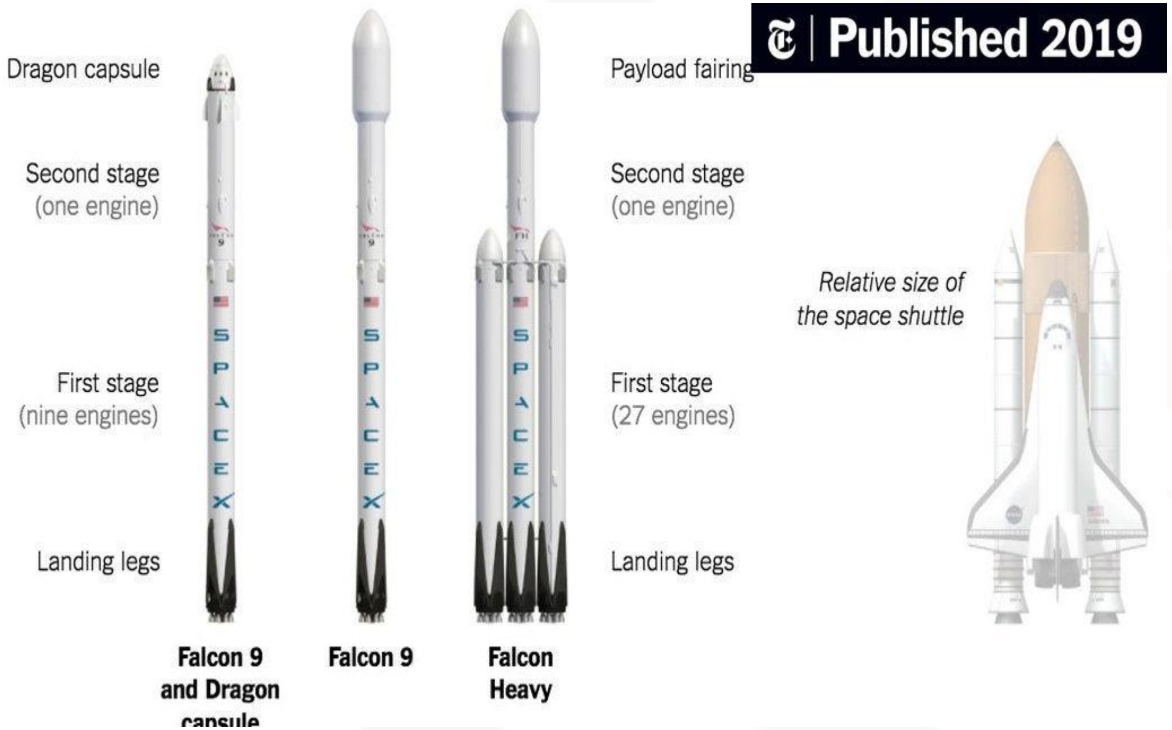

# SpaceX Falcon-9 first stage Landing Prediction

Priyanka Yadav

# OUTLINE

- Executive Summary
- Introduction
- Methodology
- Results
- Discussion
- Conclusion
- Appendix

# EXECUTIVE SUMMARY




- **Summary of methodologies:**
  - Data collecting & data wrangling;
  - Exploratory data analysis;
  - Interactive visual analytics;
  - Machine learning prediction

- **Summary of all results:**
  - EDA results
  - Interactive Visual Analytics and Dashboards
  - Predictive Analysis

# INTRODUCTION

- **Project background and context**

In this project, we will predict if the Falcon 9 first stage will land successfully. SpaceX advertises Falcon 9 rocket launches on its website with a cost of 62 million dollars; other providers cost upward of 165 million dollars each, much of the savings is because SpaceX can reuse the first stage. Therefore if we can determine if the first stage will land, we can determine the cost of a launch. This information can be used if an alternate company wants to bid against SpaceX for a rocket launch.

- **Problems you want to find answers**

To determine if the first stage will land, in order to be able to determine the cost of a launch.

# METHODOLOGY

Methodology of the machine learning prediction implements following steps:

1. Data collection by web scraping
2. Data Cleaning
3. Exploratory Data Analysis
4. Data Visualization
5. Predictive Analysis

# Data Collection

SpaceX launch data was gathered from the SpaceX RESTAPI and the data included information about launches, like rocket used, payload delivered, launch specifications, landing specifications, and landing outcome.

Falcon9 Launch data was obtained from Wiki pages via web scraping. Python BeautifulSoup package was used to webscrap some HTML tables that contain valuable Falcon9 launch records. The data was parsed from those tables and converted into a Pandas dataframe for further visualization and analysis.

GitHub URL - Click Here

# Data Wrangling

- After obtaining and creating a Pandas DF from the collected data, data was filtered using the ‘Booster Version’ column to only keep the Falcon 9 launches, then dealt with the missing data values in the ‘Landing Pad’ and ‘Payload Mass’ columns. For the ‘Payload Mass’, missing data values were replaced using mean value of column.
- Also performed some Exploratory Data Analysis (EDA) to find some patterns in the data and determine what would be the label for training supervised models

GitHub URL- Click Here

# EDA and interactive visual analytics

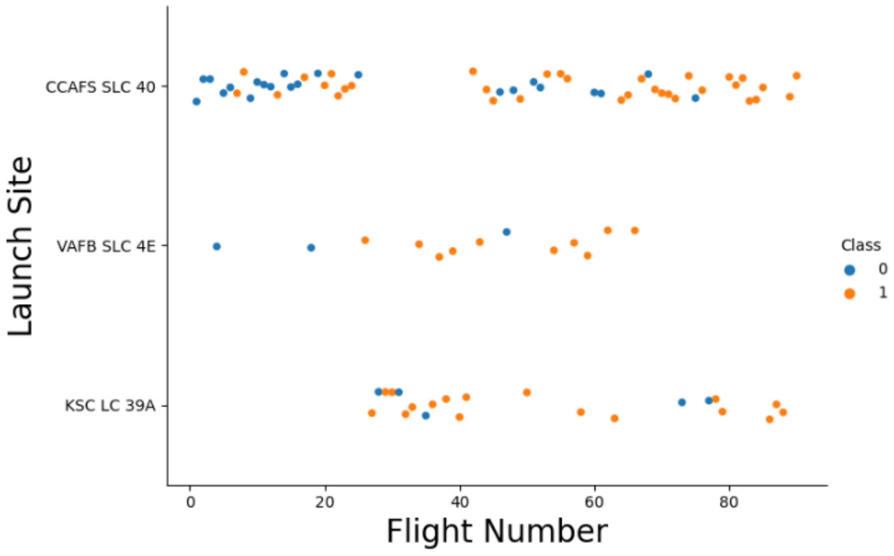
- Performed data Analysis and Feature Engineering using Pandas and Matplotlib i.e. Exploratory Data Analysis
- Preparing Data Feature Engineering
- Used scatter plots to Visualize the relationship between Flight Number and Launch Site, Payload and Launch Site, FlightNumber and Orbit type, Payload and Orbit type.
- Used Bar chart to Visualize the relationship between success rate of each orbit
- type
- Line plot to Visualize the launch success yearly trend.

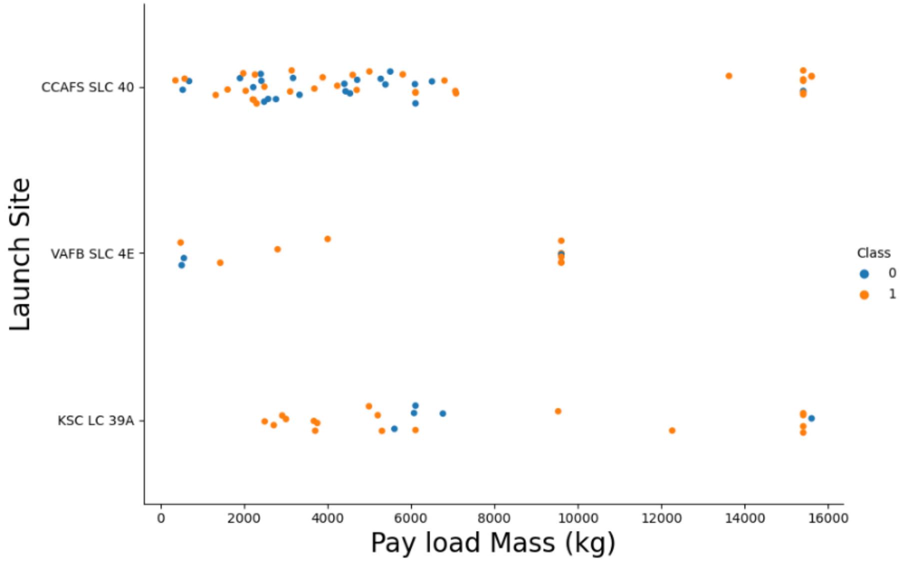
GitHub URL - 1. EDA with SQL 2. EDA with Visualization Lab 3. Interactive Visual Analytics with Folium 4. Interactive Dashboard with Plotly Dash

