IBM Developer
SKILLS NETWORK

Winning Space Race with Data Science

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Outline

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

Executive Summary

- Purpose -
- Summary of methodologies
    - Data Collection using SpaceX RESTful API and Web scraping
    - Data wrangling
    - EDA using SQL and Visualisation
    - Geospatial Visualisation with Folium
    - Dashboard created
    - Machine Learning
- Summary of all results
    - Exploratory data analysis performed
    - Interactive analytics performed (screenshots provided)
    - Predictive analysis calculated

Introduction

- Project background and context
  - The purpose of this project is to predict if the SpaceX Falcon 9 first stage will land successfully.
  - SpaceX advertises Falcon 9 launches with a cost of $62 million, while other providers cost upward of $165 million.
  - Much of SpaceX's savings are due to SpaceX being able to reuse the Falcon 9 first stage.

- Problems you want to find answers
  - If the probability of the first stage landing can be determined then a cost of launch can be calculated accounting for potential for success and failure.
  - The information can be used if an alternative company wants to bid against SpaceX for a rocket launch.

Section 1

Methodology

Methodology

Executive Summary

- Data collection methodology:
    - RESTful API used to access SpaceX data
    - Performed web scraping from Wikipedia on Falcon 9 and Falcon Heavy Launches
- Perform data wrangling to determine patterns and determine labels for training supervised models
- Perform exploratory data analysis (EDA) using visualization and SQL
- Perform interactive visual analytics using Folium and Plotly Dash
- Perform predictive analysis using classification models
    - Standardized and split data
    - Evaluated Logistic Regression, SVM, Decision Tree and KNN

Data Collection

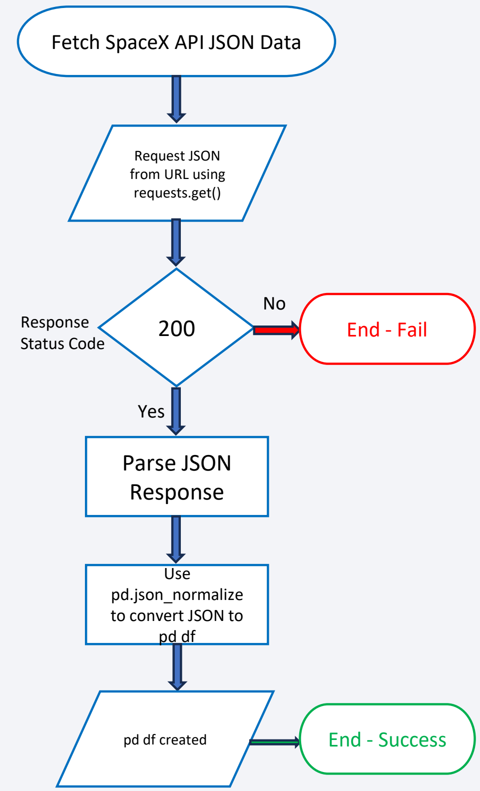
- The following slides 8 to 16 describe how data sets were collected.
- Accompanying flow charts provided where required.

Data Collection – SpaceX API (Slide 1 of 2)

RESTful API processing

- RESTful API used to access SpaceX data:
  - https://cf-courses-data.s3.us.cloud-object-storage.appdomain.cloud/IBM-DS0321EN-SkillsNetwork/datasets/API_call_spacex_api.json
- Process to Fetch, Parse and Nomalize API data shown in flowchart at RHS with end result creating a Pandas DataFrame
  - Fetch - Request JSON data from URL using requests.get() method and look for Response Status Code of 200 to indicate success
  - Parse - Parsing JSON response using json_data = response.json() to decode JSON into Python format
  - Normalize – Create a Pandas DataFrame using df = pd.json_normalize(json_data) to provide the initial basis for analysis using Pandas

Pandas DataFrame processing of API Output (next slide)

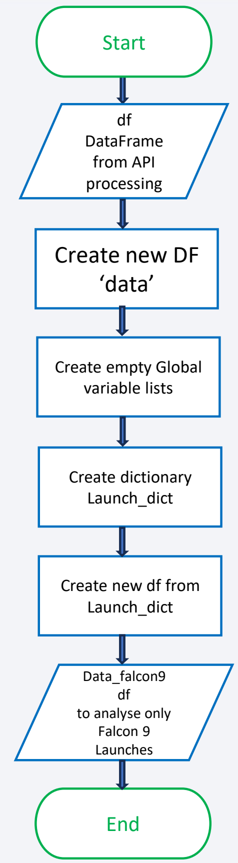


GitHub URL:
https://github.com/JWSAT/ibm_data_science_capstone/blob/main/1.%20jupyter-labs-spacex-data-collection-api.ipynb

Data Collection – SpaceX API (Slide 2 of 2)

Pandas DataFrame processing

- Created a new Pandas DataFrame keeping with features required for analysis project:
  - data = df[['rocket', 'payloads', 'launchpad', 'cores', 'flight_number', 'date_utc']]
- Created empty **Global variables** lists: BoosterVersion; PayloadMass; Orbit; LaunchSite; Outcome; Flights; GridFins; Reused; Legs; LandingPad; Block; ReusedCount; Serial; Longitude; Latitude
- Created dictionary launch_dict with the following keys: 'FlightNumber'; 'Date'; + Global variables
- Created new Pandas DataFrame from launch_dict:
  - df = pd.DataFrame.from_dict(launch_dict)
- Created new data_falcon9 DataFrame to manage only Falcon 9 launches:
  - data_falcon9 = df[df['BoosterVersion'] != 'Falcon 1']

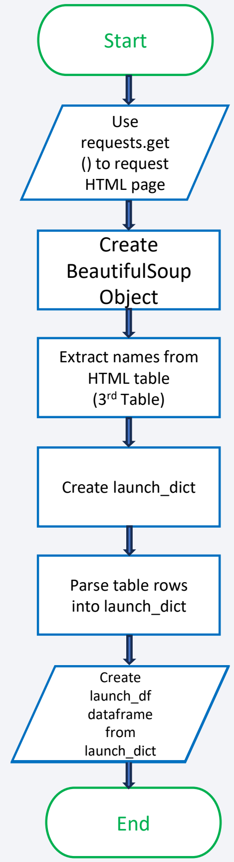


Data Collection - Scraping

Performed web scraping from Wikipedia on Falcon 9 and Falcon Heavy Launches

- Task 1: Requested Falcon9 Launch Wiki page from URL
  - Used requests.get() method to request Falcon9 Launch HTML page as HTTP response
  - Created BeautifulSoup object from HTML response
- Task 2: Extracted col/var names from HTML table header
  - Used 3rd table – actual launch table in HTML response
  - Extracted column names through iteration using .find_all('th') method
- Task 3: Created Pandas df by parsing launch HTML tables
  - Created empty dictionary launch_dict from column names
  - Parse table rows into launch_dict
  - Created launch_df data frame from launch_dict

<u>GitHub URL:</u>
https://github.com/JWSAT/ibm_data_science_capstone/blob/main/2.%20jupyter-labs-webscraping.ipynb

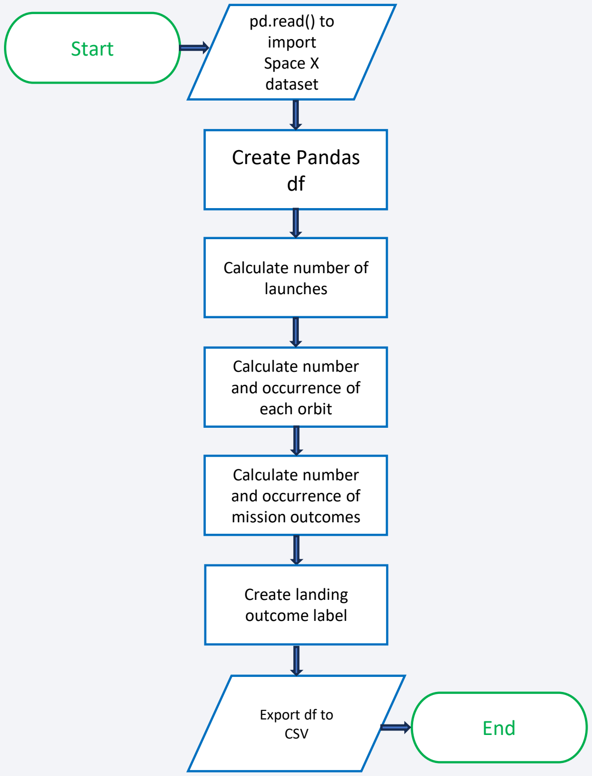


Data Wrangling

Perform initial Exploratory Data Analysis (EDA) to find patterns in data and determine labels for training supervised models. Focused on successful vs unsuccessful landings

- Initial: Loaded Space X dataset using pd.read() method and created Pandas df
- Task 1: Calculated the number of launches on each site
  - Used value_counts method on LaunchSite column of df to determine number of launches on each site
- Task 2: Calculated the number and occurrence of each orbit
  - Used value_counts method on Orbit column of df to determine number and occurrence of each orbit
- Task 3: Calculated the number and occurrence of mission outcomes of the orbits
  - Used value_counts method on Outcome column of df to determine number of landing outcomes.
    - Assigned to variable landing_outcomes
  - Used ‘for i,outcome in enumerate(landing_outcomes.keys())’ to create landing_outcomes keys
  - Used landing_outcomes keys to create bad_outcomes variable in Set form
- Task 4: Created landing outcome label from Outcome Column
  - Created landing_class list with landing_class = 0 for bad_outcome and landing_class = 1 otherwise
  - Created Class column in df and determined success rate using df[“Class”].mean() method
- Exported df to CSV: df.to_csv(‘dataset_part_2.csv”, index = False)

