literature when it comes to charging station infrastructure in order to adopt fully electric semi-trucks in the U.S. transportation system

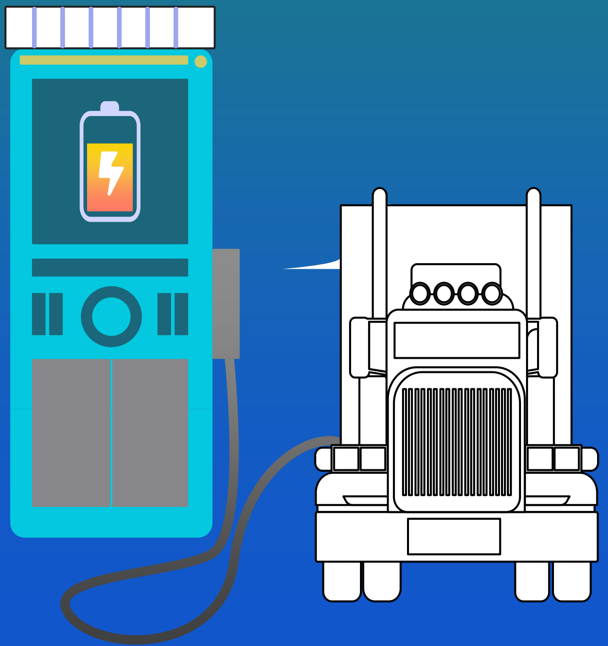
Our Cont.

We are studying the feasibility of using existing locations for charging station infrastructure to adopt fully electric semi-trucks.

Using the OD model, and the GIS analysis we will study the amount and locations of charging station infrastructure along U.S. roadways.

Main Focus

Does the U.S. have adequate charging infrastructure to adopt fully electric semi-trucks into its transportation ecosystem?

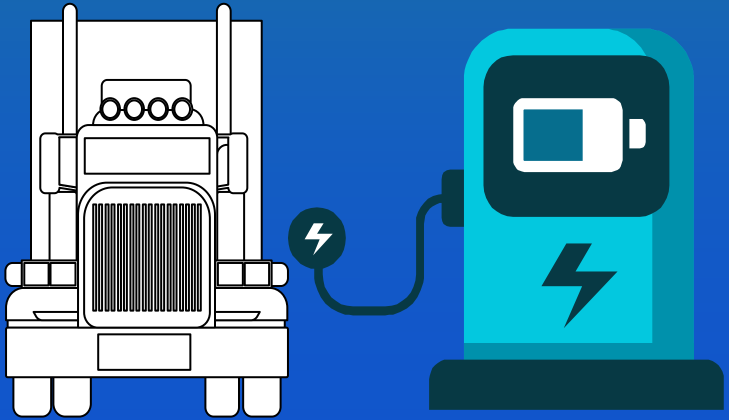


H1: Existing mega charging stations on U.S. roadways will support the transportation of fully-electric semi-trucks.

H2: Existing DC fast charging stations on U.S. roadways will support the transportation of fully-electric semi-trucks.

H3: Enhancing existing truck stops with mega charging stations on U.S. roadways will support the transportation of fully-electric semi-trucks.

Methodology



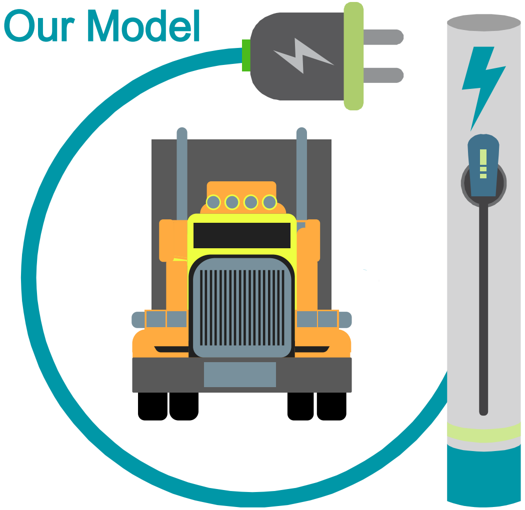
MILP

Mixed-Integer Linear Programming Model

In the model, binary variables are assigned to each arc in the superstructure expressing a scheduling decision concerning the execution of a task/changeover by an equipment unit.

**used by He, et. al. (2019)*

Our Model



<u>Definitions and Data Source</u>

CS: Charging stations

- Current mega charging station in U.S.
- Source: U.S. department of energy
- Link: Click here

OD: Origin Destinations data

- ODs for semi-trucks in U.S.
- Source: Federal Highway Administration
- Link: https://faf.ornl.gov/faf5/

$$\mathbf{Y} = \frac{\mathbf{CSx_{1\text{-}0} + CSx_{2\text{-}1} + CSx_{3\text{-}2} + CSx_{n\text{-}(n\text{-}1)}}}{\mathbf{(ODx_y/300)}} + \mathbf{e}$$

$\mathbf{ODx_y}$ = geographical distance between Origin-Destination (distance of each OD pair)

$\mathbf{CSx_{1\text{-}0}}$ = distance between origin and 1st charging station location

$\mathbf{CSx_{2\text{-}1}}$ = distance between 1st and 2nd charging station location

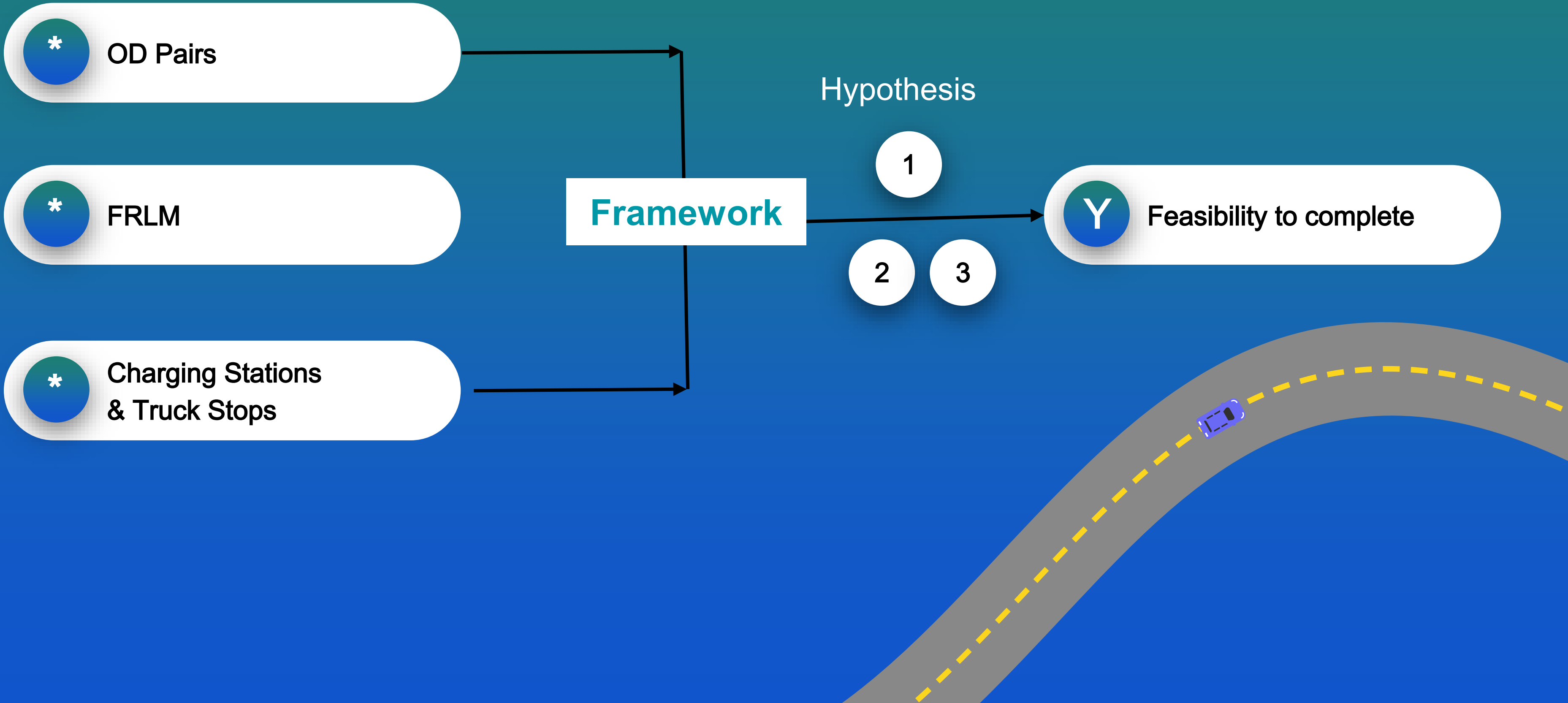
$\mathbf{CSx_{3\text{-}2}}$ = distance between 2nd and 3rd charging station location

$\mathbf{CSx_{n\text{-}(n\text{-}1)}}$ = distance between n^{th} and n^{n-1} charging station location

In current EV environment, **X** = 300 miles

Y = ability to complete OD pair with existing infrastructure

Conceptual Model



Variables

Type	Variable	Format	Data Set
Dependent Variable	● Ability to complete OD pair with existing charging station infrastructure *Binary variable	(Y/N) (1/0)	Calculated
Independent Variable	● Locations of charging stations ● Truck Stop Locations ● Distance between each charging station ● Origin Destination Pairs	Location Distance in Miles	Department of Energy Department of Transport Federal Highway Administration
Control Variable	● **Tonnage (weight of the cargo)** ● Value (U.S. dollars) ● Ton miles (1 ton carried 1 mile) cargo distance covered	Weight in tons Dollars Ton miles	Federal Highway Administration

QGIS: Geographic information system
A computer system that analyzes and displays geographically referenced information. It uses data that is attached to a unique location.

FRLM: Flow Refueling Location Model
to achieve even coverage with the minimum number of fast-charging stations along the roads.

OD: Origin Destination
Large haul ODs across the country.

