IBM Developer
SKILLS NETWORK

Winning Space Race with Data Science

PUDUPPULY RAJESH SURENDRAN
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Outline

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- Methodology
- Results
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Executive Summary

- Summary of methodologies
  - Data collection
  - Data wrangling
  - Exploratory Data Analysis with Data Visualization
  - Exploratory Data Analysis with SQL
  - Building an interactive map with Folium
  - Building a Dashboard with Plotly Dash
  - Predictive analysis (Classification)

- Summary of all results
  - Exploratory Data Analysis results
  - Interactive analytics demo in screenshots
  - Predictive analysis results

Introduction

- Project background and context
  - SpaceX is a private aerospace company that has revolutionized space transportation by drastically reducing launch costs through the reuse of rocket components. One of its most notable achievements is successfully sending spacecraft to the International Space Station. The Falcon 9 rocket, advertised at around 62 million dollars per launch, costs significantly less than competitors' rockets, which can exceed 165 million dollars. This cost advantage primarily arises from SpaceX's ability to recover and reuse the rocket's first stage.
- Questions to be answered
  - In this project, using publicly available SpaceX launch data, we aim to build machine learning models that can predict whether the first stage of a Falcon 9 rocket will successfully land and be reused. Accurate prediction of first stage landing outcomes will provide insights into launch cost estimation and reusability performance, supporting data-driven understanding of how SpaceX achieves cost-effective space missions.

Section 1

Methodology

Methodology

Executive Summary

- Data collection methodology:
  - Describes how data was collected
- Perform data wrangling
  - Describes how data was processed
- Perform exploratory data analysis (EDA) using visualization and SQL
- Perform interactive visual analytics using Folium and Plotly Dash
- Perform predictive analysis using classification models
  - Describes how to build, tune and evaluate classification models

Data Collection

Executive Summary

- Data was collected using the SpaceX API via Python REST calls, fetching mission, launch, and payload data. Web scraping was performed for supplementary site information. All raw datasets were downloaded as CSV files and stored for processing.
- Columns obtained from SpaceX REST API: 'FlightNumber', 'Date', 'BoosterVersion', 'PayloadMass', 'Orbit', 'LaunchSite', 'Outcome', 'Flights', 'GridFins', 'Reused', 'Legs', 'LandingPad', 'Block', 'ReusedCount', 'Serial', 'Longitude' and 'Latitude'.
- Columns obtained from Wikipedia Web Scraping: 'Flight No.', 'Launch site', 'Payload', 'PayloadMass', 'Orbit', 'Customer', 'Launch Outcome', 'Version Booster', 'Booster Landing', 'Date', 'Time'.

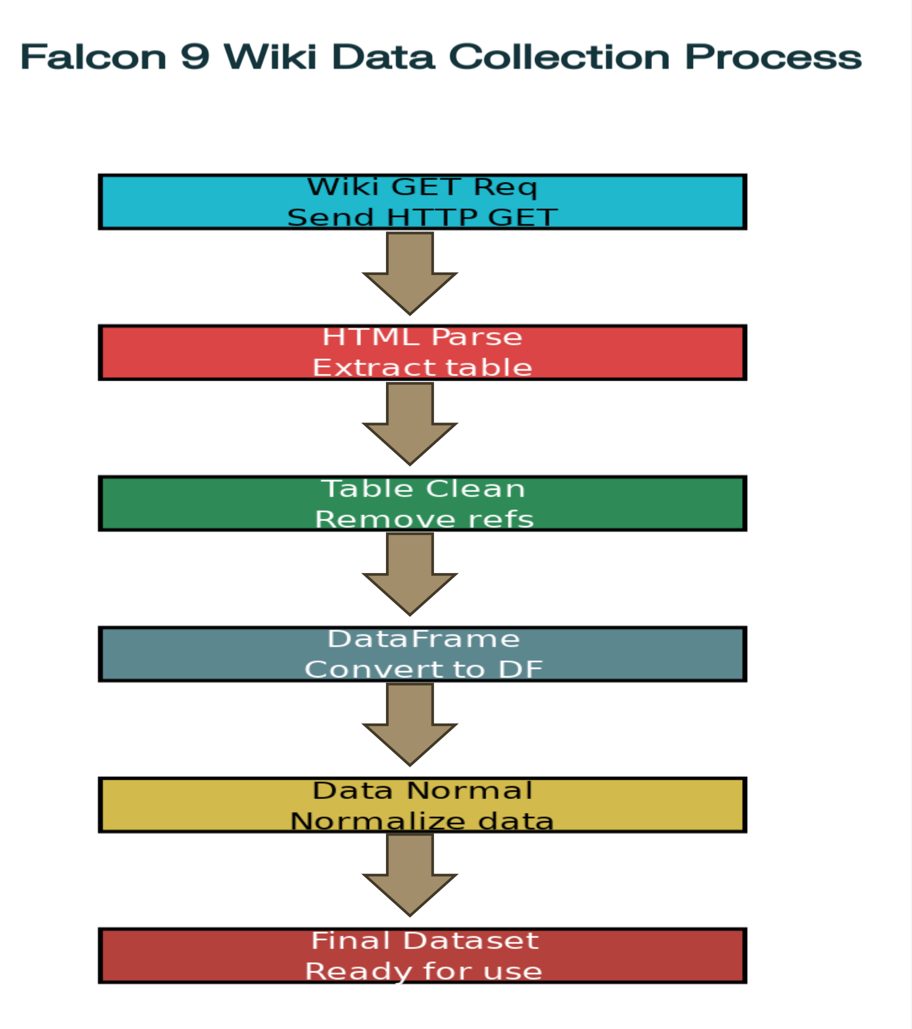
Data Collection

- **Process Steps Highlighted:**
  - SpaceX API Request - Initial data retrieval
  - JSON Response Processing - Converting raw data to structured format
  - Data Enhancement - Enriching data with additional API calls
  - Data Filtering - Focusing on Falcon 9 launches specifically
  - Data Cleaning - Handling missing values systematically
  - Final Dataset - Preparing the clean data for analysis

Github URL

Data Collection - Scraping

- Process Steps Highlighted:
  - Collected Falcon 9 launch records from Wikipedia using web scraping.
  - Sent an HTTP GET request to the launch list URL.
  - Parsed and extracted the main launch data table with BeautifulSoup.
  - Cleaned and converted the data into a Pandas DataFrame.
  - Used helper functions to remove footnotes, handle multi-value cells, and normalize data for analysis.



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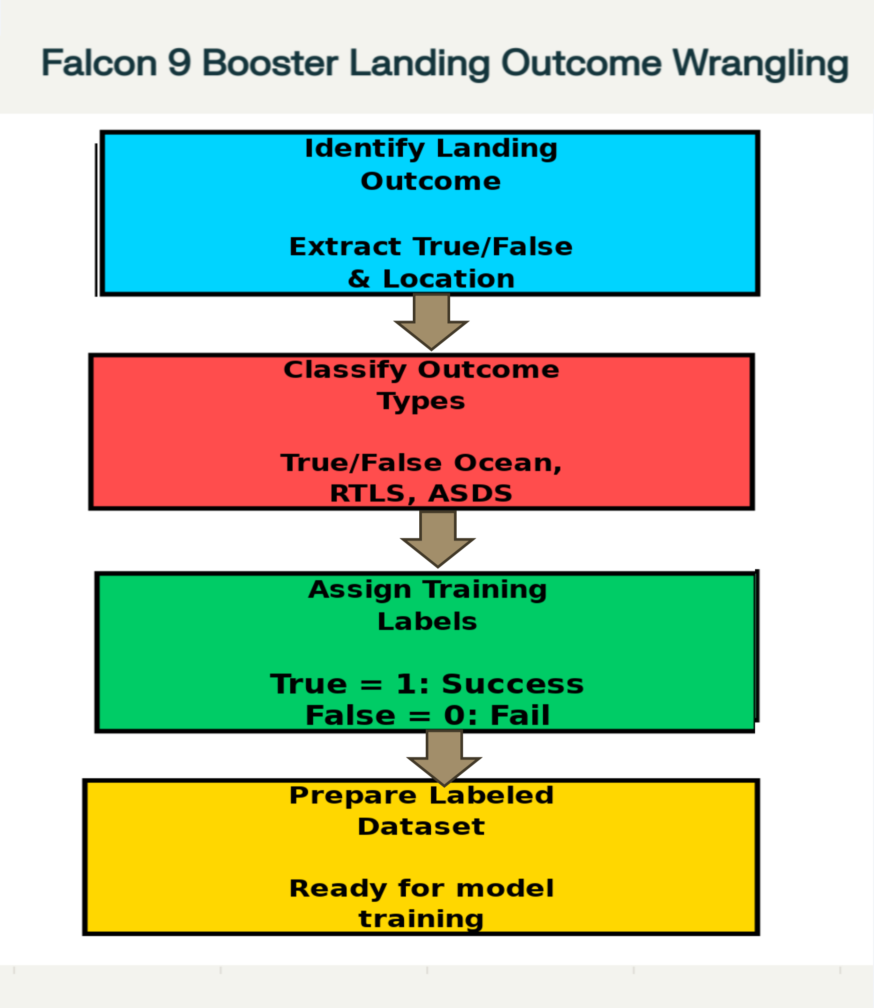
Data Wrangling

- **Process Steps Highlighted:**
- Data wrangling involved handling various booster landing outcomes in the dataset.
- Outcomes included both successful and unsuccessful landings across different locations:
  - True Ocean: Booster landed successfully in the ocean.
  - False Ocean: Booster failed to land in the ocean.
  - True RTLS: Booster landed successfully on a ground pad (Return to Launch Site).
  - False RTLS: Booster failed to land on a ground pad.
  - True ASDS: Booster landed successfully on a drone ship (Autonomous Spaceport Drone Ship).
  - False ASDS: Booster failed to land on a drone ship.
- For training, mission outcomes were converted to binary labels:
  - 1 for successful landing (any "True" case).
  - 0 for unsuccessful landing (any "False" case).