GitHub URL:
https://github.com/JWSAT/ibm_data_science_capstone/blob/main/3.%20labs-jupyter-spacex-Data%20wrangling.ipynb



EDA with Data Visualization

- The following charts were plotted:
  - Seaborn catplot for Flight Number vs Payload Mass
  - Seaborn catplot for Flight Number vs Launch Site
  - Seaborn catplot for Payload Mass vs Launch Site
  - Bar chart of Orbit Type vs Success Rate (Mean 0 to 1)
  - Scatterplot of Flight Number vs Orbit Type with Success/Failure record
  - Scatterplot of Payload Mass vs Orbit Type with Success/Failure record
  - Lineplot of Year vs Success Rate (Success Rate Over Time)
- The charts were plotted to provide preliminary insights about how each important variable would affect success rate.
- From these insights, features were selected to be used in success prediction in the future model and further Features Engineering coding was performed

GitHub URL: https://github.com/JWSAT/ibm_data_science_capstone/blob/main/4.%20edadataviz.ipynb

EDA with SQL

The following SQL queries were performed:

- Display names of unique launch sites
- Display 5 records where launch sites begin with CCA
- Display total payload mass carried by boosters launched by NASA (CRS)
- Display average payload mass carried by booster vers F9 v1.1
- List date when 1st successful ground pad landing was achieved
- List booster names where drone ship landing success with payload >4000kg and <6000kg occurred
- List total number of successful and failure mission outcomes
- List names of booster vers that have carried max payload mass
- List records with month name, failure landing_outcomes, booster version, launch_site for month in year 2015
- Rank count of landing outcomes in descending order between 2010-06-04 and 2017-03-20

GitHub URL: https://github.com/JWSAT/ibm_data_science_capstone/blob/main/5.%20jupyter-labs-eda-sql-coursera_sqllite.ipynb

Build an Interactive Map with Folium

- Location circles and markers created for: CCAFS LC-40; CCAFS SLC-40; KSC LC-39A; and VAFB SLC-4E
  - Enables visual location reference for each area under consideration, particularly with zooming in and out
- Marker clusters were created for each site to provide visual indication of launch outcomes with Green (successful) and Red (failure)
  - Enhanced visual where launch records have identical coordinates to enable easy identification of launch sites that have relatively high success rates
- Mouse position added to top right-hand corner of map
  - Enables easy identification of coordinates for points of interest
- Using CCAFS SLC 40 as reference, placed lines and markers for: nearest coastline; nearest city; nearest highway; and nearest railway
  - Provides visualization of geographic feature to enable further analysis of impact of geography on launches

GitHub URL:
https://github.com/JWSAT/ibm_data_science_capstone/blob/main/6.%20lab_jupyter_launch_site_location.ipynb

Build a Dashboard with Plotly Dash

Created SpaceX Launch Records Dashboard with following:

- Dropdown list to enable Launch Site Selection: All Sites; CCAFS LC-40; VAFB SLC-4E; KSC LC-39A; CCAFS SLC-40
- Pie Chart showing:
  - Total successful launches count if All Sites selected
  - If specific site selected then showing Success vs Failed counts for site
- Slider to selected payload mass range in kg
- Scatter Chart showing correlation of payload vs launch success
- Two callback functions:
  - 1st: 'site-dropdown' as input and 'success-pie-chart' as output
  - 2nd: 'site-dropdown' and 'payload-slider' as inputs and 'success-payload-scatter-chart' as output
- The plots and interactions were created to enable a user to work between all sites and specific sites and to focus between all payloads and select payload ranges

GitHub URL:
https://github.com/JWSAT/ibm_data_science_capstone/blob/main/7.%20caspstone_dash.py

Predictive Analysis (Classification)

Perform exploratory Data Analysis and determine Training Labels

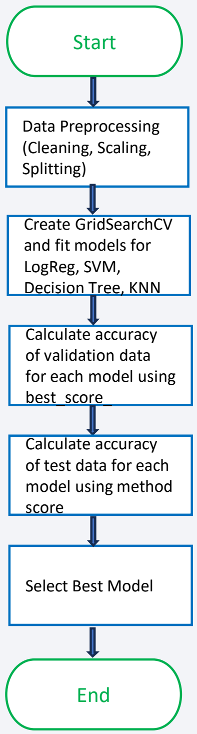
- Created NumPy array from the 'Class' column in df
- Standardized the data using StandardScalar() and fit_transform() methods
- Split data into training data (0.8) and test data (0.2) with random_state=2

Evaluated LogReg, SVM, Decision Tree and KNN to determine which method performs best using test data

- Outcome was Decision Tree for training data
- All models provided the same result for test data
- Actual test results provided later

GitHub URL:

https://github.com/JWSAT/ibm_data_science_capstone/blob/main/8.%20SpaceX_Machine%20Learning%20Prediction_Part_5.ipynb



Results

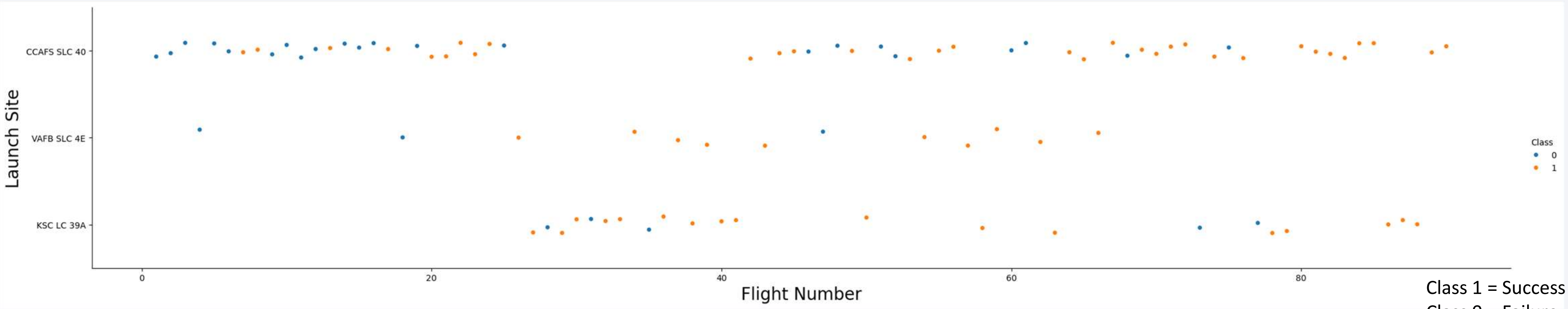
The following sections provide

- Section 2: Exploratory data analysis results
- Section 3: Launch Sites Proximities Analysis
- Section 4: Dashboard Enabling Analyst Interaction
- Section 5: Predictive analysis results

Section 2

Insights drawn from EDA

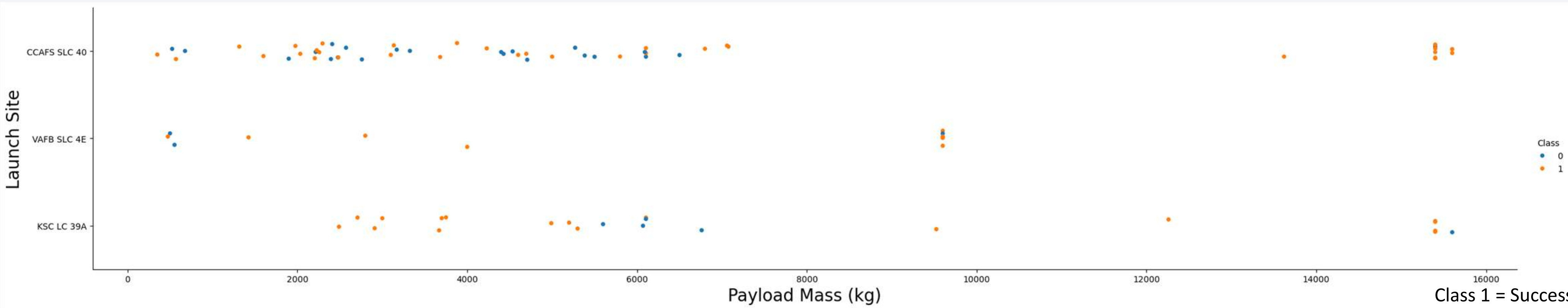
Flight Number vs. Launch Site



Class 1 = Success
Class 0 = Failure

- CCAFS SLC 40 appears to be preferred launch site
  - 23 launches before ops moved to KSC LC 39A for 12 launches indicating possible upgrades/works at SLC 40 over this period
  - Initial success rate low indicating research, development, test and evaluation activities along with operations
  - Success rate improved when majority launches returned to site
- VAFB SLC 4E has sporadic launches with majority successful from 3rd launch from site (Flight Number 26)
  - Possibly used for specialized payloads
  - High success rate
- KSC LC 39 A
  - Primary US East Coast launch site for flight numbers 27 to 41.
  - Further 10 launches have occurred from this site
  - High success rate

