IBM Developer
SKILLS NETWORK

Winning Space Race with Data Science

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May 16th 2024

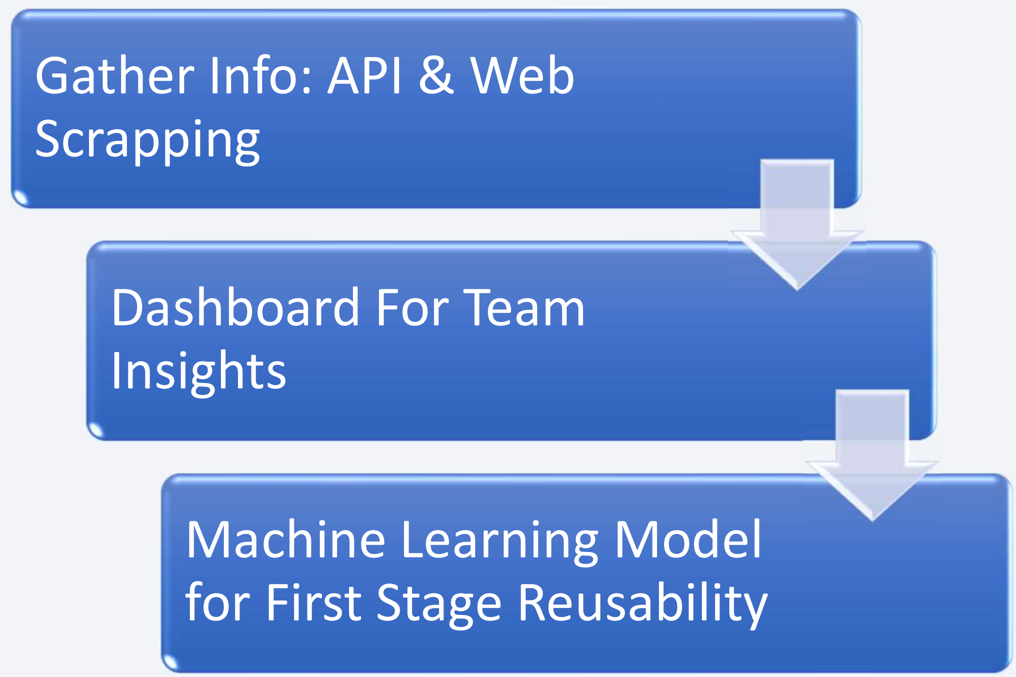
Outline

Executive Summary

- Predict the likelihood of reusing the Falcon 9's first stage.

Methodology:

- Gather and analyze data on SpaceX launches.
- Develop dashboards for team insights.
- Train a machine learning model using public information to predict first stage reusability.



Introduction

Emergence of the Commercial Space Age

Commercial space sector rapidly advancing, making space travel more accessible and affordable.

Background

- Key players in the industry:
  - **Virgin Galactic:** Providing suborbital spaceflights.
  - **Rocket Lab:** Specialized in small satellite launches.
  - **Blue Origin:** Focused on reusable sub-orbital and orbital rockets.
  - **SpaceX:** Leading the market with significant achievements.

SPACEX

Caso de estudio

BLUE ORIGIN

ROCKETLAB

Introduction

Problems to Answer

Reusability Prediction:

•Predict the likelihood of the Falcon 9's first stage successfully landing.
•Utilize machine learning techniques to forecast reusability basen on mission-specific data.

Competitive Analysis:

•Benchmark Space Y's capabilities and costs against SpaceX.
•Identify opportunities for improving cost-efficiency and reusability.

Section 1

Methodology

Methodology

Executive Summary

- Data collection methodology:
  - Describe how data was collected
- Perform data wrangling
  - Describe 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
  - How to build, tune, evaluate classification models

Data Collection

Data Source: SpaceX REST API

- Utilized the SpaceX REST API to gather comprehensive launch data.
- API endpoint used: api.spacexdata.com/v4/launches/past.
- Other relevant endpoints: /capsules, /cores, /launchpads, /payloads.

Data Retrieval Process

- Performed GET requests using the Python requests library.
- Extracted data in JSON format using the .json() method.
- JSON responses were lists of JSON objects, each representing a SpaceX launch.

Data Transformation

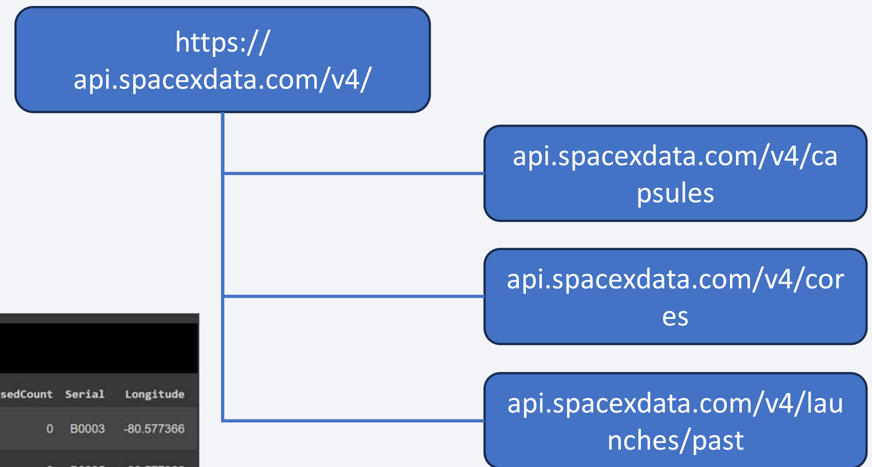
- Converted JSON data into a flat table using json_normalize.
- Transformed raw JSON into a structured Pandas dataframe for analysis.

Supplementary Data Source: Web Scraping

- Used Python's BeautifulSoup package to scrape HTML tables from relevant Wikipedia pages.
- Parsed and converted scraped HTML table data into Pandas dataframes.

Data Collection – SpaceX API

- Data collection with SpaceX REST calls using
- Completed SpaceX API calls on https://github.com/icrondond/firstrep




```
1  data_falcon9.loc[:,'FlightNumber'] = list(range(1, data_falcon9.shape[0]+1))
2  data_falcon9
```

	FlightNumber	Date	BoosterVersion	PayloadMass	Orbit	LaunchSite	Outcome	Flights	GridFins	Reused	Legs	LandingPad	Block	ReusedCount	Serial	Longitude
4	1	2010-06-04	Falcon 9	NaN	LEO	CCSFS SLC 40	None None	1	False	False	False	None	1.0	0	B0003	-80.577366
5	2	2012-05-22	Falcon 9	525.0	LEO	CCSFS SLC 40	None None	1	False	False	False	None	1.0	0	B0005	-80.577366
6	3	2013-03-01	Falcon 9	677.0	ISS	CCSFS SLC 40	None None	1	False	False	False	None	1.0	0	B0007	-80.577366
7	4	2013-09-29	Falcon 9	500.0	PO	VAFB SLC 4E	False Ocean	1	False	False	False	None	1.0	0	B1003	-120.610829
8	5	2013-12-03	Falcon 9	3170.0	GTO	CCSFS SLC 40	None None	1	False	False	False	None	1.0	0	B1004	-80.577366
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
89	86	2020-09-03	Falcon 9	15600.0	VLEO	KSC LC 39A	True ASDS	2	True	True	True	5e9e3032383ecb6bb234e7ca	5.0	12	B1060	-80.603956
90	87	2020-10-06	Falcon 9	15600.0	VLEO	KSC LC 39A	True ASDS	3	True	True	True	5e9e3032383ecb6bb234e7ca	5.0	13	B1058	-80.603956
91	88	2020-10-18	Falcon 9	15600.0	VLEO	KSC LC 39A	True ASDS	6	True	True	True	5e9e3032383ecb6bb234e7ca	5.0	12	B1051	-80.603956
92	89	2020-10-24	Falcon 9	15600.0	VLEO	CCSFS SLC 40	True ASDS	3	True	True	True	5e9e3033383ecbb9e534e7cc	5.0	12	B1060	-80.577366
93	90	2020-11-05	Falcon 9	3681.0	MEO	CCSFS SLC 40	True ASDS	1	True	False	True	5e9e3032383ecb6bb234e7ca	5.0	8	B1062	-80.577366

