Keep on Trucking: U.S. Big Rigs Turnover from Diesel to Electric

Executive Summary

The trucking industry accounts for almost 70% of all good transported across the country. This industry is now at the forefront of new technological advancements with the implementation of electric infrastructure. Now that we have a consideration for our environmental footprint, the leap into newer more ecofriendly technologies has become a common trend over the years. Our lifestyle demands high usage of gasoline and diesel in our modes of transportation. This paper helps highlight the growth of the industry over the next 20 years, the building of the infrastructure, and where the change should start to take place.

In order to determine the rise in electric trucks and to ease the number of possible factors and eliminate less important factors, we first took into consideration some assumptions. By assuming that the growth in the electric semi-trucks is going to be similar as the growth in electric cars, we can model our growth for trucks. Currently, since there is no data on electric trucks as they haven't been launched yet we have to make our assumption based off previous electric vehicles. Based on our model there should be a growth between 20% to 30% within the next 20 years.

As the growth in electric vehicles increase the demand in the infrastructure for the maintenance also increases. As with gas stations for diesel and gas-powered trucks, electric charging stations will be needed for electric trucks. There are some major routes as highlighted by the problem by using those and adding in additional factors like distance we can develop a model to highlight the number of stations we need. Based on our model shorter distances up to 400 miles should not need a station at all as the batteries will be charged and have a 100-mile buffer.

As with any new big change there needs to be a consideration of the environment and the economic growth factors. There is a significant chunk of research supporting going electric as it will open up the job market as well as helping ease the carbon emissions in the air. For simplicity purposes and for ease of work we chose one factor from each category; the air pollution and the economic growth from charging stations. Our model took into account these factors and decided which route should be worked on first which was concluded to be Jacksonville, FL, – Washington, DC. This is the longest route and is the most travelled on route as well.

Contents

1 Introduction

1.1 Restatement of the problem

1. Predict a mathematical model for what percentage of semi-trucks will be electric in a span of 5, 10, and 20 years from 2020.
2. Make a mathematical model that how many stations are needed along any given route for maintenance of the vehicle and the driver and test on the following corridors.
    a. San Antonio, TX – New Orleans, LA
    b. Minneapolis, MN – Chicago, IL
    c. Boston, MA, – Harrisburg, PA
    d. Jacksonville, FL, – Washington, DC
    e. Los Angeles, CA, – San Francisco, CA
3. Develop a model outlining which corridor should be developed first taking into account the possible factors necessary such as cost, usage, and community.

1.2 Global Assumptions

1. All the truck growth will be considered in terms of Tesla trucks.
2. All growth of the electric trucks will be considered in terms of the decline in.

2 Part 1: Shape up or ship out

As the world moves into higher advances in technology our footprint on the environment only increases. As such more environmentally friendly options for transport are starting to emerge on the market. Big companies such as Tesla have rolled out plans for electric semi-trucks to fit the needs of growing technology and the concerns for the better of the environment. This section outlines the possible growth of the industry in the upcoming 20 years.

2.1. Local Assumptions

1. All trucks are the same, there are no defective trucks, and all of the trucks have the exact same specifications.
    a. Justification: All trucks have the same mileage, lifespan, and overall lifetime depletion.
2. All electric and gas prices remain the same.
    a. Justification: All prices for gas and electricity will remain the same for simplicity.
3. Maintenance for electric will be less cost heavy than the diesel one.
    a. Justification: There are less parts to an electric vehicle than a gas/diesel powered one, therefore there is less maintenance required.

4. The boom in electric cars is the proportional to the boom in electric semis.
    a. Justification: the trend in the graphs is the same.