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EDA with Data Visualization

- **<u>summary of the key charts and the rationale behind each:</u>**
- **Scatter plot: Flight Number vs. Launch Site, colored by Class value**
  - *Why*: To visualize how launch success varies by site and across sequential flights. Helps identify patterns or trends related to specific launch locations.
- **Scatter plot: Payload Mass vs. Launch Site, colored by Class**
  - *Why*: Shows relationships between payload mass and launch site, highlighting which sites handle heavier payloads and their associated success rates.
- **Bar chart: Success Rate by Orbit Type**
  - *Why*: Compares the proportion of successful launches for different orbit types, helping pinpoint which orbits are most reliably achieved.
- **Scatter plot: Flight Number vs. Orbit Type**
  - *Why*: Analyzes how launch success and mission profiles change over time for different orbits, revealing evolution or trends within SpaceX operations.
- **These charts were used to understand the distribution, correlations, and trends among launch features, enabling deeper insights and data-driven conclusions about launch outcomes.**

Github URL

EDA with SQL

•**Summary of SQL queries performed**

- Selected unique launch site names using DISTINCT.
- Queried 5 records for launch sites starting with 'CCA'.
- Calculated total payload mass for boosters launched by NASA CRS.
- Found average payload mass for booster version F9 v1.1.
- Identified the date of first successful ground pad landing.
- Listed boosters with successful drone ship landings and payload mass between 4000 and 6000 kg.
- Counted total successful and failure mission outcomes grouped by MissionOutcome.
- Listed boosterversions that carried the maximum payload mass using an aggregate subquery.
- Displayed month, failure landing outcomes in drone ship, booster version, and launch site for launches in 2015.
- Ranked count of landing outcomes (e.g., Failure drone ship, Success ground pad) between specific dates, sorted in descending order.

Github URL

Build an Interactive Map with Folium

- **<u>Summary of Interactive Map with Folium</u>**
  - Markers were added for each launch site to pinpoint exact geographic locations and help visually identify different launch facilities.
  - Circles were placed around launch sites to highlight their areas, making the locations stand out on the map for quick identification and comparison of proximity.
  - Popups/Labels attached to markers and circles provided detailed launch site names or outcome information for user reference on hover or click.
  - Marker Clusters showed success and failure outcomes for launches at each site, with color codes distinguishing outcomes to assess performance visually.
  - Lines/Polylines were used to illustrate distances from launch sites to key points such as nearest coastline, city, highways, or railways, helping analyze geographical factors affecting site selection or logistics.
    - **Purpose**: These map features were added to visually analyze site locations, compare launch outcomes, and understand the spatial relationships of launch sites to nearby infrastructure, improving insight into operational factors and spatial distribution.

Github URL

Build a Dashboard with Plotly Dash

- **Summary of plots/graphs and interactions added to a dashboard**

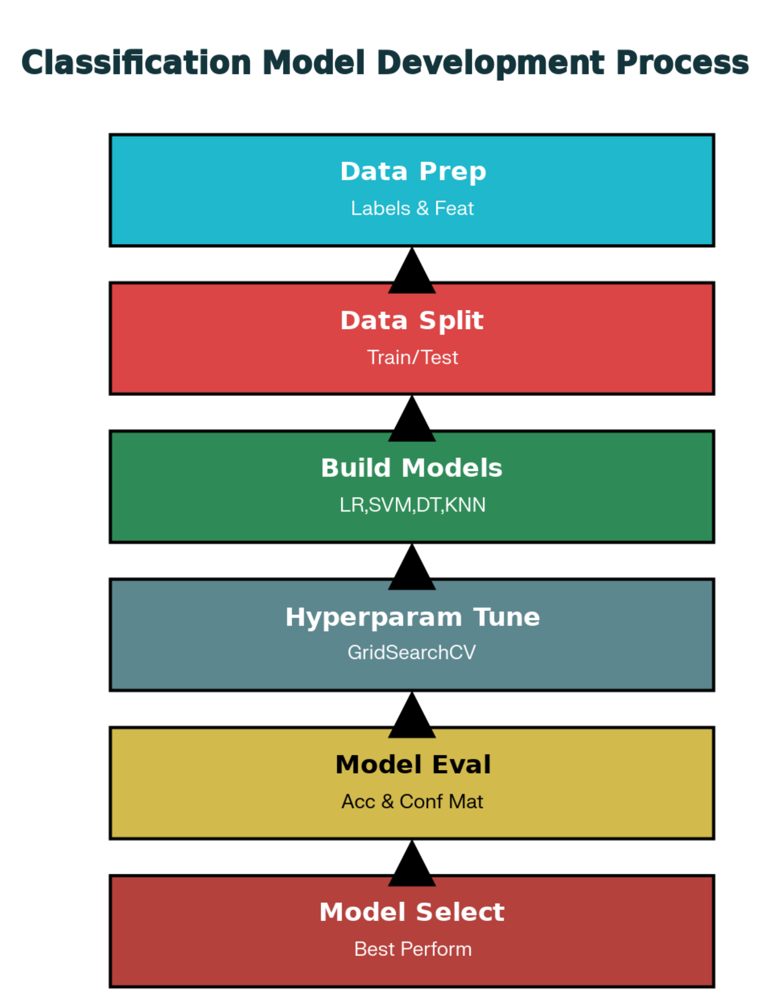
- **Pie Chart:** Visualizes launch outcome proportions (success vs. failure) for either all launch sites or a selected site.
  - *Why*: Enables users to quickly compare success rates, identify which site has the highest or lowest launch success, and analyze performance across sites.
- **Scatter Plot:** Displays the correlation between payload mass and launch outcome (success/failure), colored by booster version category, with selectable payload ranges.
  - *Why*: Helps users identify trends between payload size and successful launches. Coloring by booster version reveals if certain versions perform better with specific payloads.
- **Dropdown Selector:** Allows selection of individual launch sites or all sites for dynamic chart updates.
  - *Why*: Makes it easy for users to focus analysis on a specific site or get an overview across all sites.
- **Payload Range Slider:** Filters scatter plot data based on payload mass range.
  - *Why*: Provides flexible, interactive exploration of how payload mass affects launch outcomes, supporting deeper, customized data analysis.

These plots and interactions enhance dashboard usability, promote data exploration, and drive informed conclusions about launch performance and payload effects.

Github URL

Predictive Analysis (Classification)

- **Model Development Process: Key Steps**
- Performed exploratory data analysis, created training labels, and standardized features.
- Split the dataset into training and testing sets for robust evaluation.
- Built and tuned several classification models: Logistic Regression, Support Vector Machine (SVM), Decision Tree, and K Nearest Neighbors (KNN).
- Used GridSearchCV to search for best hyperparameters for each model with cross-validation.
- Evaluated models using accuracy score and confusion matrix on validation and test sets.
- Compared test accuracies across all models to identify the best performer.
- Selected and reported the highest accuracy model for SpaceX booster landing prediction.



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Exploratory Data Analysis Results

- **Plotted Flight Number vs. Payload Mass** - Visualized how number of flights and mass relate to landing success (color-coded).
  Showed trend: more flights → higher success rate; heavier payloads → lower chance of successful recovery.
- **Payload Mass vs. Launch Site (Categorical Plot) -** Compared payload range and success at each launch site.
  Revealed some sites don't handle heavier payloads, affecting success rates.
- **Payload Mass vs. Orbit (Categorical Plot) -** Explored which orbit types showed higher landing success with heavy payloads.
  Found Polar, LEO, ISS orbits had better heavy-payload outcomes, but GTO was mixed.
- **Bar Chart: Success Rate by Orbit Type -** Compared proportions of successful launches for each orbit.
  Identified orbits with consistently high/low mission success.
- **Line Chart: Success Rate Over Years -** Visualized yearly trend of launch success.
  Showed improvement and stabilization of landing success from 2015 onward.