Payload vs. Launch Site

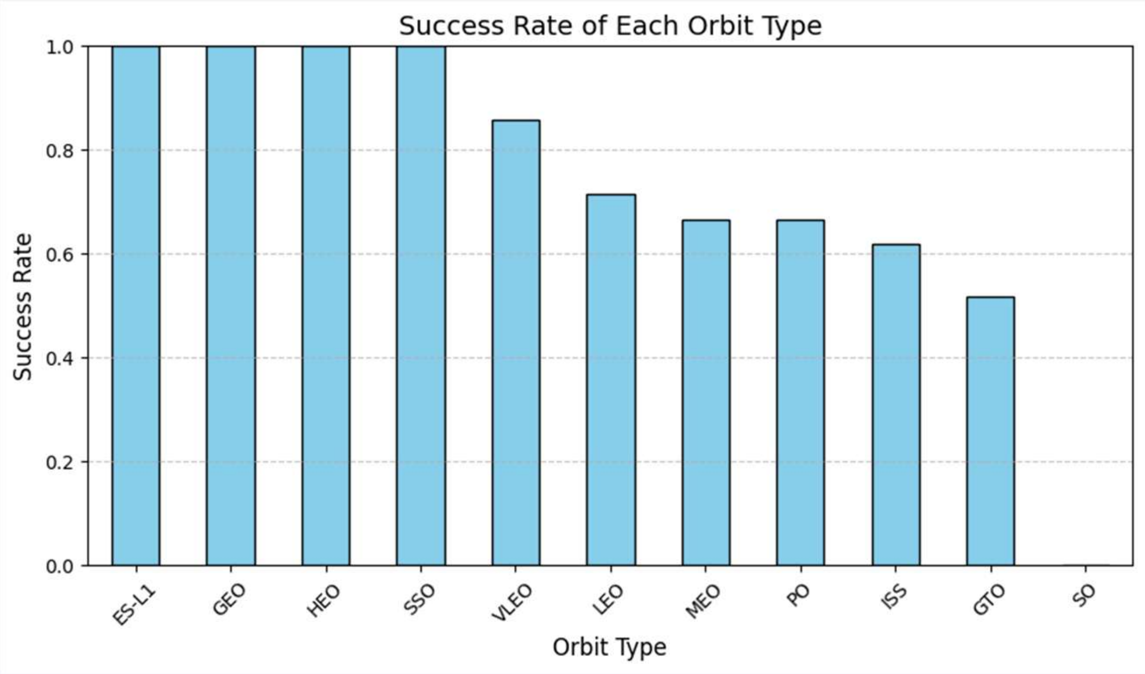


Class 1 = Success
Class 0 = Failure

- Majority of payload masses for all sites < 7,500kg
- Majority of failures occurred with payload masses < 7,500kg
  - Highest levels at CCAFS SLC 40
- 4 x launches from VAFB SLC 4E with payload mass approx. 9500kg indicates possible specialized payload
- All payload launches between 12,000kg to 16,000kg mass occurred at CCAFS SLC 40 and KSC LC 39A (US East Coast)
  - Possibly better location than VAFB SLC 4E to take advantage of relative velocity of earth rotation for east trajectory launch
  - Possible payload mass launch restrictions in place at VAFB SLC 4E

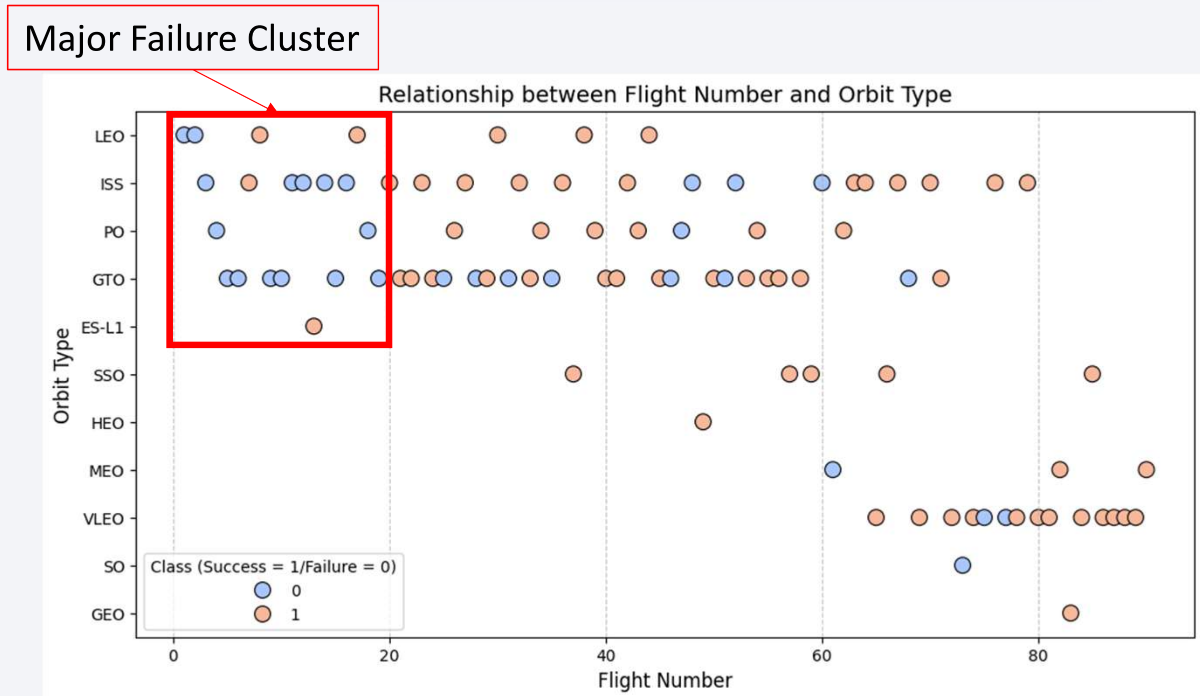
Success Rate vs. Orbit Type

- The bar chart describes the success rate for mission orbit types over the period of analysis
    - Maintains percentage in decimal format. eg 0.4 = 40%; 1.0 = 100%
- Should be read in conjunction with scatter plot on next slide.
    - Launches with lower success rates generally tend towards orbit types with larger launch numbers including:
        - LEO, PO, ISS and GTO



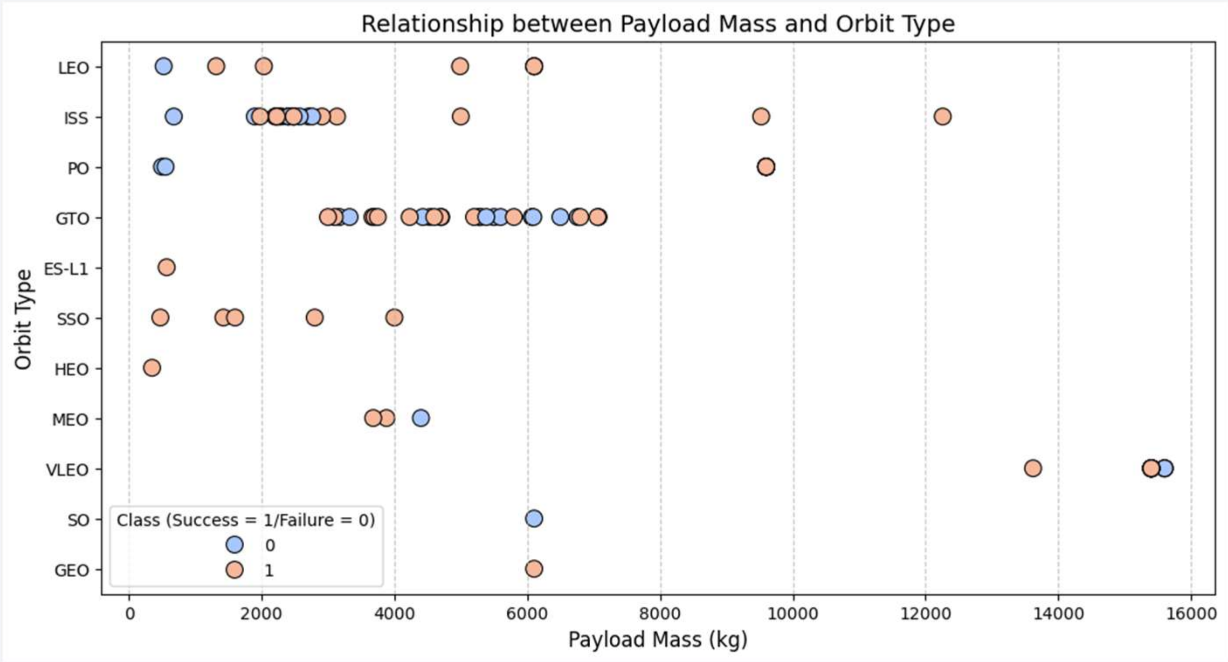
Flight Number vs. Orbit Type

- Top 5 Orbit Types supported are:
  - GTO: 27
  - ISS: 21
  - VLEO: 14
  - PO: 9
  - LEO: 7
- High failure rate with first 20 launches
  - Highlighted in Major Failure Cluster box
  - Occurred on LEO, ISS, PO and GTO
  - 15 failures
  - Success Rate 0.25
- Failures noted throughout GTO launches
  - Has the lowest success rate of all multiple launch types
  - No pattern discernable
  - Indicates potential for problematic launch orbit type