90 rows × 17 columns

Data Collection - Scraping

- Data collection via Web Scrapping

2020 [edit]

In late 2019, Gwynne Shotwell stated that SpaceX hoped for as many as 24 launches for Starlink satellites in 2020,[490] in addition to 14 or 15 non-Starlink launches. At 26 launches, 13 of which for Starlink satellites, Falcon 9 had its most prolific year, and Falcon rockets were second most prolific rocket family of 2020, only behind China's Long March rocket family.[491]

[hide] Flight No.	Date and time (UTC)	Version, Booster[b]	Launch site	Payload[c]	Payload mass	Orbit	Customer	Launch outcome	Booster landing
78	7 January 2020, 02:19:21[492]	F9 B5 △ B1049.4	CCAFS, SLC-40	Starlink 2 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)
	Third large batch and second operational flight of Starlink constellation. One of the 60 satellites included a test coating to make the satellite less reflective, and thus less likely to interfere with ground-based astronomical observations.[493]								
79	19 January 2020, 15:30[494]	F9 B5 △ B1046.4	KSC, LC-39A	Crew Dragon in-flight abort test[495] (Dragon C205.1)	12,050 kg (26,570 lb)	Sub-orbital[496]	NASA (CTS)[497]	Success	No attempt
	An atmospheric test of the Dragon 2 abort system after Max Q. The capsule fired its SuperDraco engines, reached an apogee of 40 km (25 mi), deployed parachutes after reentry, and splashed down in the ocean 31 km (19 mi) downrange from the launch site. The test was previously slated to be accomplished with the Crew Dragon Demo-1 capsule;[498] but that test article exploded during a ground test of SuperDraco engines on 20 April 2019.[419] The abort test used the capsule originally intended for the first crewed flight.[499] As expected, the booster was destroyed by aerodynamic forces after the capsule aborted.[500] First flight of a Falcon 9 with only one functional stage — the second stage had a mass simulator in place of its engine.								
80	29 January 2020, 14:07[501]	F9 B5 △ B1051.3	CCAFS, SLC-40	Starlink 3 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)
	Third operational and fourth large batch of Starlink satellites, deployed in a circular 290 km (180 mi) orbit. One of the fairing halves was caught, while the other was fished out of the ocean.[502]								
81	17 February 2020, 15:05[503]	F9 B5 △ B1056.4	CCAFS, SLC-40	Starlink 4 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Failure (drone ship)
	Fourth operational and fifth large batch of Starlink satellites. Used a new flight profile which deployed into a 212 km × 386 km (132 mi × 240 mi) elliptical orbit instead of launching into a circular orbit and firing the second stage engine twice. The first stage booster failed to land on the drone ship[504] due to incorrect wind data.[505] This was the first time a flight proven booster failed to land.								
82	7 March 2020, 04:50[506]	F9 B5 △ B1059.2	CCAFS, SLC-40	SpaceX CRS-20 (Dragon C112.3 △)	1,977 kg (4,359 lb)[507]	LEO (ISS)	NASA (CRS)	Success	Success (ground pad)
	Last launch of phase 1 of the CRS contract. Carries *Bartolomeo*, an ESA platform for hosting external payloads onto ISS.[508] Originally scheduled to launch on 2 March 2020, the launch date was pushed back due to a second stage engine failure. SpaceX decided to swap out the second stage instead of replacing the faulty part.[509] It was SpaceX's 50th successful landing of a first stage booster, the third flight of the Dragon C112 and the last launch of the cargo Dragon spacecraft.								
83	18 March 2020, 12:16[510]	F9 B5 △ B1048.5	KSC, LC-39A	Starlink 5 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Failure (drone ship)
	Fifth operational launch of Starlink satellites. It was the first time a first stage booster flew for a fifth time and the second time the fairings were reused (Starlink flight in May 2019).[511] Towards the end of the first stage burn, the booster suffered premature shut down of an engine, the first of a Merlin 1D variant and first since the CRS-1 mission in October 2012. However, the payload still reached the targeted orbit.[512] This was the second Starlink launch booster landing failure in a row, later revealed to be caused by residual cleaning fluid trapped inside a sensor.[513]								
84	22 April 2020, 19:30[514]	F9 B5 △ B1051.4	KSC, LC-39A	Starlink 6 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)

- Completed Web Scrapping on https://github.com/icrondond/firstrep

Final Data Frame To CSV

Flight No.	Launch site	Payload	Payload mass	Orbit	Customer	Launch outcome	Version Booster	Booster landing	Date	Time

Data Wrangling

Data Process

- Identifying and calculating percentage of the missing values per attribute
- Identifying type of each attribute
- Launch Per Site
- Determine number and occurrence per orbit
- Determine number and occurrence of mission
- Determine success rate

- Completed Data Wrangled on https://github.com/icrondond/firstrep

```
# Apply value_counts() on column LaunchSite
df.LaunchSite.value_counts()
```

```
LaunchSite
CCAFS SLC 40    55
KSC LC 39A      22
VAFB SLC 4E     13
Name: count, dtype: int64
```

```
# landing_outcomes = values on Outcome column
landing_outcomes=df.Outcome.value_counts()
landing_outcomes
```

```
Outcome
True ASDS      41
None None      19
True RTLS      14
False ASDS      6
True Ocean      5
False Ocean     2
None ASDS       2
False RTLS      1
Name: count, dtype: int64
```

```
df["Class"].mean()
```

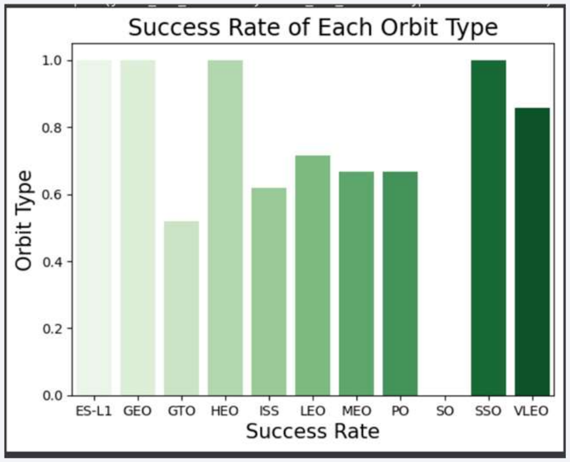
```
0.6666666666666666
```

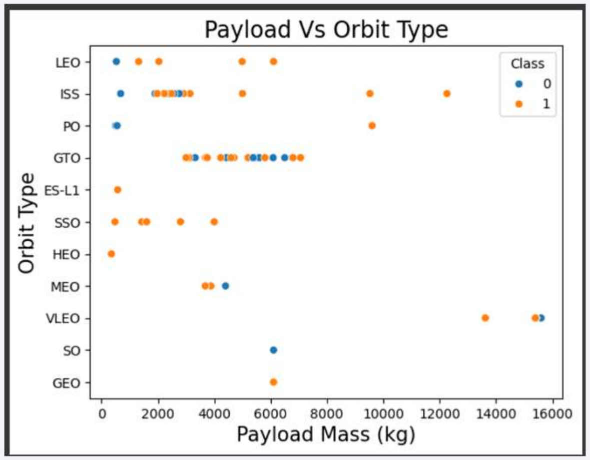
EDA with Data Visualization

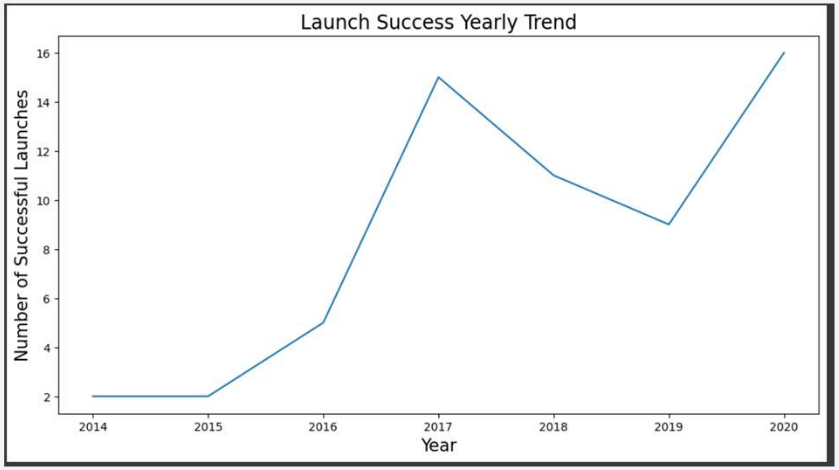
Exploratory Data Analysis

- Flight Number per launch site
- Payload Mass per Launch Site
- Succes rate per orbit type
- Payload per orbit Type
- Launch Succes Yearly Rate

