Predicting Falcon 9 First Stage Landing Success

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OUTLINE

- Executive Summary
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- Methodology
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  - Visualization – Charts
  - Dashboard
- Discussion
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EXECUTIVE SUMMARY

- **Project Objective**
  - Predict Falcon 9 landing success to optimize launch costs and improve competitiveness.
- **Data Sources**
  - Collected data from SpaceX API and Wikipedia; cleaned and formatted for analysis.
- **Exploratory Analysis**
  - Analyzed relationships between flight number, payload mass, and launch outcomes.
- **Feature Engineering**
  - Converted categorical variables to dummy variables and standardized numeric features.
- **Model Performance**
  - Tested Logistic Regression, SVM, Decision Trees, and K-Nearest Neighbors; best model achieved 0.83 accuracy.
- **Impact and Next Steps**
  - Predictions aid cost estimation and competitiveness; future work includes refining features and models.

INTRODUCTION

- **Objective:** Predict Falcon 9 first stage landing success to help estimate launch costs.
- **Data Sources:** SpaceX API and Wikipedia for historical launch records.
- **Challenge:** Forecast landing success to optimize launch expenses and bid competitiveness.
- **Approach:** Clean, analyze, and model data to predict outcomes.
- **Outcome:** Use predictions for cost estimation and strategic planning.
- **Significance:** Enhances competitive edge and cost-efficiency in space missions.

METHODOLOGY

Data Collection:

- API for SpaceX launch data
- Web scraping for historical launch records

Data Cleaning:

- Handle missing values
- Normalize and format data

Exploratory Data Analysis (EDA):

- Visualize relationships and trends
- Feature engineering with dummy variables

METHODOLOGY

- **Feature Engineering:**
  - Convert categorical data to numerical
  - Create new features for better prediction
- **Modeling:**
  - Train various models (Logistic Regression, SVM, Decision Tree, KNN)
  - Hyperparameter tuning using GridSearchCV
- **Evaluation:**
  - Compare model performances
  - Select the best model based on accuracy

RESULTS

Feature Insights

- **Key Influencers:** The primary features affecting the success of Falcon 9 first stage landings include 'FlightNumber', 'PayloadMass', 'Orbit', 'LaunchSite', 'Flights', 'GridFins', 'Reused', 'Legs', 'LandingPad', 'Block', 'ReusedCount', and 'Serial'

Confusion matrix – the same for every model

RESULTS

Unique Launch Sites

- The dataset includes the following unique launch sites:
  - CCAFS LC-40
  - VAFB SLC-4E
  - KSC LC-39A

Records with Launch Sites Starting with 'CCA'

- Examples of records where the launch site begins with 'CCA':
  - **2010-06-04:** Falcon 9 v1.0, CCAFS LC-40, Success
  - **2010-12-08:** Falcon 9 v1.0, CCAFS LC-40, Success
  - **2012-05-22:** Falcon 9 v1.0, CCAFS LC-40, Success
  - **2012-10-08:** Falcon 9 v1.0, CCAFS LC-40, Success
  - **2013-03-01:** Falcon 9 v1.0, CCAFS LC-40, Success

Confusion matrix – the same for every model

RESULTS

Total Payload Mass for NASA (CRS) Boosters

- The total payload mass carried by boosters launched for NASA (CRS) missions is **45,596 kg**.

Average Payload Mass for F9 v1.1 Booster Version

- The average payload mass for the F9 v1.1 booster version is approximately **2,535 kg**.

First Successful Ground Pad Landing

- The first successful landing outcome on a ground pad occurred on **2015-12-22**.

Confusion matrix – the same for every model

RESULTS

Booster Versions with Success in Drone Ship and Specific Payload Mass

- The following booster versions achieved success on a drone ship with payload masses between 4,000 kg and 6,000 kg:
  - F9 FT B1022
  - F9 FT B1026
  - F9 FT B1021.2
  - F9 FT B1031.2

Confusion matrix – the same for every model

RESULTS

Count of Landing Outcomes

- The total number of successful and failed landing outcomes are as follows:
  - **Success:** 38
  - **Failure (drone ship):** 5
  - **Failure (ocean):** 5
  - **Failure (parachute):** 2
  - **Failure:** 3
  - **No attempt:** 22
  - **Precluded (drone ship):** 1
  - **Uncontrolled (ocean):** 2