CS: Charging Station
Existing Mega charging stations (to support electric semi-trucks)

Google MAPS API
Integrate locations, routes, given parameters to product customized results

AER All-electric range

1. Geographical terrain
2. Weather conditions
3. Temperature Hot & Cold
4. Traffic
5. Driver fatigue

Manufacturers claim 500 AER
Due to these factors, we conservatively use 300 AER

DATA SOURCES

OD Pairs

U.S. official records
Freight Analysis Framework

Federal Highway Administration

Source

FAF5.4.1 (2017) vs 2050

Charging Stations

Mega Chargers
DC Fast Chargers

U.S. Department of Energy

Source

February 2023

Truck Stops

Truck stops with federal regulations

U.S. Department of Transportation

Source

February 2023

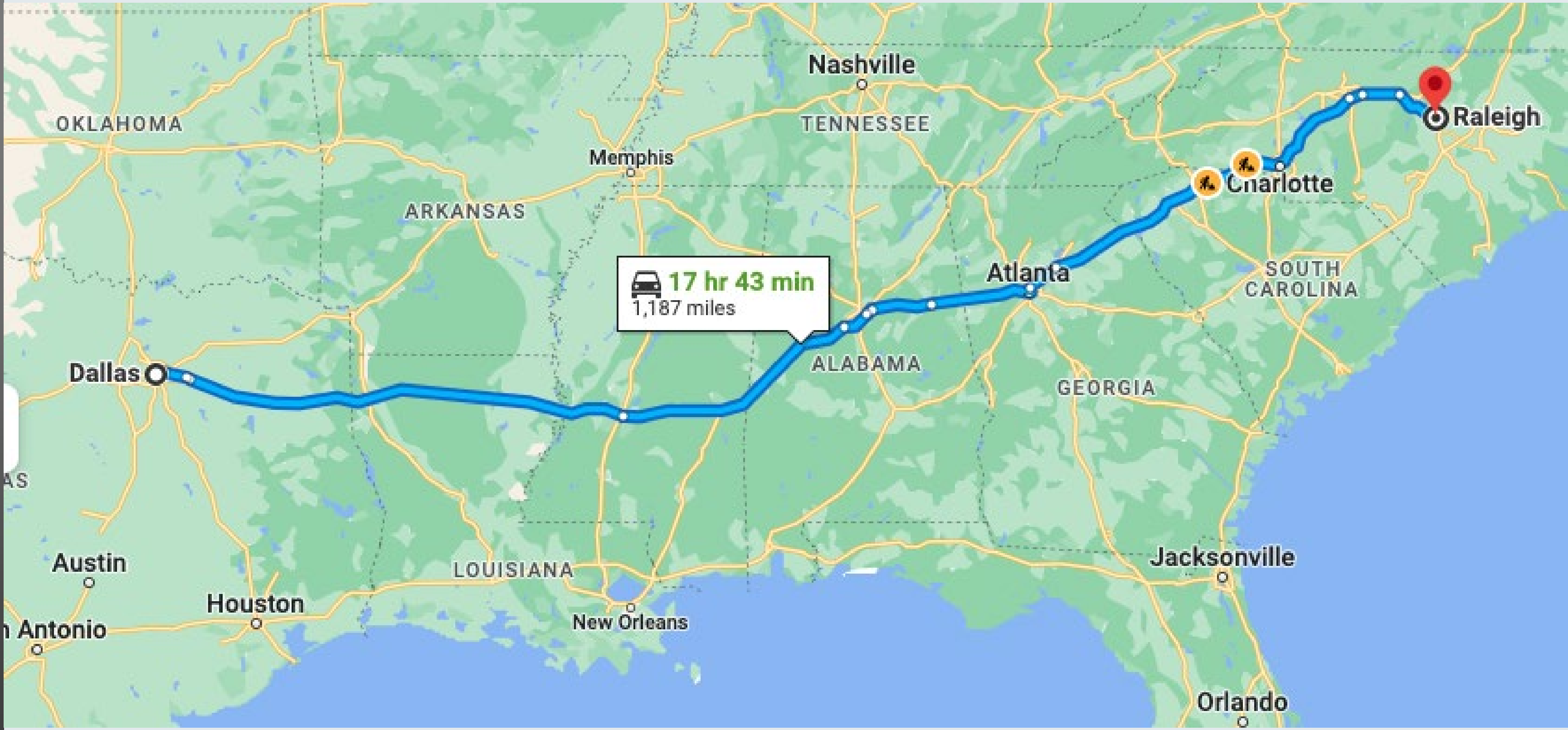
Table 3: OD routes in U.S. roadways. (Freight Analysis Framework from BTS and FHA, 2017).

	The number of Routes	Tonnage (in 1000s)
Total Population Truck Rail Water Air (include truck-air) Multiple modes & mail Pipeline Other and unknown No domestic mode	2,269,417	19,786,384
Restrict Mode = "Truck"	817,186	12,800,256
Distribution Band > 250 miles *also eliminates "origin=destination"	594,773	2,008,954
Eliminate "Rest of State" (no specific location) (Alaska & Hawaii also removed)	281,201	729590
Summation of all Commodity groups per OD pair (SCTG2) 42 groups and Summation of Domestic/Import/Export per domestic OD pair	6,392	729590
Population Dataset	**6,392**	729590

Dallas, TX to Raleigh, NC

Row 9 | OD route number: 484373 | Dallas, TX to Raleigh, NC

Mega Charger



Row 9 | OD route number: 484373 | Dallas, TX to Raleigh, NC

Mega Charger

$\mathbf{ODx_y}$ = geographical distance between Origin-Destination = **1,190 miles**

$\mathbf{MGCx_{1\text{-}0}}$ = distance between origin and 1st charging station. **within 300 miles? then $CSx_{1\text{-}0} = 0$**

$\mathbf{MGCx_{2\text{-}1}}$ = distance between 1st and 2nd charging station. **within 300 miles? then $CSx_{2\text{-}1} = 0$**

$\mathbf{MGCx_{3\text{-}2}}$ = distance between 2nd and 3rd charging station. **within 300 miles? then $CSx_{3\text{-}2} = 0$**

$\mathbf{MGCx_{D\text{-}3}}$ = distance between 3rd and destination location. **within 300 miles? then $CSx_{D\text{-}3} = 0$**

$$Y = \frac{MGCx_{1\text{-}0} + MGCx_{2\text{-}1} + MGCx_{3\text{-}2} + MGCx_{D\text{-}3}}{ODx_y/300}$$

$$Y = \frac{0 + 0 + 0 + 0}{1190/300} = \frac{0}{3.96} = 0$$

Y = 0.75 (means Y < 1, means route is NOT operable)

*IF route is not operable, then, **Y = 0***

Row 9 | OD route number: 484373 | Dallas, TX to Raleigh, NC

DC fast charger

dallas

raleigh

Electric

Charger Types: DC Fast

Connectors: All

Find Stations

Show stations within 2 miles of the route

110 stations along the route

See Route Directions

Download list of stations on route

Fuel City Dallas - Tesla Supercharger
801 S Riverfront Blvd
Dallas, TX 75207
DC Fast

1.0 mi from route

Row 9 | OD route number: 484373 | Dallas, TX to Raleigh, NC

DC fast charger

$\mathbf{ODx_y}$ = geographical distance between Origin-Destination = **1,190 miles**

$\mathbf{CGSx_{1\text{-}0}}$ = distance between origin and 1st charging station. **within 300 miles? then $CSx_{1\text{-}0} = 1$**

$\mathbf{CGSx_{2\text{-}1}}$ = distance between 1st and 2nd charging station. **within 300 miles? then $CSx_{2\text{-}1} = 1$**

$\mathbf{CGSx_{3\text{-}2}}$ = distance between 2nd and 3rd charging station. **within 300 miles? then $CSx_{3\text{-}2} = 0$**

$\mathbf{CGSx_{D\text{-}3}}$ = distance between 3rd and destination location. **within 300 miles? then $CSx_{D\text{-}3} = 1$**

$$Y = \frac{CGSx_{1\text{-}0} + CGSx_{2\text{-}1} + CGSx_{3\text{-}2} + CGSx_{D\text{-}3}}{ODx_y/300}$$

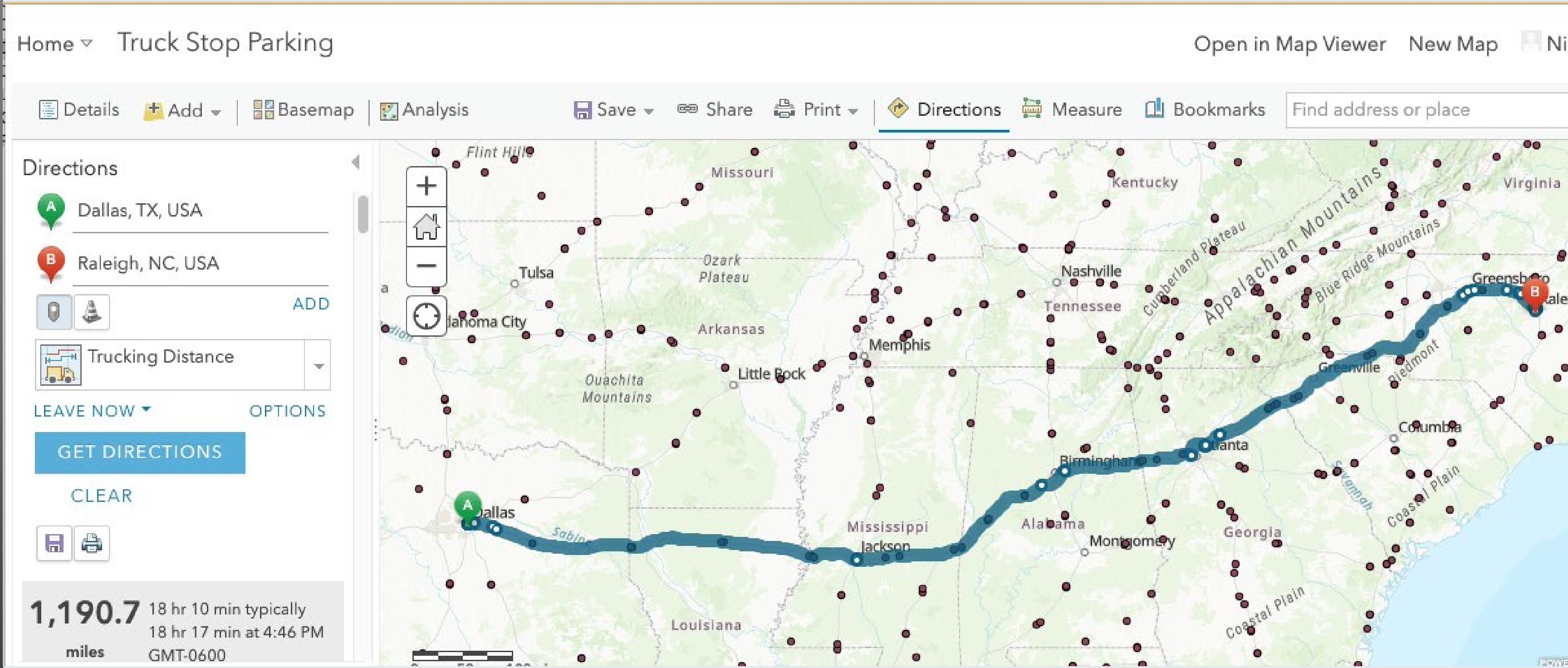
$$Y = \frac{1 + 1 + 0 + 1}{1190/300} = \frac{3}{3.96} = 0.75$$

Y = 0.75 (means Y < 1, means route is NOT operable)

IF route is not operable, then, Y = 0

Row 9 | OD route number: 484373 | Dallas, TX to Raleigh, NC

Truck Stops



Truck Stops

ODx_y = geographical distance between Origin-Destination = **1,190 miles**

$TRSx_{1\text{-}0}$ = distance between origin and 1st truck stop. **within 300 miles? then $CSx_{1\text{-}0} = 0$**

$TRSx_{2\text{-}1}$ = distance between 1st and 2nd truck stop. **within 300 miles? then $CSx_{2\text{-}1} = 1$**

$TRSx_{3\text{-}2}$ = distance between 2nd and 3rd truck stop. **within 300 miles? then $CSx_{3\text{-}2} = 1$**