- Complete chart collection on
  https://github.com/icrondond/firstrep







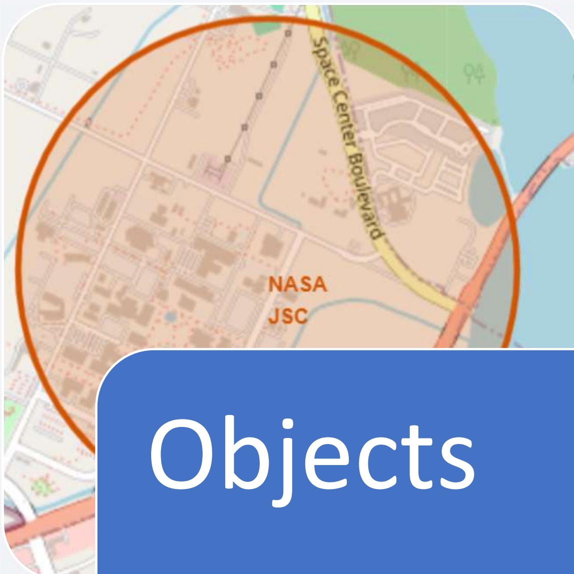
EDA with SQL

SQL queries performed

- Names of the unique launch sites in the space mission
- Launch sites begin with the string 'CCA’
- Total payload mass carried by boosters launched by NASA (CRS)
- Average payload mass carried by booster version F9 v1.1
- Date of the first successful landing outcome in ground pad
- Boosters withe success in drone ship and payload mass between than 4000 but less than 6000 successful and failure mission outcomes
- Booster versions which carried maximum payload mass.
- Landing outcomes Failure (drone ship) or Success (ground pad) between 2010-06-04 and 2017-03-20, in descending order.

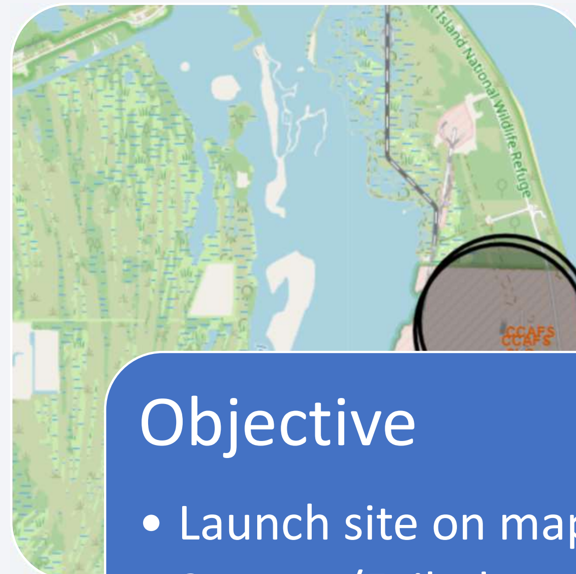
Complete SQL queries on https://github.com/icrondond/firstrep

Build an Interactive Map with Folium



Objects

- Marker
- Line
- Circle

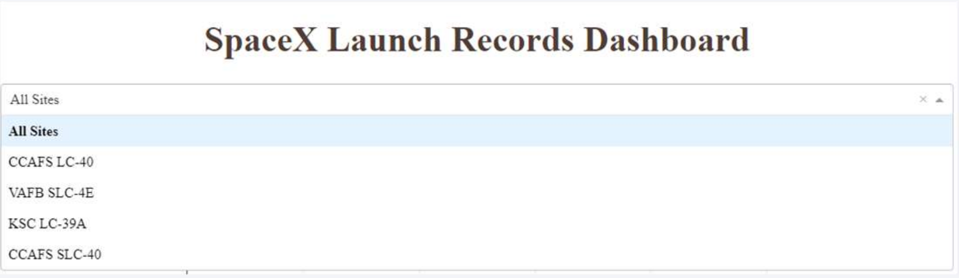


Objective

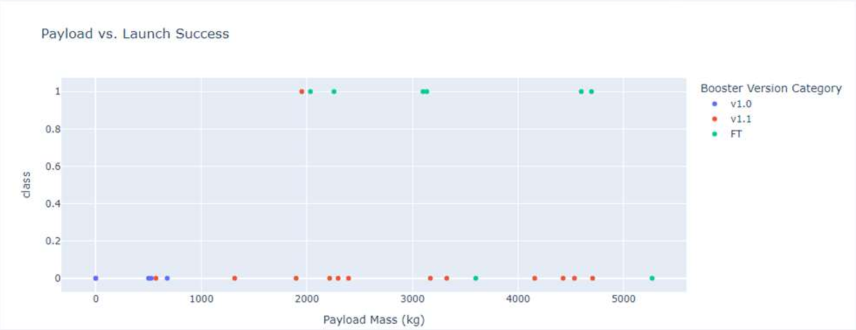
- Launch site on map
- Success/Failed Launches
- Distance between proximities

Complete Map on https://github.com/icrondond/firstrep

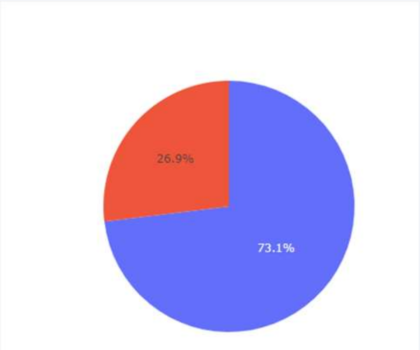
Build a Dashboard with Plotly Dash



- Capture insights per Launch site
- Understand success rate per launch site

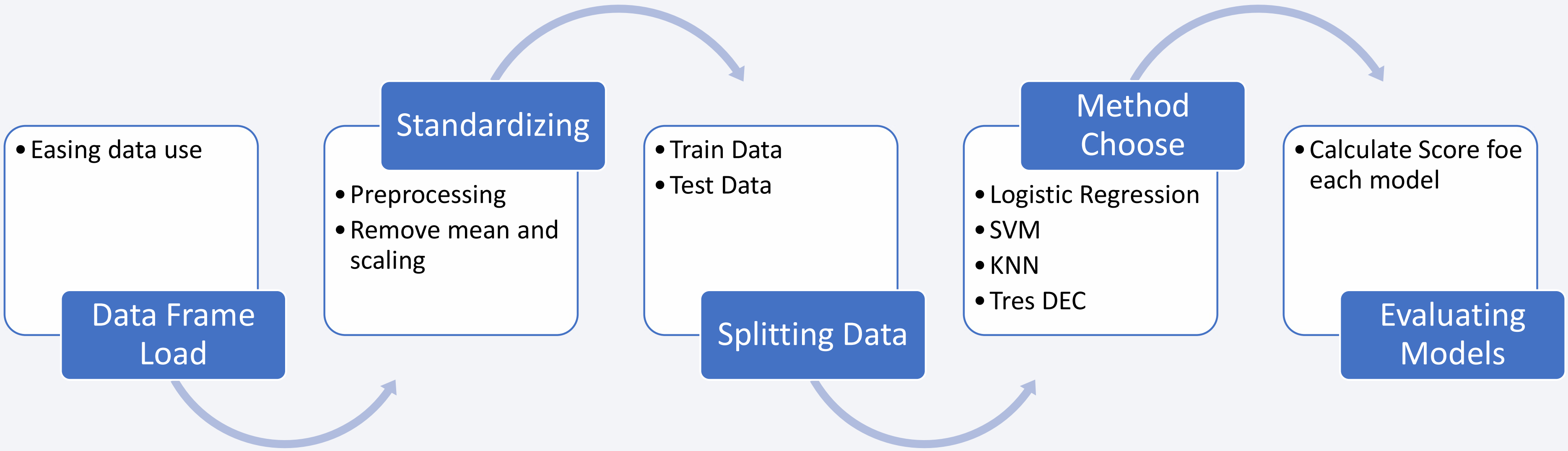


- Insights based on successful depending payload mass



Complete Dash on
https://github.com/icrondond/firstrep

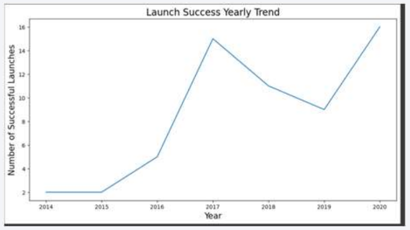
Predictive Analysis (Classification)