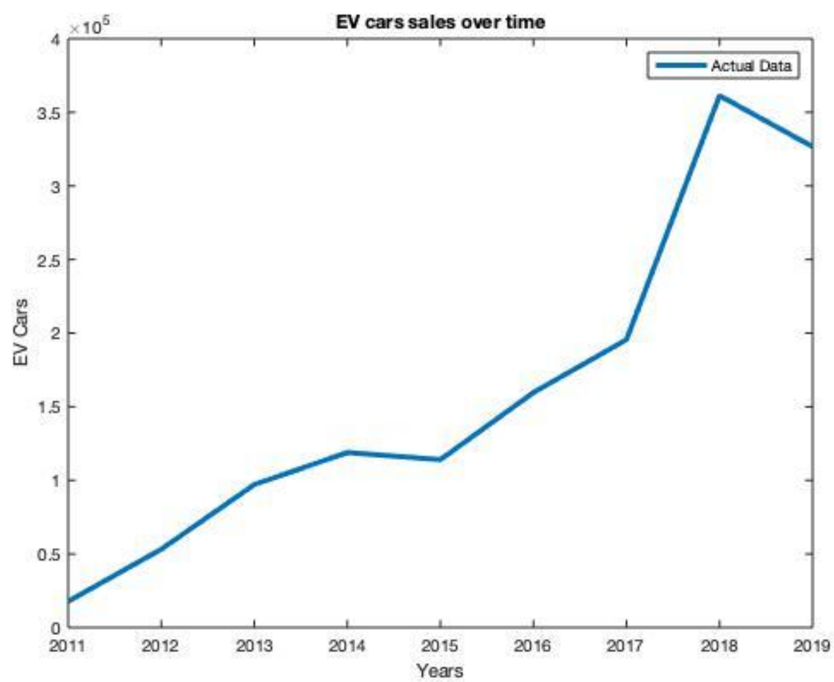
2.2 Variables

Symbol	Definition	Units
Δ	No. Of EV's sold as a function of time	#
Γ	Years	#
Θ	No. Of diesel sold as a function of time	#

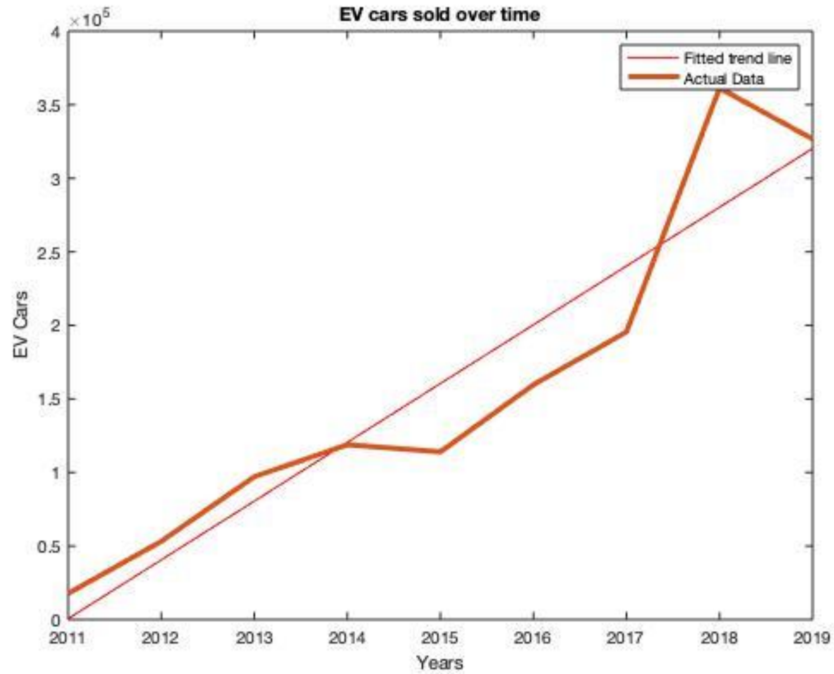
2.3 Model Development

As there are no electric truck sales records, we opted to use the equation from the trend line of the graph of the growth in EV sales from the years 2011 – 2019. Our reasoning was that electric cars are now very common compared to when they were relatively new. As the tesla semi is first an electric car, we opted to use the growth in the sales of electric cars as our model.