$TRSx_{D\text{-}3}$ = distance between 3rd truck stop and destination. **within 300 miles? then $CSx_{D\text{-}3} = 1$**

$$Y = \frac{TRSx_{1\text{-}0} + TRSx_{2\text{-}1} + TRSx_{3\text{-}2} + TRSx_{D\text{-}3}}{ODx_y/300}$$

$$Y = \frac{0 + 1 + 1 + 1}{1190/300} = \frac{3}{3.96} = 0.75$$

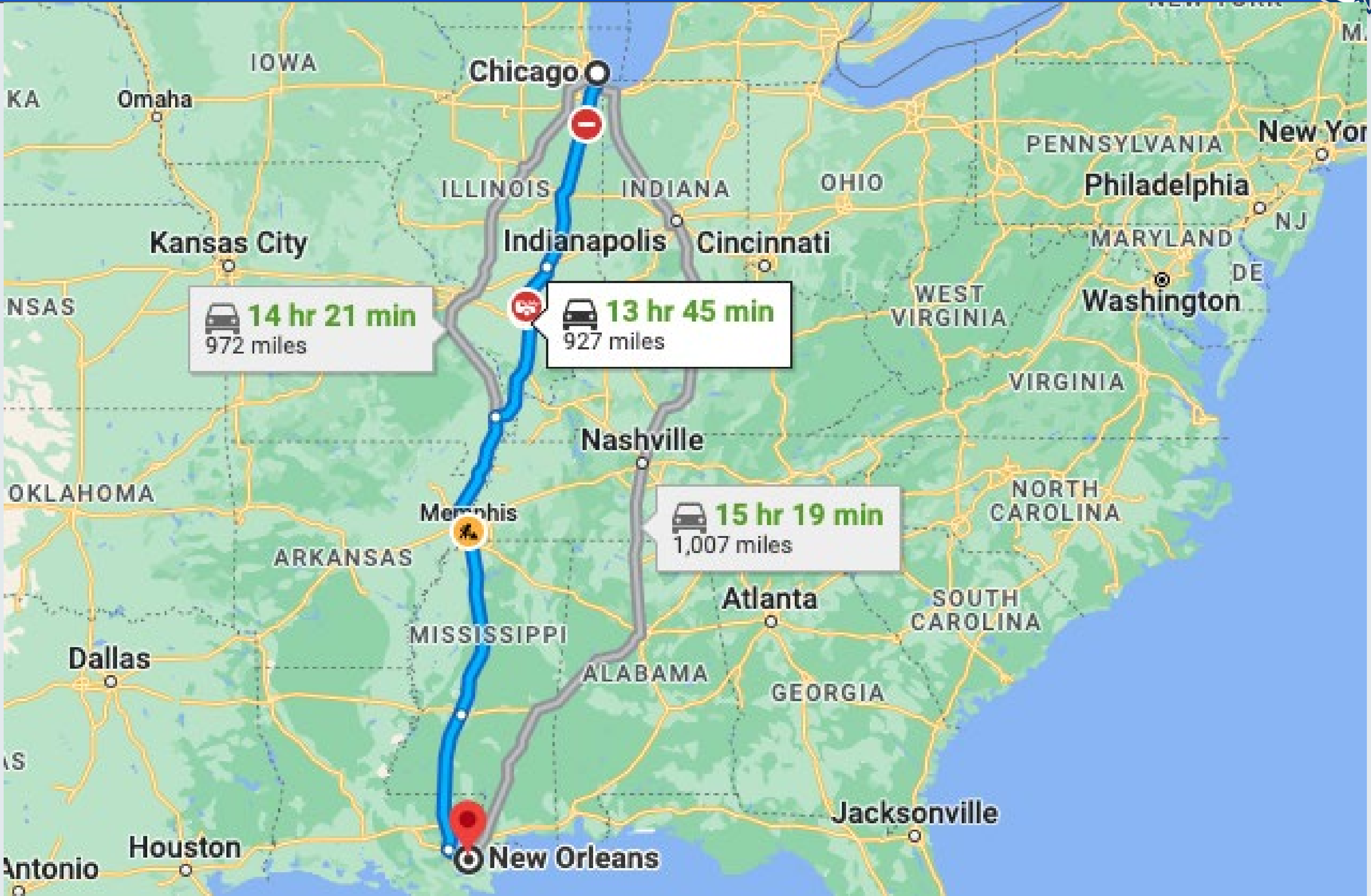
Y = 0.75 (means Y < 1, means route is NOT operable)

*IF route is NOT operable, then, **Y = 0***

Chicago, IL to New Orleans, LA

Row 10 | OD route number: 171223 | Chicago, IL to New Orleans, LA

Mega Charger



Row 10 | OD route number: 171223 | Chicago, IL to New Orleans, LA

Mega Charger

ODx_y = geographical distance between Origin-Destination = **926 miles**

$MGCx_{1\text{-}0}$ = distance between origin and 1st charging station. **within 300 miles? then $CSx_{1\text{-}0} = 0$**

$MGCx_{2\text{-}1}$ = distance between 1st and 2nd charging station. **within 300 miles? then $CSx_{2\text{-}1} = 0$**

$MGCx_{3\text{-}2}$ = distance between 2nd and 3rd charging station. **within 300 miles? then $CSx_{3\text{-}2} = 0$**

$MGCx_{D\text{-}3}$ = distance between 3rd and destination location. **within 300 miles? then $CSx_{D\text{-}3} = 0$**

$$Y = \frac{MGCx_{1\text{-}0} + MGCx_{2\text{-}1} + MGCx_{3\text{-}2} + MGCx_{D\text{-}3}}{ODx_y/300}$$

$$Y = \frac{0 + 0 + 0 + 0}{926/300} = \frac{0}{3.08} = 0$$

Y = 0 (means Y < 1, means route is not operable)

*IF route is NOT operable, then, **Y = 0***

Row 10 | OD route number: 171223 | Chicago, IL to New Orleans, LA

DC fast charger

chicago

new orleans

Electric

Charger Types: DC Fast

Connectors: All

Show stations within 2 miles of the route

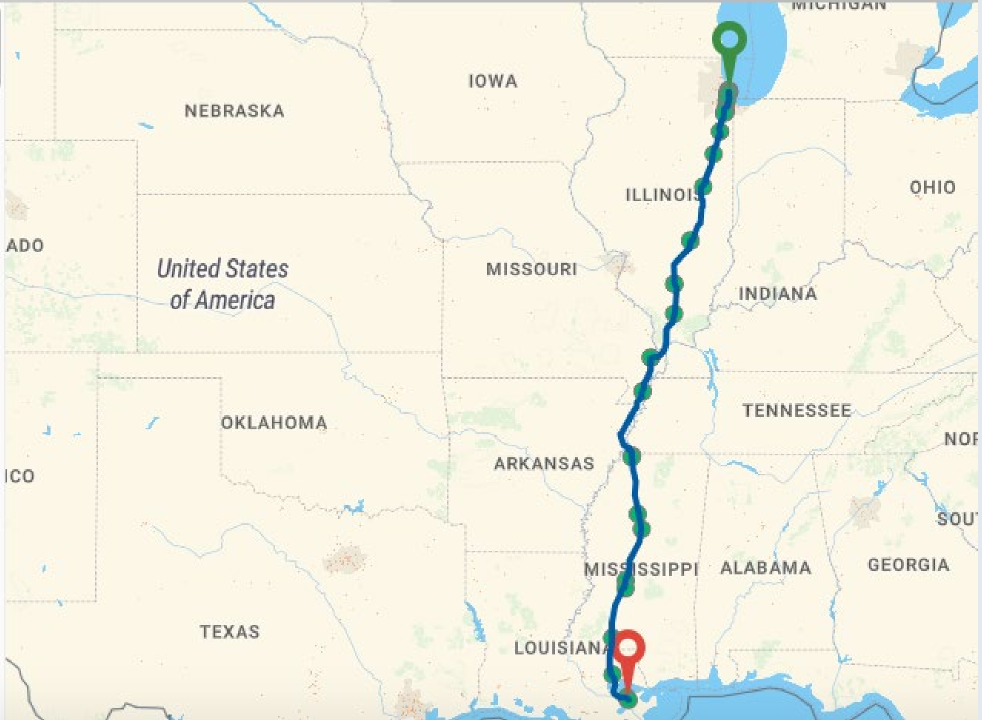
38 stations along the route

See Route Directions

Download list of stations on route

The Aqua at Lakeshore East - Tesla Supercharger
225 North Columbus Drive
Chicago, IL 60601
DC Fast
0.7 mi from route

Water Tower Place DCFC



Row 10 | OD route number: 171223 | Chicago, IL to New Orleans, LA

DC fast charger

ODx_y = geographical distance between Origin-Destination = **926 miles**

$CGSx_{1\text{-}0}$ = distance between origin and 1st charging station. **within 300 miles? then $CSx_{1\text{-}0}$ = 1**

$CGSx_{2\text{-}1}$ = distance between 1st and 2nd charging station. **within 300 miles? then $CSx_{2\text{-}1}$ = 1**

$CGSx_{3\text{-}2}$ = distance between 2nd and 3rd charging station. **within 300 miles? then $CSx_{3\text{-}2}$ = 1**

$CGSx_{D\text{-}3}$ = distance between 3rd and destination location. **within 300 miles? then $CSx_{D\text{-}3}$ = 1**

$$Y = \frac{CGSx_{1\text{-}0} + CGSx_{2\text{-}1} + CGSx_{3\text{-}2} + CGSx_{D\text{-}3}}{ODx_y/300}$$

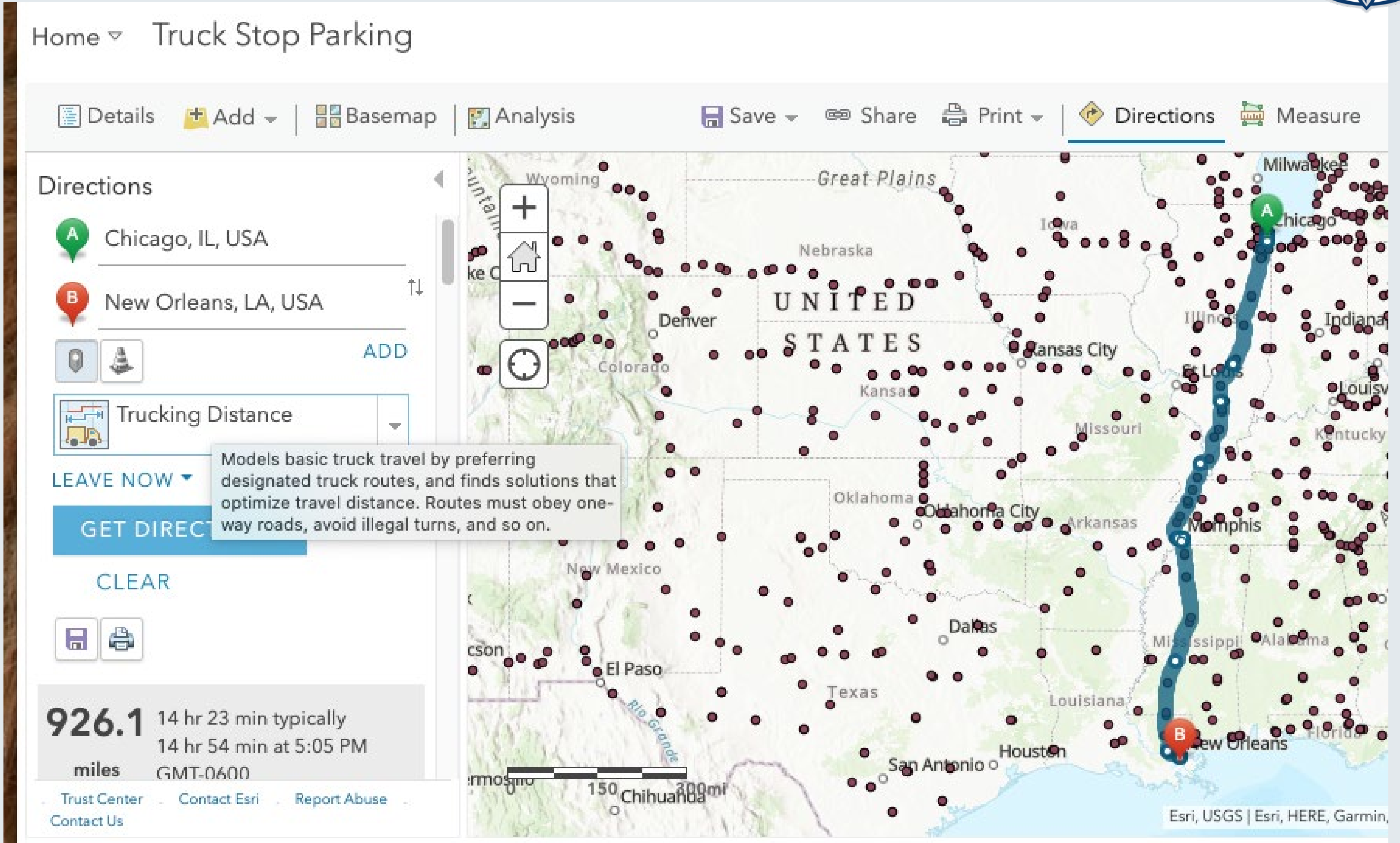
$$Y = \frac{1 + 1 + 1 + 1}{926/300} = \frac{4}{3.08} = 1.29$$