Interactive analytics demo Results

- **Summary of Interactive Analytics Demo:**
- Folium Maps:
  Launch sites marked and labeled; circles highlight areas; colored clusters show success vs. failure; lines/polylines reveal how close each site is to cities, coastlines, highways, and railways—all for instant spatial and outcome analysis.
- Dashboard Plots:
  - Pie charts: Compare launch success/failure ratios by site or overall.
  - Scatter plots: Show how payload and booster type affect launch success.
  - Dropdowns and sliders: Let users explore data for specific sites and payload ranges interactively.
- *These visuals offer quick, meaningful insights into launch site logistics, outcome patterns, and key operational factors.*

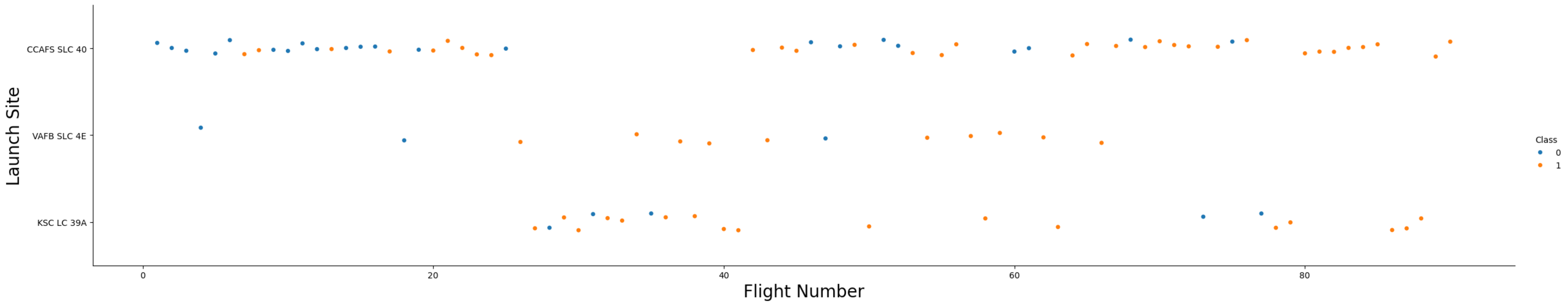
Predictive Analysis Results

- **Feature Engineering**
  Categorical variables one-hot encoded, relevant features selected for model training.
- **Model Building and Evaluation**
  - Multiple classifiers tested: Logistic Regression, SVM, Decision Tree, KNN.
  - GridSearchCV used for hyperparameter tuning and best model selection.
  - Accuracy scores and confusion matrices compared for each model.
- **Best Model Selection**
  - Final model chosen based on highest validation accuracy and robustness on test set.
- *Predictive analysis enabled reliable classification of Falcon 9 booster landing success based on launch features, data trends, and optimized model evaluation.*

Section 2

Insights drawn from EDA

Flight Number vs. Launch Site



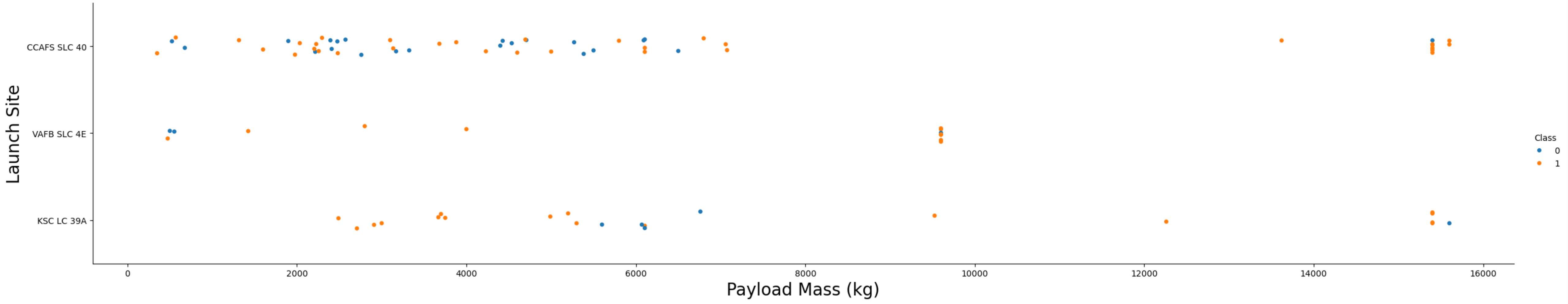
•**Each point represents a Falcon 9 launch, plotted by its Flight Number and Launch Site.**

•**Color indicates landing success: orange (1) for successful, blue (0) for unsuccessful.**

•**Observation: CCAFS SLC 40 had the most launches, while other sites handled fewer. Success rates increased in later flight numbers.**

This plot quickly highlights site-wise success trends and improvement over time.

Payload vs. Launch Site



•Higher payload mass generally correlated with more successful landings (orange points) across all launch sites.

•CCAFS SLC 40 handled most launches, often with heavier payloads.

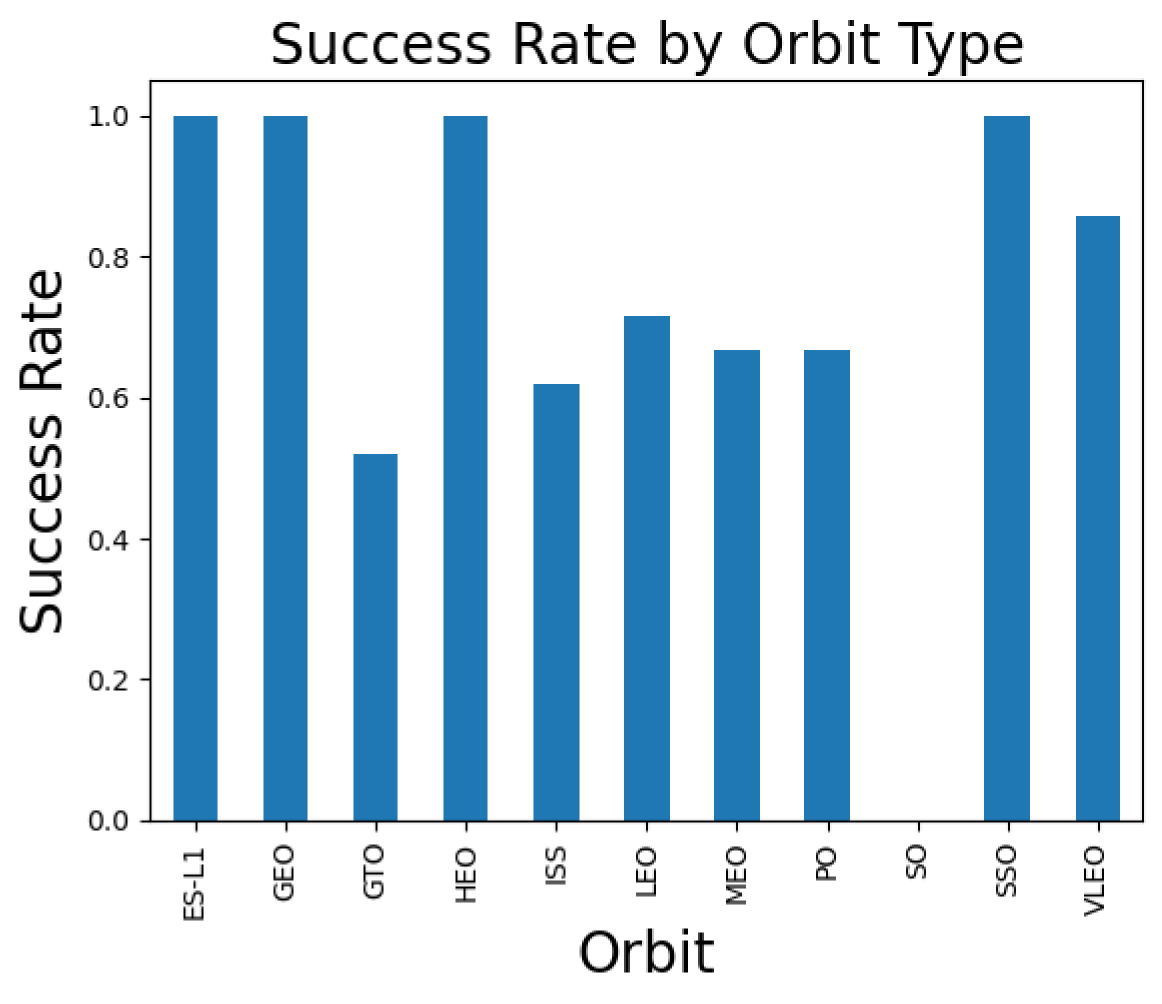
•KSC LC 39A and VAFB SLC 4E had fewer, but mostly successful heavy-payload launches.

•Failure (blue) occurred at lower payload masses and was less frequent with higher masses.