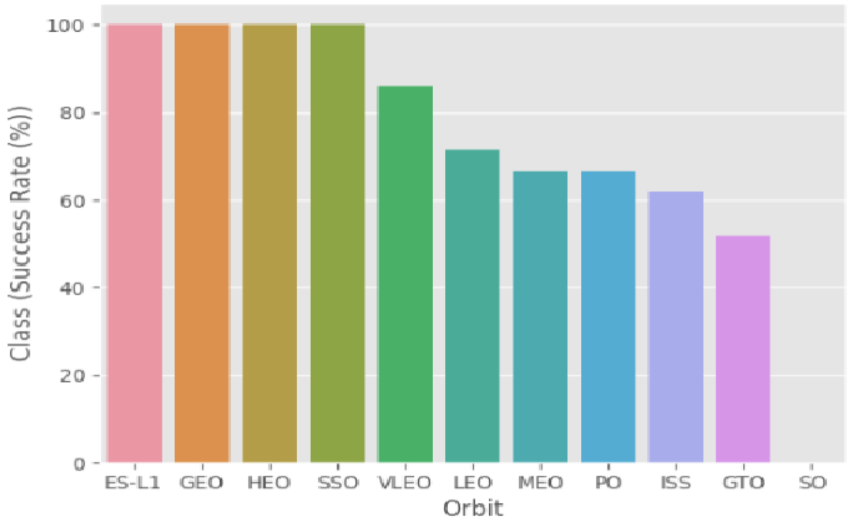
# EDA with Data Visualization

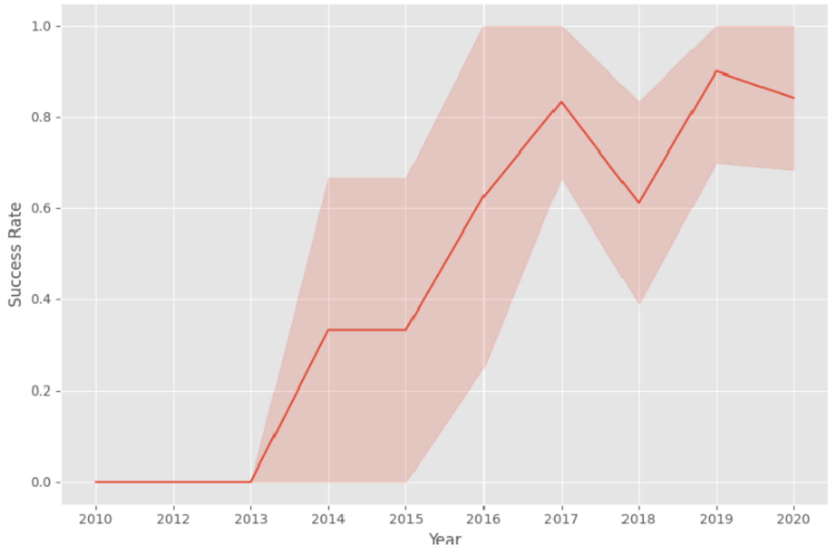
- Performed data Analysis and Feature Engineering using Pandas and Matplotlib.i.e.
  - Exploratory Data Analysis
  - Preparing Data Feature Engineering
- Used scatter plots to Visualize the relationship between Flight Number and Launch Site, Payload and Launch Site, FlightNumber and Orbit type, Payload and Orbit type.
- Used Bar chart to Visualize the relationship between success rate of each orbit type
- Line plot to Visualize the launch success yearly trend.
- GitHub URL - EDA with Visualization Lab

# EDA with Data Visualization (Plots)



# EDA with SQL

- List the date when the first successful landing outcome in ground pad was achieved

```
%sql SELECT MIN(DATE) FROM 'SPACEXTBL' WHERE "Landing _Outcome" = "Success (ground pad)";
```

- List the names of the boosters which have success in drone ship and have payload mass greater than 4000 but less than 6000
  - %sql SELECT DISTINCT Booster_Version, Payload FROM SPACEXTBL WHERE "Landing _Outcome" = "Success (drone ship)" AND PAYLOAD_MASS KG_ > 4000 AND PAYLOAD_MASS KG_ < 6000;

- List the total number of successful and failure mission outcomes

```
%sql SELECT "Mission_Outcome", COUNT("Mission_Outcome") as Total FROM SPACEXTBL GROUP BY "Mission_Outcome";
```

- GitHub URL - EDA with SQL

# Build an Interactive Map with Folium

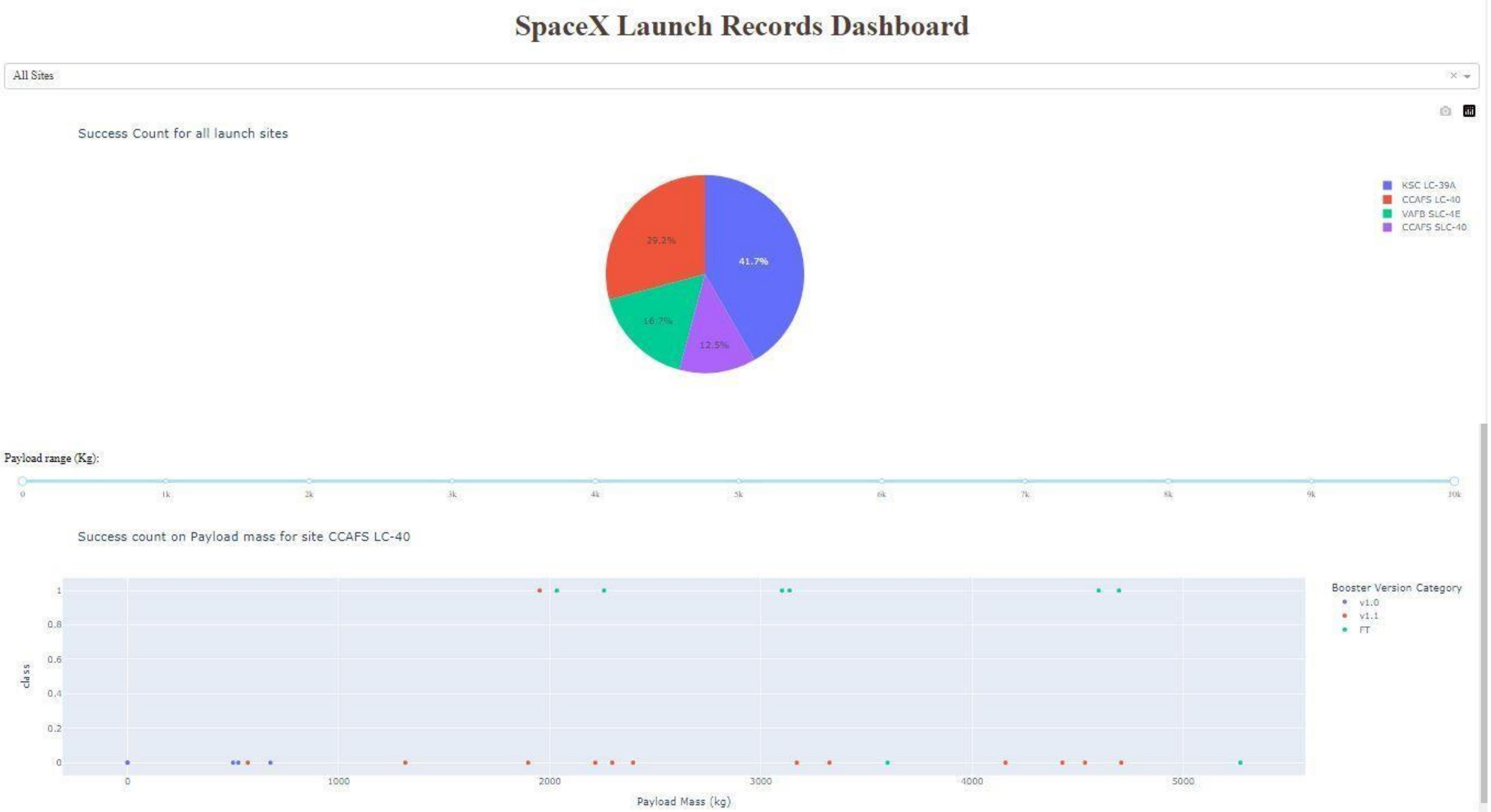
- Created folium map to marked all the launch sites, and created map objects such  as markers, circles, lines to mark the success or failure of launches for each  launch site.
- Created a launch set outcomes (failure=0 or success=1).
- GitHub URL - Interactive Visual Analytics with Folium

# Build a Dashboard with Plotly Dash

- Built an interactive dashboard application with Plotly dash by:
  - Adding a Launch Site Drop-down Input Component
  - Adding a callback function to render success-pie-chart based on selected site dropdown
  - Adding a Range Slider to Select Payload
  - Adding a callback function to render the success-payload-scatter-chart scatter plot

- GitHub URL - Interactive Dashboard with Plotly Dash

# SpaceX Dash App



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# Predictive Analysis (Classification)

- Summary of how the best performing classification model was built, evaluated, improved, and found. After loading the data as a Pandas Dataframe, started the performance of exploratory Data Analysis and determine Training Labels by;
  - creating a NumPy array from the column Class in data, by applying the method to_numpy() then assigned it to the variable Y as the outcome variable.
  - Then standardized the feature dataset (x) by transforming it using preprocessing.StandardScaler() function from Sklearn.
  - After which the data was split into training and testing sets using the function train_test_split from sklearn.model_selection with the test_size parameter set to 0.2 and random_state to 2.

# Predictive Analysis (Classification)

- In order to find the best ML model/ method that would performs best using the test data between SVM, Classification Trees, k nearest neighbors and Logistic Regression;
  - First created an object for each of the algorithms then created a GridSearchCV object and assigned them a set of parameters for each model.
  - For each of the models under evaluation, the GridsearchCV object was created with cv=10, then fit the training data into the GridSearch object for each to Find best Hyperparameter.
  - After fitting the training set, we output GridSearchCV object for each of the models, then displayed the best parameters using the data attribute best_params_ and the accuracy on the validation data using the data attribute best_score_.
  - Finally using the method score to calculate the accuracy on the test data for each model and plotted a confussion matrix for each using the test and predicted outcomes.