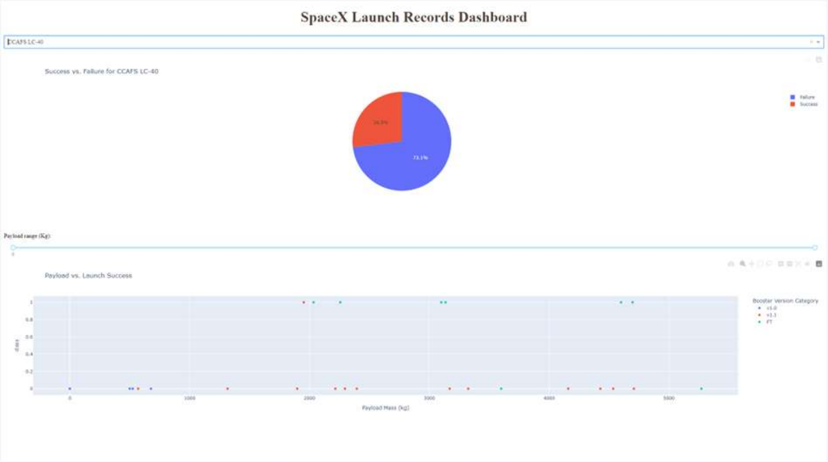


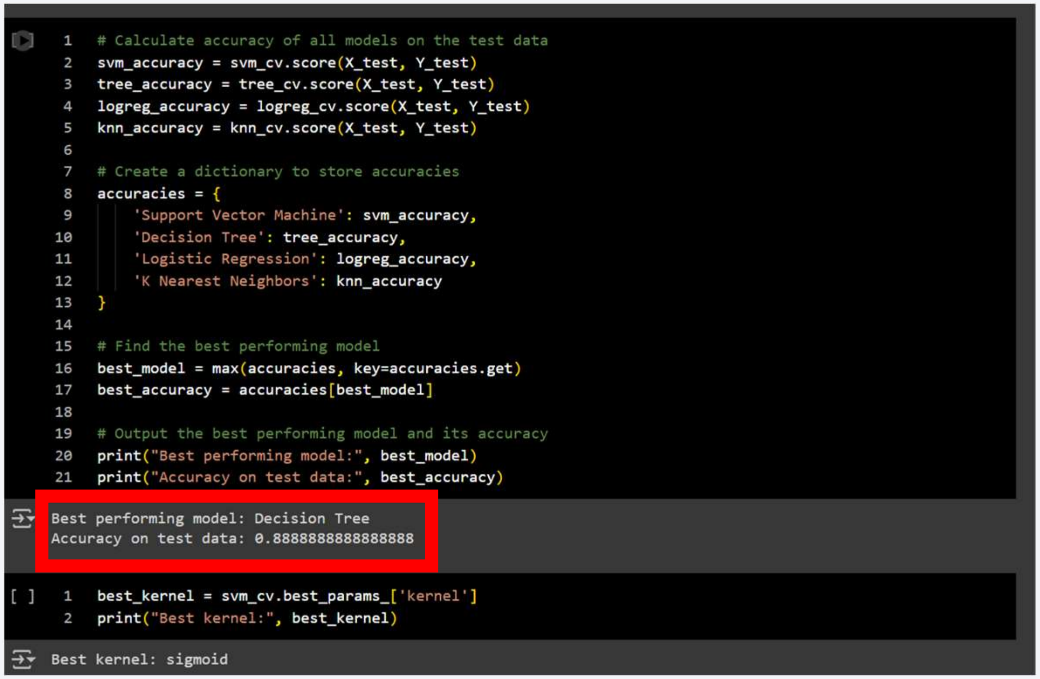
Complete Model Analysis on
https://github.com/icrondond/firstrep

Results

- Exploratory data analysis results
- Interactive analytics demo in screenshots
- Predictive analysis results