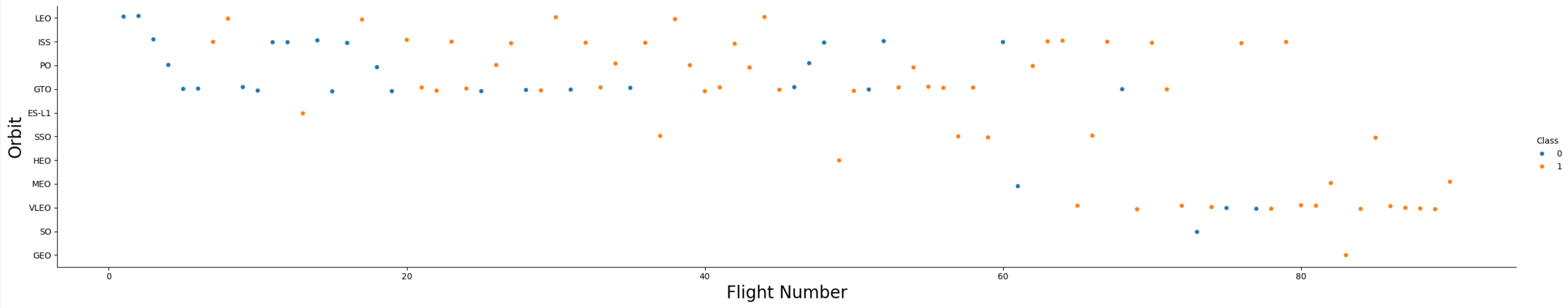
Success Rate vs. Orbit Type

Orbit type strongly influences Falcon 9 landing success.

- **100% Success rates for ES-L1, GEO, HEO and SSO orbits.**
- **SO orbit with 0% success rate**
- **Most other orbits (GTO, ISS, LEO, MEO, PO) show moderate success rates, generally between 50% and 85%.**



Flight Number vs. Orbit Type

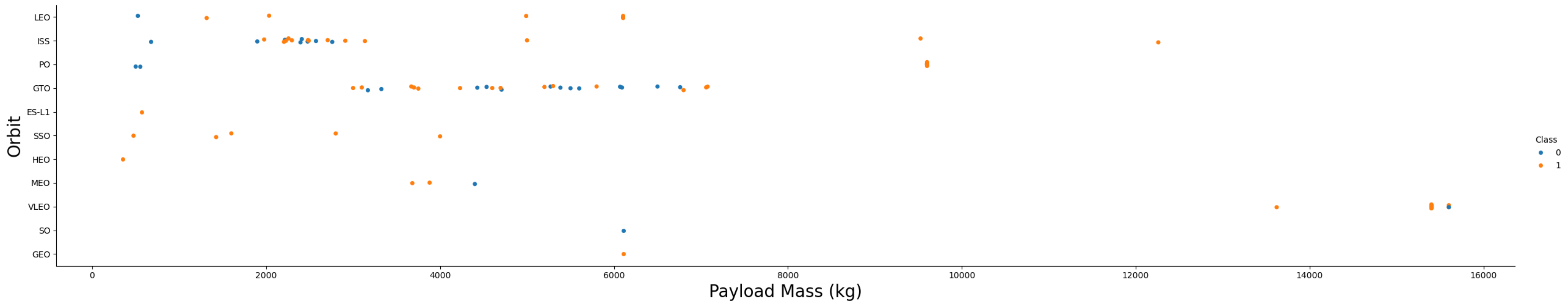


•Some orbits (e.g., LEO, ISS) had mixed outcomes, with both successes and failures across different flights.

•Orbits like SSO, GEO, and ES-L1 showed mostly successful landings, indicated by the higher proportion of orange points (Class 1).

•No clear trend of success or failure based solely on flight number, suggesting orbit type plays a key role in landing outcomes.

Payload vs. Orbit Type

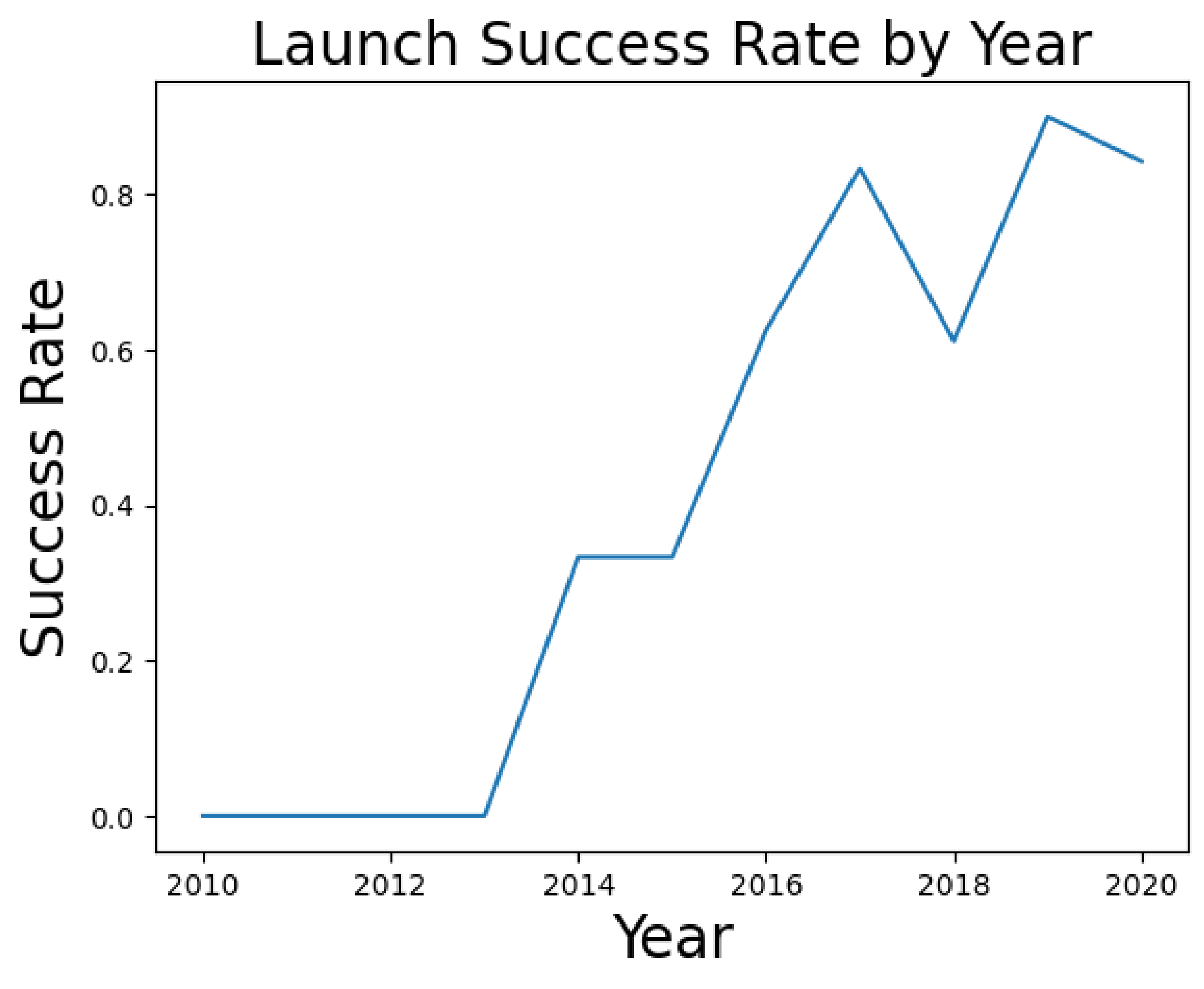


- Successful landings (orange) are more common at higher payload masses across orbits.
- Certain orbits (SSO, ES-L1, GEO, HEO, SO) display only successful landings, regardless of mass.
- GTO, ISS, and LEO orbits have both successes and failures, especially at moderate payloads.
- Higher payloads do not reduce success in most orbits, which highlights Falcon 9's capability.

Launch Success Yearly Trend

The line plot shows the launch success rate by year for Falcon 9

- **Key insights:**
- **Success rate was negligible from 2010–2013.**
- **Marked improvement began in 2014, with sharp increases each year.**
- **By 2017–2020, annual success rate surpassed 80%, reflecting rapid learning and operational maturity.**



All Launch Site Names

```
[10]: %sql SELECT DISTINCT "Launch_Site" FROM SPACEXTABLE

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

[10]:

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

- **This query returns the unique launch site names from the SpaceX dataset. It helps identify all locations used for launches, ensuring no duplicates in the list.**

Launch Site Names Begin with 'CCA'

[11]:
```
%sql SELECT * FROM SPACEXTABLE 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

- **This query helps to filter and inspect early launches from Cape Canaveral launch sites, showing missions, payloads, and outcomes.**

Total Payload Mass

```
[12]: %sql SELECT SUM(PAYLOAD_MASS__KG_) FROM SPACEXTABLE WHERE Customer = 'NASA (CRS)'

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

[12]:

SUM(PAYLOAD_MASS__KG_)
45596

- **This result sums up the payload mass of all launches where NASA CRS was the customer.**

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_) FROM SPACEXTABLE WHERE "Booster_Version" = 'F9 v1.1'

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

[13]:

AVG(PAYLOAD_MASS__KG_)
2928.4

- **This calculates the mean payload size for all launches performed by the F9 v1.1 booster, helping assess the typical capacity and mission profile for that version.**

First Successful Ground Landing Date

```
[14]: %sql SELECT MIN(Date) FROM SPACEXTABLE WHERE "Landing_Outcome" = 'Success (ground pad)'