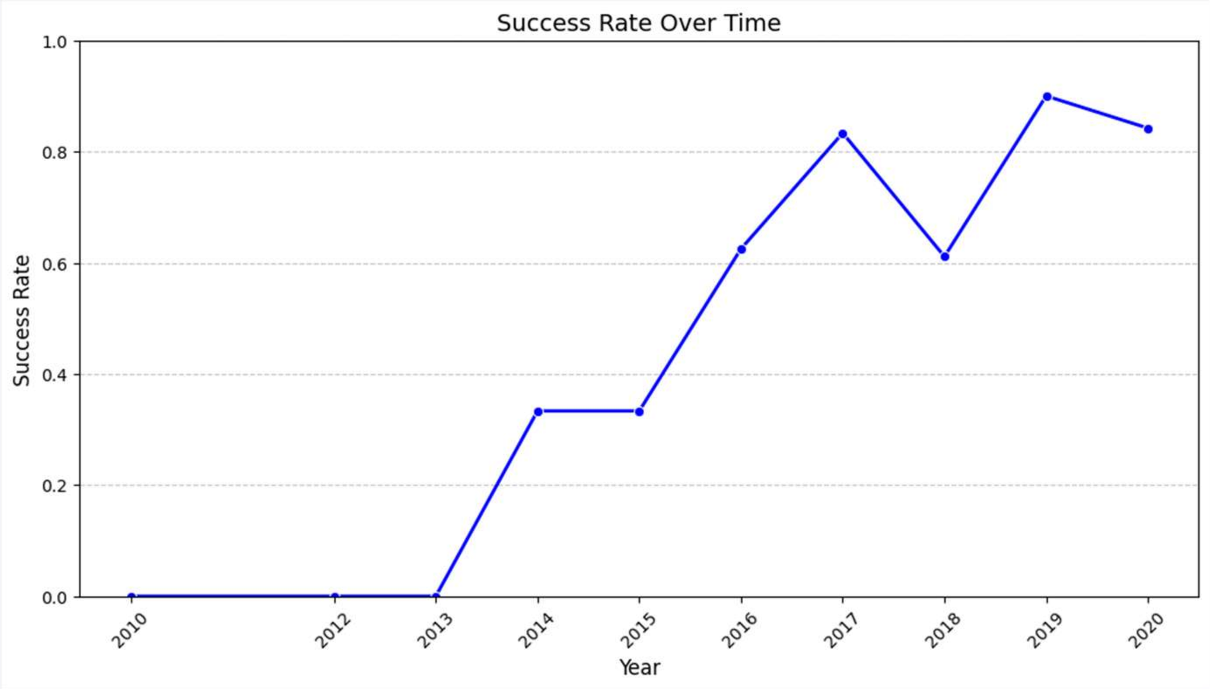
Payload vs. Orbit Type

- Lowest success rates on multiple launch orbit types are GTO and ISS.
  - ISS success rates improve at payloads > 2,800kg
  - No pattern discernable for GTO payload
- 100% success rate with SSO:
  - All payloads ≤ 4,000kg



Launch Success Yearly Trend

- Line graph shows yearly launch success rate from 2010 to 2020.
- Success Rates increase in trend from 2013 to 2020
  - Succcess Rate for 2017, 2019 and 2020 > 0.8
- Low success rates for 2014 and 2015 (<0.4) possibly indicate combination of R&D as well as operational launches
- Capability appears mature by 2017 – noting slightly reduced success rate in 2018



All Launch Site Names

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

[10]:
```
%sql SELECT DISTINCT LAUNCH_SITE as "Launch_Sites" FROM SPACEXTBL;
```

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

[10]:

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

- Screenshot of SQL Query used to identify the four unique launch sites from the SpaceX Table.
  - 2 x Cape Canaveral locations
  - 1 x Kennedy Space Center location
  - 1 x Vandenberg Air Force Base location

Launch Site Names Begin with 'CCA'

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

```
[11]: %sql SELECT * FROM SPACEXTBL WHERE LAUNCH_SITE LIKE 'CCA%' LIMIT 5;
 * sqlite:///my_data1.db
Done.
```

[11]:

Date	Time (UTC)	Booster_Version	Launch_Site	Payload	PAYLOAD_MASS__KG_	Orbit	Customer	Mission_Outcome	Landing_Outcome
2010-06-04	18:45:00	F9 v1.0 B0003	CCAFS LC-40	Dragon Spacecraft Qualification Unit	0	LEO	SpaceX	Success	Failure (parachute)
2010-12-08	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)
2012-05-22	7:44:00	F9 v1.0 B0005	CCAFS LC-40	Dragon demo flight C2	525	LEO (ISS)	NASA (COTS)	Success	No attempt
2012-10-08	0:35:00	F9 v1.0 B0006	CCAFS LC-40	SpaceX CRS-1	500	LEO (ISS)	NASA (CRS)	Success	No attempt
2013-03-01	15:10:00	F9 v1.0 B0007	CCAFS LC-40	SpaceX CRS-2	677	LEO (ISS)	NASA (CRS)	Success	No attempt

- Screen shot of SQL query and results to display 5 records related to Cape Canaveral launch sites.
- The first launch on 04 Jun 10 was for SpaceX to qualify its Dragon Spacecraft
- NASA was the customer for the other four launches
- All missions were successful
- All landing outcomes were Failures – noting that ‘No attempt’ is a failure for the purposes of this evaluation.

Total Payload Mass

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

```
[12]: %sql SELECT SUM(PAYLOAD_MASS__KG_) AS "Total payload mass by NASA (CRS)" FROM SPACEXTBL WHERE CUSTOMER = 'NASA (CRS)';

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

[12]:

Total payload mass by NASA (CRS)
45596

- NASA Commercial Resupply Services (CRS) is a commercial program to resupply the ISS from the USA.
- Above is the SQL query and result for the total payload mass carried by SpaceX boosters in support of NASA (CRS).
- The total is 45,596kg

Average Payload Mass by F9 v1.1

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

```
[13]: %sql SELECT AVG(PAYLOAD_MASS__KG_) AS "Average payload mass by Booster Version F9 v1.1" FROM SPACEXTBL WHERE BOOSTER_VERSION = 'F9 v1.1';
```

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

[13]:

Average payload mass by Booster Version F9 v1.1
2928.4

- Above is the SQL query and result for the average payload mass by Booster Falcon9 v1.1
- The result is 2,928.4kg

First Successful Ground Landing Date

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

Hint:Use min function

```
[16]: %sql SELECT MIN(DATE) AS "Date of first successful landing outcome in ground pad" FROM SPACEXTBL WHERE LANDING_OUTCOME = 'Success (ground pad)';
```

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

[16]:

Date of first successful landing outcome in ground pad
2015-12-22

- Above is the SQL query and result for the date the first successful landing outcome in ground pad was achieved.
- This occurred on 22 December 2015

Successful Drone Ship Landing with Payload between 4000 and 6000

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

```
[18]: %sql SELECT BOOSTER_VERSION FROM SPACEXTBL WHERE LANDING_OUTCOME = 'Success (drone ship)' AND PAYLOAD_MASS__KG_ BETWEEN 4000 AND 6000;
 * sqlite:///my_data1.db
Done.
```

[18]:

Booster_Version
F9 FT B1022
F9 FT B1026
F9 FT B1021.2
F9 FT B1031.2

- Above is the SQL query and result listing the names of boosters which have successfully landed on drone ship and had payload mass greater than 4,000kg but less than 6,000kg.
- B1022 and B1026 were first flight events
- B1021.2 and B1031.2 were second flight events – hence successfully reused boosters

Total Number of Successful and Failure Mission Outcomes

List the total number of successful and failure mission outcomes

[19]:
```
%sql SELECT number_of_success_outcomes, number_of_failure_outcomes FROM (SELECT COUNT(*) AS number_of_success_outcomes FROM SPACEXTBL WHERE MISSION_OUTCO
```

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

[19]:

number_of_success_outcomes	number_of_failure_outcomes
100	1

- SQL Query
  - %sql SELECT number_of_success_outcomes, number_of_failure_outcomes FROM (SELECT COUNT(*) AS number_of_success_outcomes FROM SPACEXTBL WHERE MISSION_OUTCOME LIKE 'Success%') success_table, (SELECT COUNT(*) number_of_failure_outcomes FROM SPACEXTBL WHERE MISSION_OUTCOME LIKE 'Failure%') failure_table
- The number of mission success outcomes was 100 and the number of mission failure outcomes was 1
- Overall mission success rate is 99%
- Even if there is a landing failure for the Falcon 9 booster in the mission, the customer can be assured of a very high likelihood for mission success.

Boosters Carried Maximum Payload

List the names of the booster_versions which have carried the maximum payload mass. Use a subquery

[21]:
```
%sql SELECT DISTINCT BOOSTER_VERSION FROM SPACEXTBL WHERE PAYLOAD_MASS__KG_ =(SELECT MAX(PAYLOAD_MASS__KG_) FROM SPACEXTBL);
```

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

[21]:

Booster_Version
F9 B5 B1048.4
F9 B5 B1049.4
F9 B5 B1051.3
F9 B5 B1056.4
F9 B5 B1048.5
F9 B5 B1051.4
F9 B5 B1049.5
F9 B5 B1060.2
F9 B5 B1058.3
F9 B5 B1051.6
F9 B5 B1060.3
F9 B5 B1049.7

- Above is the SQL query and the result is at left hand side for the names of the booster versions that have carried the maximum payload mass.
- 12 x results returned
- All were re-use boosters conducting 2^{nd} through to 7^{th} launch.

2015 Launch Records – Failed Landing Outcomes Drone Ship