Y = 1.29 (means Y ≥ 1, means route is operable)

*IF route is operable, then, **Y = 1***

Row 10 | OD route number: 171223 | Chicago, IL to New Orleans, LA

Truck Stops



Truck Stops

ODx_y = geographical distance between Origin-Destination = **926 miles**

$TRSx_{1\text{-}0}$ = distance between origin and 1st truck stop. **within 300 miles? then $CSx_{1\text{-}0} = 1$**

$TRSx_{2\text{-}1}$ = distance between 1st and 2nd truck stop. **within 300 miles? then $CSx_{2\text{-}1} = 1$**

$TRSx_{3\text{-}2}$ = distance between 2nd and 3rd truck stop. **within 300 miles? then $CSx_{3\text{-}2} = 1$**

$TRSx_{D\text{-}3}$ = distance between 3rd and truck stop. **within 300 miles? then $CSx_{D\text{-}3} = 1$**

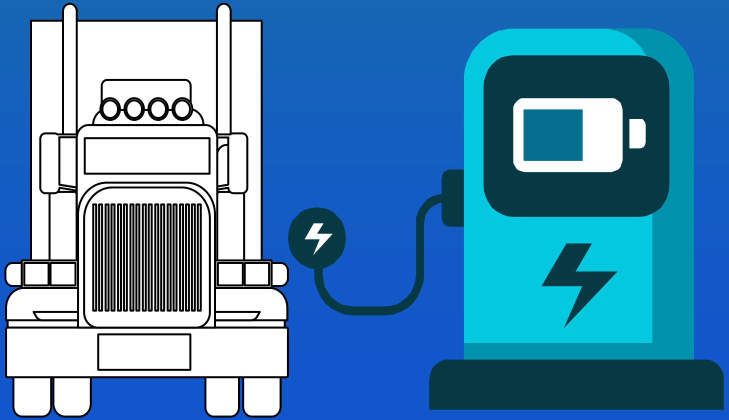
$$Y = \frac{TRSx_{1\text{-}0} + TRSx_{2\text{-}1} + TRSx_{3\text{-}2} + TRSx_{D\text{-}3}}{ODx_y/300}$$

$$Y = \frac{1 + 1 + 1 + 1}{926/300} = \frac{4}{3.08} = 1.29$$

Y = 1.29 (means $Y \geq 1$, means route is operable)

*IF route is operable, then, **Y = 1***

Results



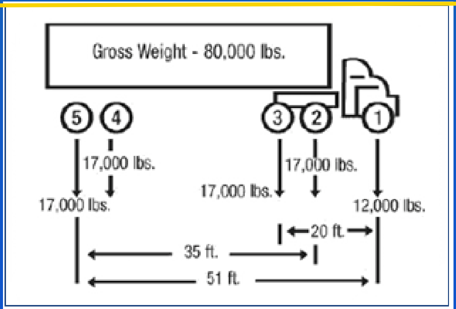
Tonnage Carried by trucks by FAF

U.S. DOT

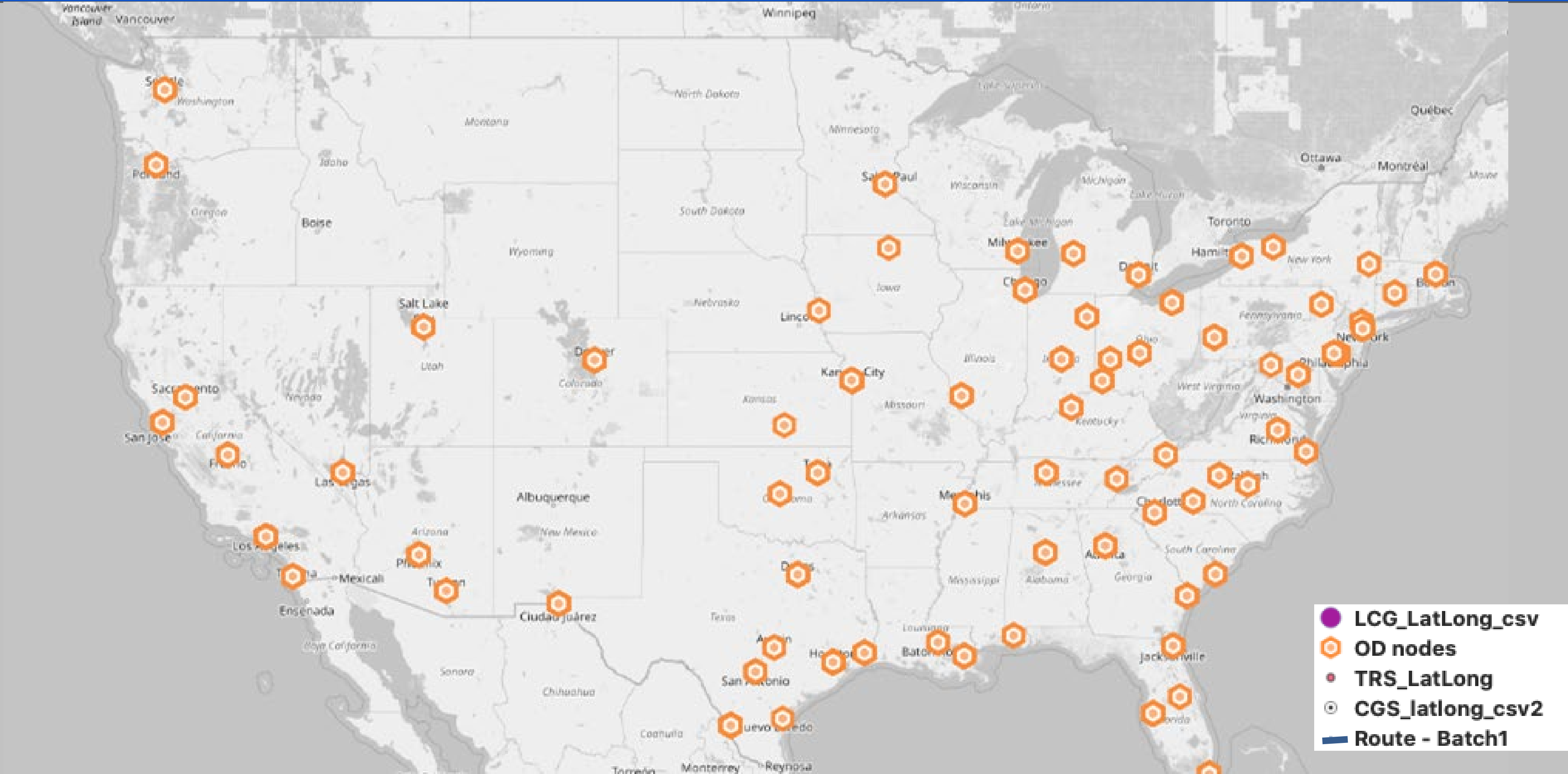
45,000 lbs
(22.5 tons)

35,000 lbs
(17.5 tons)

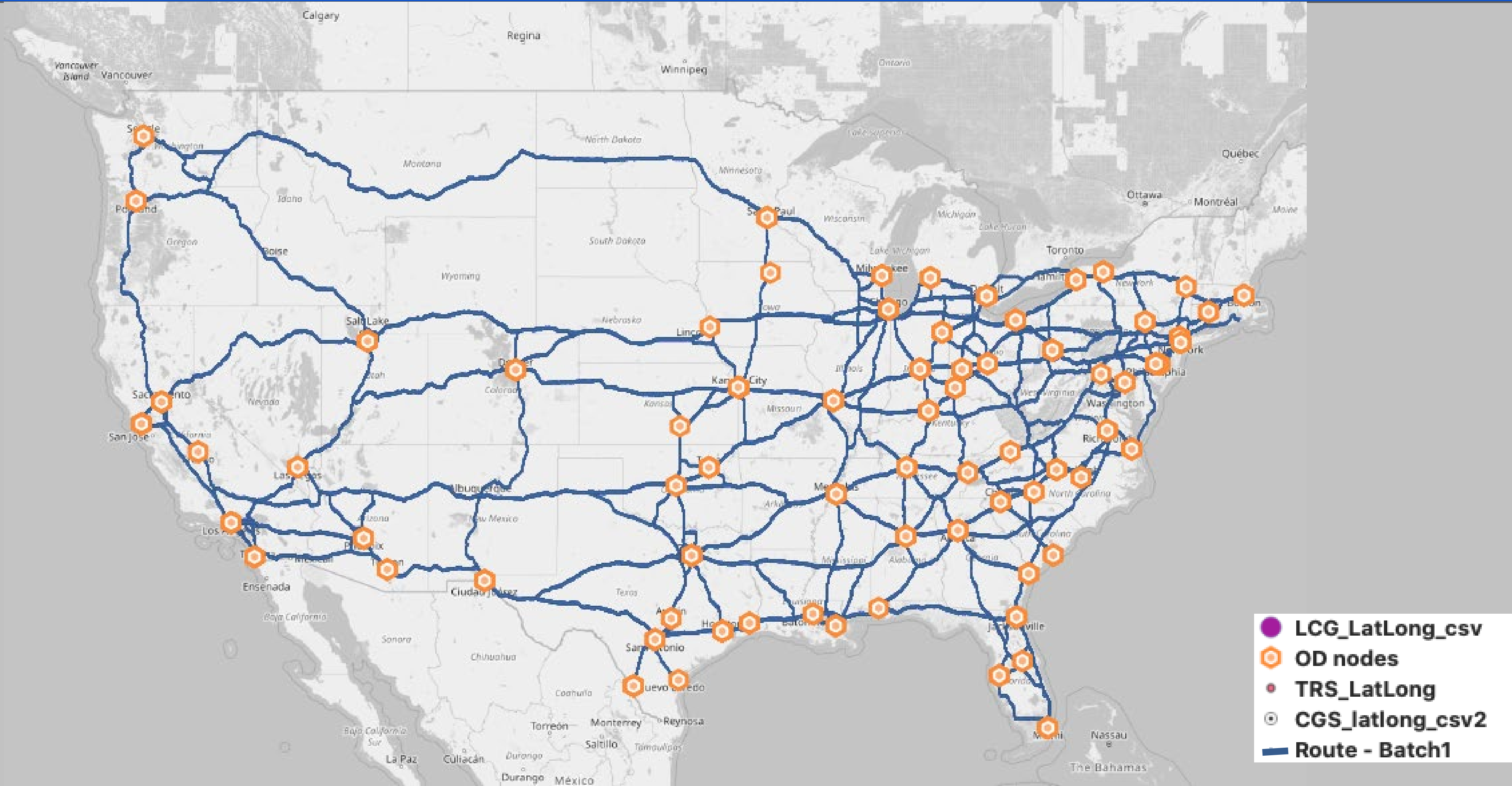
Federal Limit
80,000 lbs
(40 tons)