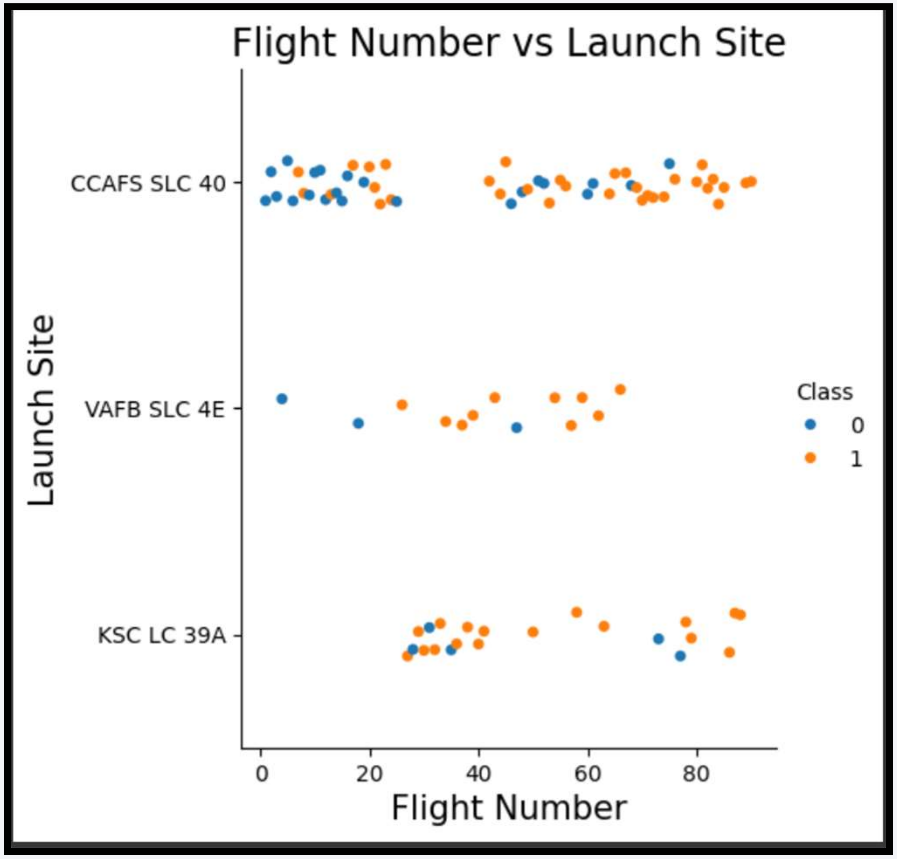
Section 2

Insights drawn from EDA

Flight Number vs. Launch Site

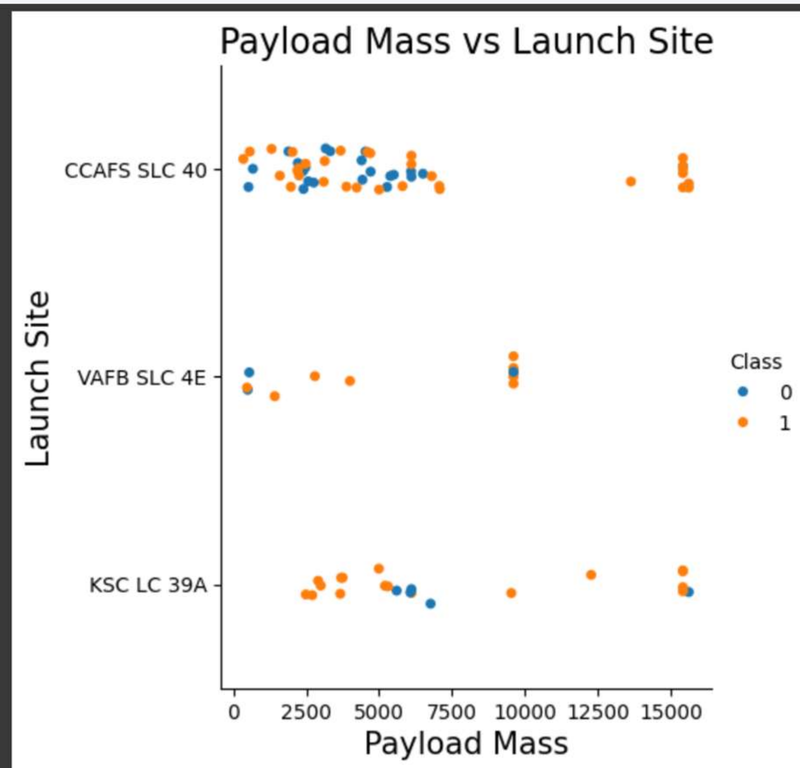
- CCAFS SLC mayor number of launch site

- Visual inference of more success rate in VAFB SLC 4E



Payload vs. Launch Site

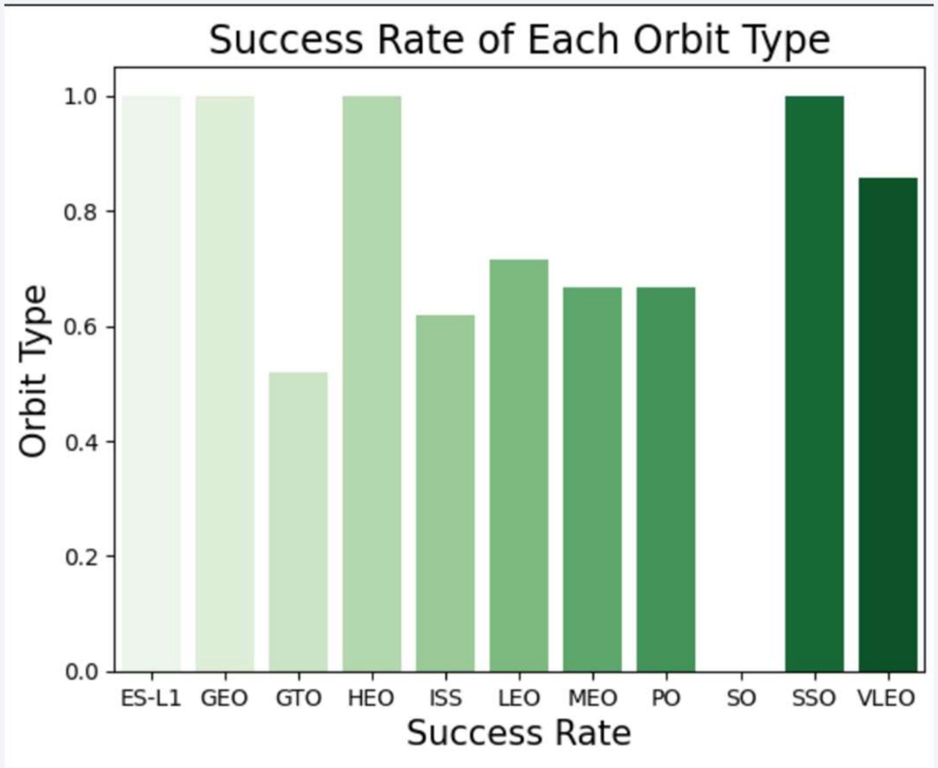
- More payload mass over success launch over 15000kg
- Les success rate on CCAFS SLC 40 in payload mass range 0 to 7500
- More number of launches in CCAFS SLC 40



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).

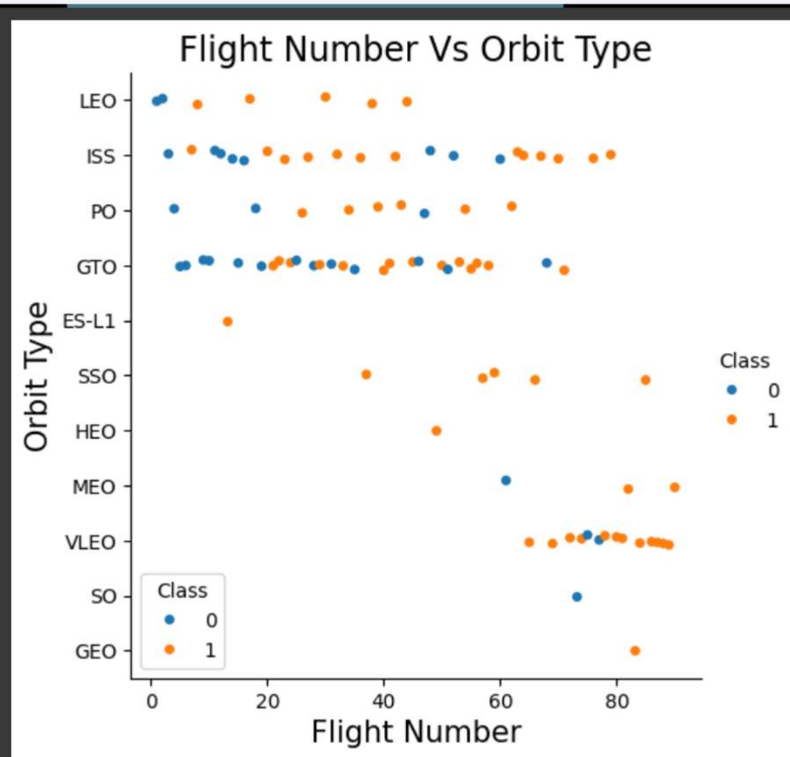
Success Rate vs. Orbit Type

- Success RATE 1 (100%)
  - ES-L1
  - GEO
  - HEO
  - SSO
- Success Rate under 0.5
  - GTO



Flight Number vs. Orbit Type

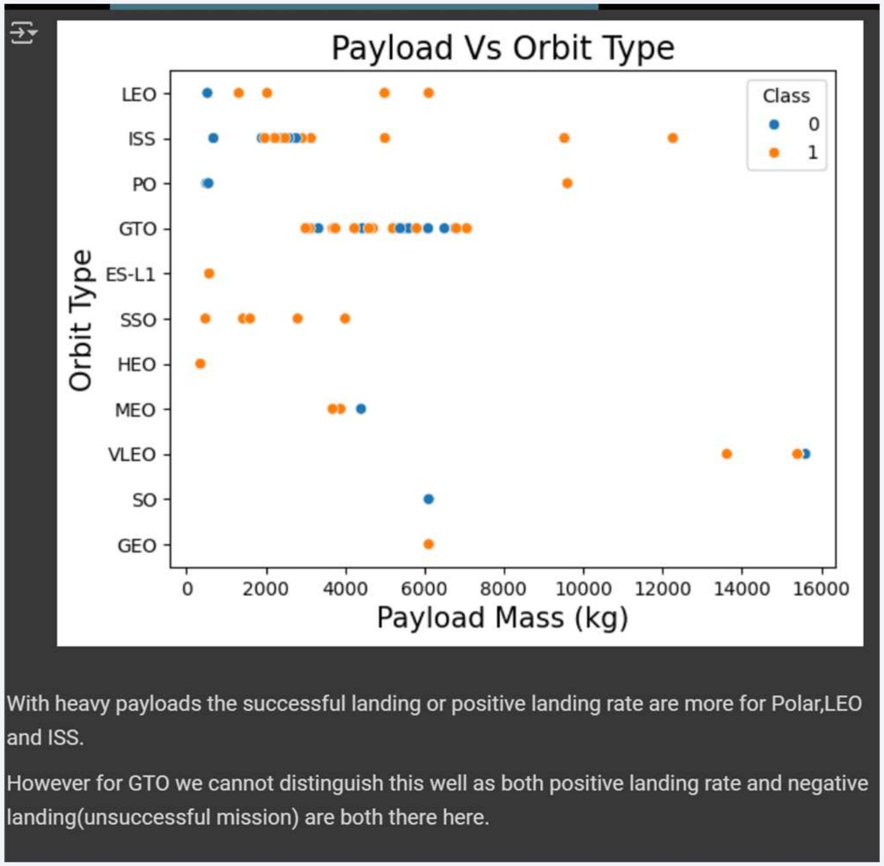
- VLEO support most number od flights
- ES-L1, SSO, HEO high rate of success
- GTO most number of flights unsuccess



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.