Confusion matrix – the same for every model

RESULTS

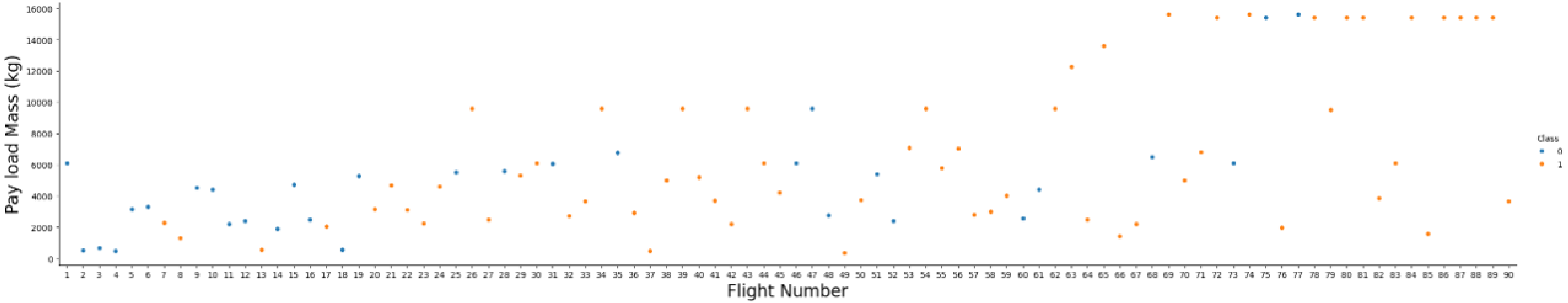
Booster Versions with Maximum Payload Mass

- The booster versions carrying the maximum payload mass are:
  - F9 B5 B1048.4
  - F9 B5 B1049.4
  - F9 B5 B1051.3
  - F9 B5 B1056.

Confusion matrix – the same for every model

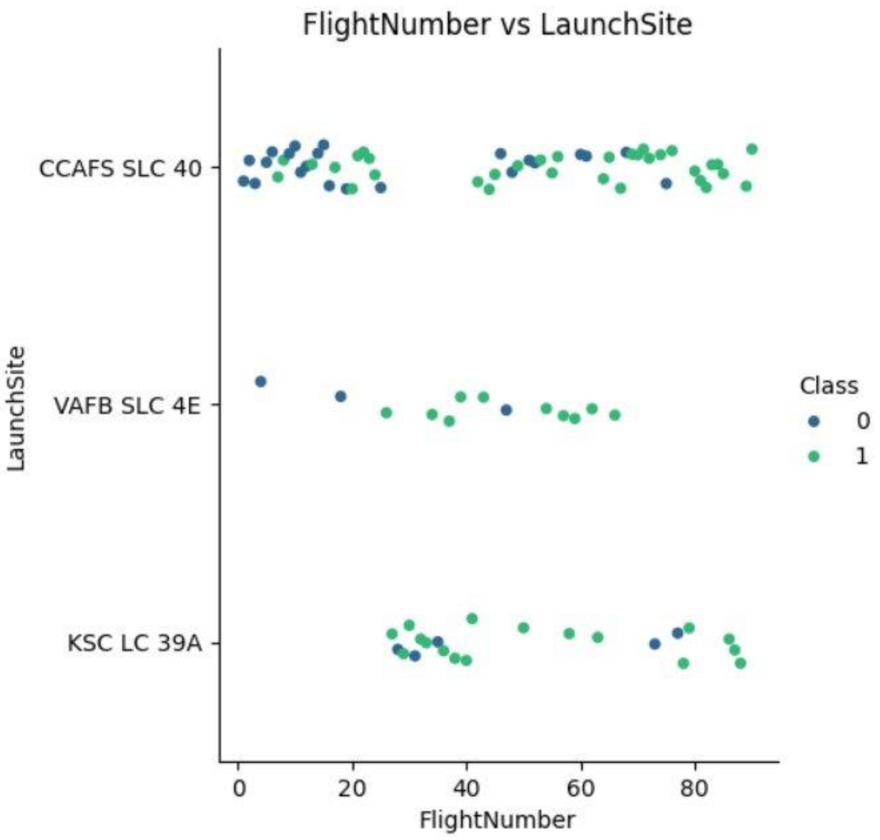
RESULTS

- **Flight Number Impact:** As the flight number increases, the likelihood of a successful landing for the Falcon 9 first stage improves.
- **Payload Mass Effect:** Larger payload masses do not significantly hinder the success rate of the first stage landings; successful returns are common even with heavier payloads.