OD Points


LCG_LatLong_csv
OD nodes
TRS_LatLong
CGS_latlong_csv2
Route - Batch1

OD Points


Calgary
Regina
Winnipeg
Vancouver
Québec
Ottawa
Montréal
Toronto
North Dakota
Montana
Minnesota
Idaho
Wisconsin
Michigan
Oregon
South Dakota
Boise
Wyoming
Iowa
Nebraska
Salt Lake
Kansas City
Missouri
Nevada
Colorado
Illinois
Kentucky
West Virginia
Washington
San Jose
North Carolina
New Mexico
Albuquerque
Texas
Ensenada
Ciudad Juárez
Sonora
Chihuahua
Coahuila
Torreón
Monterrey
Reynosa
Saltillo
La Paz
Culiacán
Durango
México
Nassau
The Bahamas
LCG_LatLong_csv
OD nodes
TRS_LatLong
CGS_latlong_csv2
Route - Batch1

Mega Charging Stations

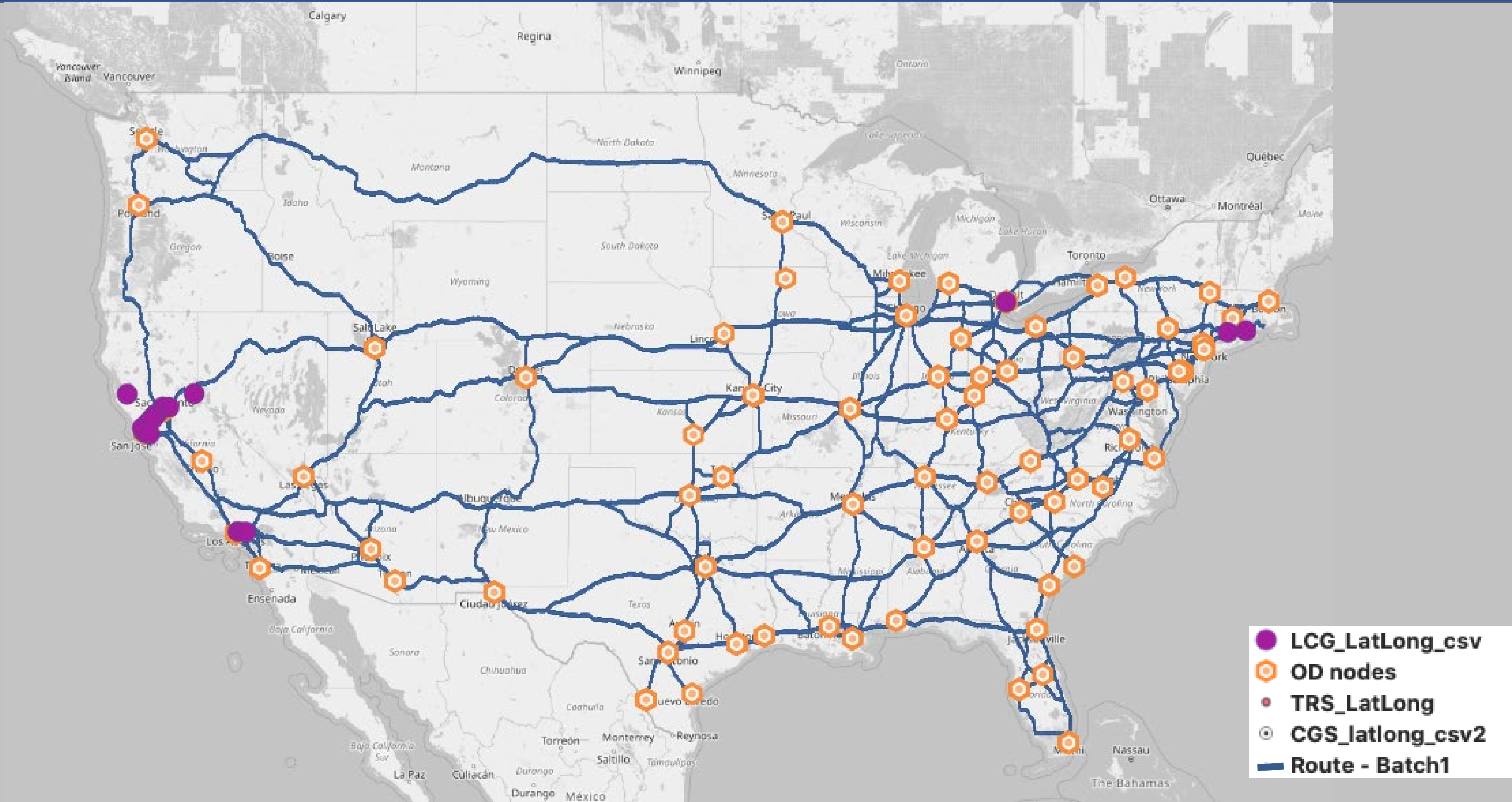
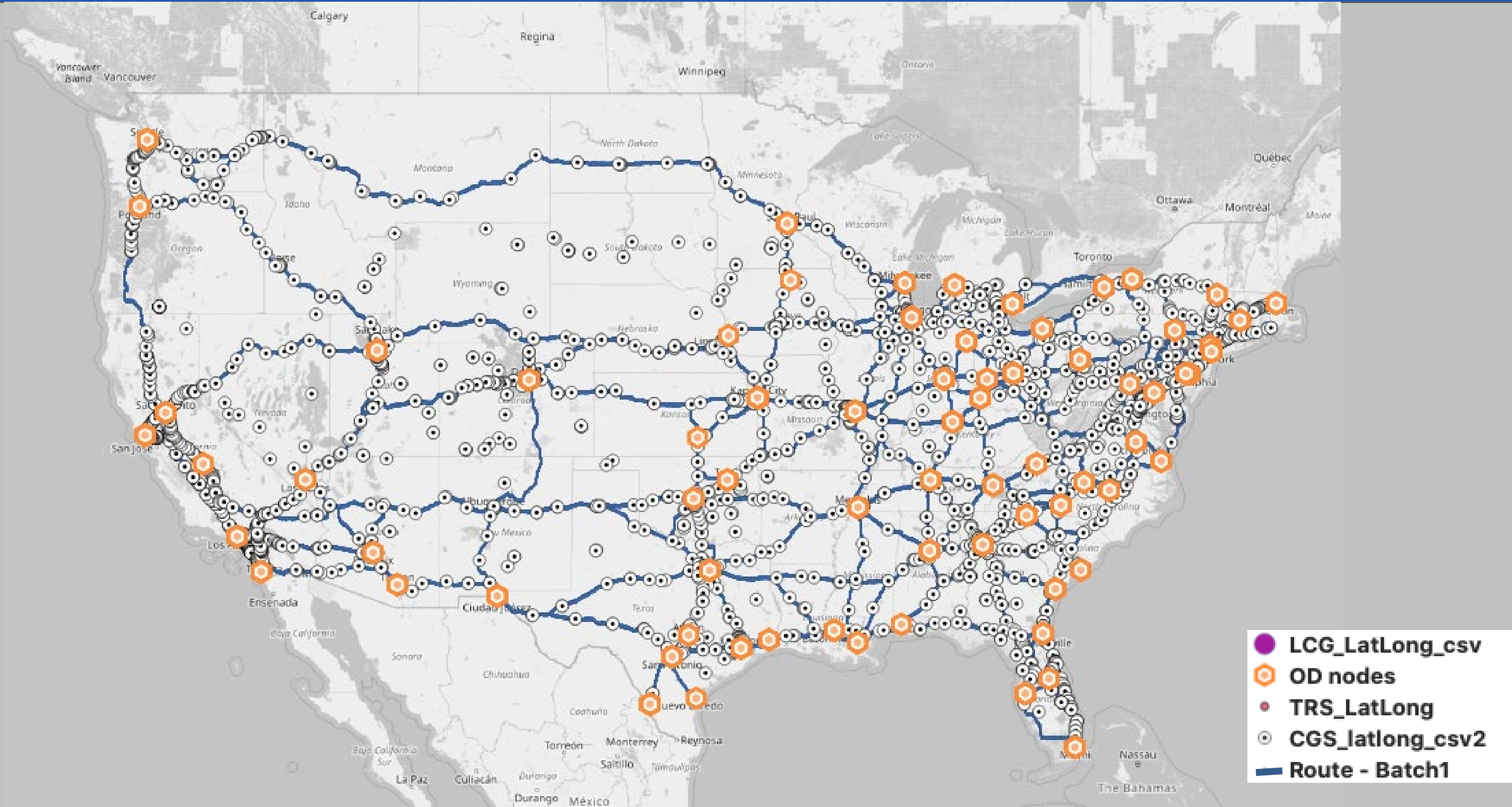


Table 5: DC Fast Charging Station Locations
(Alternative Fuels Data Center from U.S. Department of Energy, Feb 2023).

Type of station	Number of stations
All alternate fuel	58,835
All levels of electric chargers	51,073
DC fast only	6,931
2 or more EVSE	3,016
Total	3,016