# Predictive Analysis (Classification)

- The table below shows the test data accuracy score for each of the methods comparing them to show which performed best using the test data between SVM, Classification Trees, k nearest neighbors and Logistic Regression;

Out[32]:

| | 0 |
|---|---|
| **Method** | Test Data Accuracy |
| **Logistic_Reg** | 0.944444 |
| **SVM** | 0.833333 |
| **Decision Tree** | 0.777778 |
| **KNN** | 0.833333 |

- GitHub URL - [Machine Learning Prediction]



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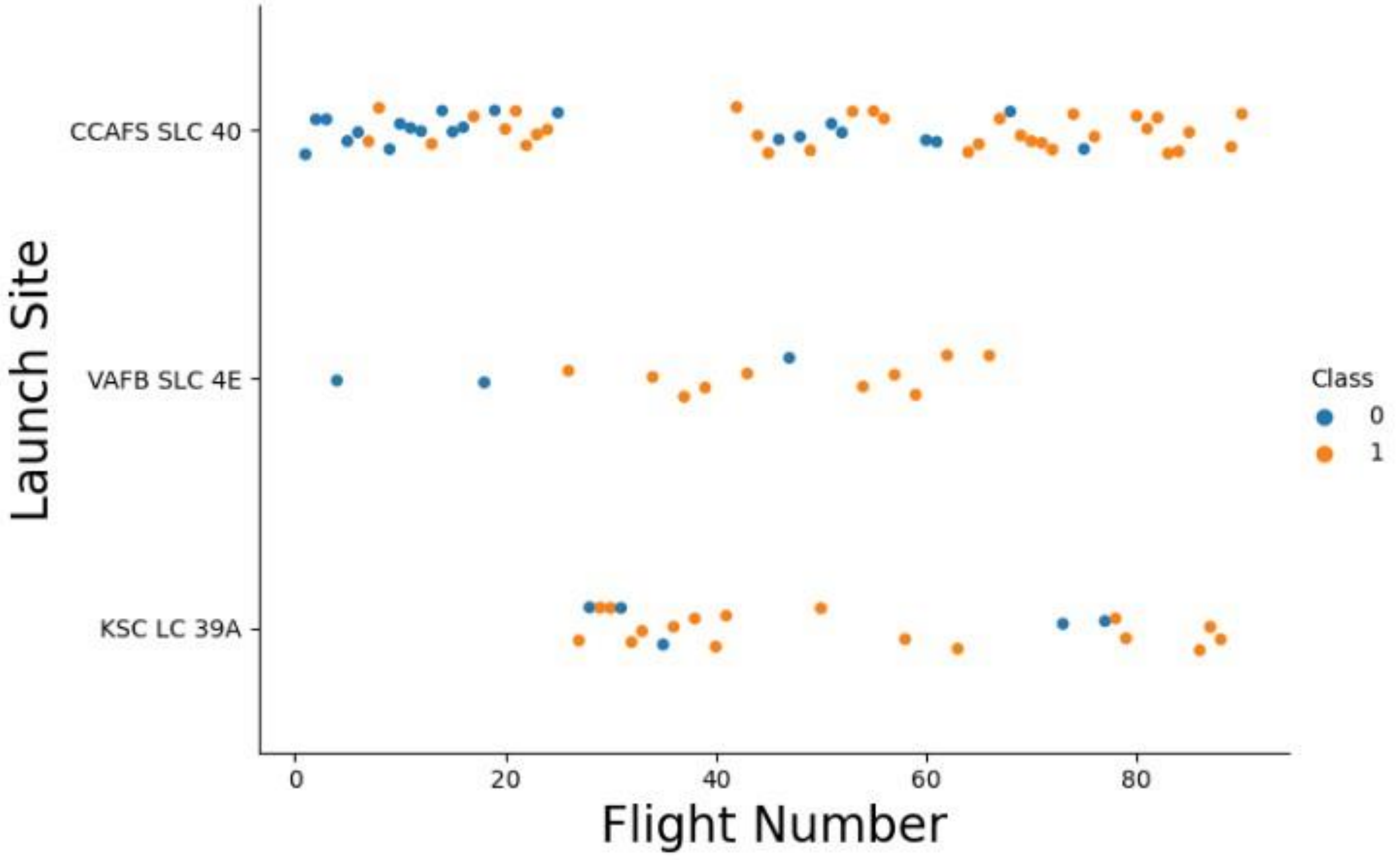
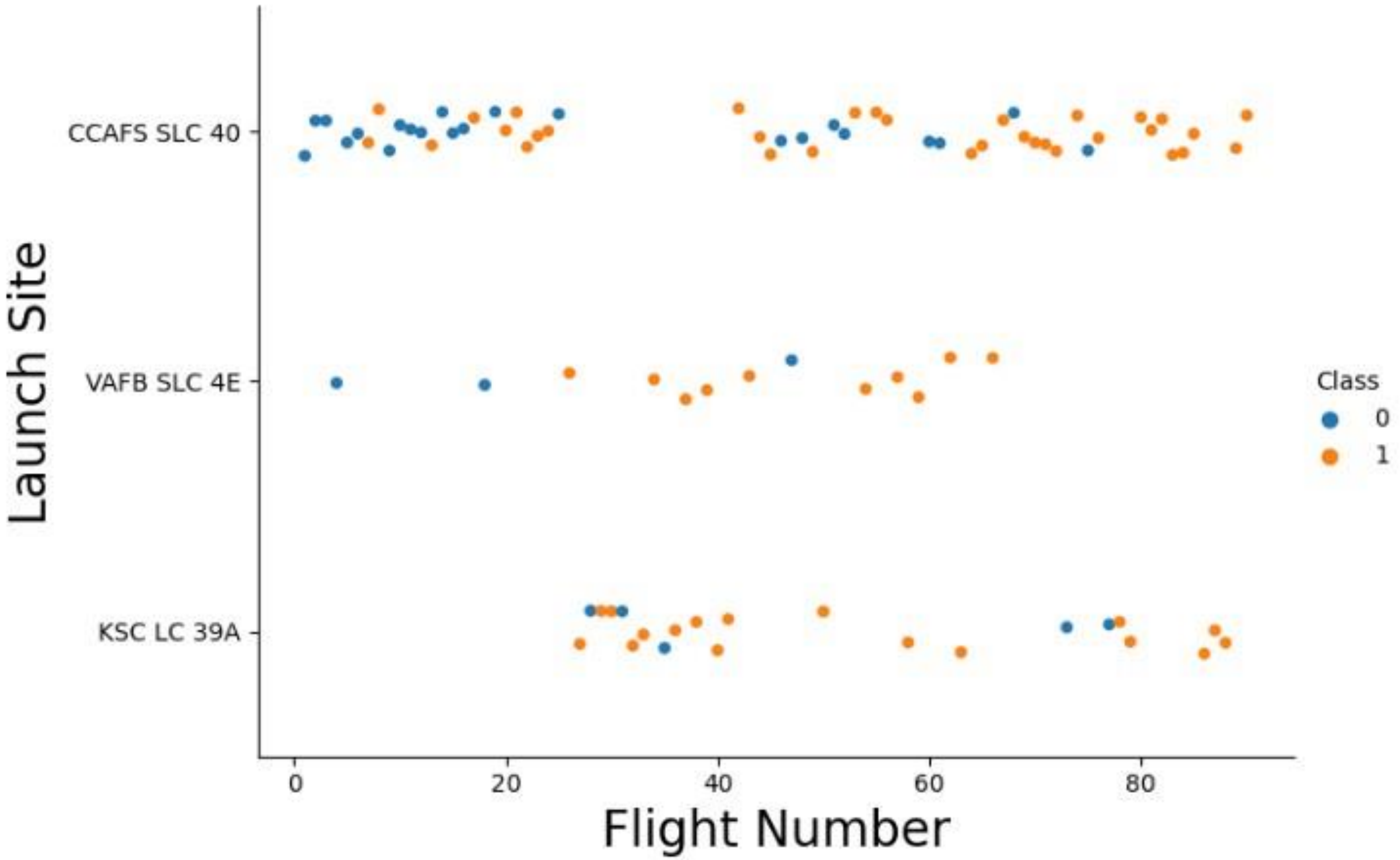
SKILLS NETWORK