```
('January', 'Failure (drone ship)', 'F9 v1.1 B1012', 'CCAFS LC-40')
('April', 'Failure (drone ship)', 'F9 v1.1 B1015', 'CCAFS LC-40')
```

```
conn = sqlite3.connect("my_data1.db")
cursor = conn.cursor()

query = """
SELECT
    CASE substr(Date, 6, 2)
        WHEN '01' THEN 'January'
        WHEN '02' THEN 'February'
        WHEN '03' THEN 'March'
        WHEN '04' THEN 'April'
        WHEN '05' THEN 'May'
        WHEN '06' THEN 'June'
        WHEN '07' THEN 'July'
        WHEN '08' THEN 'August'
        WHEN '09' THEN 'September'
        WHEN '10' THEN 'October'
        WHEN '11' THEN 'November'
        WHEN '12' THEN 'December'
    END AS Month_Name,
    Landing_Outcome,
    Booster_Version,
    Launch_Site
FROM SPACEXTBL
WHERE
    substr(Date, 0, 5) = '2015'
    AND Landing_Outcome LIKE '%Failure%'
    AND Landing_Outcome LIKE '%drone ship%';
"""

cursor.execute(query)
results = cursor.fetchall()

for row in results:
    print(row)
```

- List the failed landing_outcomes in drone ship, their booster versions, and launch site names for in year 2015

- Present your query result with a short explanation here

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

- This task was to rank the count of landing outcomes between the dates 2010-06-04 and 2017-03-20, in descending order
- The SQL query used was:
  - %sql SELECT LANDING_OUTCOME, COUNT(LANDING_OUTCOME) AS Landing_Count FROM SPACEXTBL WHERE DATE BETWEEN '2010-06-04' AND '2017-03-20' GROUP BY LANDING_OUTCOME ORDER BY COUNT(LANDING_OUTCOME) DESC;
- Results are at right hand side:
  - Success green
  - Failure red
- Controlled (ocean): Booster performed successful controlled landing on ocean with no recovery of the booster conducted
- Precluded (drone ship): External factors prohibited an attempt at landing on a drone ship

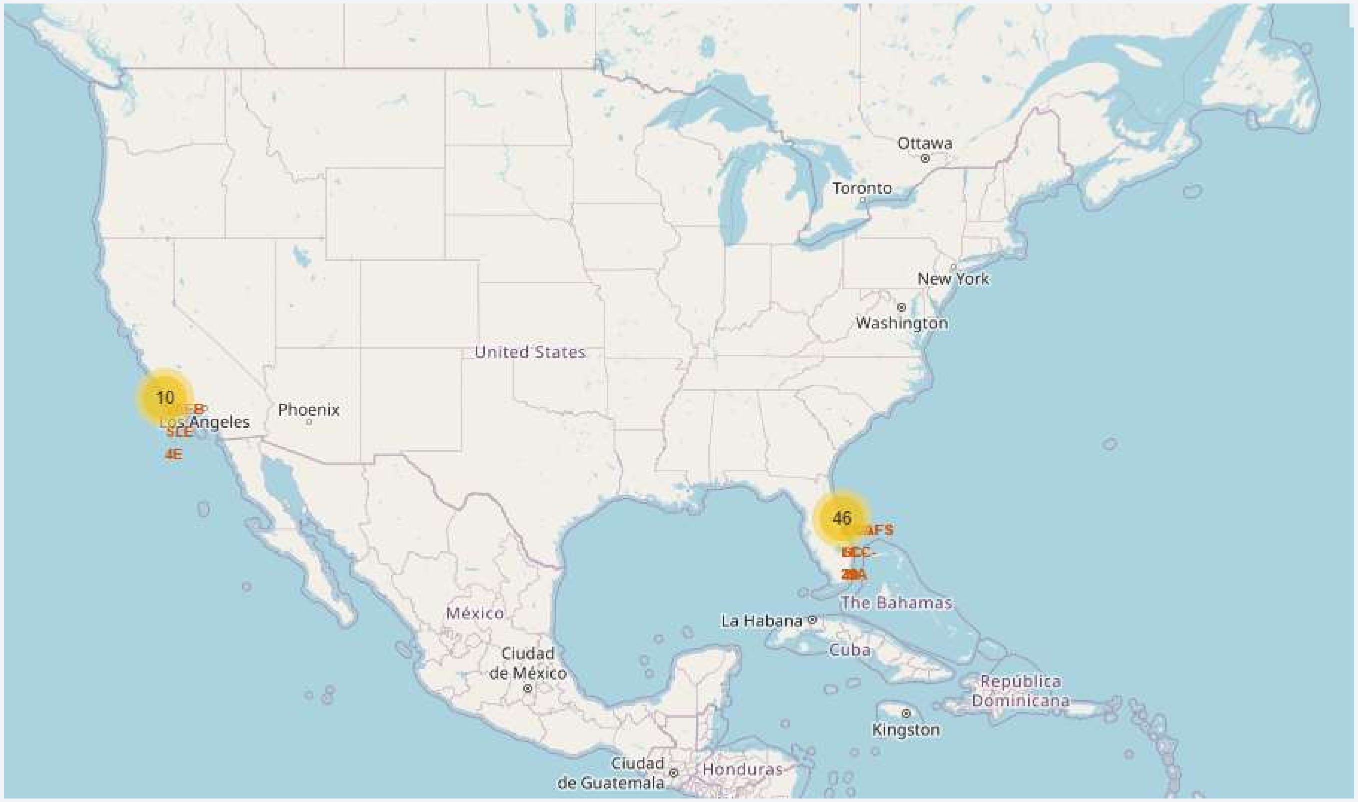
Landing_Outcome	Landing_Count
No attempt	10
Success (drone ship)	5
Failure (drone ship)	5
Success (ground pad)	3