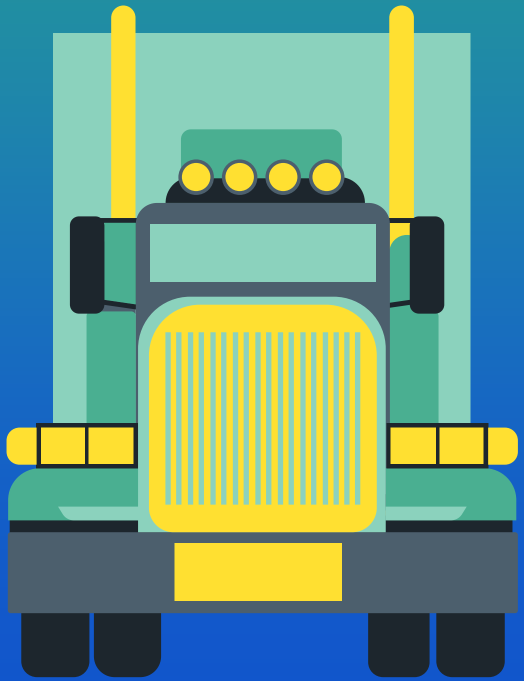
DC Fast Charging Stations



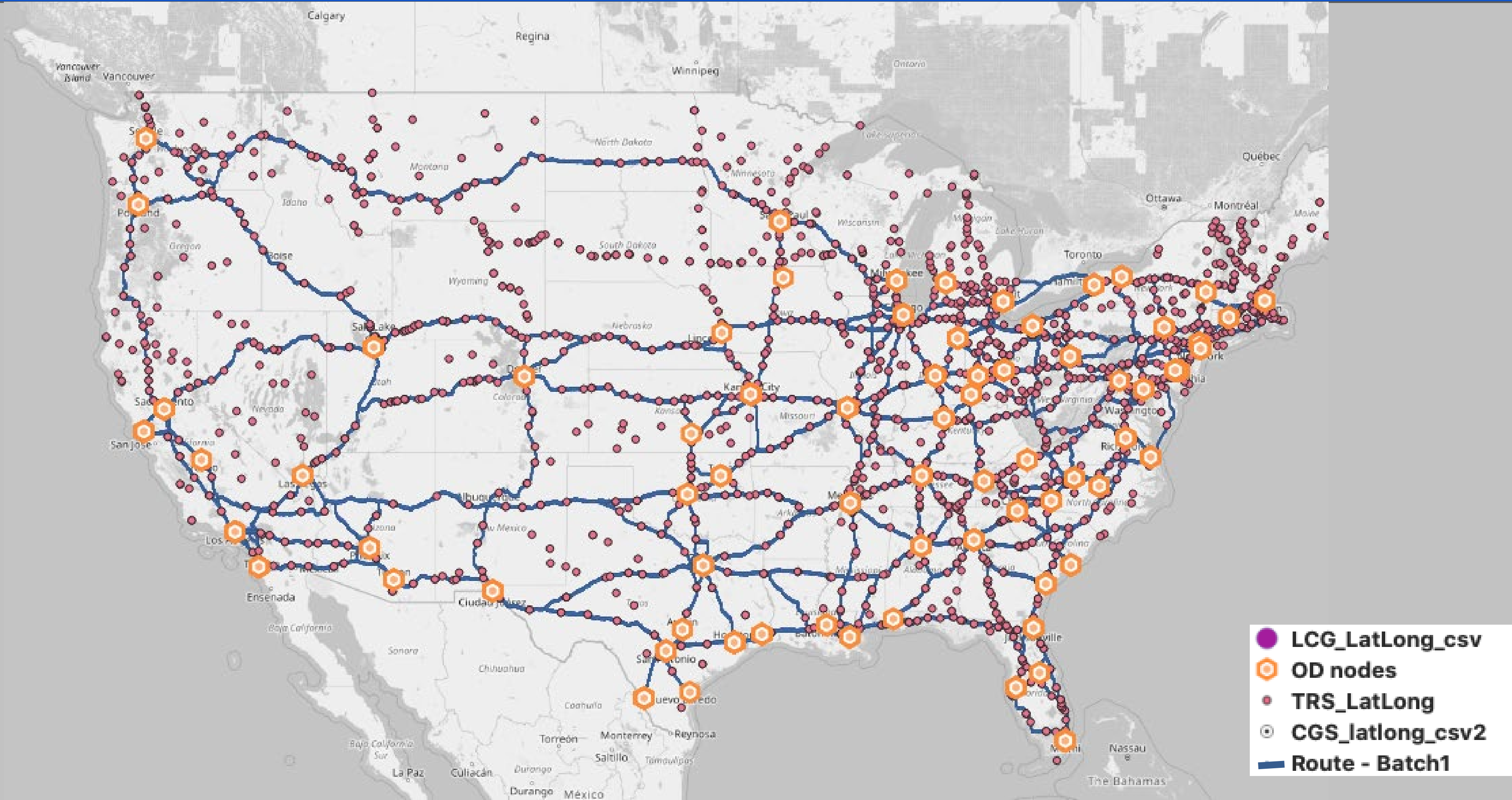
Jason's Law required the USDOT to conduct a survey and comparative assessment in consultation with relevant State motor carrier representatives to:

Truck Stops	Number of locations
All of U.S.	1,916

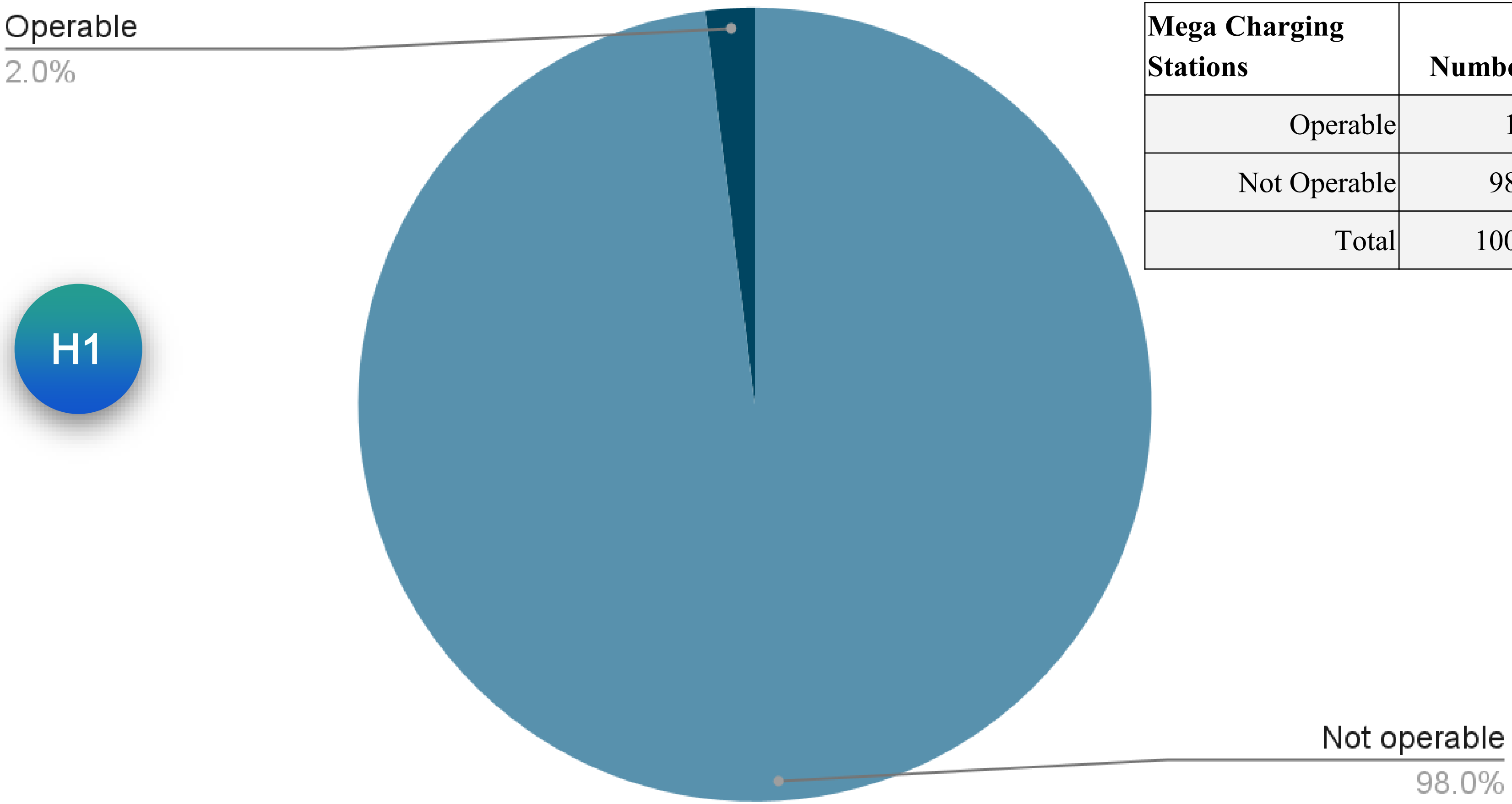
1. Evaluate the capability of the State to provide adequate parking and rest facilities for commercial motor vehicles engaged in interstate transportation;
2. Assess the volume of commercial motor vehicle traffic in the State;
3. Develop a system of metrics to measure the adequacy of commercial motor vehicle parking facilities in the State.



Truck Stops


Calgary
Regina
Winnipeg
Vancouver
Ontario
North Dakota
Minnesota
Montana
Idaho
Oregon
Boise
Wyoming
South Dakota
Nebraska
Wisconsin
Michigan
Québec
Ottawa
Montréal
Toronto
Nevada
Colorado
Kansas
Missouri
San Jose
Ensenada
Baja California
Sonora
Chihuahua
Coahuila
Torreón
Monterrey
Reynosa
Saltillo
Tamaulipas
La Paz
Culiacán
Durango
México
Nassau
The Bahamas
LCG_LatLong_csv
OD nodes
TRS_LatLong
CGS_latlong_csv2
Route - Batch1

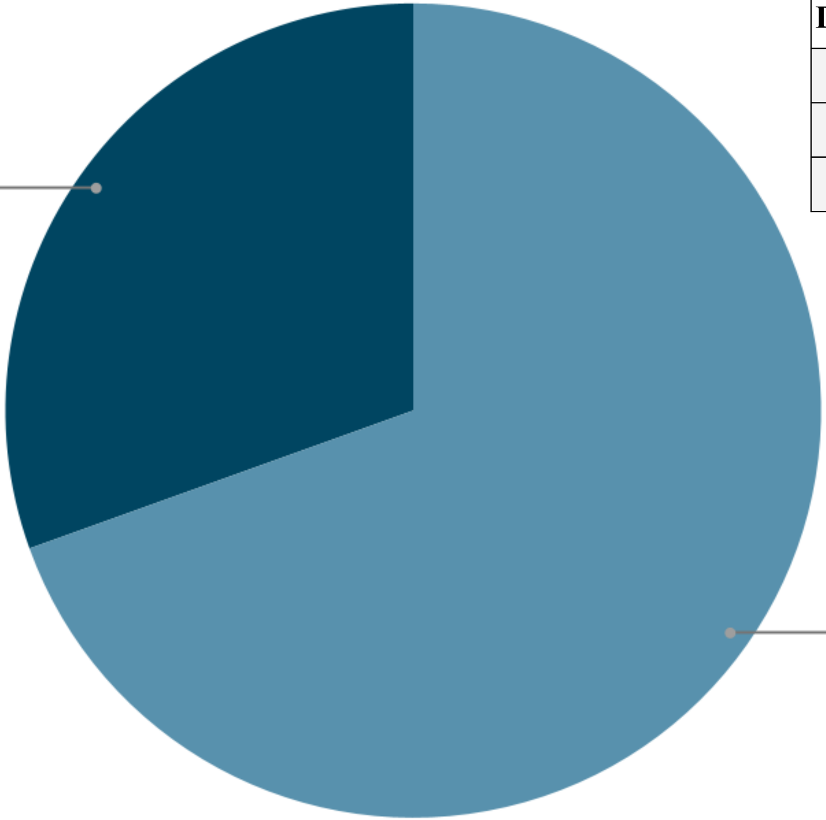
Mega Charging Station Feasibility



Mega Charging Stations	Number	Percent
Operable	16	2%
Not Operable	984	98%
Total	1000	

H1

DC Fast Charging Stations

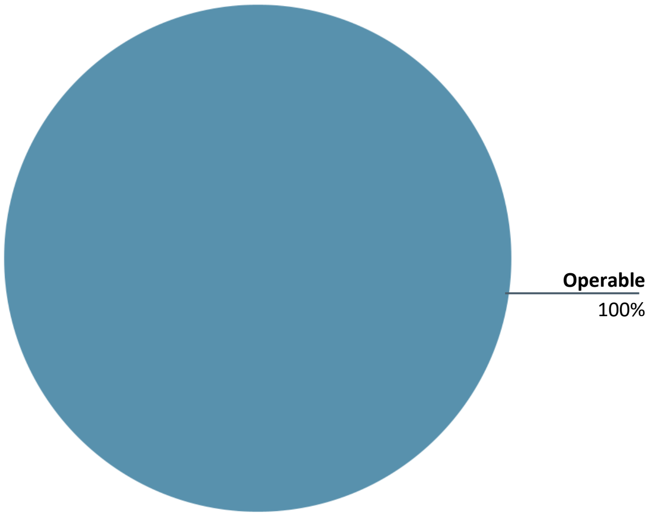


DC Charging Stations	Number	Percent
Operable	695	69.5%
Not Operable	305	30.5%
Total	1000	