# Insights from EDA

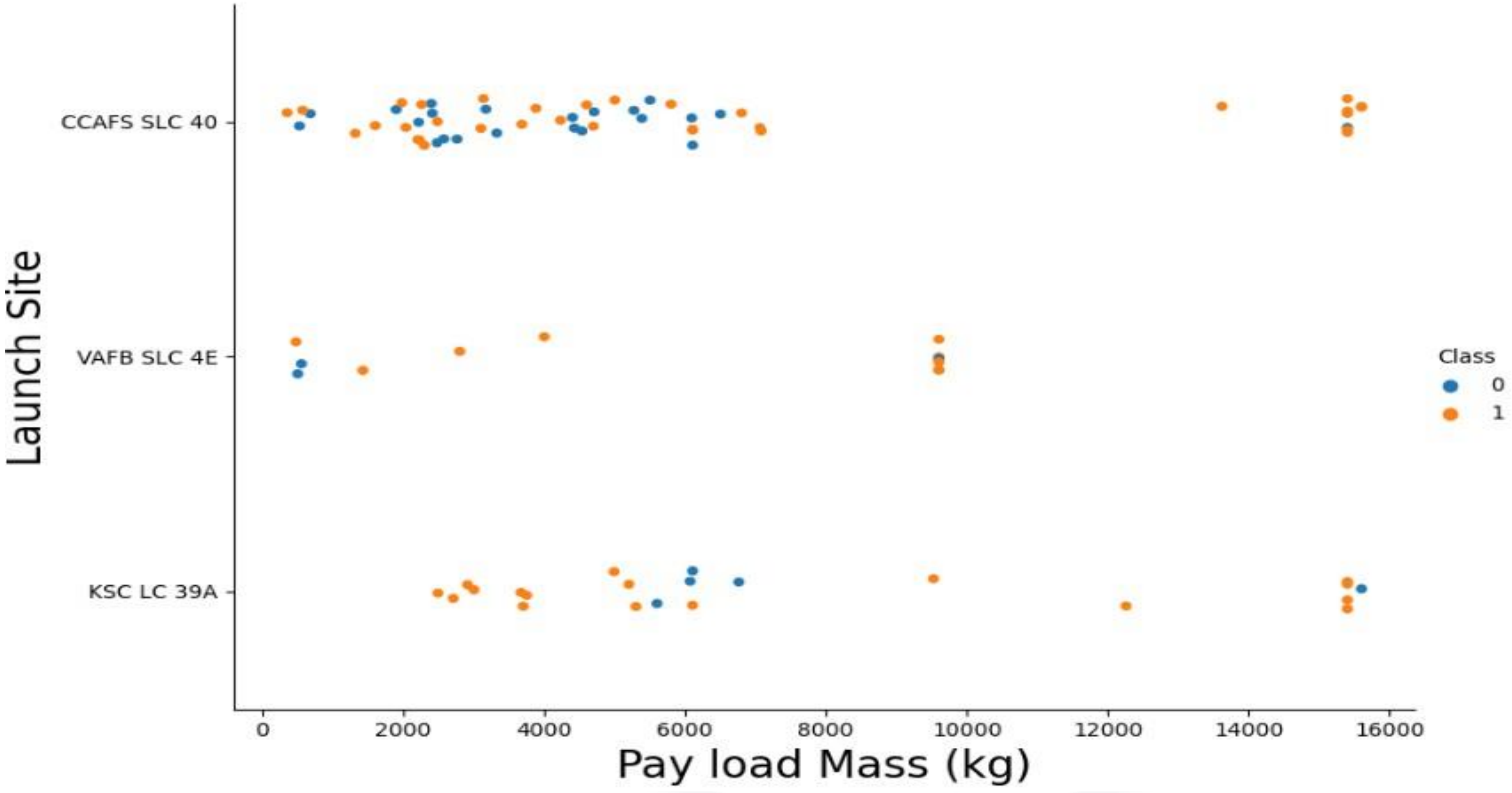
# Flight Number vs. Launch Site



# Flight Number vs. Launch Site with explanations

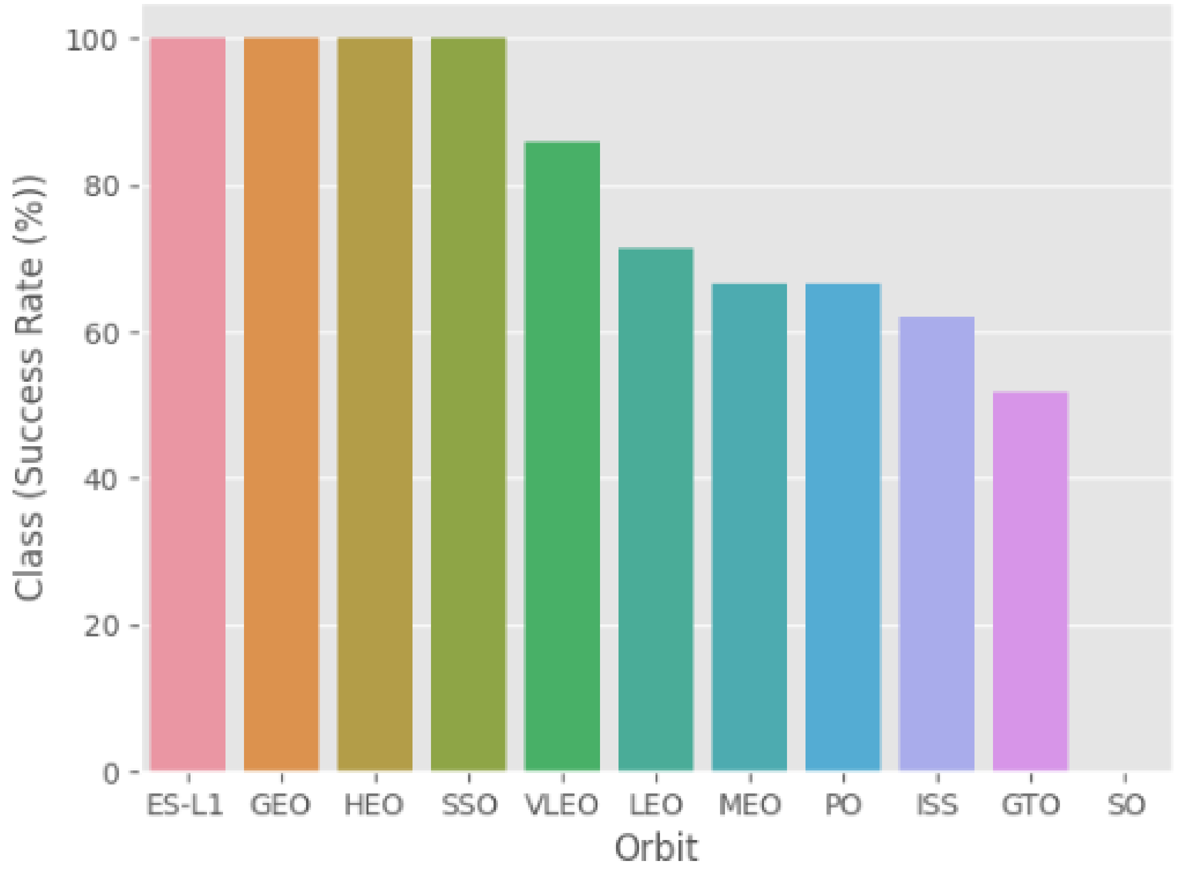


# Payload vs. Launch Site



# Success Rate vs. Orbit Type

Bar chart for the success rate of each orbit type



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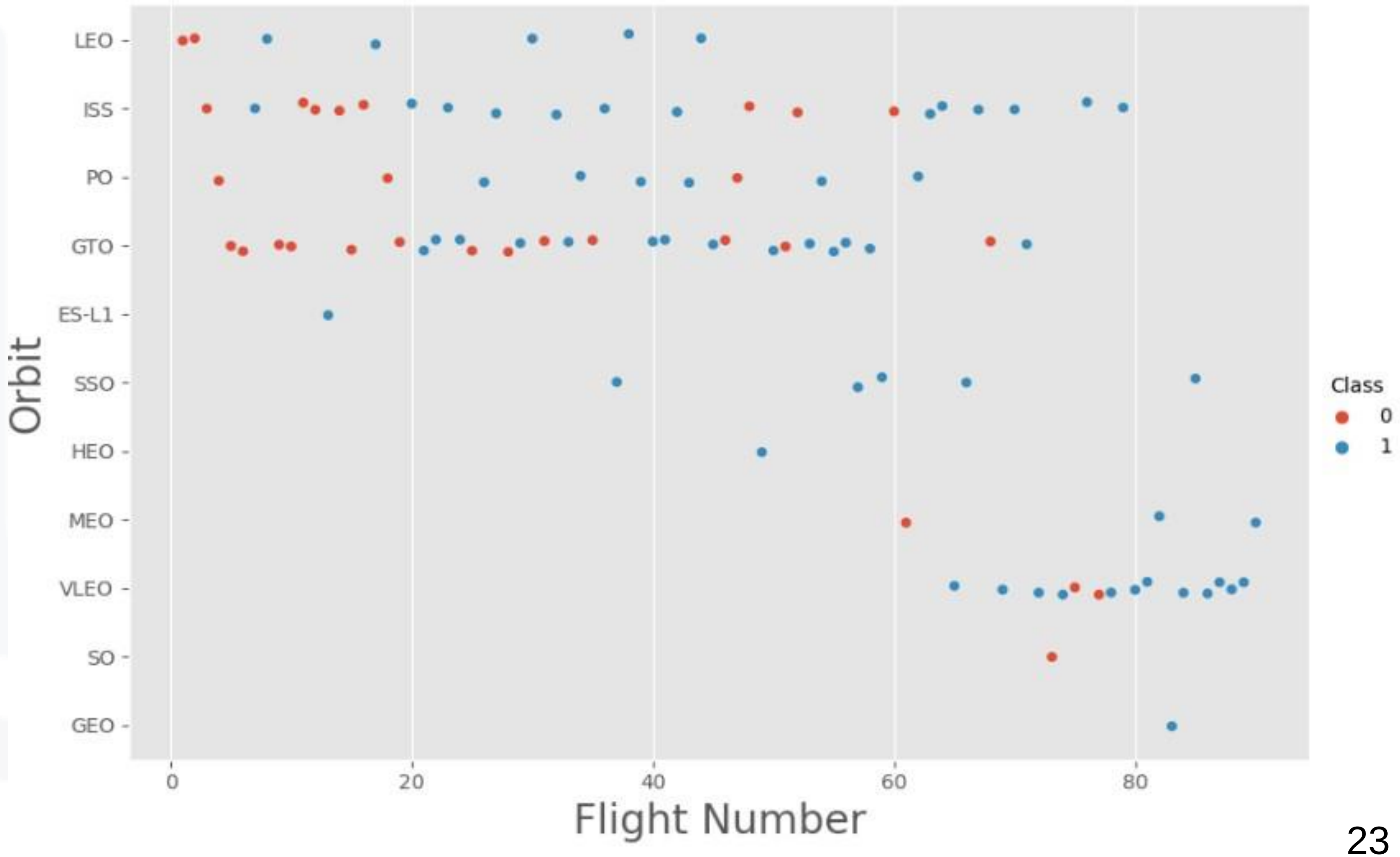
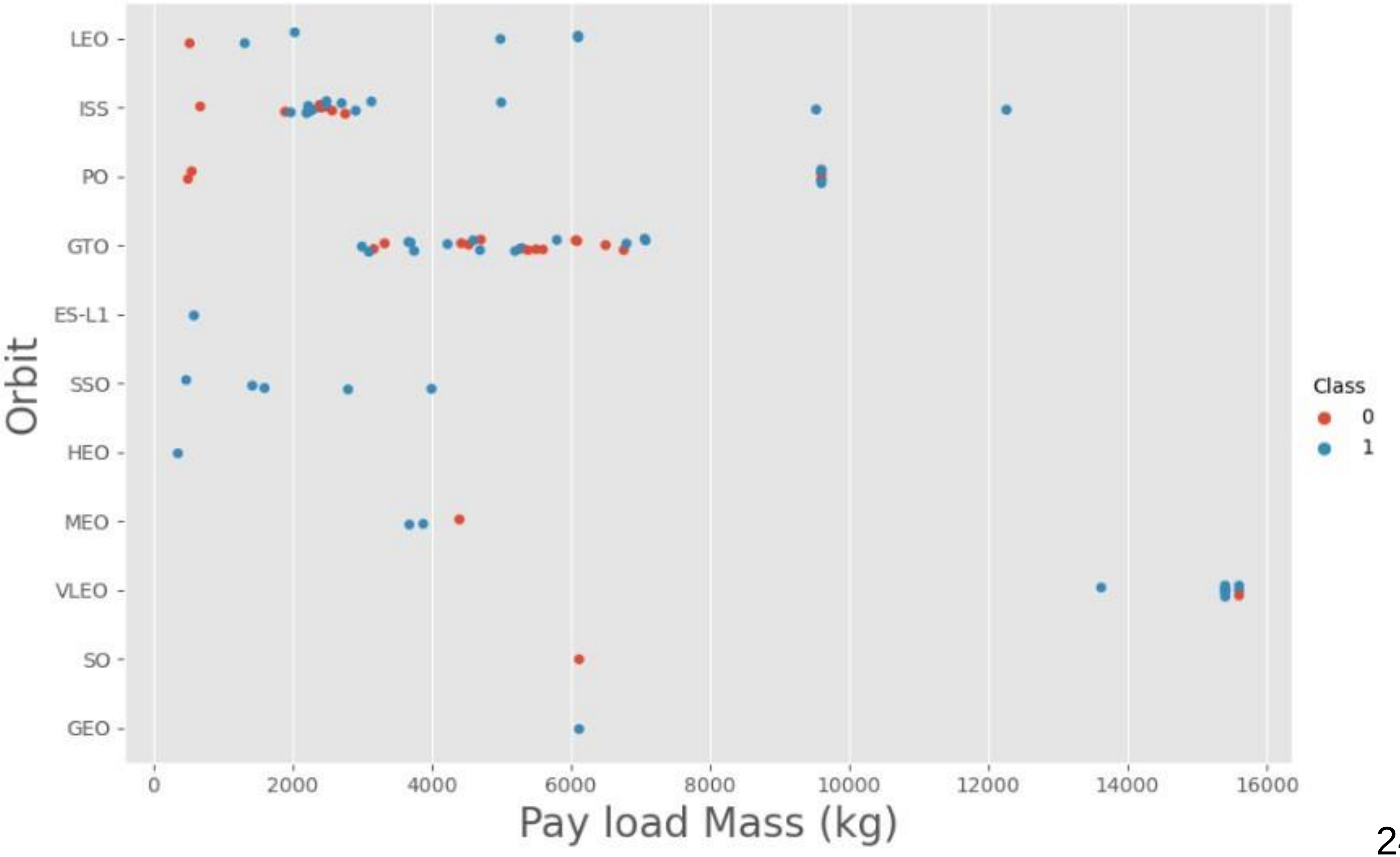
# Flight Number vs. Orbit Type