Controlled (ocean)	3
Uncontrolled (ocean)	2
Failure (parachute)	2
Precluded (drone ship)	1

Section 3

Launch Sites Proximities Analysis

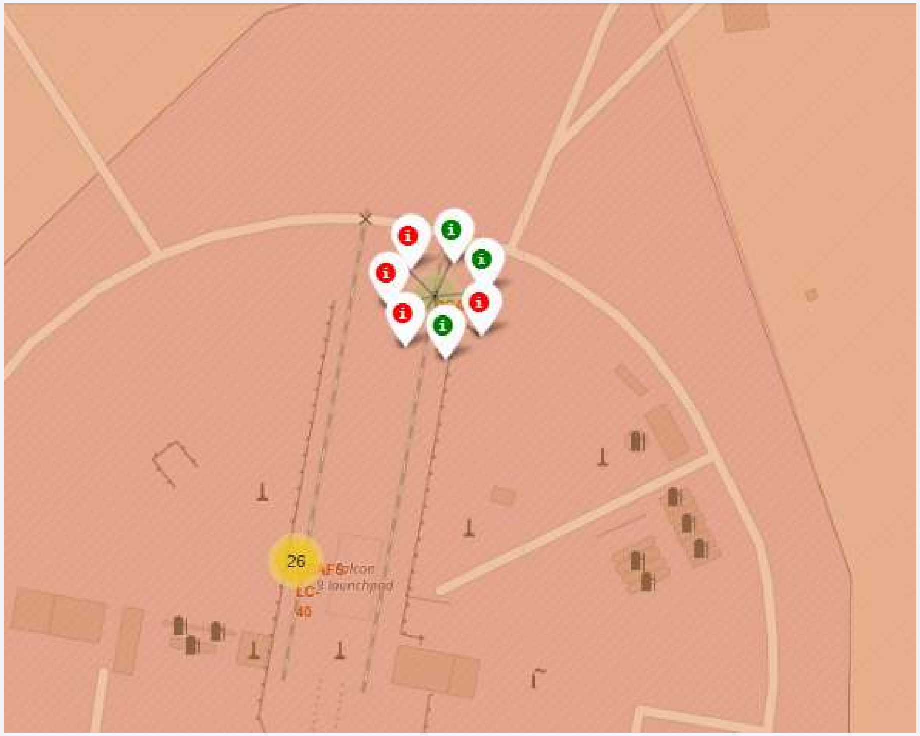
View of Major Launch Site Areas

- Major Launch Sites locations are:
  - 3 x southern east coast USA (Florida):
    - CCAFS LC-40
    - CCAFS SLC-40
    - KSC LC-39A
  - 1 x southern west coast USA (California):
    - VAFB SLC-4E
- The majority of launches occurred on the east coast:
  - 46 vs 10
- Launch sites are located in southern area close to the equator
  - Utilizes max relative velocity of earth rotation at the equator
- Proximity to coastlines provide element of safety should launch failure occur
  - Clear of population centers and infrastructure
  - Clear zones can be promulgated for shipping traffic to remain clear of area



Success vs Failure at CCAFS SLC-40

- Image at right hand side shows success vs failure of launches as CCAFS SLC-40
  - Success = green (3)
  - Failure = red (4)
- The failure rate (4) was slightly higher than the success rate (3) at this location.
- Very low number of 7 launch events indicates that adjacent CCAFS LC-40 with 26 launch events is preferred launch location



Range of CCAFS SLC-40 to Major Infrastructure

- CCAFS SLC-40 is located 19.73 km from Cape Canaveral city center (Fig 1)
  - Significant distance from population center to ensure safety of people on ground in the event of launch problems
- CCAFS SLC-40 is located 0.87 km from the ocean (Fig 2)
  - Ocean can easily be cleared as a range area to support launch recoveries and launch failures
  - Falcon 9 capability developments include the use of autonomous drone ships for recovery
- CCAFS SLC-40 ranges to key infrastructure (Fig 2)
  - Nearest road not directly linked to launch site – 0.5 km
  - Nearest rail terminal – 1.22 km
  - Rail and road support critical for logistic and operational support of launches

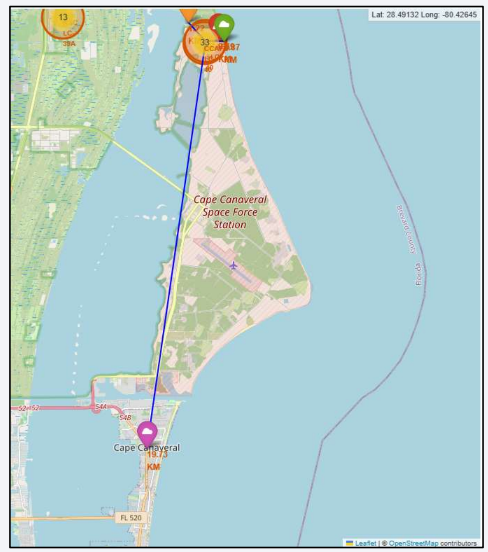