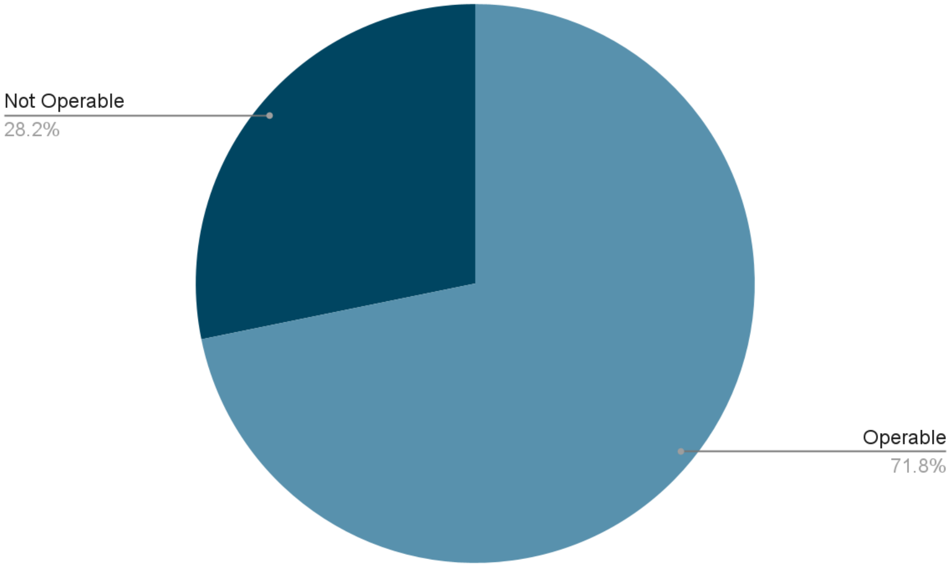
H2

H3

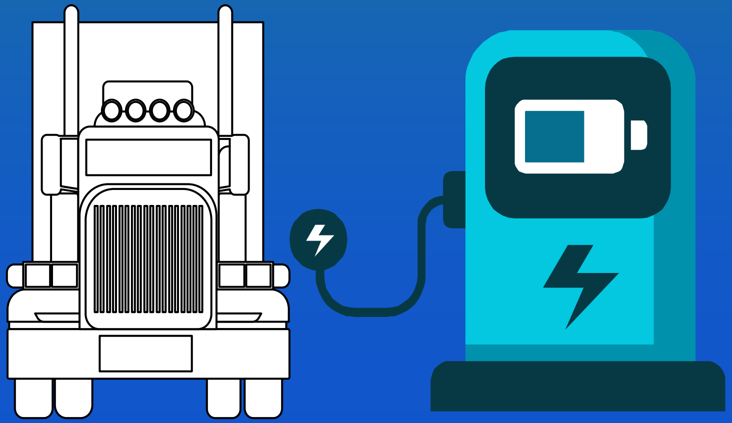
Truck Stops in route		
Operable	1000	100%
Not Operable	0	0%



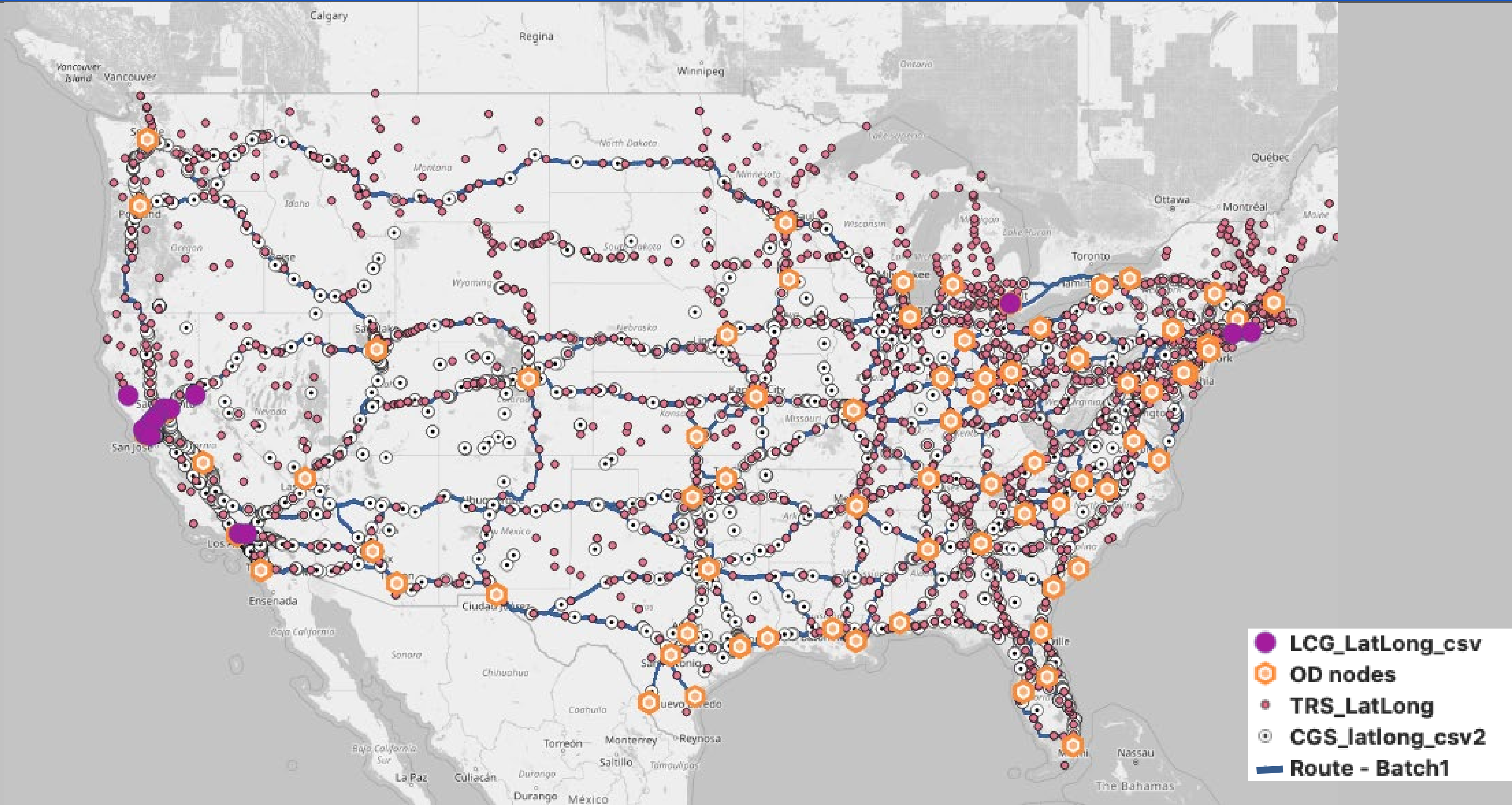
Truck Stops at Origin		
Operable	718	72%
Not Operable	282	28%
Total	1000	



Discussion



All points together

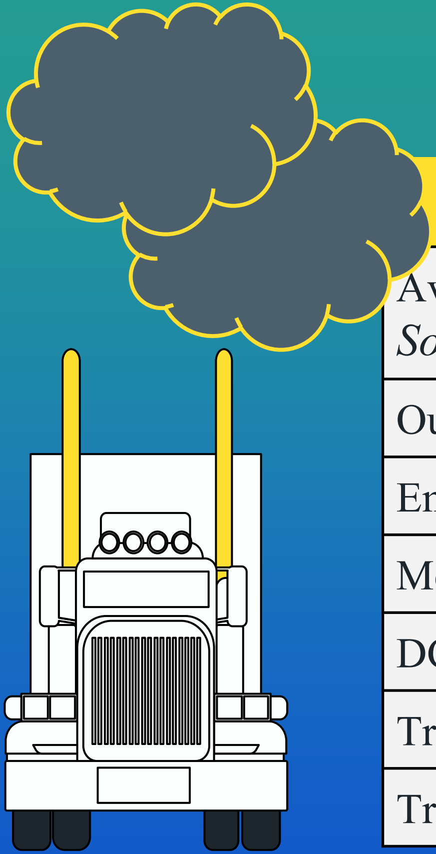


Hypothesis	Station	Feasibility	Support	Remarks
Hypothesis 1	Mega Charging station	2%	Not supported	There are **not** enough mega charging stations to complete the OD routes.
Hypothesis 2	DC fast charging station	69.5%	**Supported**	Existing DC fast charging stations can support majority of the OD routes. But low charging capacity.
Hypothesis 3	Truck stop	100% (in-route) 72% (origin)	**Supported**	Converting truck stops in-route makes it 100% feasible. Truck stop location at the origin feasibility 72%.

Truck Loads

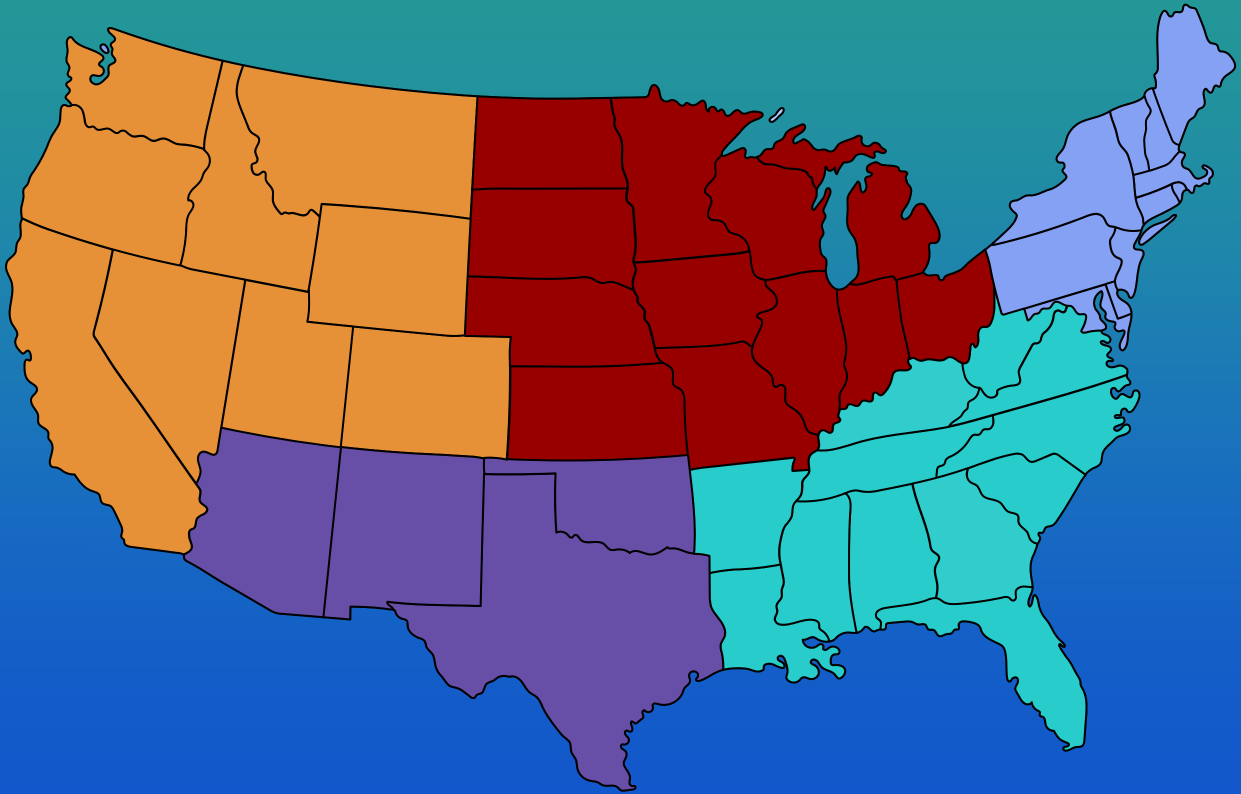
Description	OD routes	Truck Loads
Total	1,000 routes	26264485
Mega Chargers	17 routes (2%)	1204443 (5%)
DC fast chargers	695 routes (69.5%)	20920848 (80%)
Truck Stop in route	1000 routes (100%)	26264485 (100%)
Truck Stop at origin factor	718 routes (72%)	14194800 (54%)