We used this graph:



And found this trend line:

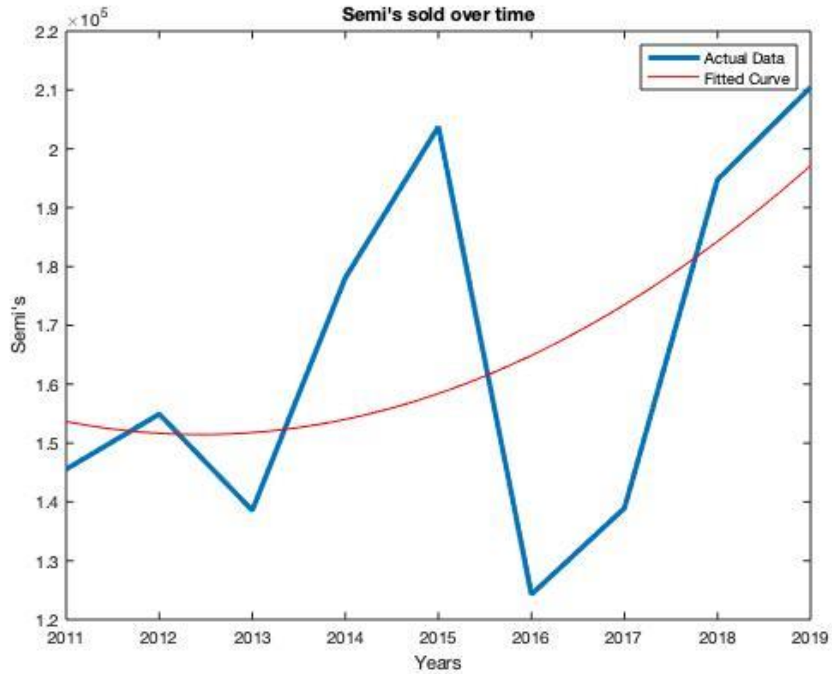


The equation for the trend line for the electric trucks is:

$$(\Delta\Gamma) = 3.996 \times 10^4 \times \Gamma - 8.03 \times 10^7$$

To find the percentages of electric cars vs total cars in 2025, 2030 and 2040 we need the growth in the usage of diesel cars and predict the cars in the 2025, 2030, 2040. Then we can add that number to the number electric cars in that respective year and then find the percentage.

Graph of the diesel trucks:



The equation for the trend curve for the diesel semi's over time is:

$$\Theta(\Gamma) = 1062 * \Gamma - (4.273 \times 10^{6} * \Gamma) + 4.3 \times 10^{9}$$

2.4 Results

As predicted by the two models there will be a total of 2,597,750 semis on the road in 2025. Of those 2,597,750, 559,000 will be electric. Therefore in 2025 the percent of electric semi-trucks will be 21.51%. In 2030 we will have a total of 3,024,600 trucks. Of those 818,800 will be electric. So the percent of electric trucks in 2030 will be 27.07%. Lastly in 2040 we will have 3,917,600 total trucks. Of those 1,218,400 will be electric trucks. So, the percent of electric semi's will be 31.10%.

2.5 Strengths and Weaknesses

As with any model there are going to be strengths and weaknesses. A major weakness to this model is present within the fact that we have no real growth data since electric trucks have not been launched into the market yet. Instead we have to use electric vehicle data and figure out how to apply that toward our electric car data. A major advantage in this model however, is the simplicity it has, numbers can easily be plugged in and a value for truck interest can be found.

3 Part 2: In it for the long haul

As with any new transportation, the infrastructure is needed to maintain it. With diesel trucks, gas stations and rest stops are needed to maintain the truck and the driver. Based on this information, we can assume that charging stations are needed. The following section highlights how many charging stations are needed for specific routes along the United States.