Scatter point of Flight number vs. Orbit type



# Payload vs. Orbit Type

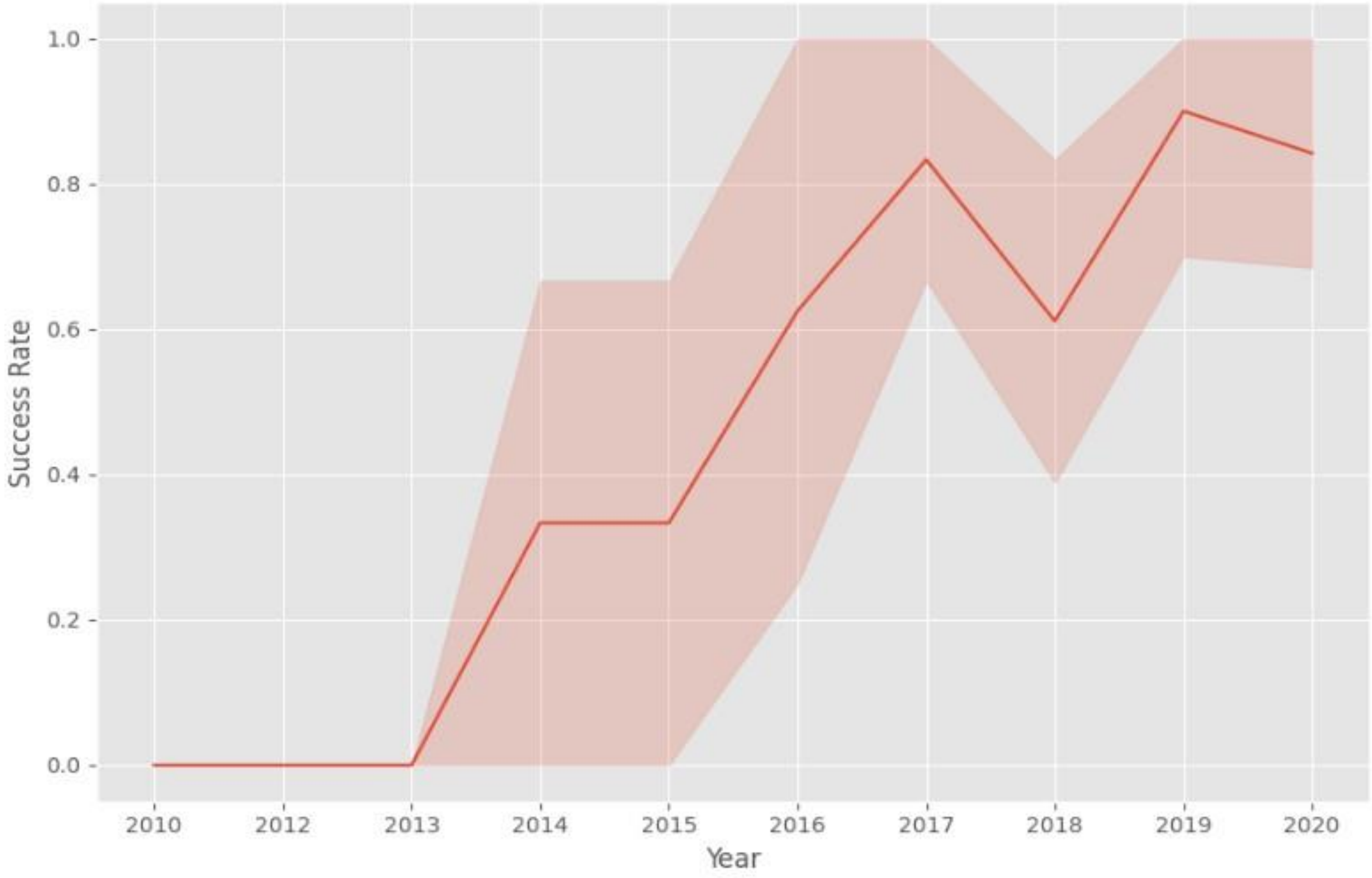
- With heavy payloads the successful landing or positive landing rate are more for  Polar,LEO and ISS.
- However for GTO we cannot distinguish this well as both positive landing rate and Negative landing (unsuccessful mission) both have near equal chances.



# Launch Success Yearly Trend

- Since 2013, the success rate kept going up till 2020

Line chart of yearly average success rate



# All Launch Site Names

- Find the names of the unique launch sites

- Used ‘SELECT DISTINCT’ statement to return only the unique launch sites from the ‘LAUNCH_SITE’ column of the SPACEXTBL table

## Task 1

Display the names of the unique launch sites in the space mission

In [31]:

```
%sql SELECT DISTINCT LAUNCH_SITE as "Launch_Sites" FROM SPACEXTBL;
```

```
 * sqlite:///my_data1.db
Done.
```

Out[31]:

| Launch_Sites |
|---|
| CCAFS LC-40 |
| VAFB SLC-4E |
| KSC LC-39A |
| CCAFS SLC-40 |

# Launch Site Names Begin with 'CCA'

- 5 records where launch sites begin with `CCA`

## Task 2

Display 5 records where launch sites begin with the string 'CCA'

In [72]:
```
%sql SELECT * FROM 'SPACEXTBL' WHERE Launch_Site LIKE 'CCA%' LIMIT 5;
```

```
 * sqlite:///my_data1.db
Done.
```

Out[72]:

| Date | Time (UTC) | Booster_Version | Launch_Site | Payload | PAYLOAD_MASS__KG_ | Orbit | Customer | Mission_Outcome | Landing _Outcome |
|---|---|---|---|---|---|---|---|---|---|
| 04-06-2010 | 18:45:00 | F9 v1.0 B0003 | CCAFS LC-40 | Dragon Spacecraft Qualification Unit | 0 | LEO | SpaceX | Success | Failure (parachute) |
| 08-12-2010 | 15:43:00 | F9 v1.0 B0004 | CCAFS LC-40 | Dragon demo flight C1, two CubeSats, barrel of Brouere cheese | 0 | LEO (ISS) | NASA (COTS) NRO | Success | Failure (parachute) |
| 22-05-2012 | 07:44:00 | F9 v1.0 B0005 | CCAFS LC-40 | Dragon demo flight C2 | 525 | LEO (ISS) | NASA (COTS) | Success | No attempt |
| 08-10-2012 | 00:35:00 | F9 v1.0 B0006 | CCAFS LC-40 | SpaceX CRS-1 | 500 | LEO (ISS) | NASA (CRS) | Success | No attempt |
| 01-03-2013 | 15:10:00 | F9 v1.0 B0007 | CCAFS LC-40 | SpaceX CRS-2 | 677 | LEO (ISS) | NASA (CRS) | Success | No attempt |

# Total Payload Mass

- Total payload carried by boosters from NASA

## Task 3

Display the total payload mass carried by boosters launched by NASA (CRS)

In [17]:
```
%sql SELECT SUM(PAYLOAD_MASS__KG_) as "Total Payload Mass(Kgs)", Customer FROM 'SPACEXTBL' WHERE Customer = 'NASA (CRS)';
```

```
 * sqlite:///my_data1.db
Done.
```

Out[17]:

| Total Payload Mass(Kgs) | Customer |
|---|---|
| 45596 | NASA (CRS) |

# Average Payload Mass by F9 v1.1

- Average payload mass carried by booster version F9 v1.1

## Task 4

Display average payload mass carried by booster version F9 v1.1

```
%sql SELECT AVG(PAYLOAD_MASS__KG_) as "Payload Mass Kgs", Customer, Booster_Version FROM 'SPACEXTBL' WHERE Booster_Version LIKE 'F9 v1.1%';
```

```
 * sqlite:///my_data1.db
Done.
```

| Payload Mass Kgs | Customer | Booster_Version |
|---|---|---|
| 2534.6666666666665 | MDA | F9 v1.1 B1003 |

# First Successful Ground Landing Date

- Find the dates of the first successful landing outcome on ground pad

## Task 5

List the date when the first succesful landing outcome in ground pad was acheived.