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

[14]:

MIN(Date)
2015-12-22

- **This query finds the earliest date when a Falcon 9 booster successfully landed on a ground pad, marking a major milestone in SpaceX's reusability achievements.**

Successful Drone Ship Landing with Payload between 4000 and 6000

```
[17]: %sql SELECT "Booster_Version" FROM SPACEXTABLE WHERE "PAYLOAD_MASS__KG_" = (SELECT MAX("PAYLOAD_MASS__KG_") FROM SPACEXTABLE)
 * sqlite:///my_data1.db
Done.
```

[17]:

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

- **This query filters launches with a successful drone ship landing and looks for missions carrying moderate-to-heavy payloads (between 4000 and 6000 kg), showing which booster versions achieved these challenging operational feats.**

Total Number of Successful and Failure Mission Outcomes

```
[16]: %sql SELECT "Mission_Outcome", COUNT(*) AS Total FROM SPACEXTABLE GROUP BY "Mission_Outcome"

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

[16]:

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

- **This query summarizes the total number of successful and failed mission outcomes in the SpaceX database.**

Boosters Carried Maximum Payload

```
[17]: %sql SELECT "Booster_Version" FROM SPACEXTABLE WHERE "PAYLOAD_MASS__KG_" = (SELECT MAX("PAYLOAD_MASS__KG_") FROM SPACEXTABLE)

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

[17]:

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

- **This query returns all booster versions that achieved the highest payload mass for any SpaceX mission.**

2015 Launch Records

```
[18]: %sql SELECT substr(Date, 6,2) AS Month, "Landing_Outcome", "Booster_Version", "Launch_Site" FROM SPACEXTABLE
        WHERE "Landing_Outcome" = 'Failure (drone ship)' AND substr(Date,0,5)='2015'
```

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

[18]:

Month	Landing_Outcome	Booster_Version	Launch_Site
01	Failure (drone ship)	F9 v1.1 B1012	CCAFS LC-40
04	Failure (drone ship)	F9 v1.1 B1015	CCAFS LC-40

- **Both failed drone ship landings in 2015 involved F9 v1.1 booster versions and were launched from Cape Canaveral, indicating early landing challenges before successful improvements.**

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

[19]:
```
%sql SELECT "Landing_Outcome", COUNT(*) AS OutcomeCount FROM SPACEXTABLE WHERE Date BETWEEN '2010-06-04' AND '2017-03-20'
    GROUP BY "Landing_Outcome" ORDER BY OutcomeCount DESC
```

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

[19]:

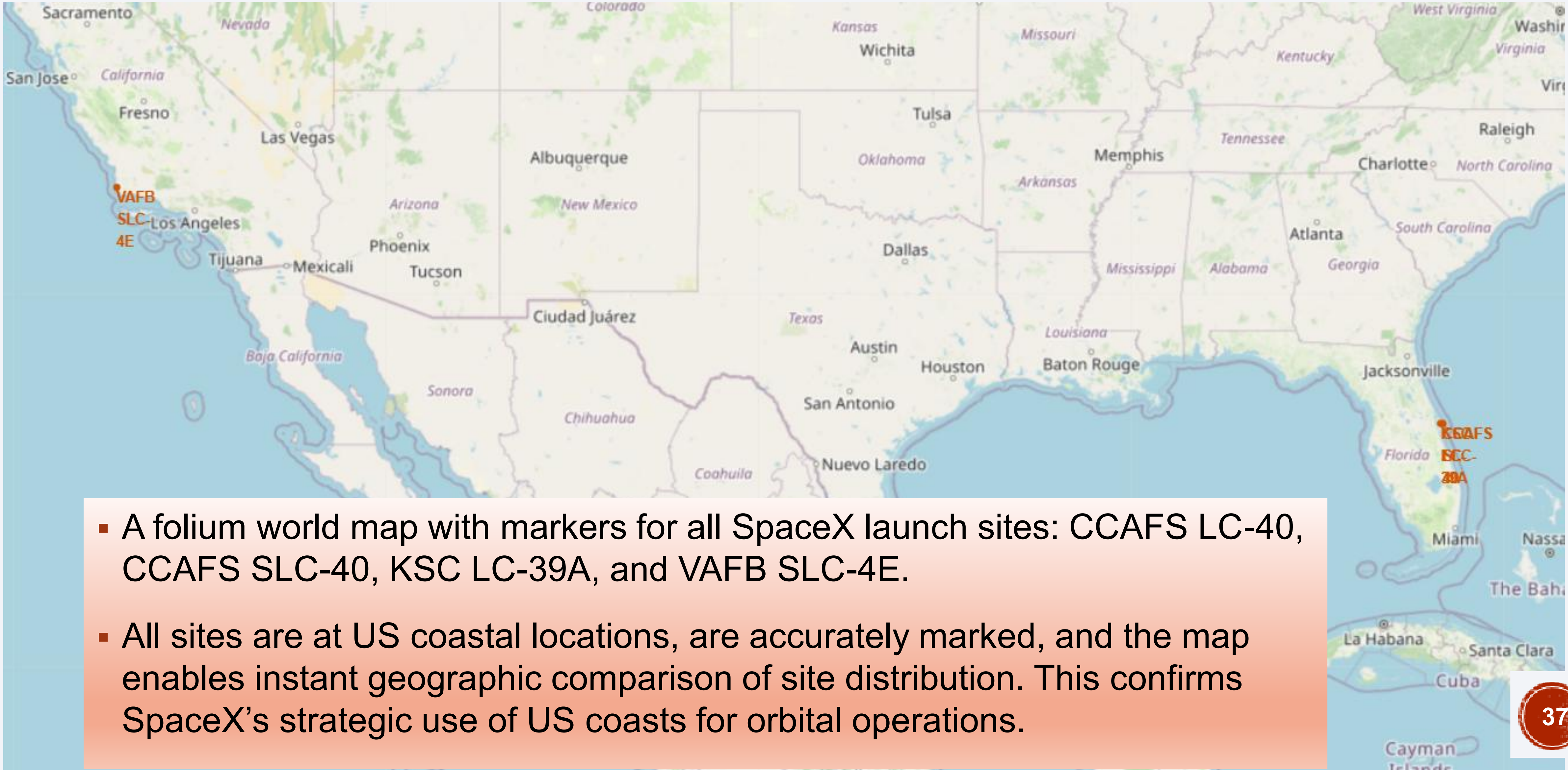
Landing_Outcome	OutcomeCount
No attempt	10
Success (drone ship)	5
Failure (drone ship)	5
Success (ground pad)	3
Controlled (ocean)	3
Uncontrolled (ocean)	2
Failure (parachute)	2
Precluded (drone ship)	1

- **This query counts and ranks all types of landing outcomes within the specified date range. "No attempt" is most common, while both successful and failed drone ship landings occur equally. Ground pad successes and ocean landings are less frequent.**