3.1 Local Assumptions

1. There is no established charging infrastructure to nurture electric vehicles.
   a. Justification: With the implementation of electric semis there needs to be new set of charging stations to sustain the semi's travel.
2. All the semis can travel around 600 miles on a charge.
   a. Justification: Tesla made a battery upgrade which keeps it mileage at a new constant 600 miles per charge.
3. Gas stations and exit stops are the ideal locations to integrate semi chargers.
   a. Justification: As a driver travels for long distances, places like gas stops, and exit rest stops are an ideal place to rest and charge the semis at the same time.
4. The rate at which power is lost is constant.
   a. Justification: Energy lost in traffic stops/delays is neglected.
5. Every group of trucks arrive at the same time.
6. All trucks start the routes with a full battery charge.
7. All trucks go at a constant speed 60 mph.

3.2 Variables

Symbol	Definition	Units
d	The total distance of the trip	miles
r	Range per charge	miles
β	Average AADTT (Annual Average Daily Truck Traffic (business/commercial vehicles Class 4 and above))	#
η	Number of charging stations	#
φ	Number of chargers on the route	#

3.3 Model Development

For our model we tried to find the relation between mileage and distance. Our purpose for this part of the model was to find the number of charging stations we need per route. Our equation represents the number of charge stations that are needed in one trip. By inputting the distance in the equation that we derived we get the number or charging stations needed, this distance itself comes from the mileage of the vehicle.

In order to first get the number of trucks on the road we have to take into account the annual number of vehicles found on the road, for our purposes we labeled this as **γ.** Making the assumption that at this point in time all of the AADTT (Annual Average Daily Truck Traffic) is in electric trucks we can derive the amount of trucks on the road this is given by

$$(Average\ AADT) = \beta$$

In order to take this into account with the distance we will need to divide by the total distance of the route:

$$\left(\frac{average\ AADT}{Distance}\right) = \frac{\beta}{d}$$

From the above equation we get the number of trucks per mile of the route. We want to now know how many chargers should be at each charging station. Therefore, we need to multiply by the number of miles between two charging stations or the range of the car minus 100 miles:

$$(\text{range} - 100) * \left(\frac{average\ AADT}{Distance}\right) = \frac{\beta(\text{r} - 100)}{d}$$

Obviously not all the cars can be charging at the same time, so we assumed that the average speed on the highway is 60 miles per hour. As the tesla mega charger only takes 30 minutes for an 80% charge, we can assume that for the next batch of tesla semis to charge we need to have a 30-minute time difference in the arrivals of the two batches. As the trucks travel at 60 miles per hour that means that the trucks will travel 30 miles in 30 minutes. So, the next batch of tesla trucks has to be 30 miles behind. Therefore, to find the number of batches between two chargers we need to divide the distance between two chargers by 30:

$$\frac{(range\ -\ 100)}{30}$$

As we now have the number of batches between two consecutive chargers on the route, we can divide the equation by that to find the number of trucks in a batch:

$$\frac{(range-100)*(\frac{average\ AADT}{Distance})}{\frac{range-100}{30}} = \frac{\beta(r-100)}{d} * \frac{30}{r-100}$$

But that's the same thing as:

$$30 \times \frac{(Average\ AADTT)}{total\ distance} = \frac{\beta}{\mathrm{d}} \times 30$$

Because the (r - 100)'s cancel out. And as the number of chargers must equal the number of trucks (Each truck can only use one charger) So we're left with:

$$30 \times \frac{(Average\ AADTT)}{total\ distance} = \frac{\beta}{\mathrm{d}} \times 30$$