RESULTS

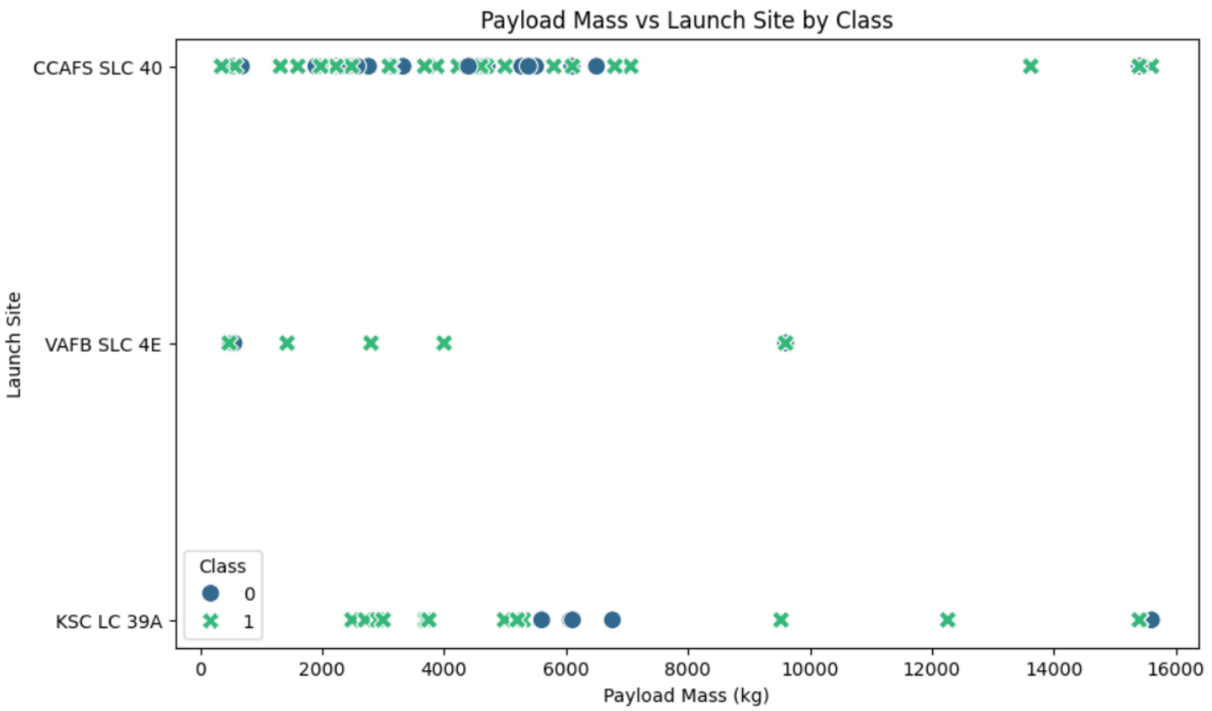
- **Flight Number Impact:** As the flight number increases, the likelihood of the Falcon 9 first stage landing successfully improves. This trend suggests that SpaceX's iterative advancements and refinements in rocket technology contribute to more reliable landings over time.
- **Launch Site and Success Rates:** Unsuccessful launches were predominantly associated with lower flight numbers and occurred primarily from the CCAFS SLC 40 Launch Site. This indicates that early missions from this site faced more challenges compared to later launches.



Confusion matrix – the same for every model

RESULTS

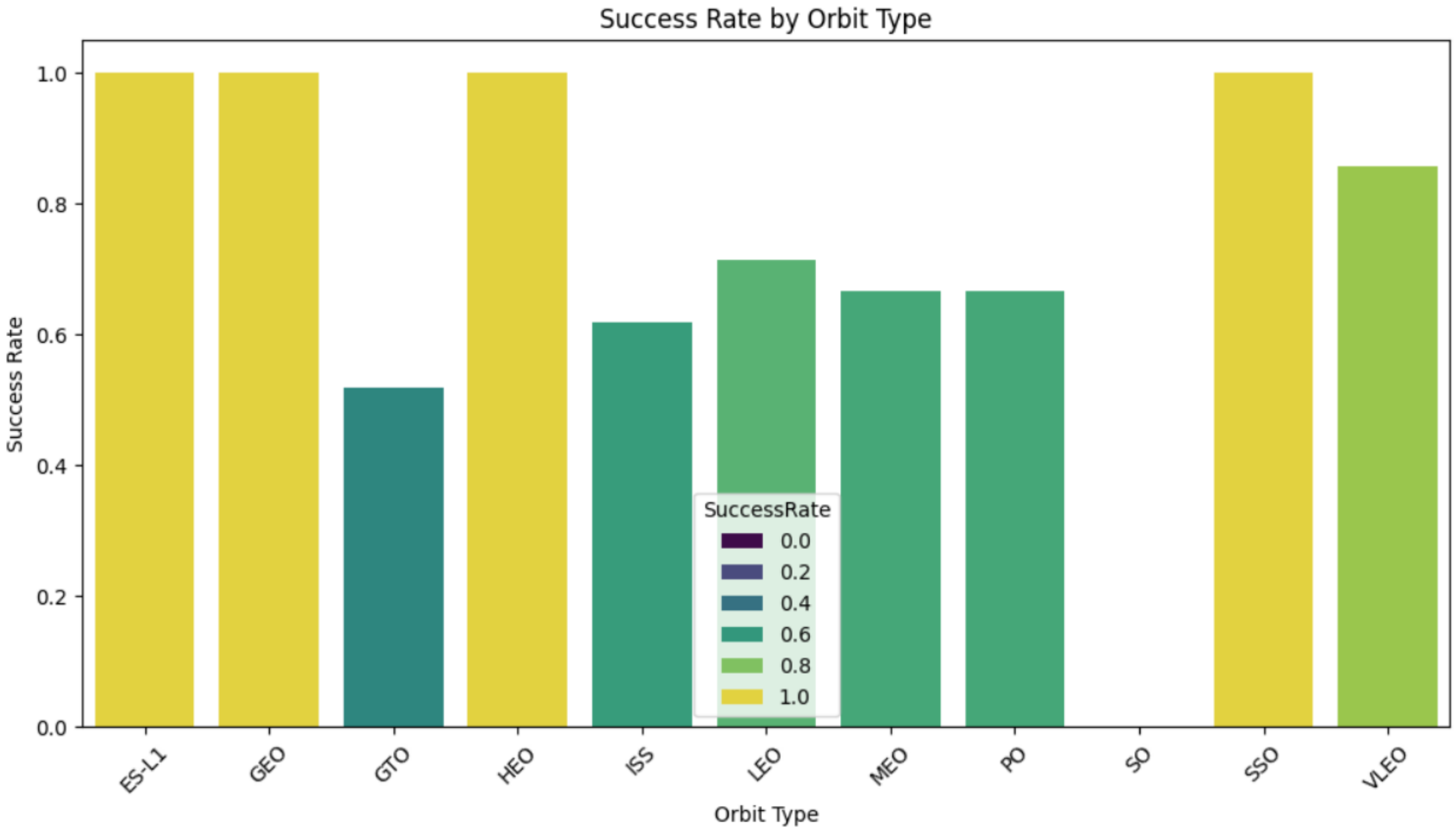
Payload Mass Distribution: The VAFB-SLC launch site has not been used for launching rockets with heavy payload masses (greater than 10,000 kg). This indicates a specific focus or limitation on payload capacities for this particular launch site.