Fig 1: Range to Cape Canaveral City Center

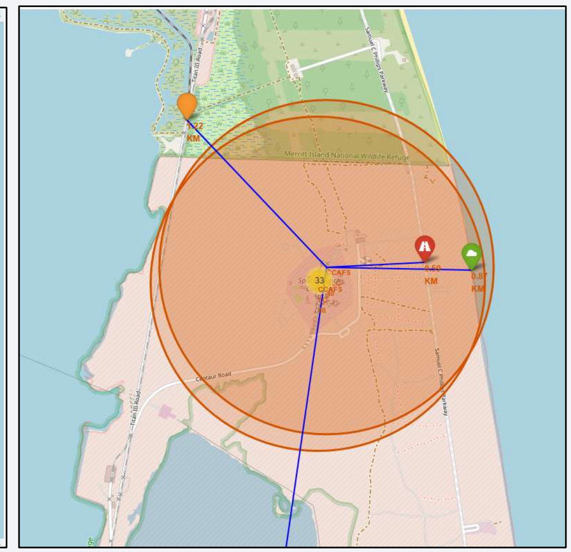
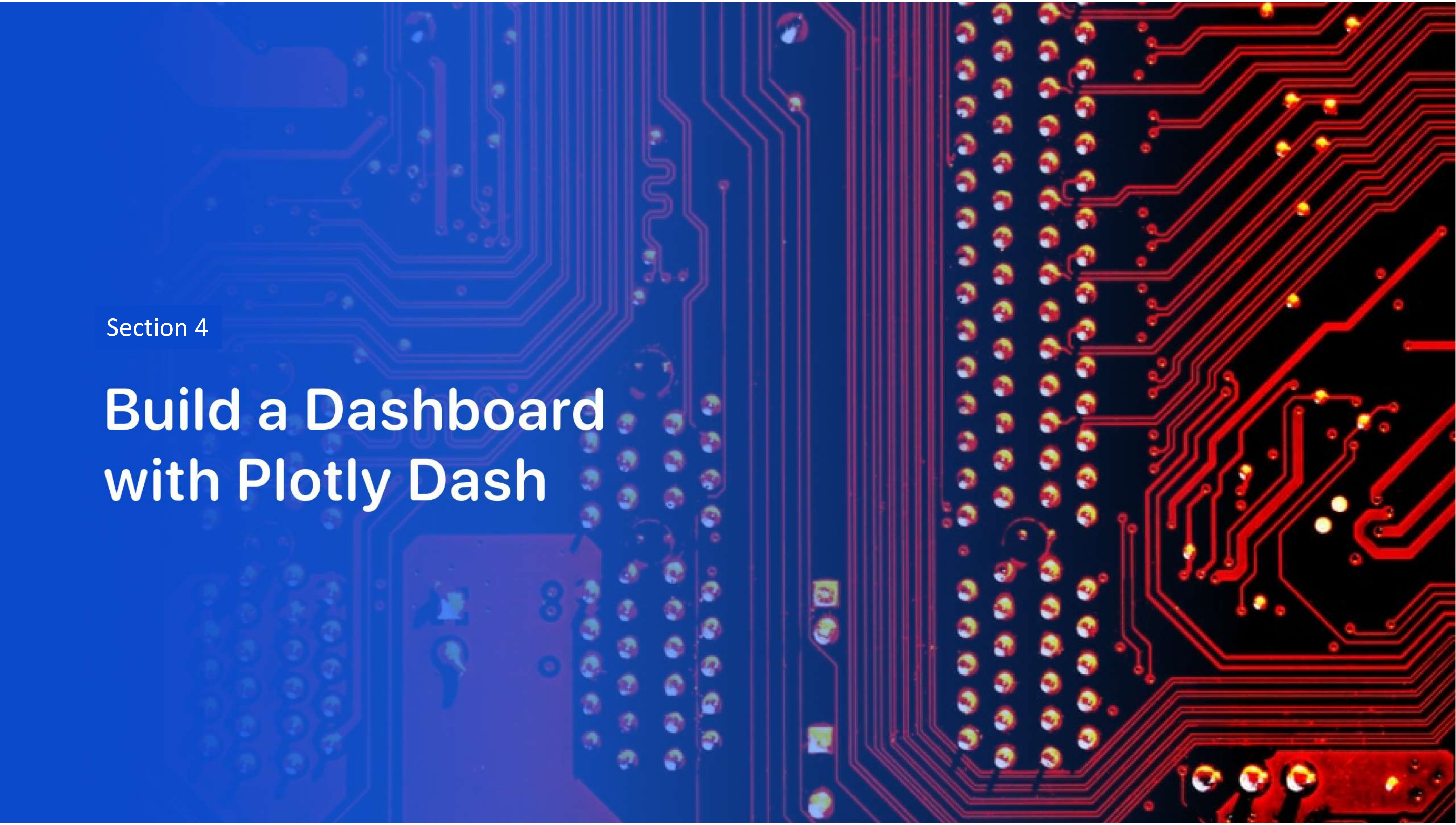


Fig 2: Ranges to key infrastructure

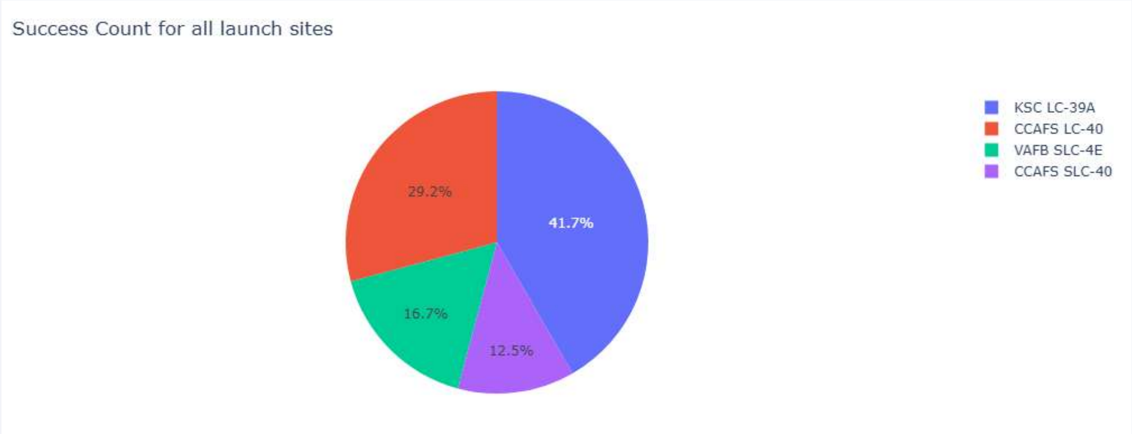


Section 4

Build a Dashboard with Plotly Dash

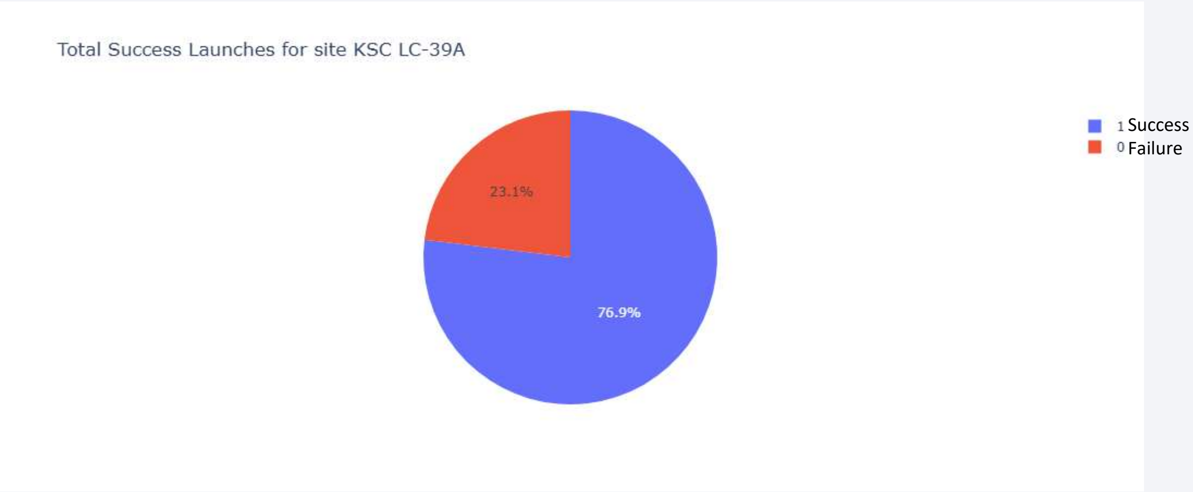
Success Count For All Launch Sites

- Pie chart shows success as a percentage of the whole of the launch data set
- Sites in descending order are
  - KSC LC-39A
  - CCAFS LC-40
  - VAFB SLC-4E
  - CCAFS SLC-40
- Success vs Failure ratio requires individual site selection



Ratio of Success vs Failure for KSC LC-39A Launches

- KSC LC-39A has the highest launch success ratio of the four sites evaluated
  - Success = 76.9 %
  - Failure = 23.1 %
- Per slides 19 and 20:
  - Success rates at this launch site indicates it was focused on operational outcomes rather than R&D and Test and Evaluation



Success Count On Payload Mass For All Sites

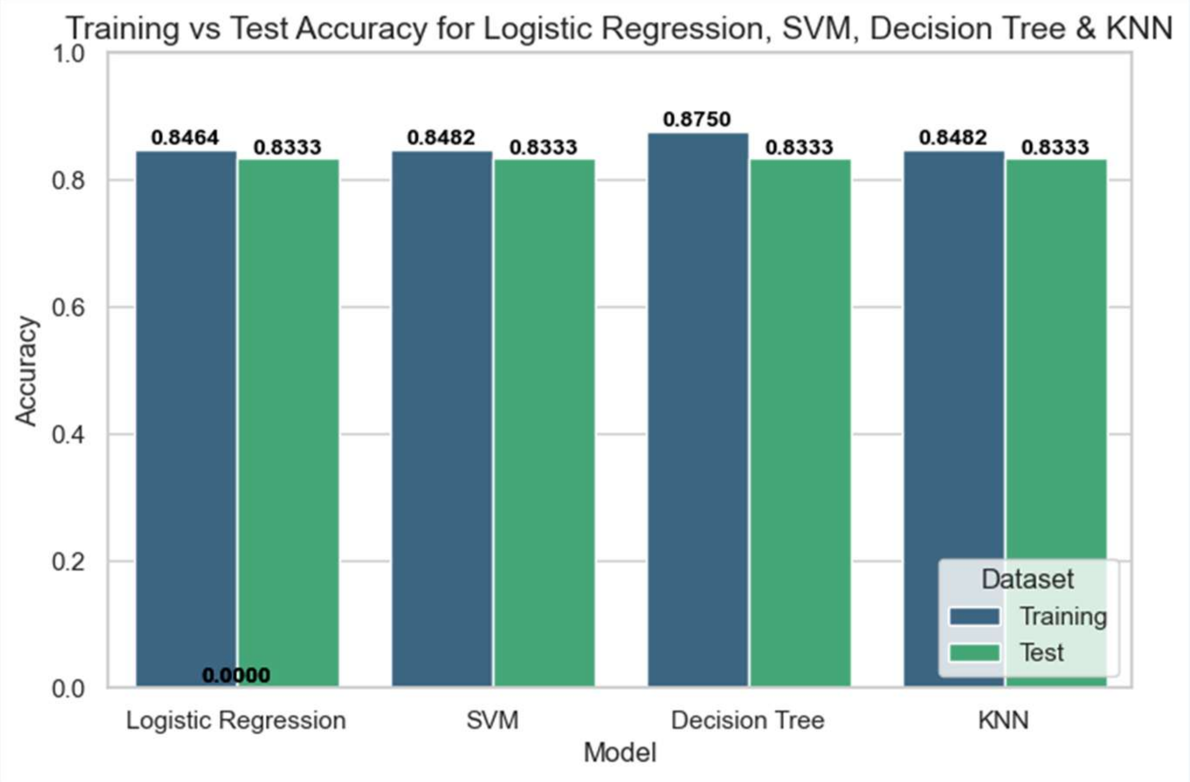
- The most successful Booster version against multiple events was the FT (13 success/7 failure) followed by B4 (6 success/5 failure)
- No success on FT at payload masses > 5, 300kg
- Success rate for B4 of 1 / 2 at 9, 600kg payload mass indicates that this version was designed for high payload capacity.
- High failure rates for v1.0 and v1.1 indicate that these systems were not specifically designed for reuse, but potentially v1.1 was used for development of reuse capability due to single module success.

Section 5

Predictive Analysis (Classification)

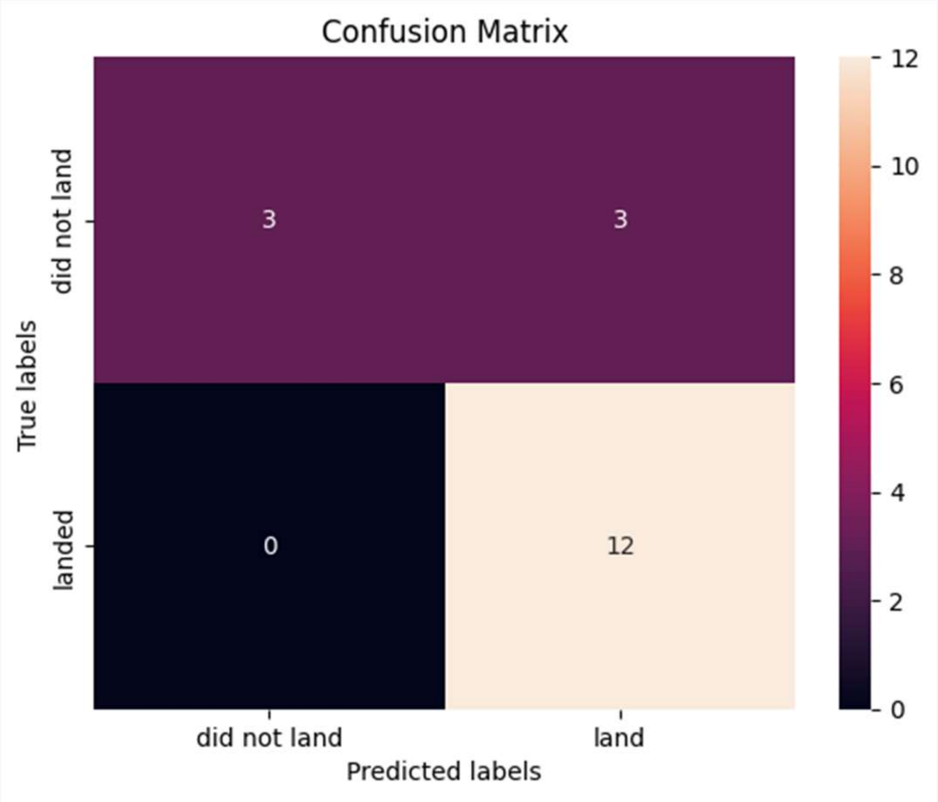
Classification Accuracy

- Models evaluated were Logistic Regression, SVM, Decision Tree and KNN
- Decision Tree had the highest Training Data outcome of 0.8750
- Test Data Accuracy for all models was 0.8333



Confusion Matrix – Decision Tree

- Decision Tree shows outcome for the 18 elements of training data applied to the Decision Tree
  - Reflects the 0.8333 Test Accuracy on Slide 45