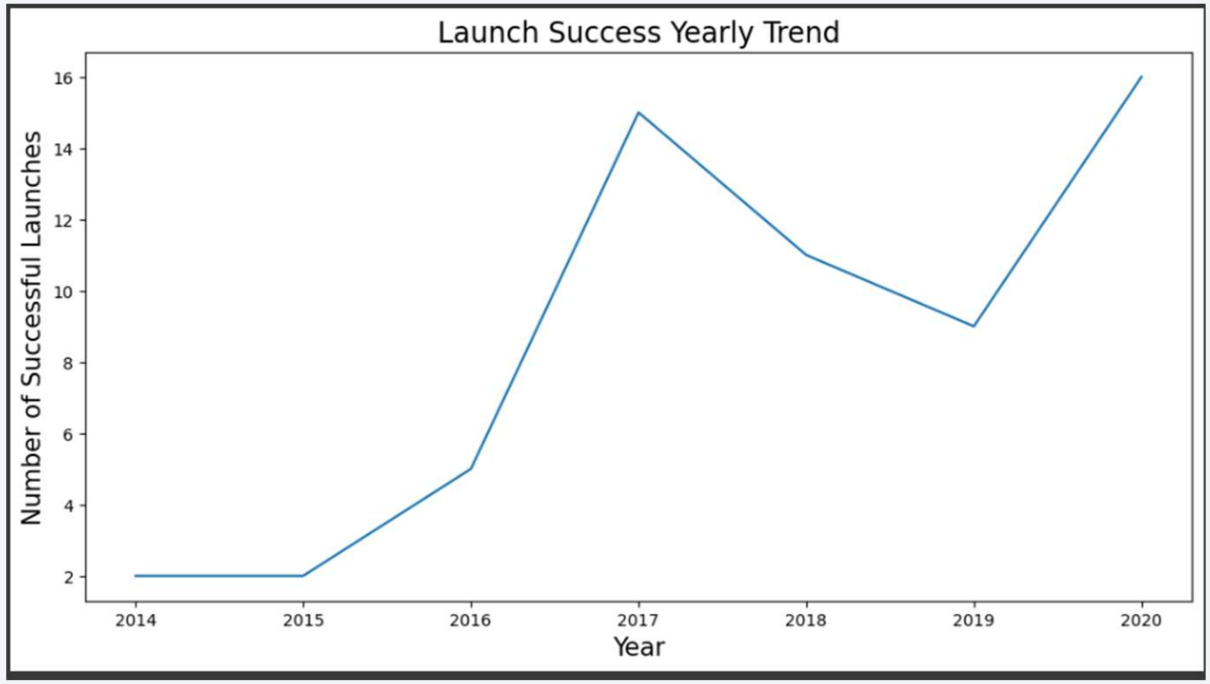
Payload vs. Orbit Type

- High rate of success SSO, ES-L1, HEO, CEO
- VLEO most payload mass with unsuccess launch
- VLEO most payload mass with success launch



Launch Success Yearly Trend

- Increasing tend between 2015 and 2017
- Drop falling to 2019
- Recuperation and increase to 2020 I



All Launch Site Names

- Through the SQL query all unique registers (sites) where found

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

```
1  %sql SELECT DISTINCT LAUNCH_SITE FROM SPACEXTABLE
```

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

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

Launch Site Names Begin with 'CCA'

- Query to find all register related to CCA sites

```
1   %sql SELECT * FROM SPACEXTABLE WHERE LAUNCH_SITE LIKE 'CCA%' LIMIT 5
```

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

Date	Time (UTC)	Booster_Version	Launch_Site	Payload	PAYLOAD_MASS__KG_	Orbit	Custor
2010-06-04	18:45:00	F9 v1.0 B0003	CCAFS LC-40	Dragon Spacecraft Qualification Unit	0	LEO	Space)
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
2012-05-22	7:44:00	F9 v1.0 B0005	CCAFS LC-40	Dragon demo flight C2	525	LEO (ISS)	NASA (COTS
2012-10-08	0:35:00	F9 v1.0 B0006	CCAFS LC-40	SpaceX CRS-1	500	LEO (ISS)	NASA (CRS)
2013-03-01	15:10:00	F9 v1.0 B0007	CCAFS LC-40	SpaceX CRS-2	677	LEO (ISS)	NASA (CRS)

Total Payload Mass

- Through the SQL query was captured the total payload mass carried by boosters from NASA
- 45.596 Kg

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

 * sqlite:///my_data1.db
Done.
SUM(PAYLOAD_MASS__KG_ )
45596
```

Average Payload Mass by F9 v1.1

- Result of the average payload mass carried by booster version F9 v1.1
- 2,9 Tons

```
[ ]   1   %sql SELECT AVG(PAYLOAD_MASS__KG_) FROM SPACEXTABLE WHERE Booster_Version  =

 * sqlite:///my_data1.db
Done.
AVG(PAYLOAD_MASS__KG_)
2928.4
```

First Successful Ground Landing Date

- Date of the first successful ground landing
- 22nd December of 2015

```
[ ]  1  %sql SELECT MIN(DATE) FROM SPACEXTABLE WHERE Landing_Outcome = 'Success (grc

 * sqlite:///my_data1.db
Done.
MIN(DATE)
2015-12-22
```

Successful Drone Ship Landing with Payload between 4000 and 6000

- Four (4) boosters have successfully landed on drone ship with a payload mass range between 4000 and 6000 kg

```
[ ]  1  %sql SELECT Booster_Version FROM SPACEXTABLE WHERE Landing_Outcome = 'Succes
```

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

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

Total Number of Successful and Failure Mission Outcomes

- Total number of successful and failure mission outcomes

```
[ ]  1  %sql SELECT Landing_Outcome, COUNT(*) FROM SPACEXTABLE GROUP BY Landing_Outc
```

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

Landing_Outcome	COUNT(*)
Controlled (ocean)	5
Failure	3
Failure (drone ship)	5
Failure (parachute)	2
No attempt	21
No attempt	1
Precluded (drone ship)	1
Success	38
Success (drone ship)	14
Success (ground pad)	9
Uncontrolled (ocean)	2

Boosters Carried Maximum Payload

- List of the twelve names of booster that have carried maximum payload mass

```
1  %sql SELECT Booster_Version FROM SPACEXTABLE WHERE PAYLOAD_MASS__KG_ = (SELE
```

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

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

2015 Launch Records

- List the failed landing outcomes in drone ship, for year 2015

```
[ ]   1   %sql SELECT substr(Date, 6,2) AS Month, Landing_Outcome, Booster_Version FRC

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

Month	Landing_Outcome	Booster_Version
01	Failure (drone ship)	F9 v1.1 B1012
04	Failure (drone ship)	F9 v1.1 B1015

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

- Ranking of landing outcomes Failure (drone ship) and Success (ground pad) between 2010-06-04 and 2017-03-20

```
[ ]  1  %sql SELECT Landing_Outcome, COUNT(*) FROM SPACEXTABLE WHERE Date BETWEEN '2
```