*Hint:Use min function*

```
%sql SELECT MIN(DATE) FROM 'SPACEXTBL' WHERE "Landing _Outcome" = "Success (ground pad)";
```

```
 * sqlite:///my_data1.db
Done.
```

| MIN(DATE) |
|---|
| 01-05-2017 |

# Successful Drone Ship Landing with Payload between 4000 and 6000

- List of Boosters which have successfully landed on drone ship and had payload mass greater than 4000 but less than 6000

## Task 6

List the names of the boosters which have success in drone ship and have payload mass greater than 4000 but less than 6000

```
]: # %sql SELECT * FROM 'SPACEXTBL'
```

```
]: %sql SELECT DISTINCT Booster_Version, Payload FROM SPACEXTBL WHERE "Landing _Outcome" = "Success (drone ship)" AND PAYLOAD_MASS__KG_ > 4000 AND PAYLOA
```

```
 * sqlite:///my_data1.db
Done.
```

| Booster_Version | Payload |
|---|---|
| F9 FT B1022 | JCSAT-14 |
| F9 FT B1026 | JCSAT-16 |
| F9 FT B1021.2 | SES-10 |
| F9 FT B1031.2 | SES-11 / EchoStar 105 |

# Total Number of Successful and Failure Mission Outcomes

- Calculate the total number of successful and failure mission outcomes

## Task 7

List the total number of successful and failure mission outcomes

```
%sql SELECT "Mission_Outcome", COUNT("Mission_Outcome") as Total FROM SPACEXTBL GROUP BY "Mission_Outcome";
```

```
 * sqlite:///my_data1.db
Done.
```

| Mission_Outcome | Total |
|---|---|
| Failure (in flight) | 1 |
| Success | 98 |
| Success | 1 |
| Success (payload status unclear) | 1 |

# Boosters Carried Maximum Payload

- List of the boosters which have carried the maximum payload mass

```
%sql SELECT "Booster_Version",Payload, "PAYLOAD_MASS__KG_" FROM SPACEXTBL WHERE "PAYLOAD_MASS__KG_" = (SELECT MAX("PAYLOAD_MASS__KG_") FROM SPACEXTBL)
```

```
 * sqlite:///my_data1.db
Done.
```

| Booster_Version | Payload | PAYLOAD_MASS__KG_ |
|---|---|---|
| F9 B5 B1048.4 | Starlink 1 v1.0, SpaceX CRS-19 | 15600 |
| F9 B5 B1049.4 | Starlink 2 v1.0, Crew Dragon in-flight abort test | 15600 |
| F9 B5 B1051.3 | Starlink 3 v1.0, Starlink 4 v1.0 | 15600 |
| F9 B5 B1056.4 | Starlink 4 v1.0, SpaceX CRS-20 | 15600 |
| F9 B5 B1048.5 | Starlink 5 v1.0, Starlink 6 v1.0 | 15600 |
| F9 B5 B1051.4 | Starlink 6 v1.0, Crew Dragon Demo-2 | 15600 |
| F9 B5 B1049.5 | Starlink 7 v1.0, Starlink 8 v1.0 | 15600 |
| F9 B5 B1060.2 | Starlink 11 v1.0, Starlink 12 v1.0 | 15600 |
| F9 B5 B1058.3 | Starlink 12 v1.0, Starlink 13 v1.0 | 15600 |
| F9 B5 B1051.6 | Starlink 13 v1.0, Starlink 14 v1.0 | 15600 |
| F9 B5 B1060.3 | Starlink 14 v1.0, GPS III-04 | 15600 |
| F9 B5 B1049.7 | Starlink 15 v1.0, SpaceX CRS-21 | 15600 |

# 2015 Launch Records

- List of failed landing outcomes in drone ship, with their booster versions,  and launch site names in 2015

## Task 9

List the records which will displav the month names, failure landing_outcomes in drone ship ,booster versions, launch_site for the months in year 2015.

```
%sql SELECT substr(Date,7,4), substr(Date, 4, 2),"Booster_Version", "Launch_Site", Payload, "PAYLOAD_MASS__KG_", "Mission_Outcome", "Landing _Outcome"
```

```
 * sqlite:///my_data1.db
Done.
```

| substr(Date,7,4) | substr(Date, 4, 2) | Booster_Version | Launch_Site | Payload | PAYLOAD_MASS__KG_ | Mission_Outcome | Landing _Outcome |
|---|---|---|---|---|---|---|---|
| 2015 | 01 | F9 v1.1 B1012 | CCAFS LC-40 | SpaceX CRS-5 | 2395 | Success | Failure (drone ship) |
| 2015 | 04 | F9 v1.1 B1015 | CCAFS LC-40 | SpaceX CRS-6 | 1898 | Success | Failure (drone ship) |

# Rank Landing Outcomes Between 2010-06-04 and 2017-03-20

- Rank the count of landing outcomes (such as Failure (drone ship) or Success (ground pad)) between the date 2010-06-04 and 2017-03-20, in descending order

## Task 10

Rank the count of successful landing_outcomes between the date 04-06-2010 and 20-03-2017 in descending order.

```
%sql SELECT * FROM SPACEXTBL WHERE "Landing _Outcome" LIKE 'Success%' AND (Date BETWEEN '04-06-2010' AND '20-03-2017') ORDER BY Date DESC;
```

```
 * sqlite:///my_data1.db
Done.
```

| Date | Time (UTC) | Booster_Version | Launch_Site | Payload | PAYLOAD_MASS__KG_ | Orbit | Customer | Mission_Outcome | Landing _Outcome |
|---|---|---|---|---|---|---|---|---|---|
| 19-02-2017 | 14:39:00 | F9 FT B1031.1 | KSC LC-39A | SpaceX CRS-10 | 2490 | LEO (ISS) | NASA (CRS) | Success | Success (ground pad) |
| 18-10-2020 | 12:25:57 | F9 B5 B1051.6 | KSC LC-39A | Starlink 13 v1.0, Starlink 14 v1.0 | 15600 | LEO | SpaceX | Success | Success |
| 18-08-2020 | 14:31:00 | F9 B5 B1049.6 | CCAFS SLC-40 | Starlink 10 v1.0, SkySat-19, -20, -21, SAOCOM 1B | 15440 | LEO | SpaceX, Planet Labs, PlanetIQ | Success | Success |
| 18-07-2016 | 04:45:00 | F9 FT B1025.1 | CCAFS LC-40 | SpaceX CRS-9 | 2257 | LEO (ISS) | NASA (CRS) | Success | Success (ground pad) |
| 18-04-2018 | 22:51:00 | F9 B4 B1045.1 | CCAFS SLC-40 | Transiting Exoplanet Survey Satellite (TESS) | 362 | HEO | NASA (LSP) | Success | Success (drone ship) |

# Launch Sites Proximities Analysis

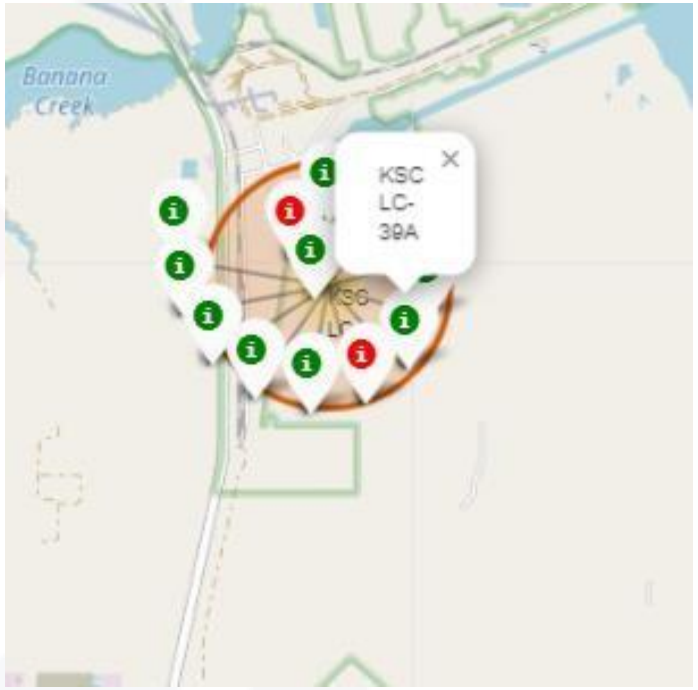
# Markers of all launch sites on global map


- All launch sites are in proximity to the Equator, (located southwards of the US map). Also all the laumch sites are in very close proximity to the coast.