Section 3

Launch Sites Proximities Analysis

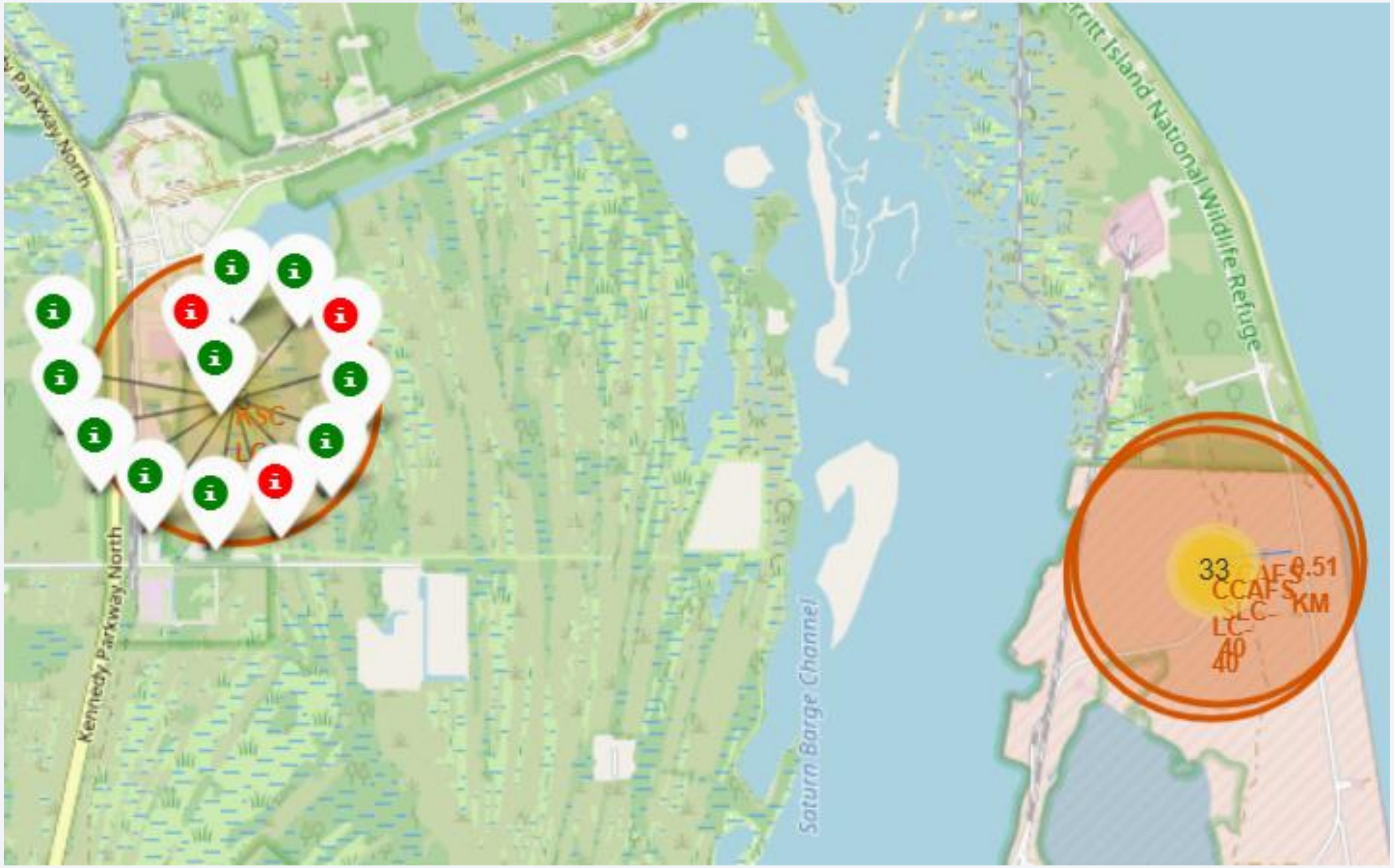
SpaceX Launch Sites on a Global Map



- A folium world map with markers for all SpaceX launch sites: CCAFS LC-40, CCAFS SLC-40, KSC LC-39A, and VAFB SLC-4E.
- All sites are at US coastal locations, are accurately marked, and the map enables instant geographic comparison of site distribution. This confirms SpaceX's strategic use of US coasts for orbital operations.

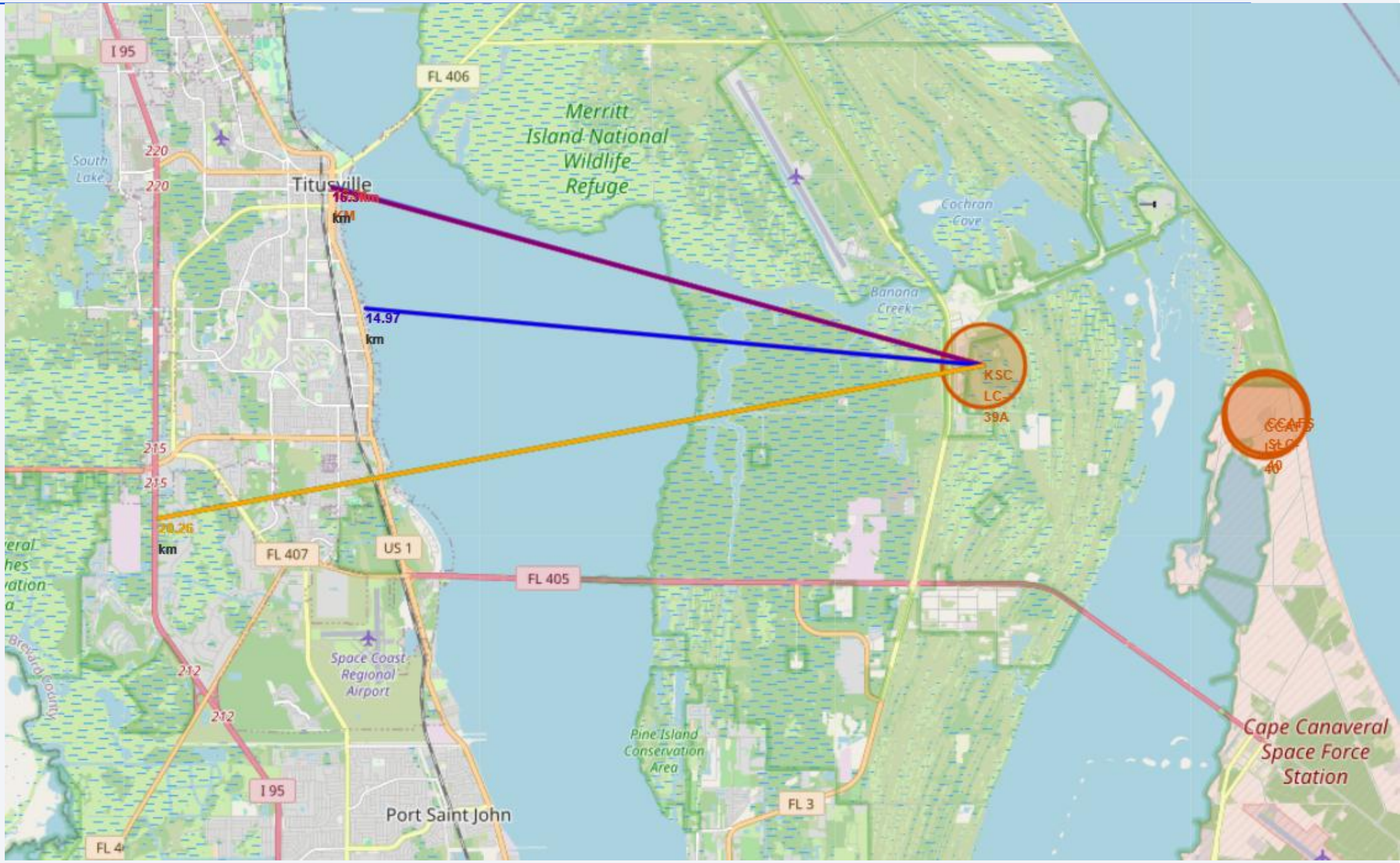
SpaceX Launch Outcomes Map – Success vs. Failure

- A folium map shows launch site markers color-coded: green for successful launches, red for failures.
- Clusters at Cape Canaveral and Kennedy Space Center highlight most launches. Green dominates, indicating high success rates; occasional red markers reflect limited failures. This visual immediately communicates SpaceX's overall reliability and spatial distribution of launch outcomes.



KSC LC-39A Proximity to Local Infrastructure

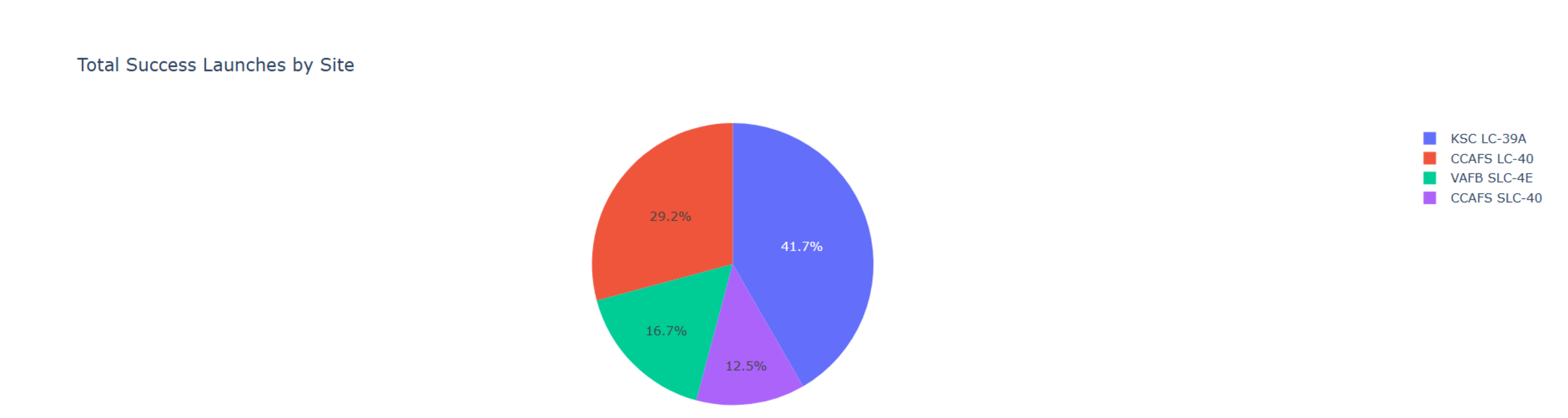
- Kennedy Space Center Launch Complex 39A is the central launch site.
- Colored lines connect the launch site to:
  - Titusville (nearest city): *20.26 km (purple line)*.
  - Coastline: *14.97 km (blue line)*.
  - Highway: *26.34 km (orange line)*.
- KSC LC-39A is close to Titusville (city), the coastline, and a major highway. These short distances enable efficient transport and safe launches. The map shows direct connections and measured distances to key infrastructure.