- Correct outcomes:
  - True Positive (landed) = 12
  - True Negative (did not land) = 3
  - False Negative (landed but shown as did not land) = 0
- Incorrect outcome:
  - False Positive (did not land but shown as landed) = 3
- Further model refinement could lower False Positive
  - Look at elements to include removing certain booster types that were possibly not designed to land V1.0 and V1.1
  - Look at supported orbits as some orbits have higher failure rates than others. Determine what orbits will be supported.
  - Model is already quite small, so further data from ongoing Falcon 9 launches should improve the model.



Conclusions

- Geography of launch site location is critical:
  - Proximity to equator utilizes earth's relative velocity of rotation
  - Close proximity to coastline and road, rail and runway infrastructure supports logistics and operations
  - Sufficient space from population centers is essential for safety of population in event of launch failure
- Decision Tree deemed best model for prediction of whether or not first stage of Falcon 9 will land following launch.
- Factors to consider in the model:
  - Prioritize reducing False Positives
  - More launch data should improve model
  - Booster versions not designed for first stage recovery should be removed from model
  - Orbit type supported should also be considered further as some types have higher levels of failure inherent

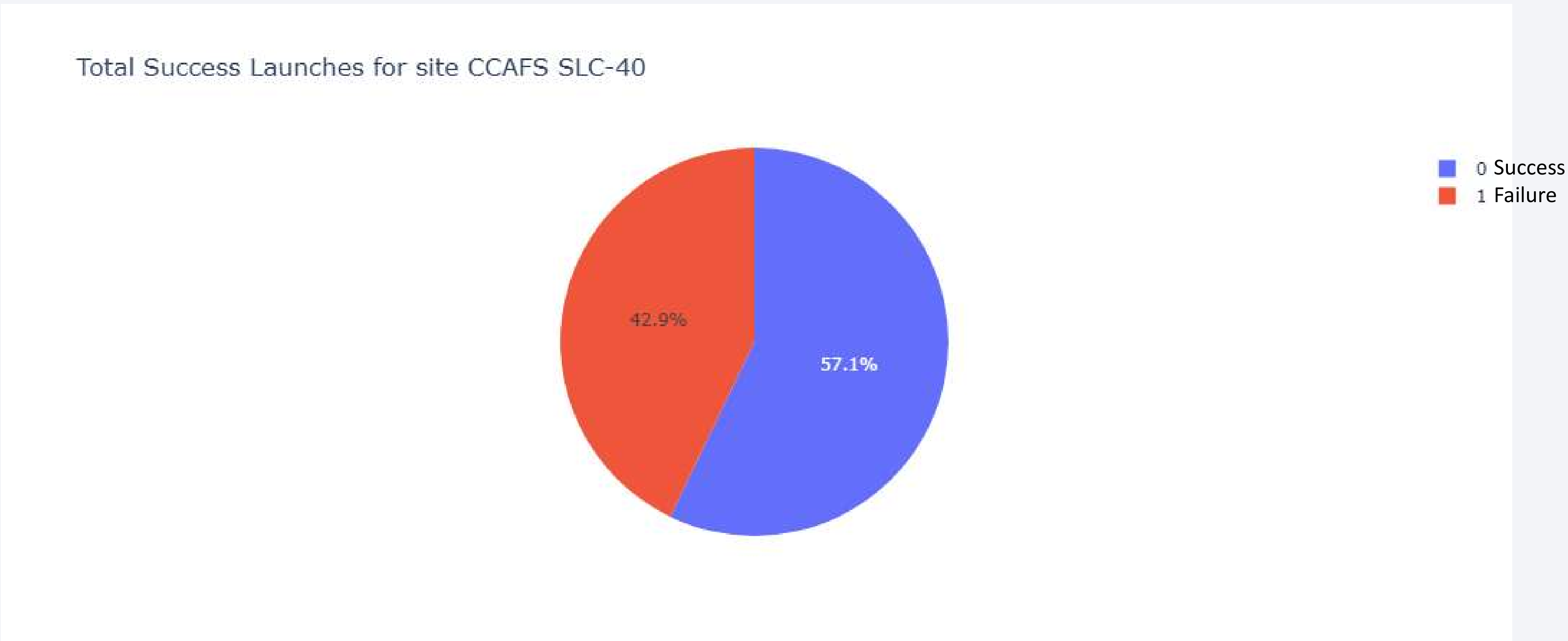
Appendices

1. Launch Success vs Failure percentages for CCAFS SLC-40

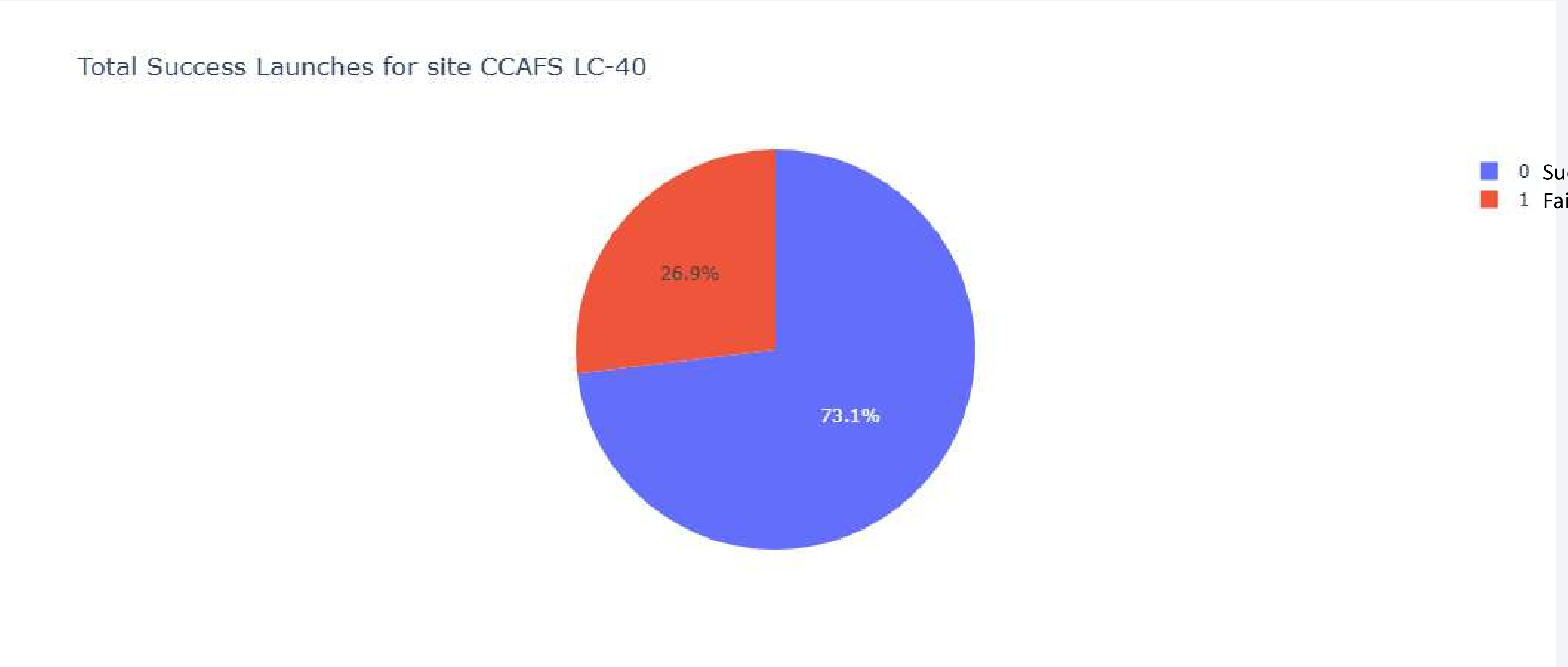
2. Launch Success vs Failure percentages for CCAFS LC-40

3. Launch Success vs Failure percentages for VAFB SLC-4E

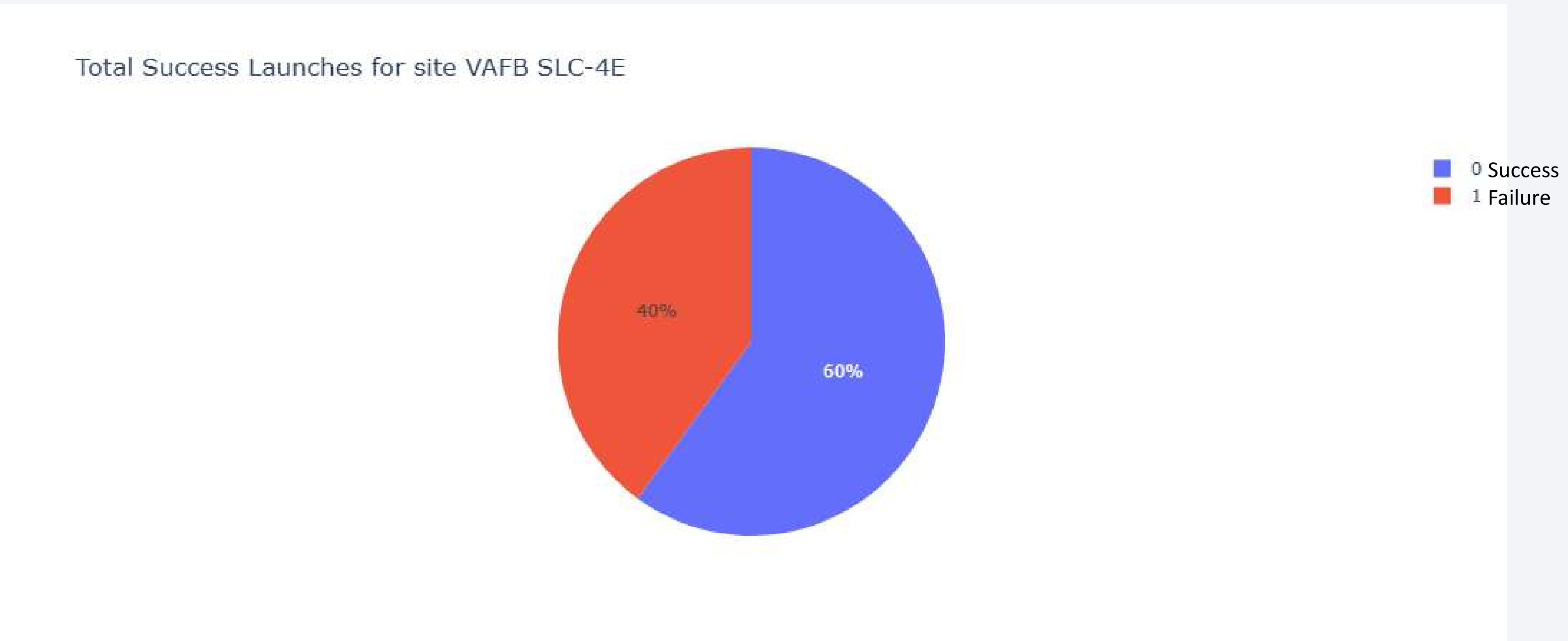
Appendix 1: Launch Success vs Failure percentages for CCAFS SLC-40



Appendix 2: Launch Success vs Failure percentages for CCAFS LC-40



Appendix 3: Launch Success vs Failure percentages for VAFB SLC-4E




Thank you!