Taking into account the area of a specific segment we can get the:
Equation for finding the number of charging stations:

$$\eta = \frac{d}{r-100}$$

Equation for finding the number of chargers on route:

$$\varphi = 30 \times \frac{\beta}{d}$$

3.4 Results

We wanted to consider two main factors in the ranking of these routes: how it boosts the economy and how much the route's air was polluted. The route's air is directly dependent on the number of trucks that travel on that route. We can see how many trucks there are based on the AADTT (Annual Average Daily Truck Traffic). The more the trucks the more the pollution as there are currently no electric trucks on the road. Now for the economic standpoint. The more the stations in a given route the more the economy improves. The only thing that determines the number of stations is the length of a route. Based on factors discussed we found that the ranking went like this: Jacksonville to DC, LA to SF, Boston to Harrisburg, Minneapolis to Chicago, San Antonio to New Orleans. Jacksonville topped out as the first that needed charging stations because of the route's length and highest concentration of trucks passing through.

3.5 Strengths and Weaknesses

This model will represent the number of charges a semi will need for a particular trip by a given distance. We also know how to spread the chargers across the trip. Our model also allocates a safety of 100 miles so this ensures the truck will have enough charge to go make it to the charging station. This model represents a perfect world scenario. However, in reality there are always alterations with the factors affecting the model. In this model we assume all the trucks go at 60 mph for sakes of simplicity. This wouldn't 100% represent how it will be like in reality as the speeds will definitely vary amongst driver and driving conditions. Factors like traffic and weather can affect the amount of charge left a driver has to make it to the next stop. This is why we added a 100-mile safety in our model so the driver would not be stranded in the middle of the route for running out of charge.

4 Part 3: I like to move it, move it

As with any new development economic and environmental costs need to be factored in. Locations, the amount of goods, and the overall development cost need to be factored in for a specific area. The following model reflects the targeted area for electric truck development based on our factors where we can isolate which area is ideal to start development.

4.1 Local Assumptions

1. Which corridor locations are important?
    a. Justification: The place where there is key imports and busy worktimes should be prioritized to be developed.
2. How many trucks are even used at the corridor?
    a. Justification: Going with the other assumption, knowing the number of trucks that are used per corridor is important as we know where the concentration of trucks is and thereby, we know where there should be developed of electric infrastructure.
3. Distance of the corridors
    a. Justification: Some distances are short and would not require much development as those resources are better off to be utilized with places that have longer distance spans.
4. Air Quality
    a. Justification: Air quality is an important factor as it concerns the wellbeing of the environment and the workers. Development is essential for the places

that have more air pollution as the implementation of electric infrastructure deals with the condition as fast as possible.

4.2 Variables

Symbol	Definition	Units
Ψ	Distance between corridors	miles
Ω	Number of trucks used	#
Π	Cost	$

4.3 Model Development

To determine which place is ideal to focus development, we need to see which places use more trucks and transport more resources. We will also take into account of distance between the corridors. What we came up was to rank each location through 3 factors which are the number of trucks, the distance, and the quality of the air. the total cost.
In order to start development, we need to take into account the factors, for our purposes air quality and the distance. The following chart shows the air quality data for each of the given corridors this is derived from the number of trucks present on that route given by AADTT and give it a ranking

Corridor	AADTT	Ranking (greatest to least)
San Antonio, TX, to/from New Orleans, LA	142881	5
Minneapolis, MN, to/from Chicago, IL	256344	4
Boston, MA, to/from Harrisburg, PA	306665	3
Jacksonville, FL, to/from Washington, DC	1512898	1
Los Angeles, CA, to/from San Francisco, CA	531045	2

From this we can conclude that wherever there are the most trucks there is the most air pollution along that route. From our data we can see that the most trucks travel along the Jacksonville, FL, to/from Washington, DC corridor as this is the longest and most travelled on route by trucks.

For considerations of economic growth, we can factor in the number of charging stations per route given by the distance.