# Launch outcomes for each site on the map With Color Markers

## Florida Sites

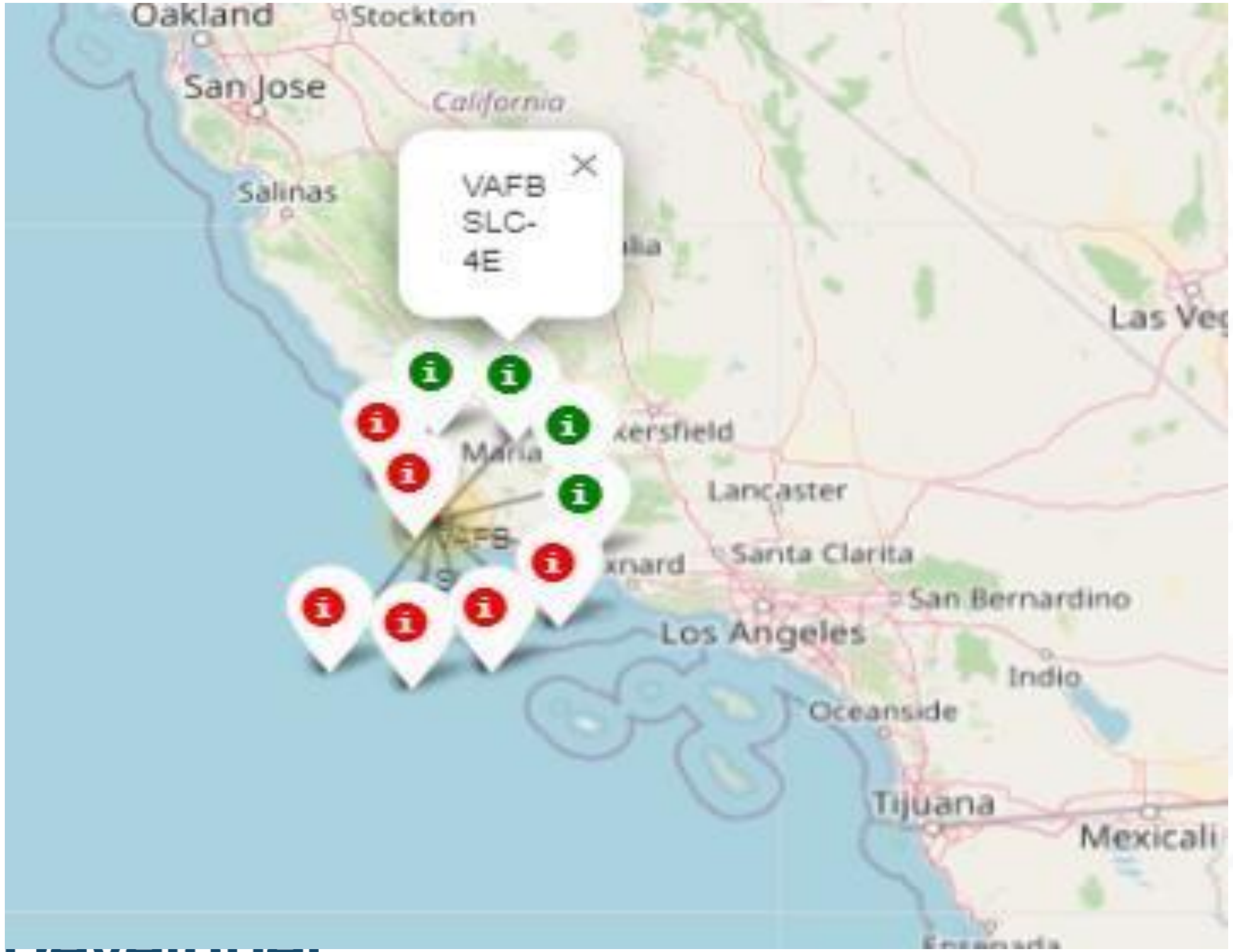





- In the Eastern coast (Florida) Launch site KSC LC-39A has relatively high success rates compared to CCAFS SLC-40 & CCAFS LC-40.

# Launch outcomes for each site on the map With Color Markers

## West Coast/ Carlifonia




- In the West Coast (Californai) Launch site VAFB SLC-4E has relatively lower success rates 4/10 compared to KSC LC-39A launch site in the Eastern Coast of Florida.

# Distances between a launch site to its proximities


- Launch site CCAFS SLC-40 proximity to coastline is 0.86km



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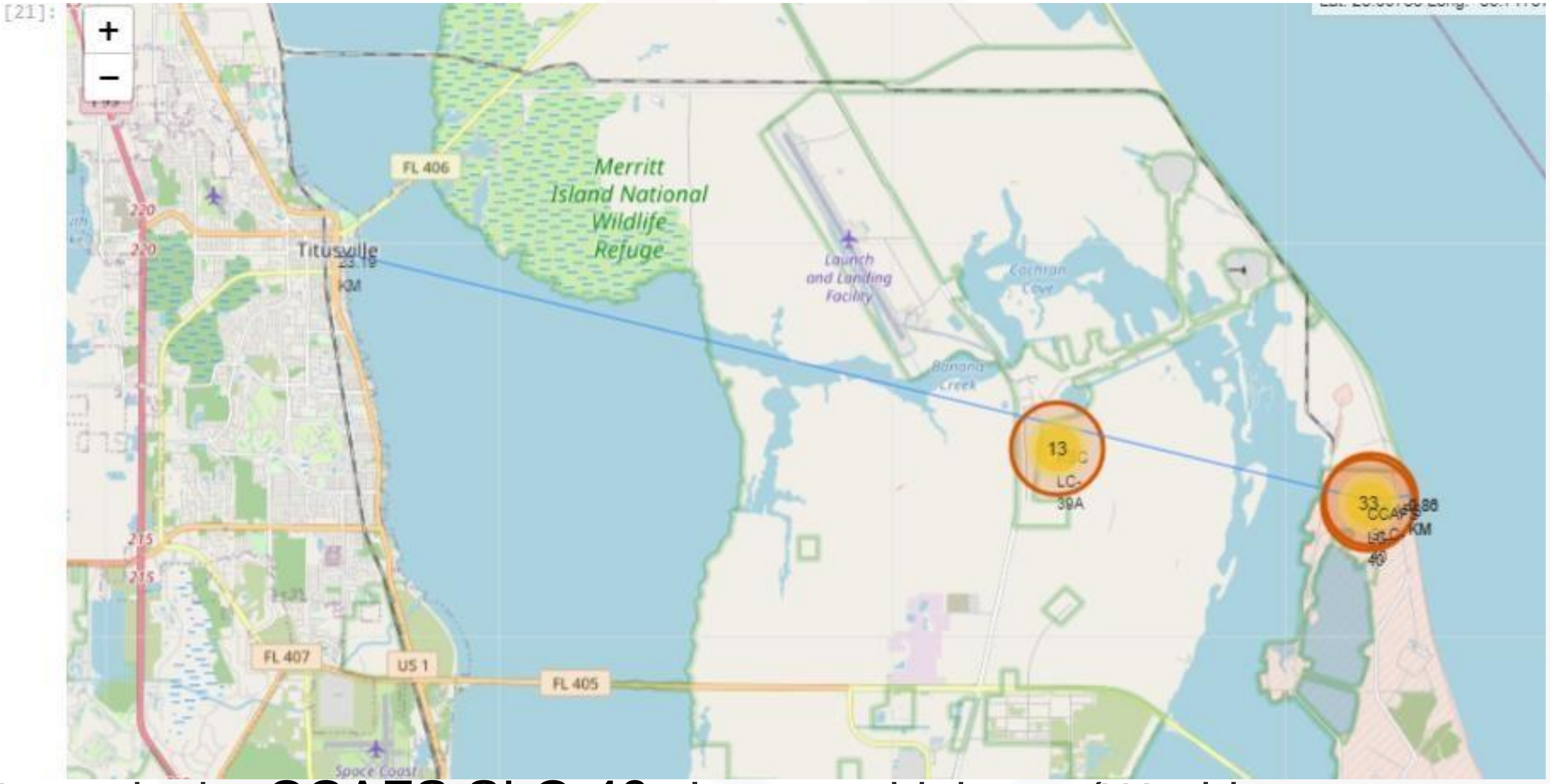
# Distances between a launch site to its proximities