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

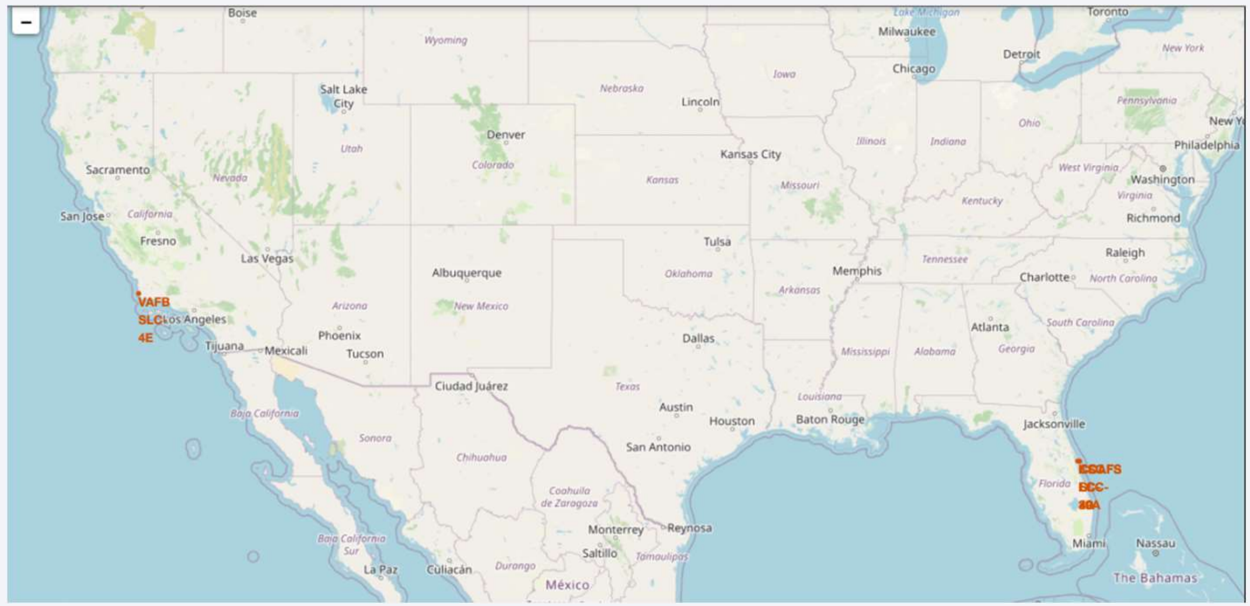
Landing_Outcome	COUNT(*)
No attempt	10
Success (drone ship)	5
Failure (drone ship)	5
Success (ground pad)	3
Controlled (ocean)	3
Uncontrolled (ocean)	2
Failure (parachute)	2
Precluded (drone ship)	1

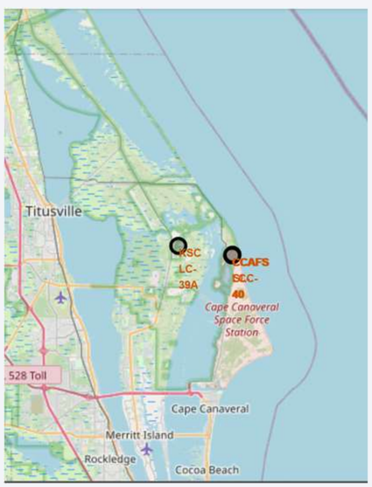
Section 3

Launch Sites Proximities Analysis

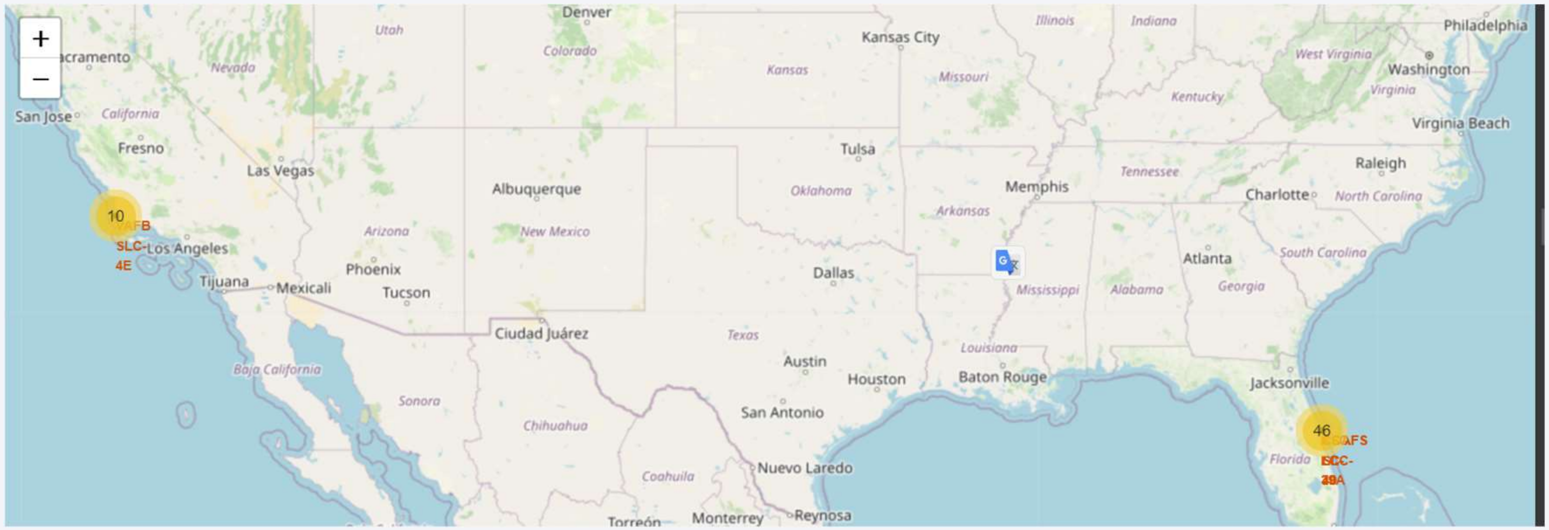
Launch Sites

- Inference of proximity to coast to success launch's





Success & failed launches per site



- Facilitate the identification of success rate per site

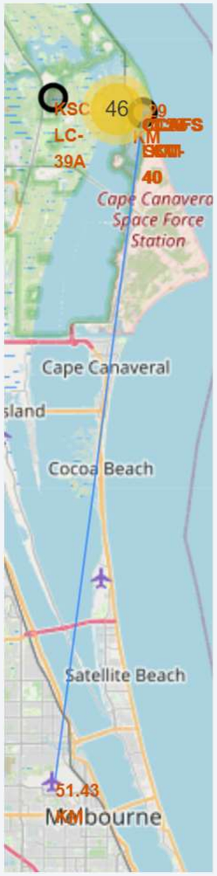
Distances between launch sites proximities