Section 4

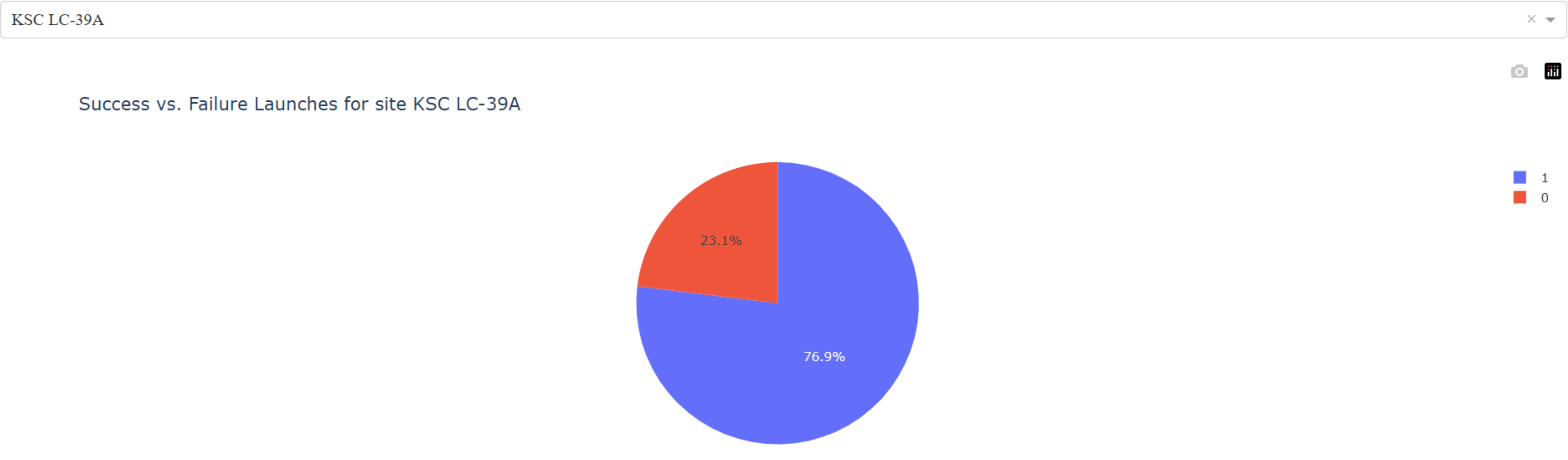
Build a Dashboard with Plotly Dash

Total Sucessful Launches by Site



- The pie chart divides total successful launches among all SpaceX sites (CCAFS LC-40, CCAFS SLC-40, KSC LC-39A, VAFB SLC-4E).
- Each slice represents the proportion of successes at each site.
- Majority of launch successes come from Cape Canaveral sites (CCAFS LC-40, CCAFS SLC-40), with Kennedy Space Center and Vandenberg contributing smaller shares. This highlights Cape Canaveral's central role in SpaceX operations and overall launch reliability.

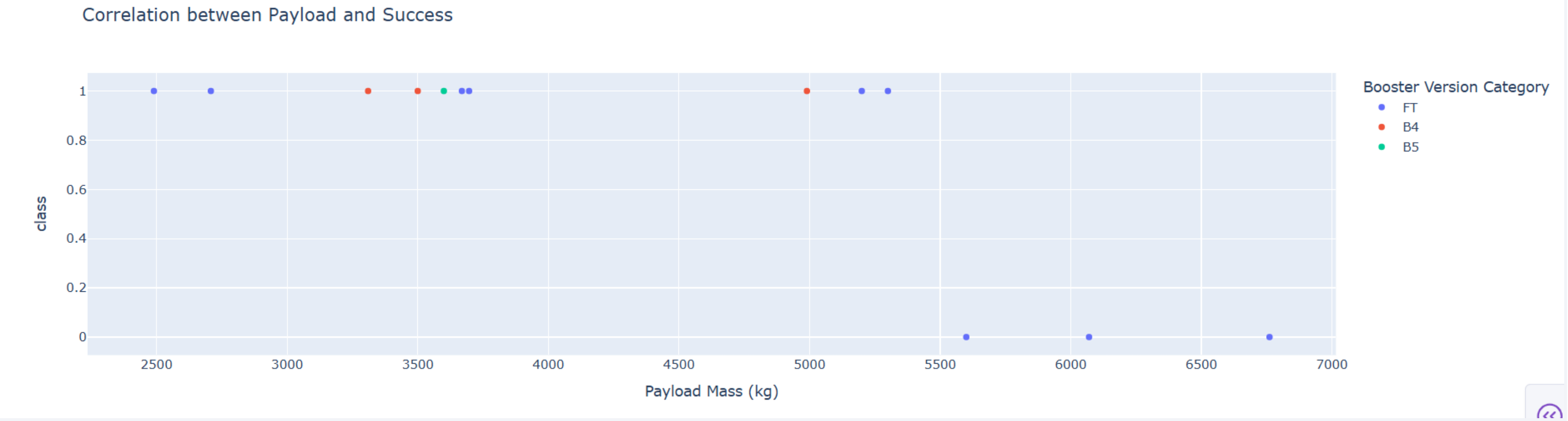
Success vs Failure Launches for KSC LC-39A

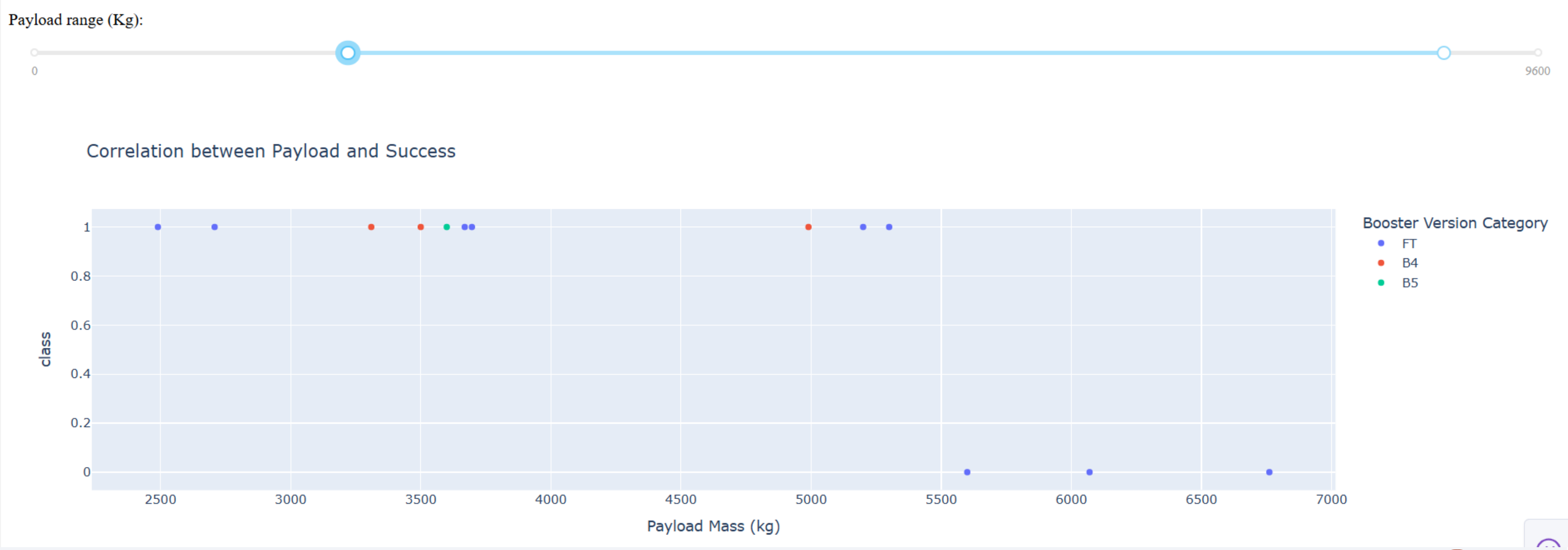


- Blue shows launches from KSC LC-39A that succeeded (76.9%), red shows failures (23.1%).
- Most launches from KSC LC-39A are successful. The site has a strong reliability record, though some failures do occur. This breakdown helps quickly assess performance at this individual launch site.