RESULTS

Success Rate by Orbit Type

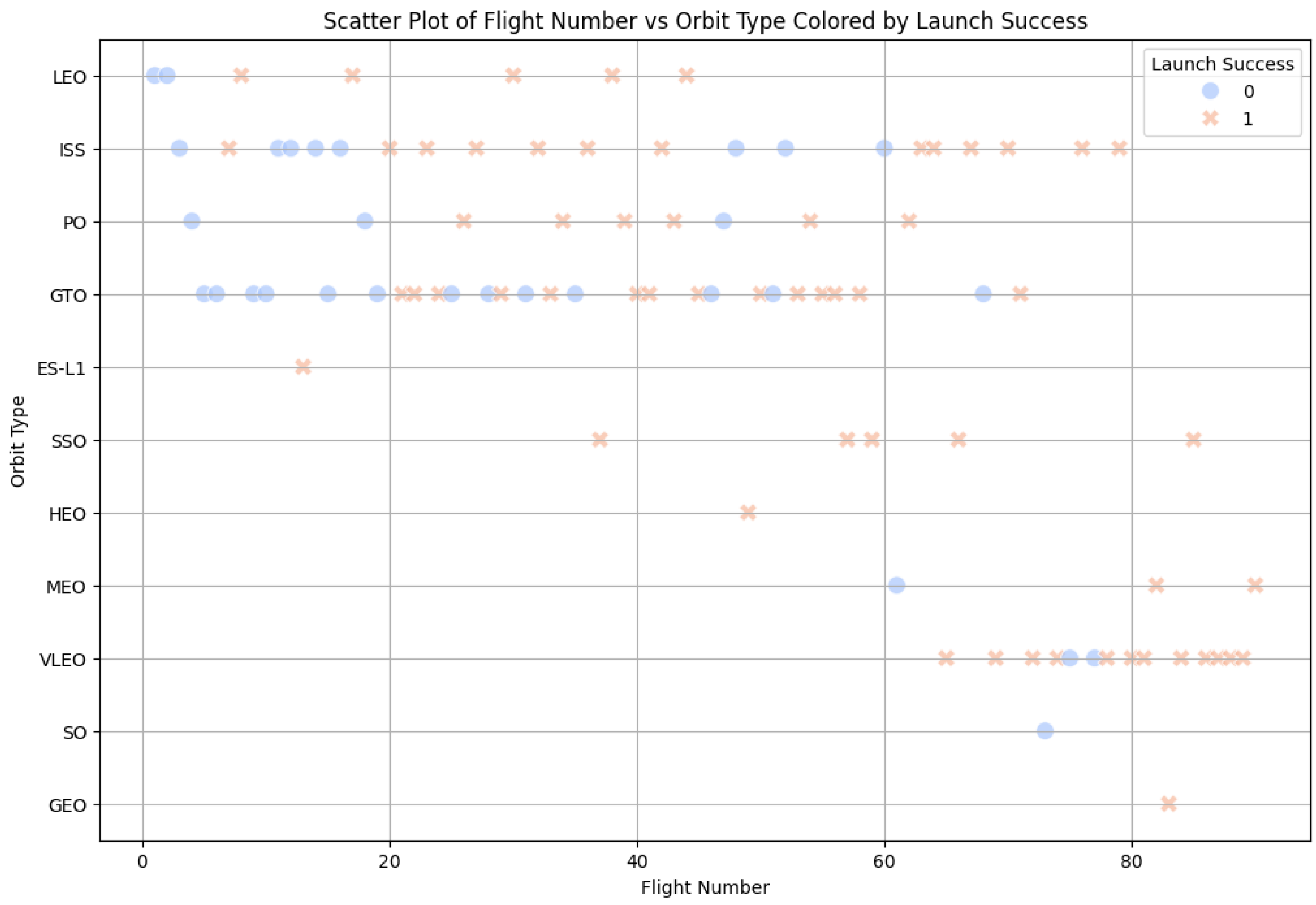
- **High Success Rates:** The most successful launches were associated with orbit types ES-L1, GEO, HEO, and SSO.