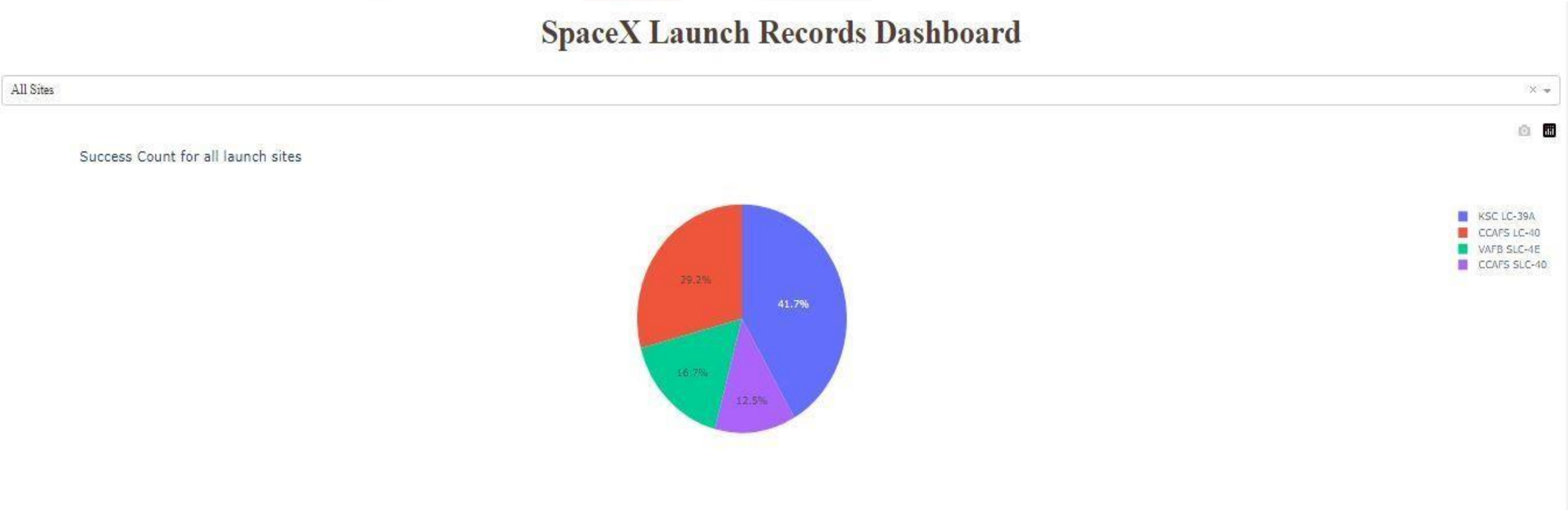



- Launch site CCAFS SLC-40 closest to highway (Washington Avenue) is 23.19km

Section 4

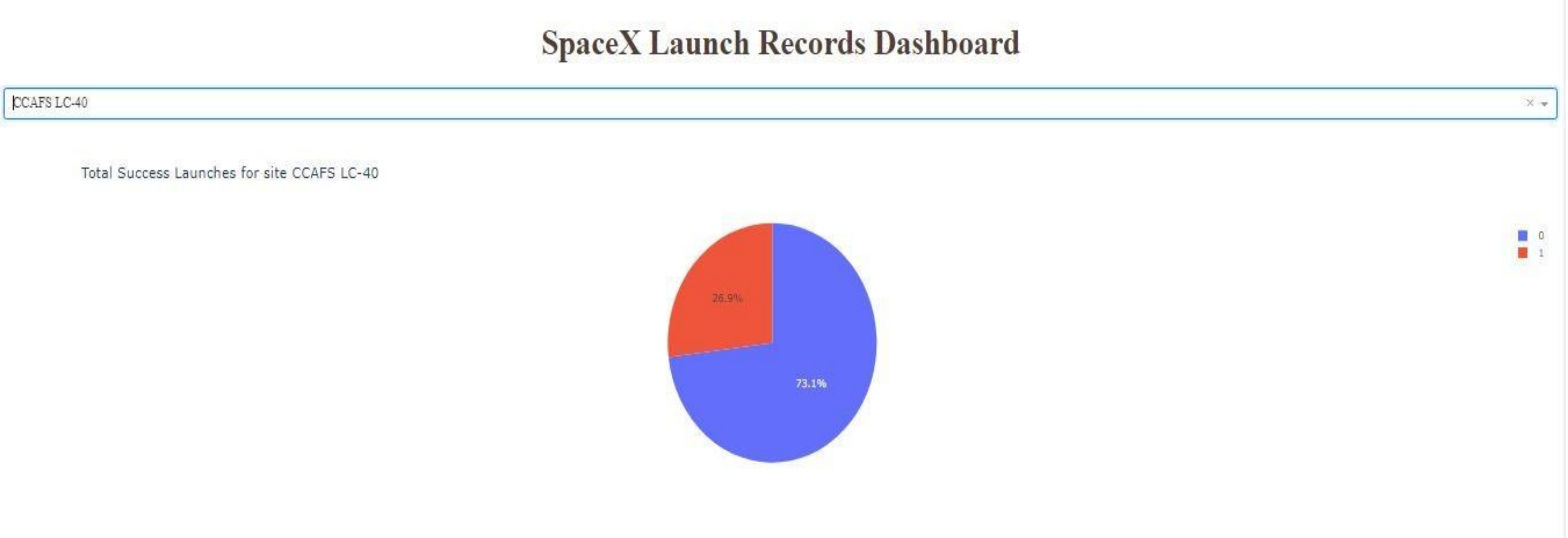
# Build a Dashboard with Plotly Dash

# Pie-Chart for launch success count for all sites




- Launch site KSC LC-39A has the highest launch success rate at 42% followed by CCAFS LC-40 at 29%, VAFB SLC-4E at 17% and lastly launch site CCAFS SLC-40 with a success rate of 13%

# Pie chart for the launch site with 2nd highest launch success ratio

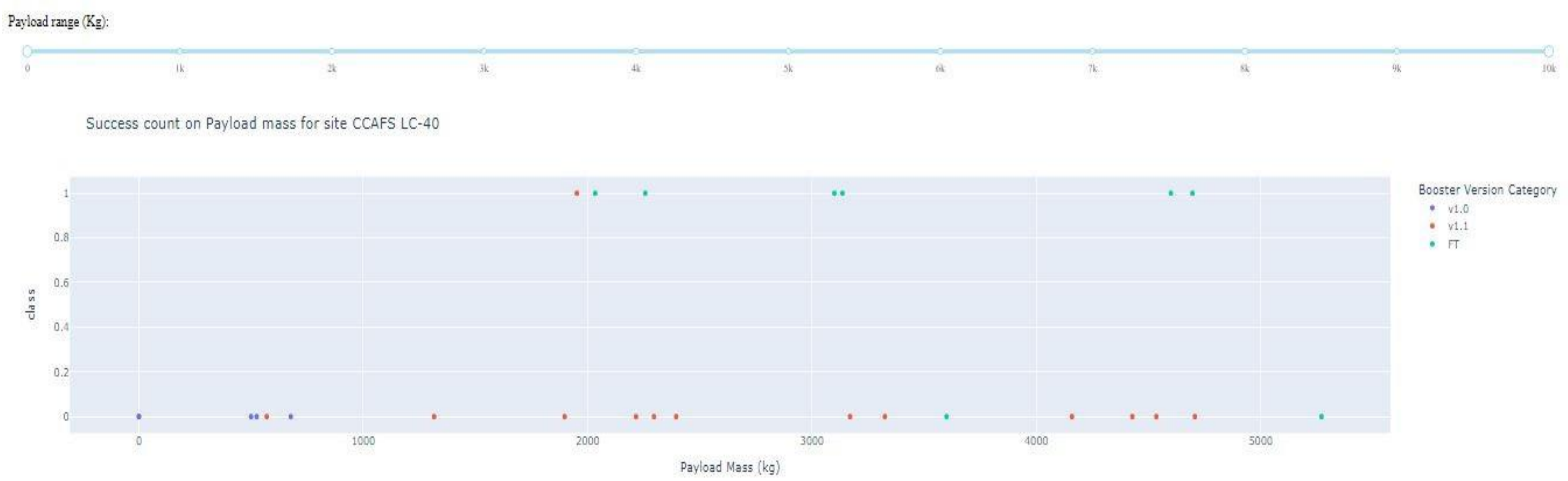



- Launch site CCAFS LC-40 had the 2nd highest success ratio of 73% success against 27% failed launches



# Payload vs. Launch Outcome scatter plot for all sites




- For Launch site CCAFS LC-40 the booster version FT has the largest success rate from a payload mass of >2000kg

Section 5

# Predictive Analysis (Classification)

# Classification Models Accuracy

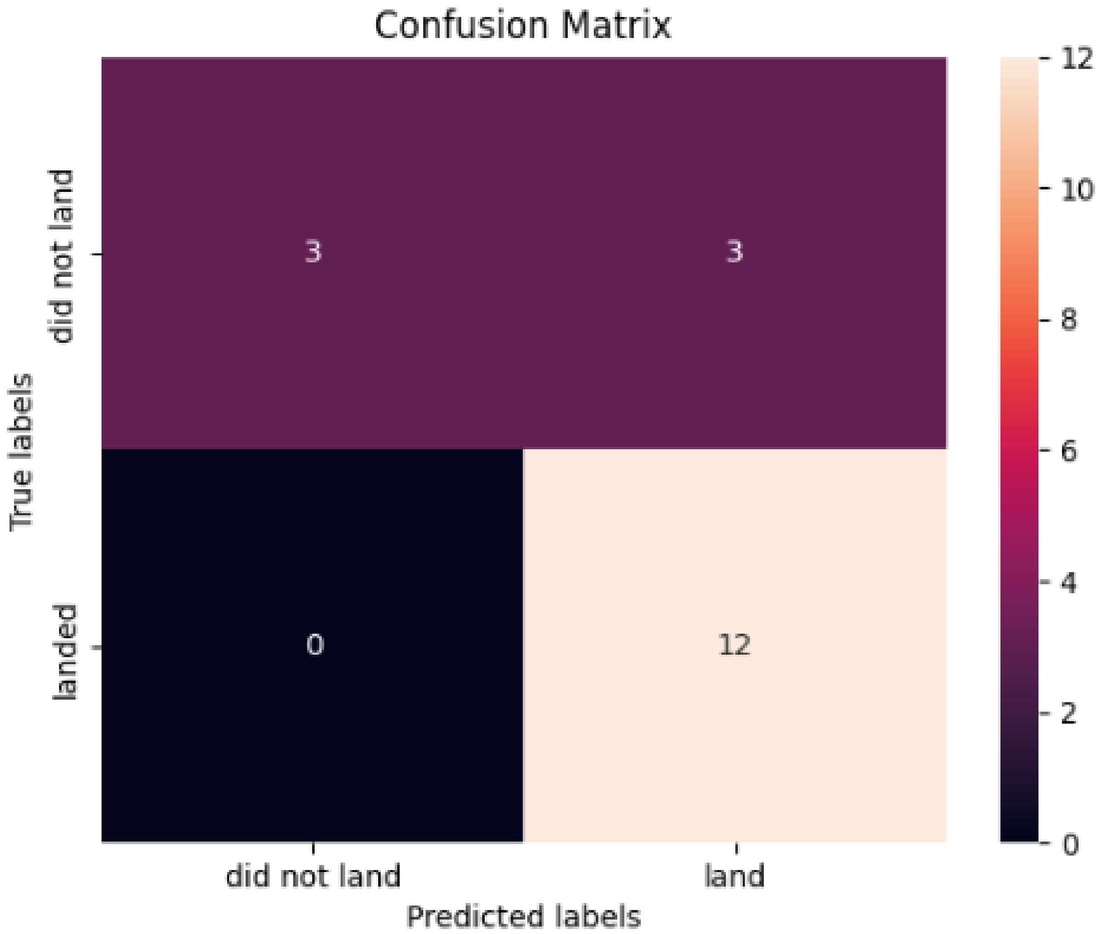
Out[68]:

| | 0 |
|---|---|
| **Method** | Test Data Accuracy |
| **Logistic_Reg** | 0.833333 |
| **SVM** | 0.833333 |
| **Decision Tree** | 0.833333 |
| **KNN** | 0.833333 |

*All the methods perform equally on the test data: i.e. They all have the same accuracy of 0.833333 on the test Data*

# Confusion Matrix

- All the 4 classification model had the same confusion matrixes and were able equally distinguish between the different classes. The major problem is false positives for all the models.



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# Conclusions

- Different launch sites have different success rates. CCAFS LC-40, has a success rate of 60 %, while KSC LC-39A and VAFB SLC 4E has a success rate of 77%.
- We can deduce that, as the flight number increases in each of the 3 launcg sites, so does the success rate. For instance, the success rate for the VAFB SLC 4E launch site is 100% after the Flight number 50. Both KSC LC 39A and CCAFS SLC 40 have a 100% success rates after 80th flight
- If you observe Payload Vs. Launch Site scatter point chart you will find for the VAFB-SLC launchsite there are no rockets launched for heavypayload mass(greater than 10000).
- Orbits ES-L1, GEO, HEO & SSO have the highest success rates at 100%, with SO orbit having the lowest success rate at ~50%. Orbit SO has 0% success rate.
- LEO orbit the Success appears related to the number of flights; on the other hand, there seems to be no relationship between flight number when in GTO orbit

# Conclusions Cont….

- With heavy payloads the successful landing or positive landing rate are more for Polar,LEO and ISS. However for GTO we cannot distinguish this well as both positive landing rate and negative landing(unsuccessful mission) are both there here
- Anf finally the sucess rate since 2013 kept increasing till 2020.

# Thank you!