Correlation between Payload and Success

- **Most successful launches (class = 1) occur for payloads between 2500–5500 kg.**
- **Booster versions FT, B4, B5 all included, but FT version (blue) dominates the success region.**
- **Higher payloads (>5500 kg) tend to have higher failure rates (class = 0).**
- **The range slider confirms the success zone visually as you filter.**

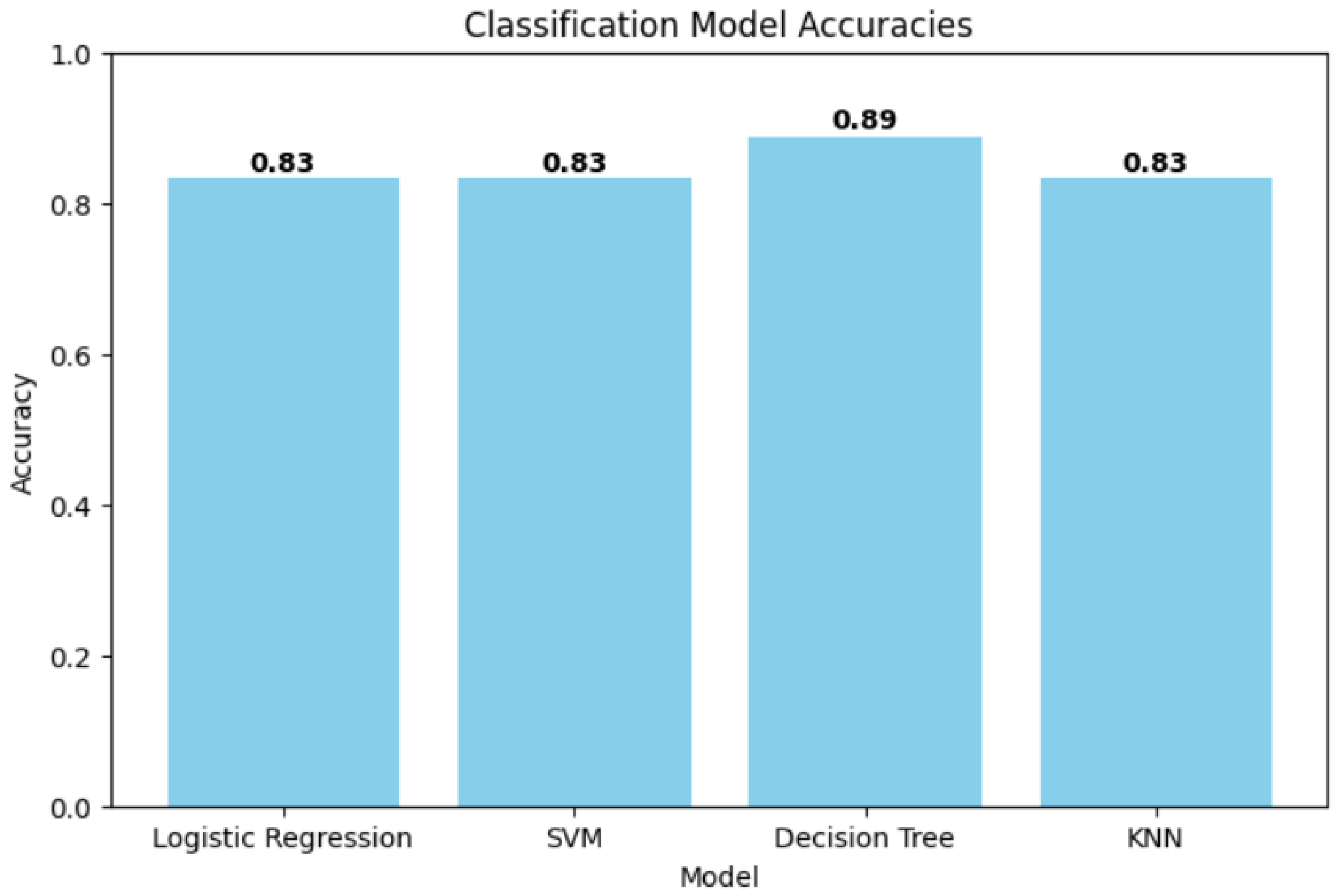




Section 5

Predictive Analysis (Classification)

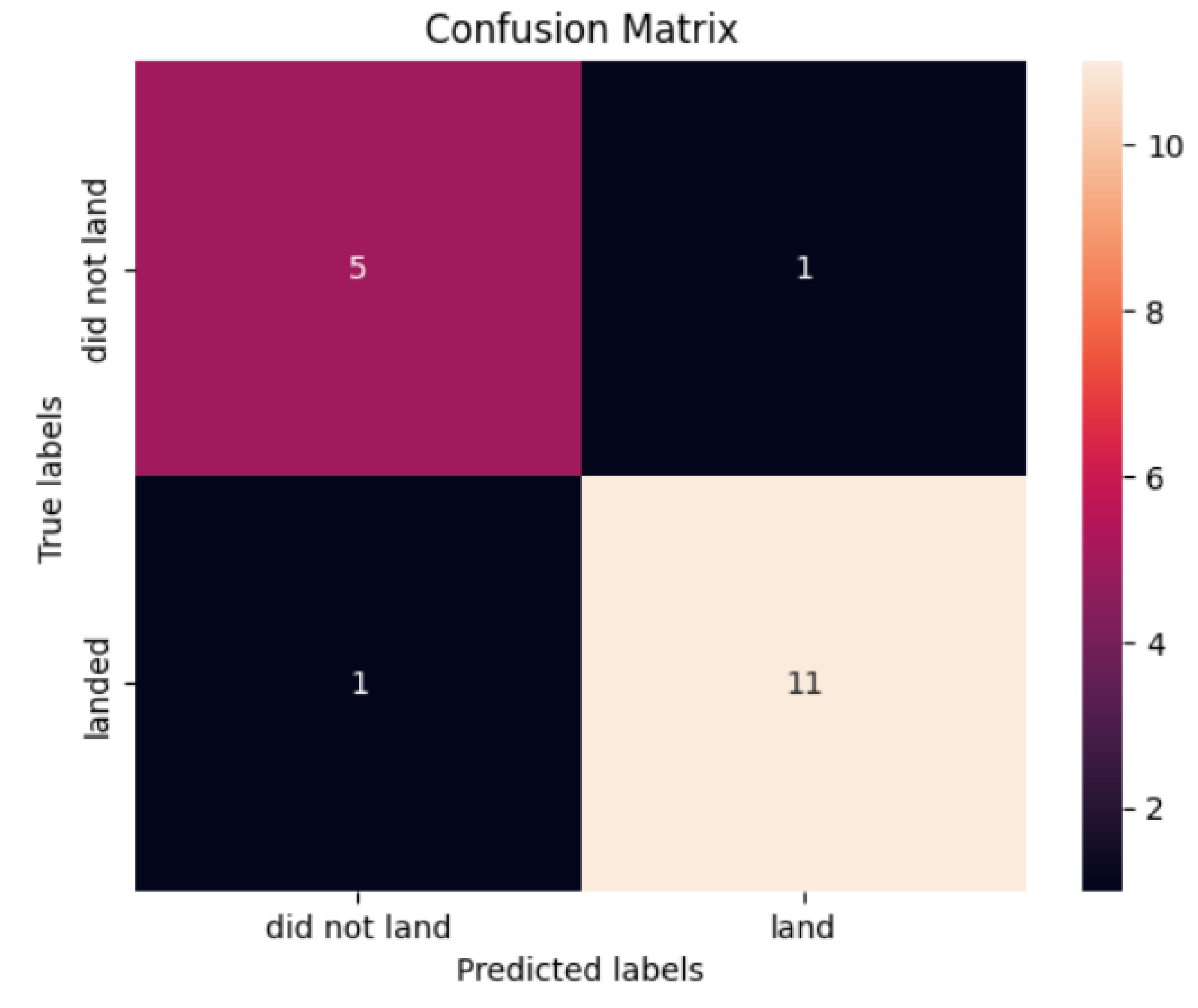
Classification Accuracy




```
The best performing model is Decision Tree with an accuracy of 0.8889
```

Confusion Matrix

- The best model very accurately distinguishes between landed and did-not-land cases, making only 2 errors out of 18. High numbers along the diagonal (top-left and bottom-right) indicate strong predictive performance.



Conclusions

- SpaceX launch analysis revealed clear trends: Most launches were concentrated at Cape Canaveral facilities, and launch success rates have steadily increased over time, especially after 2017.
- Sites are strategically located: All launch sites are near coastlines, highways, and railways for efficient logistics and safety, while maintaining a safe distance from cities.
- Modeling results: All tested classification models (Logistic Regression, SVM, Decision Tree, KNN) achieved similarly high accuracy, successfully predicting landing outcomes with notable precision; the confusion matrix showed very few misclassifications.
- Key insight: The typical payload mass range and the FT booster version observed the highest landing success.
- Dashboards and maps provided interactive ways to explore launch outcomes, payload-performance trends, and site infrastructure proximity.
- Overall, this project demonstrates how data-driven approaches can clarify operational strengths, inform future decision-making, and showcase advancements in the reusability and reliability of Falcon 9 launches.

Appendix

- Link to New Dataset1 Created:-

https://github.com/Rajesh4Github/IBM-Applied-Data-Science-Capstone-Project/blob/6cb298f557f06cea18924d98b9430579d81a5678/dataset_part_1.csv

- Link to New Dataset2 Created:-

https://github.com/Rajesh4Github/IBM-Applied-Data-Science-Capstone-Project/blob/6cb298f557f06cea18924d98b9430579d81a5678/dataset_part_2.csv

Link to Machine Learning Prediction Notebook:-

https://github.com/Rajesh4Github/IBM-Applied-Data-Science-Capstone-Project/blob/6cb298f557f06cea18924d98b9430579d81a5678/SpaceX_Machine%20Learning%20Prediction_Part_5%20(1).ipynb

Link to Repository:-

https://github.com/Rajesh4Github/IBM-Applied-Data-Science-Capstone-Project.git

Thank you!