RESULTS

Scatter Plot: Flight Number vs Orbit Type

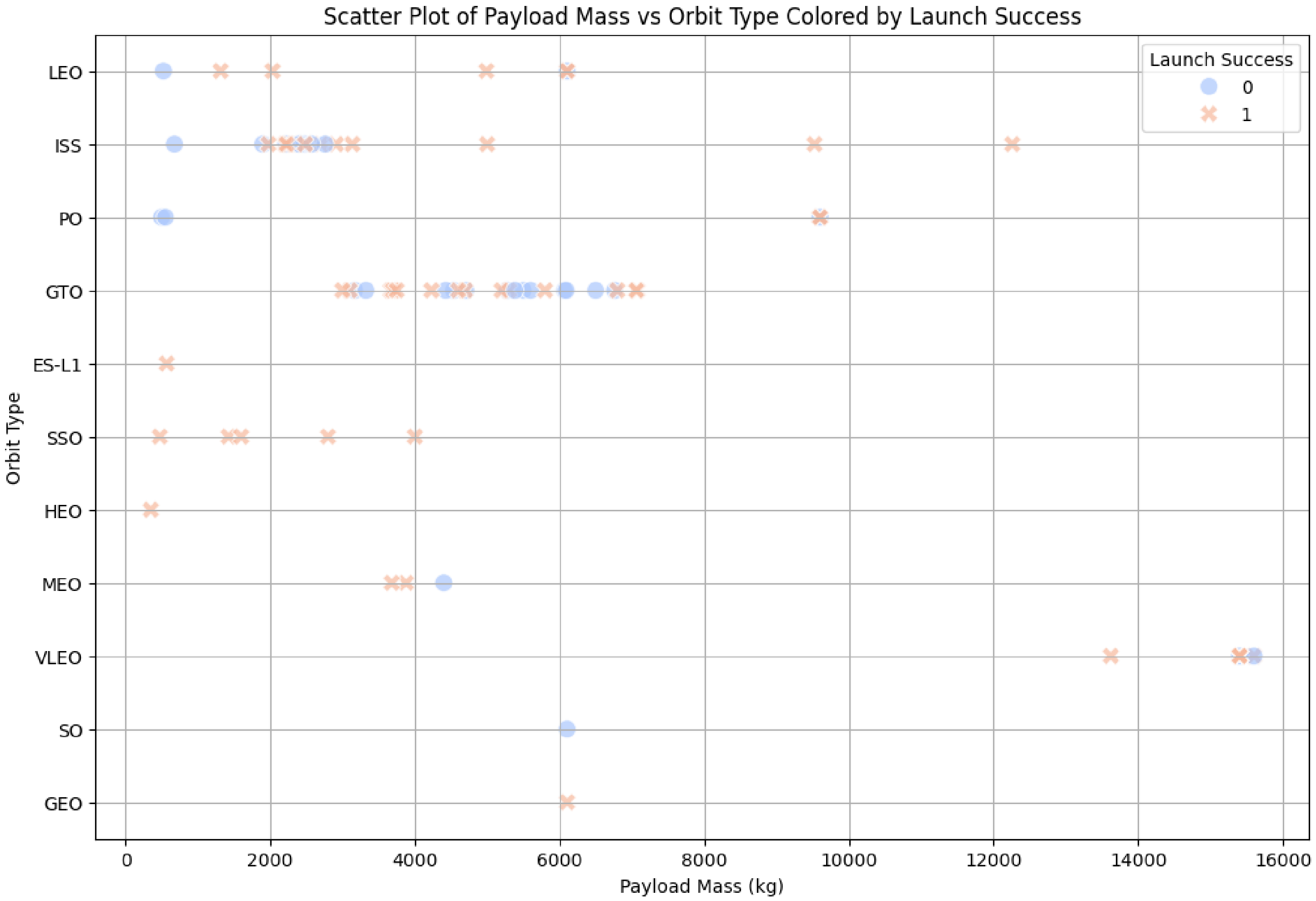
- **Observation:** In the Low Earth Orbit (LEO), a higher Flight Number is associated with increased launch success. Conversely, for the Geostationary Transfer Orbit (GTO), there is no clear relationship between Flight Number and success.



RESULTS

Scatter Plot: Payload Mass vs Orbit Type

- **Observation:** For heavy payloads, successful landings are more common in Polar, Low Earth Orbit (LEO), and International Space Station (ISS) orbits. In contrast, for the Geostationary Transfer Orbit (GTO), the distinction between successful and unsuccessful landings is less clear, with both outcomes present across the range of payload masses.