Emissions



Description	Emission
Average freight truck in the U.S. emits *Source: Environmental Defense Fund*	161.8 grams of CO_2 per ton-mile.
Our sample 1000 route ton miles	415748347304 ton miles
Emissions (Metric Tons)	67268082 metric tons
Mega Chargers	1346432 (2%)
DC fast chargers	36804676 metric tons (54.7%)
Truck Stop in route	67268082 metric tons (100%)
Truck stop origin factor	36243143 metric tons (54%)

Feasibility by regions



SOUTHEAST

Washington DC, Georgia, North Carolina
South Carolina, Virginia, West Virginia
Kentucky, Tennessee, Mississippi, Alabama
Delaware, Maryland, Florida, Louisiana, Arkansas

NORTHEAST

Massachusetts, Rhode Island
Connecticut, Vermont, New Hampshire,
Maine, Pennsylvania, New Jersey, New York

SOUTHWEST

New Mexico, Arizona, Oklahoma, Texas

MIDWEST

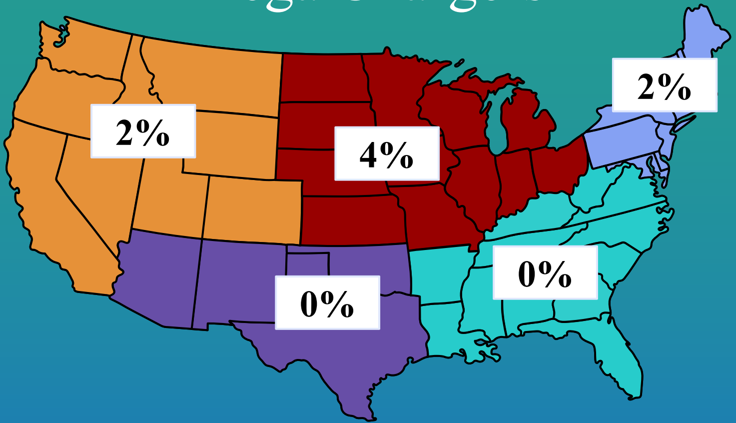
Minnesota, Wisconsin, Illinois, Ohio, Indiana
Michigan, Missouri, Iowa, Kansas, Nebraska
North Dakota, South Dakota

WEST

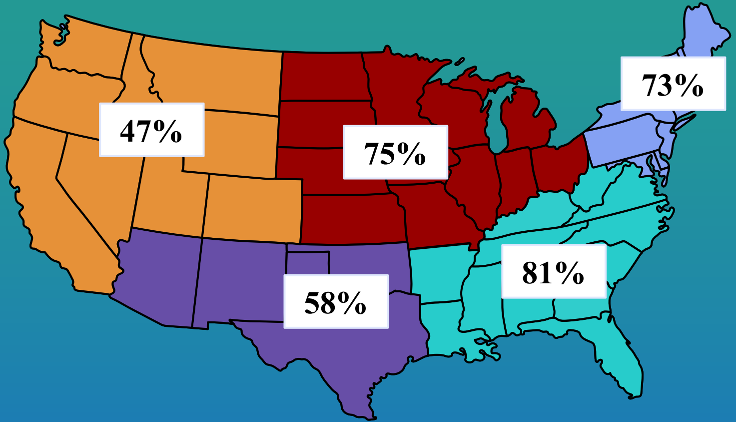
California, Colorado, Nevada, Hawaii, Alaska
Oregon, Utah, Idaho, Montana, Wyoming,
Washington

Origin location in that region, to everywhere

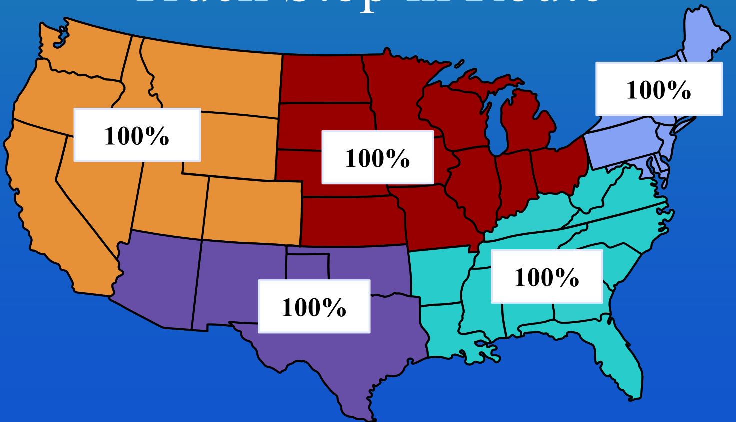
Mega Chargers



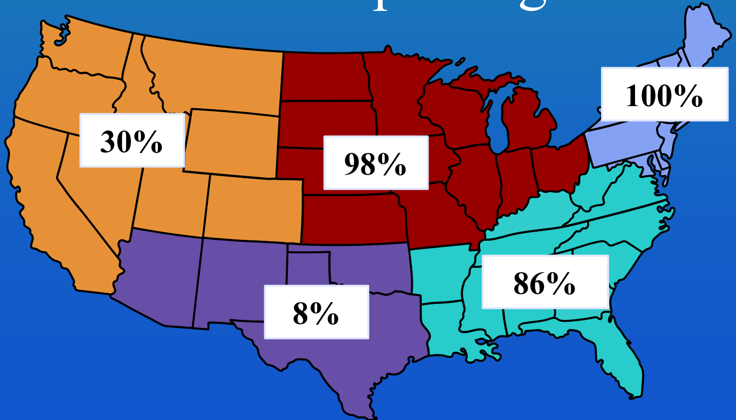
DC Fast

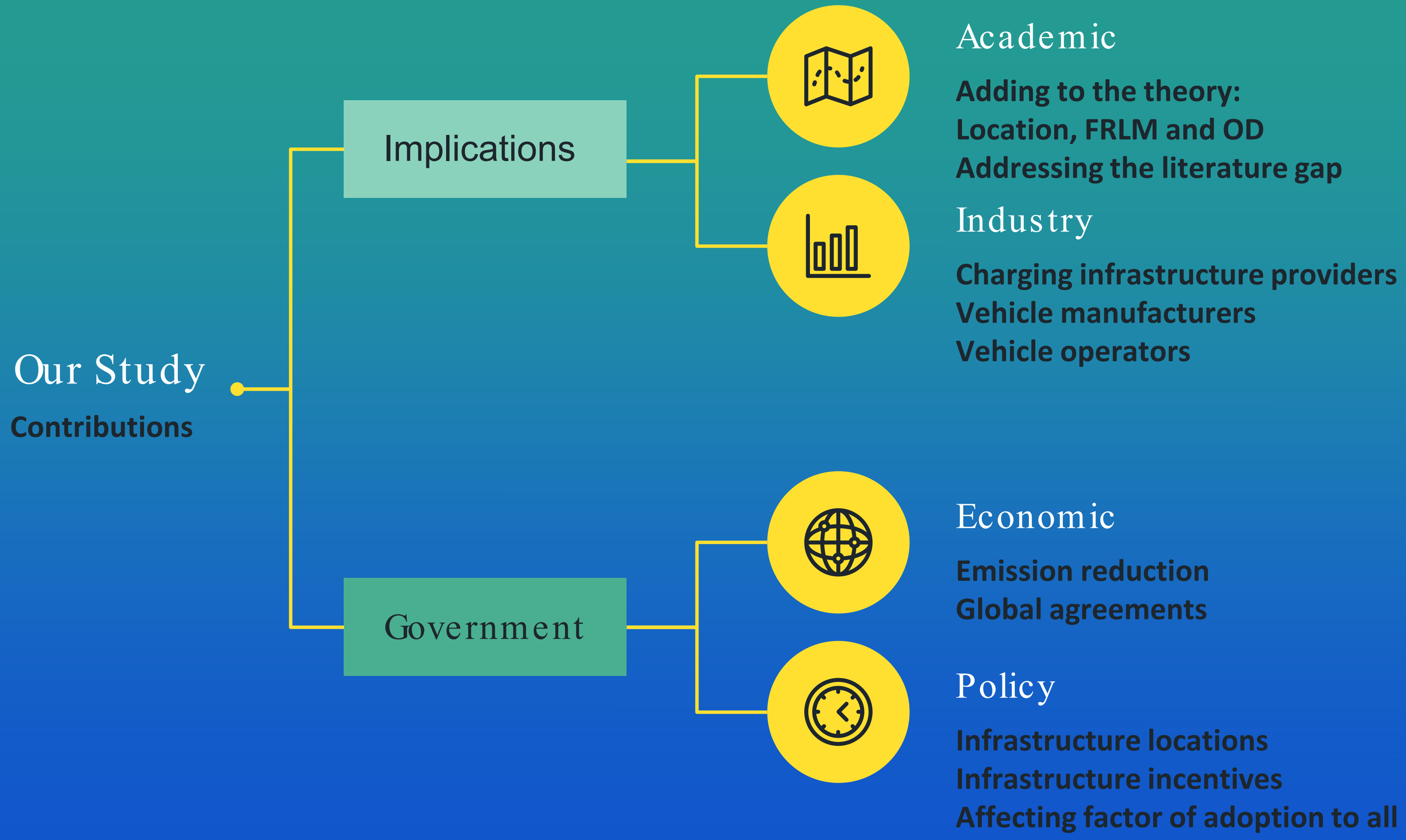


Truck Stop in Route



Truck Stops Origin




Our Study
Contributions
Implications
Academic
Adding to the theory:
Location, FRLM and OD
Addressing the literature gap
Industry
Charging infrastructure providers
Vehicle manufacturers
Vehicle operators
Government
Economic
Emission reduction
Global agreements
Policy
Infrastructure locations
Infrastructure incentives
Affecting factor of adoption to all

Limitations

Projection Tonnage

We used 2017 dataset
2050 Dataset from FAF (same OD, tonnage doubled)

Mile Range

AER 300 miles
AER may increase

Mega chargers

In construction not included

DC Fast charger theory only

Takes 3 hours to charge. Single EVSE can max. Service 8 vehicles per day (without wait)

Weight of truck

Truck weight increased due to battery weight (meaning less cargo)

Future Research

Battery & AER	Optimized battery will increase AER, and charging behavior.
Network Capacity	Theoretical vs actual capacity
Highway Density	Which will be the most density roadways (overlaps of OD routes in highways)
Policy Impact	Rank based on which charging locations will have most impact for policy, and industry.
Carbon footprint calculation	Calculate actual carbon footprint reduction Significant impact on emission reduction,

FLORIDA ATLANTIC UNIVERSITY

Thank you!

Dr. Nihat Ahmed
Dr. David Menachof
Dr. Milad Baghersad
Dr. Chul Woo Yoo