Corridor	Distance	# of stations	Ranking (greatest to least)
San Antonio, TX, to/from New Orleans, LA	544 miles	1	2
Minneapolis, MN, to/from Chicago, IL	355 miles	0	5
Boston, MA, to/from Harrisburg, PA	383 miles	0	3
Jacksonville, FL, to/from Washington, DC	706 miles	1	1
Los Angeles, CA, to/from San Francisco, CA	382 miles	0	4

4.4 Results

From our given results we have a conclusion that the most air pollution will result from the greatest number of trucks travelling each route keeping in mind the distance this is given by AADTT. From the table we can see that this is on the Jacksonville, FL, to/from Washington, DC corridor. Air pollution wise the most trucks run on this route therefore if they get converted to electric, they air pollution will be eased a significant amount. In terms of economic growth, we can take the number of charging stations as a factor, the greatest number of charging stations is 1 on both the San Antonio, TX, to/from New Orleans, LA and Jacksonville, FL, to/from Washington, DC routes. Therefore, since the overall revenue from these two corridors will be about the same then our other factor which is air pollution comes into place and since Jacksonville, FL, to/from Washington, DC has the most pollution we can say that route will benefit the most.

4.5 Strengths and Weaknesses

Our model has many strengths one of the major ones being accuracy, the simplicity has allowed us to take into account the number of trucks coming in and helped us decide the charging stations. By doing so we could easily give a rough estimate about which route would produce the most revenue and which corridor should be worked on for environmental purposes. Our model like any good model has its flaws. The basis for our model is quite simple this may simplify the workload and ease the calculations however; it ends up looking over many factors. For the environmental impact we only took into account the air pollution, but many other factors also come into play. Some examples are light and noise pollution caused by highways and lights along them. For economic factors we assumed every factor to be a constant which is not possible in a real-world job market. Overall, however, our model is simple yet accurate.

5 Conclusion

A further connection

Overall, the implementation of electric infrastructure does indicate good prospects followed by it. The use of electric vehicles is more efficient and cost effective to transport goods across the nation. It declutters air pollution and this new infrastructure more longevity accompanied by lesser costs like maintenance and gasoline. The trucking industry is the bloodline of our countries' economy with outputting more than $700 billion dollars. This also comes with a great mileage amongst the entire industry as it was estimated that the registered trucks in the U.S traveled a total of 450.4 billion miles [6]. With this immense mileage, going electric is ideal as it is eco-friendly and at the same time removes the need of gasoline expenditures. With these cost cutting measures, the truck industry has fewer net losses. However, with this transition comes with new costs of establish a charging station network. Tesla has accumulated over 1,200 supercharges at 1,400 stations as of last year [7] keeping up with the demand of electric vehicles. With this shift integrated in the trucking industry, the numbers for mega chargers will also rise. With vendors like Walmart, Ups, and PepsiCo investing in this venture, the infrastructure will grow alongside the rise of electric semis.

6 References

Brainstorming

[1] https://nacfe.org/wp-content/uploads/2018/05/NACFE_infographic.jpg

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[3] https://blogs.gartner.com/bill-ray/2019/08/27/electric-cars-will-drive-semiconductor-growth/

Modeling

[4] https://seekingalpha.com/article/4296420-tesla-semi-can-be-profitable-niche-player-in-strong-growth-market-for-heavy-duty-trucks

[5] https://www.bizjournals.com/sanjose/news/2017/11/27/tesla-semi-truck-price-cost-fuel-tsla.html

[6] https://www.thomasnet.com/insights/trucking-usa-key-trends-and-future-outlooks-for-the-trucking-industry/