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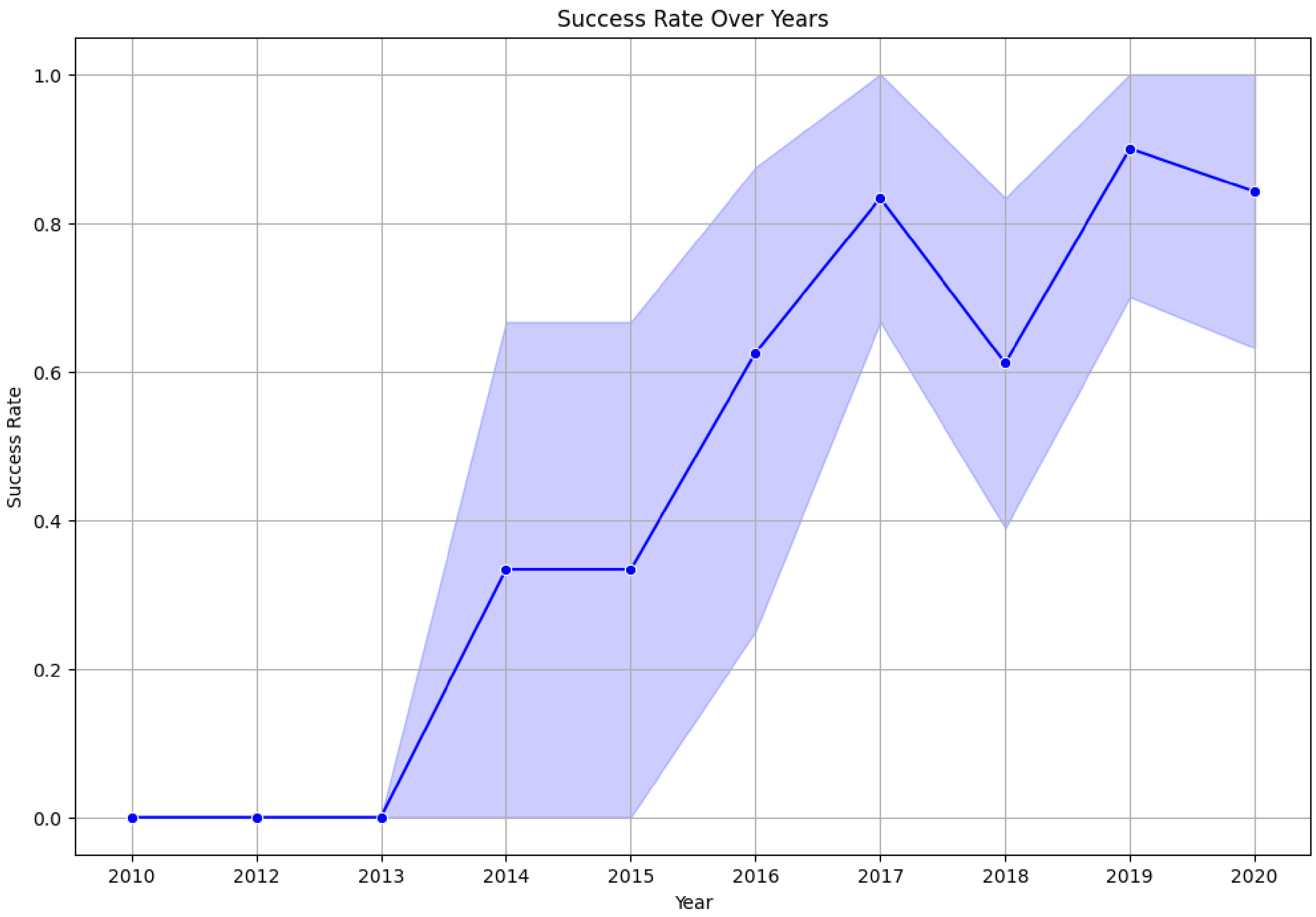
RESULTS

Trend in Launch Success Rate (2013-2020)

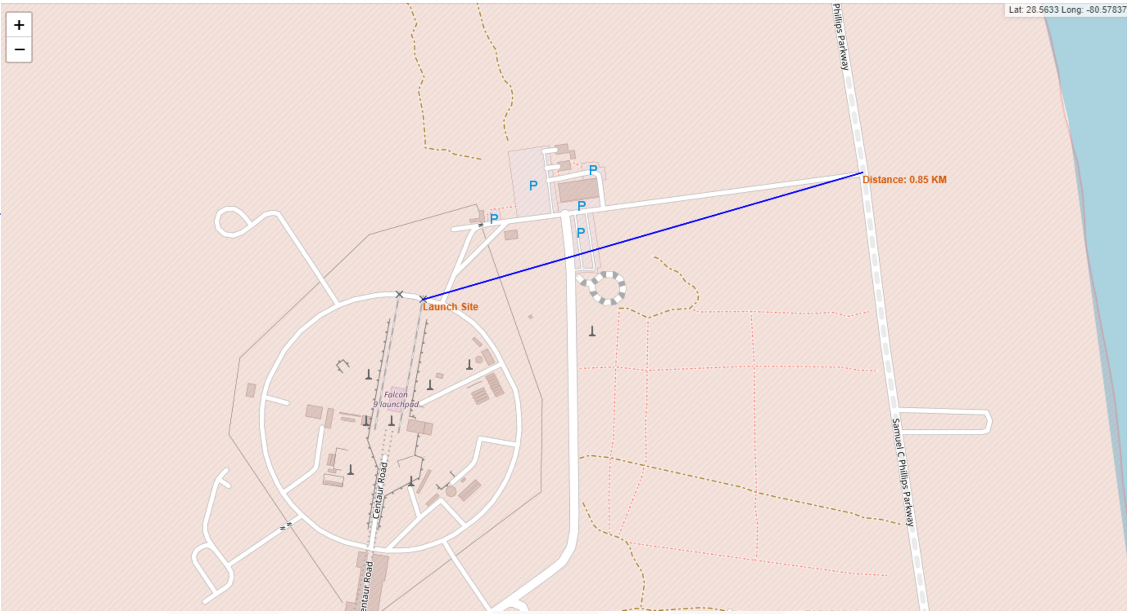
- **Observation:** The success rate of Falcon 9 first stage landings has shown a consistent increase from 2013 through 2020. This upward trend indicates ongoing improvements in landing success over the years.

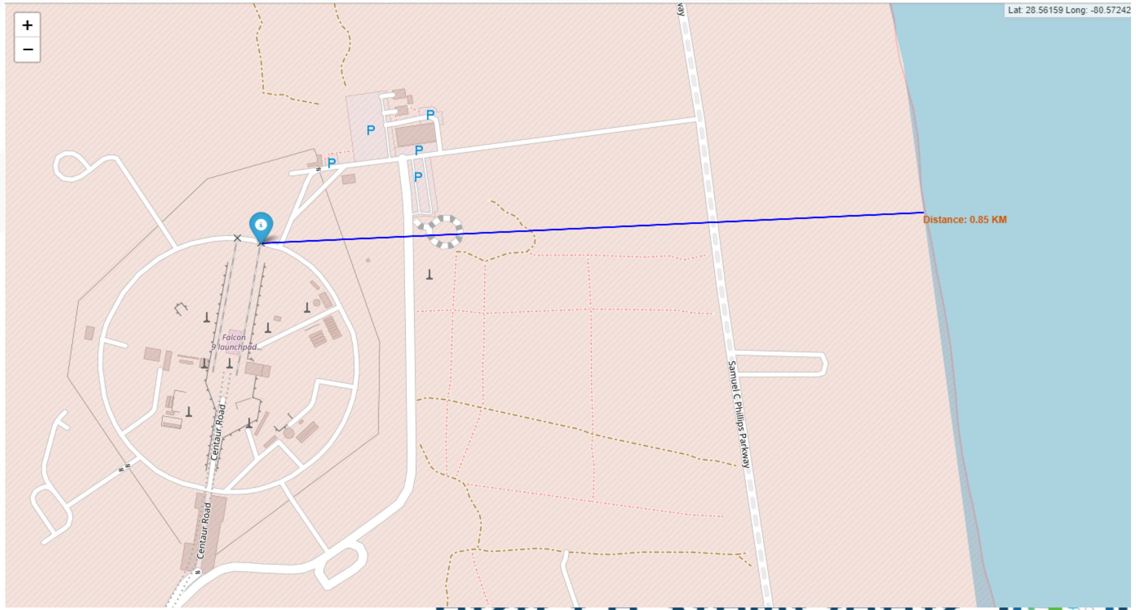


RESULTS

Proximity of Launch Sites to Coastline and Highways

- **Observation:** Launch sites are strategically located near coastlines and major highways. This placement facilitates transportation of rocket components and helps manage the risks associated with launches, such as potential accidents or debris.