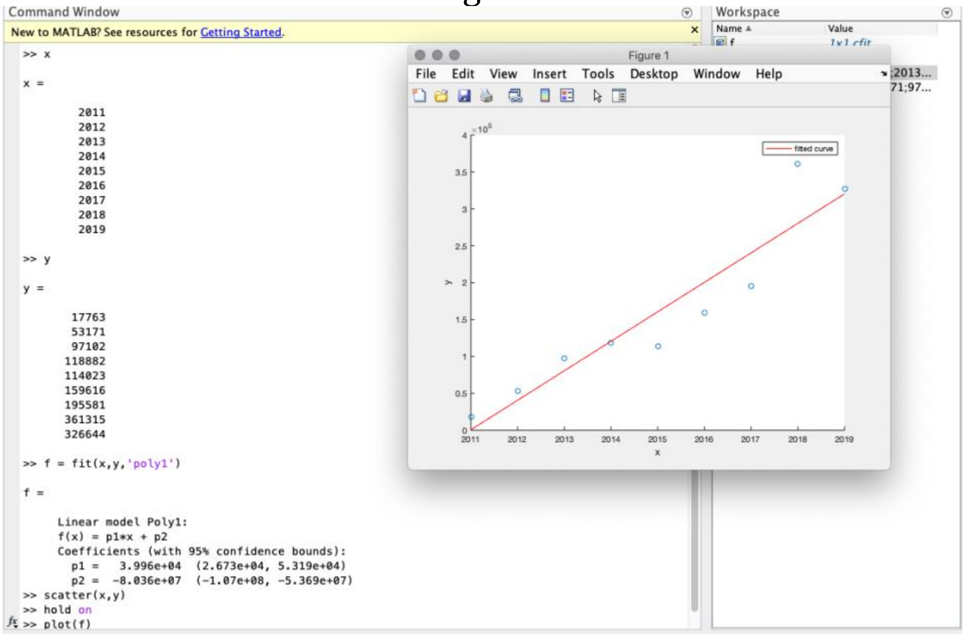
[7] https://insideevs.com/news/342510/tesla-now-operates-over-12000-superchargers-at-1400-stations/

Data

[7] https://docs.google.com/spreadsheets/d/1lczyzI0QziuVgZ-N-vQeyQimss1GaUX-l5HOp-pK8TE/edit#gid=1397896553

7 Appendix

Code for Part 1 of the challenge:




```
>> x

x =

        2011
        2012
        2013
        2014
        2015
        2016
        2017
        2018
        2019

>> y

y =

      145562
      154919
      138563
      178094
      203764
      124282
      138952
      194790
      210466

>> f

f =

     Linear model Poly2:
     f(x) = p1*x^2 + p2*x + p3
     Coefficients (with 95% confidence bounds):
       p1 =        1062  (-3355, 5478)
       p2 =  -4.273e+06  (-2.207e+07, 1.353e+07)
       p3 =      4.3e+09  (-1.363e+10, 2.223e+10)
>> plot(x,y,"LineWidth", 3)
hold on
```

```
        2015
        2016
        2017
        2018
        2019

>> y

y =

      145562
      154919
      138563
      178094
      203764
      124282
      138952
      194790
      210466

>> f

f =

     Linear model Poly2:
     f(x) = p1*x^2 + p2*x + p3
     Coefficients (with 95% confidence bounds):
       p1 =        1062  (-3355, 5478)
       p2 =  -4.273e+06  (-2.207e+07, 1.353e+07)
       p3 =     4.3e+09  (-1.363e+10, 2.223e+10)
>> plot(x,y,"LineWidth", 3)
hold on
plot(f)
legend("Fitted Curve","Actual Data")
legend("Fitted Curve","Actual Data")
legend("Actual Data", "Fitted Curve")
xlabel("Years")
ylabel("Semi's")
title("Semi's sold over time")
>> |
```

Code for Part 2 & 3 of the challenge:

NumberOfChargersAndStations.java   Settings

```java
public class NumberOfChargersAndStations{
  public static void main (String args[]){
    double range = 600; // This range represent the range of a base Tesla Semi.
    double distance = ; // Insert the total distance of the route.
    double AADTTValue = ;// Insert the AADTT value or the Annual Average Daily Truck Traffic .
    int stations = distance/(range - 100);
    int chargers = (int)(30 * (AADTTValue/distance));
    System.out.println("Chargers per charging station = " + chargers);
    System.out.println("Stations = " + stations);
  }
}
```