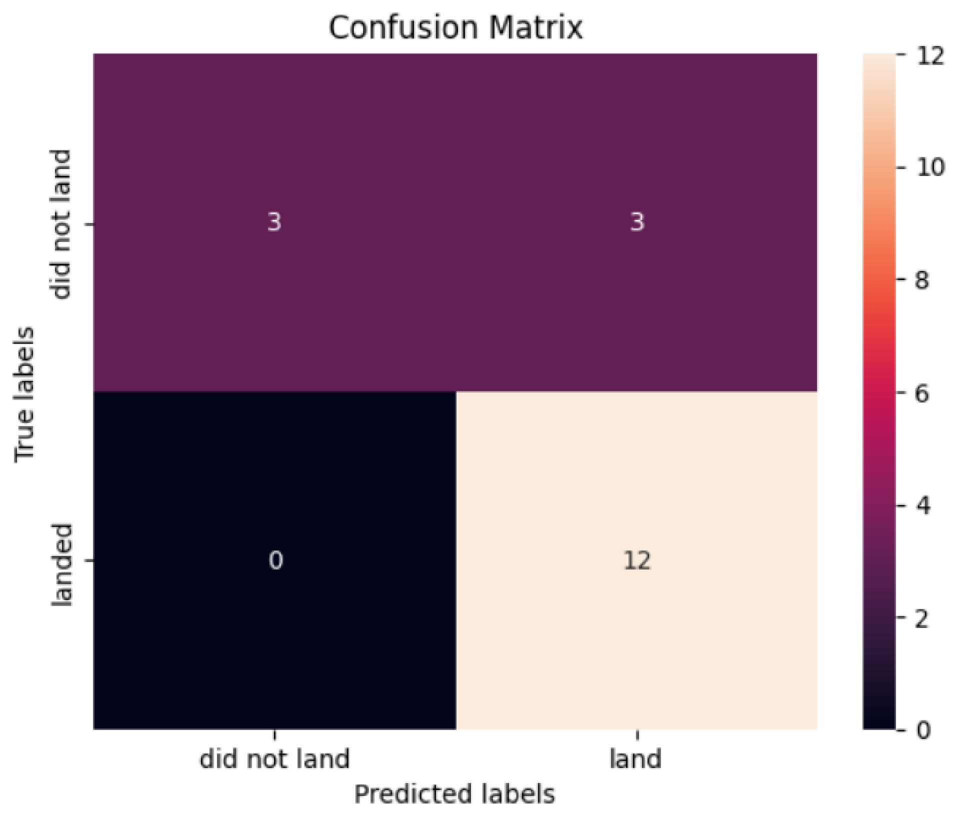




RESULTS

Model Performance:

- **Logistic Regression Test Accuracy:** 0.83
- **Support Vector Machine Test Accuracy:** 0.83
- **Decision Tree Test Accuracy:** 0.83
- **K-Nearest Neighbors:**0.83
- **Conclusion**: All tested models demonstrated effectiveness in predicting Falcon 9 first stage landing success.



Confusion matrix – the same for every model

DASHBOARD

<The GitHub link of the Cognos dashboard goes here.>

DISCUSSION

Launch Site Distribution

- The majority of launches originate from **CCAFS LC-40**, with **VAFB SLC-4E** and **KSC LC-39A** also being significant sites. This distribution indicates CCAFS LC-40's prominent role in SpaceX launches.

Payload Mass and Launch Success

- **NASA's CRS missions** involve substantial payloads, totaling 45,596 kg. The **F9 v1.1** booster version has an average payload mass of about 2,535 kg, which suggests efficient payload handling in its design.

DISCUSSION

Landing Success Trends

- The **first successful ground pad landing** occurred on **2015-12-22**, marking a milestone in landing capabilities.
- Successful landings on drone ships are linked with payloads between 4,000 kg and 6,000 kg, reflecting strategic payload management.

Outcome Distribution

- **Successful landings** dominate the dataset with **38 successes** compared to a variety of failure outcomes. The frequency of **"No attempt"** outcomes (22 occurrences) highlights areas for operational improvements.

DISCUSSION

Booster Performance

- The booster versions with the **maximum payload mass** are from the F9 B5 series, indicating these models are optimized for heavy payloads.

Yearly Success Rate

- Since **2013**, the success rate of landings has shown a steady increase, demonstrating improved technology and reliability over time.

DISCUSSION

Geographic and Operational Insights

- Launch sites are strategically positioned near coastlines and highways, facilitating transportation and operational efficiency. This proximity likely impacts launch safety and logistics.

Orbit and Payload Mass Analysis

- **LEO** and **Polar orbits** show higher success rates with heavy payloads, while **GTO** orbits exhibit mixed success rates, emphasizing the need for further analysis of launch conditions and mission parameters.

OVERALL FINDINGS & IMPLICATIONS

Findings

Successful Landings and Flight Number

- As the flight number of Falcon 9 launches increases, the likelihood of a successful first-stage landing improves. This suggests that experience and repeated attempts enhance the chances of landing success.

Impact of Payload Mass

- The data reveals that successful landings are achievable even with substantial payload masses. Heavy payloads do not necessarily compromise landing success, particularly in orbits such as LEO and Polar.

Launch Site Trends

- The majority of launches occur from CCAFS LC-40, with other sites like VAFB SLC-4E and KSC LC-39A also being active. Each site shows varying success rates and payload capacities, influencing operational strategies.

Implications

Operational Strategy

- The increase in successful landings with higher flight numbers suggests that focusing on continuous improvement and learning from each launch can enhance overall success rates. Future missions should leverage this trend to optimize landing procedures.

Payload Management

- The successful landing of rockets with heavy payloads indicates that payload mass can be managed effectively without compromising landing success. This could inform future mission planning, particularly for payload-heavy launches.

Site Optimization

- The geographic distribution of launch sites near coastlines and highways underscores the importance of strategic site selection for operational efficiency and safety. Future site planning should consider these factors to support successful launches and minimize logistical challenges.

CONCLUSION

Predictive Model Effectiveness

- The machine learning models tested—Logistic Regression, Support Vector Machines, Decision Trees, and K-Nearest Neighbors—demonstrated effectiveness in predicting the success of Falcon 9 first-stage landings. All models performed well, highlighting the robustness of our predictive approach.

Significant Predictive Features

- Key features such as flight number, payload mass, and launch site were identified as significant predictors of landing success. This emphasizes the importance of these factors in designing and evaluating future launches.

Trends and Operational Insights

- Analysis revealed that as the flight number increases, the likelihood of a successful landing also increases. Additionally, heavier payloads do not negatively impact landing success as much as previously thought. Launch sites near coastlines and highways are well-positioned for operational efficiency.

APPENDIX

- Please visit my github to see the whole repository, including datasets and Jupyter Notebooks made during this analysis:

https://github.com/Screachail/Predicting-Falcon-9-First-Stage-Landing-Success.git