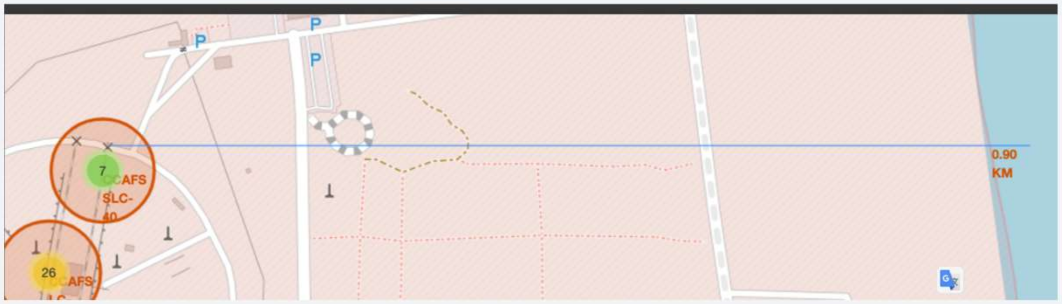
Launch sites proximity to railways

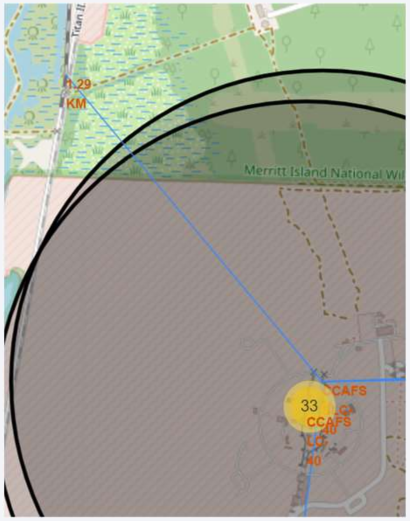
Launch proximity to highways

Launch sites proximity to coastline

Launch sites distance from cities

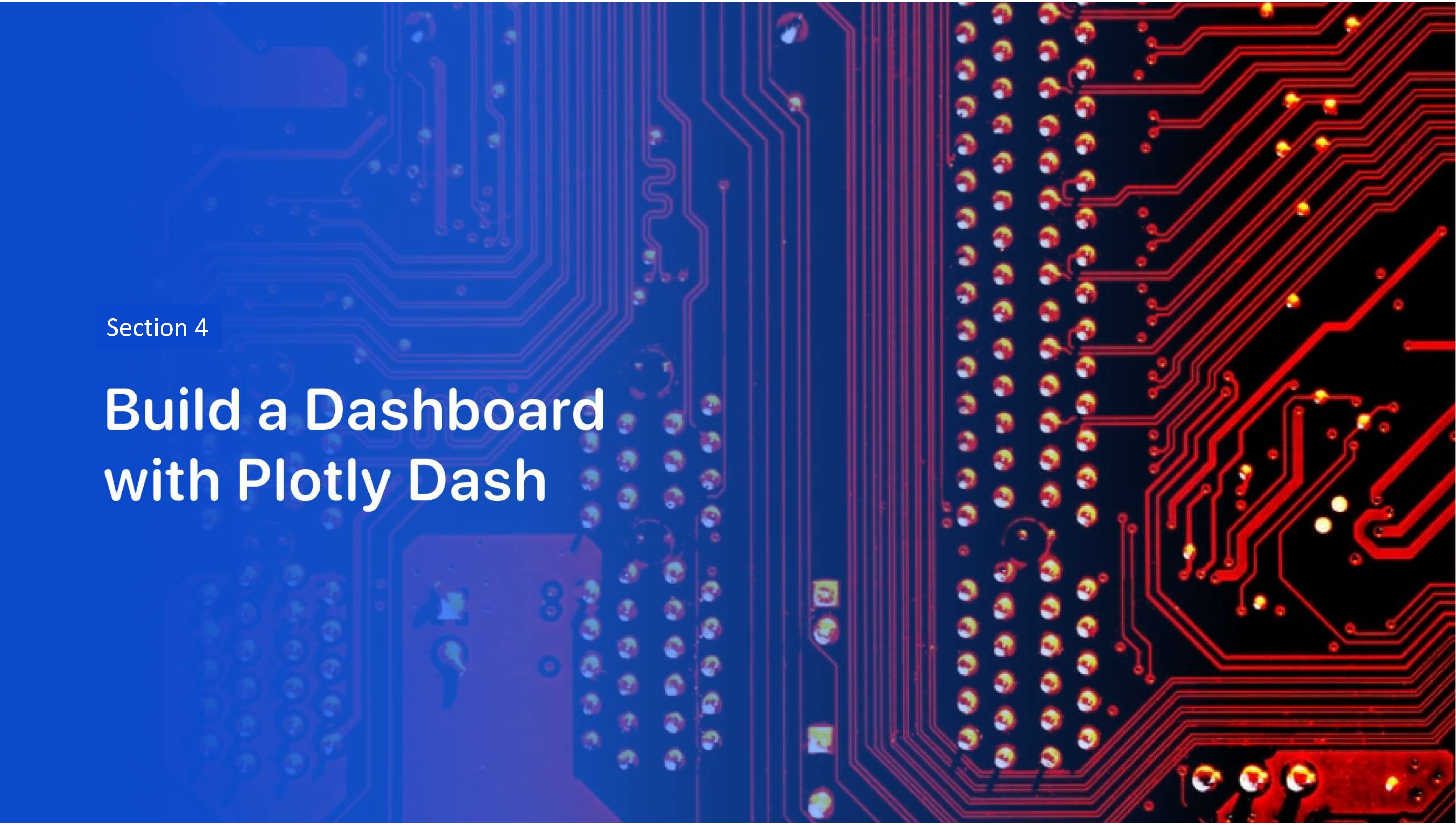




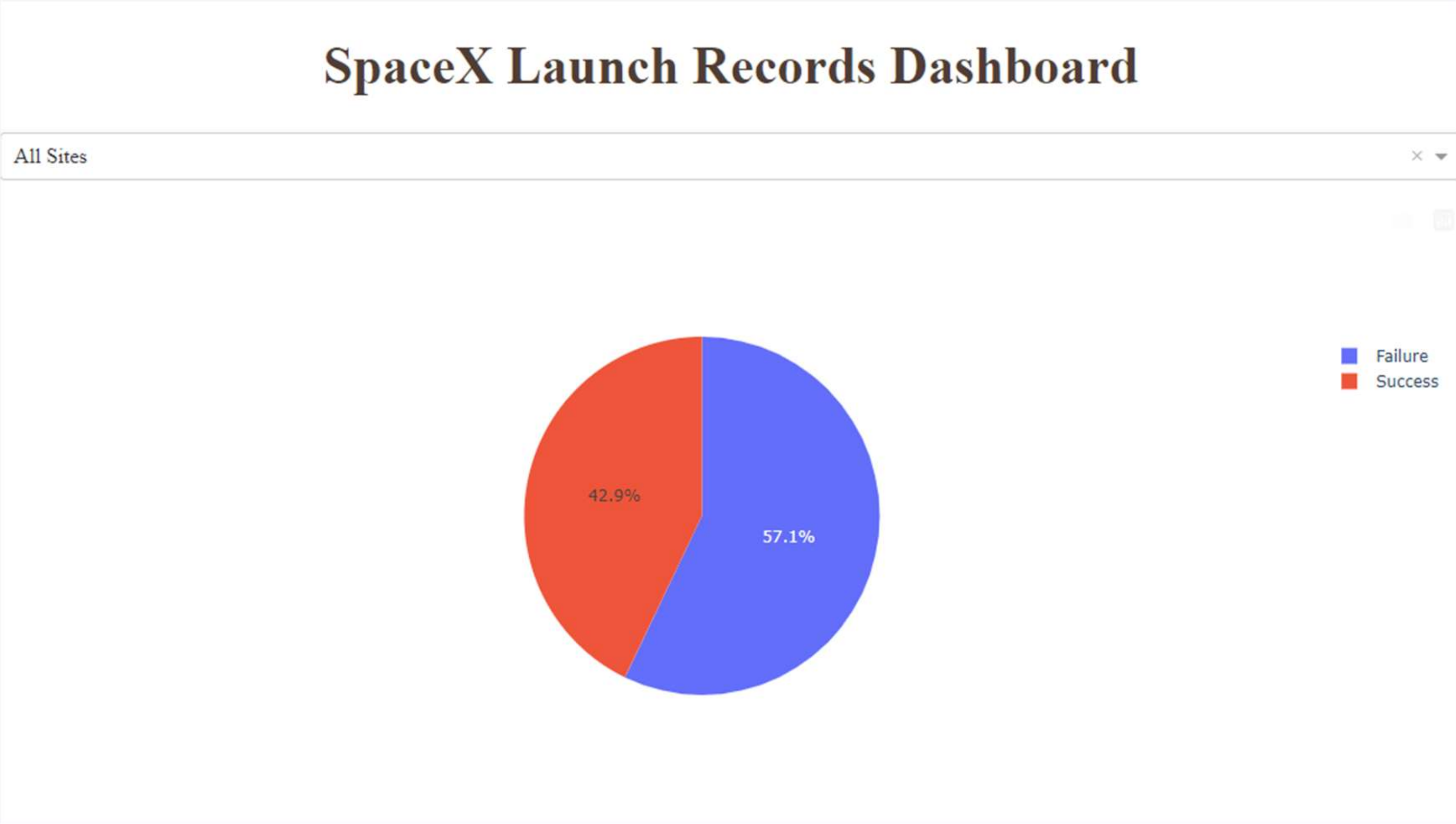


Section 4

Build a Dashboard with Plotly Dash

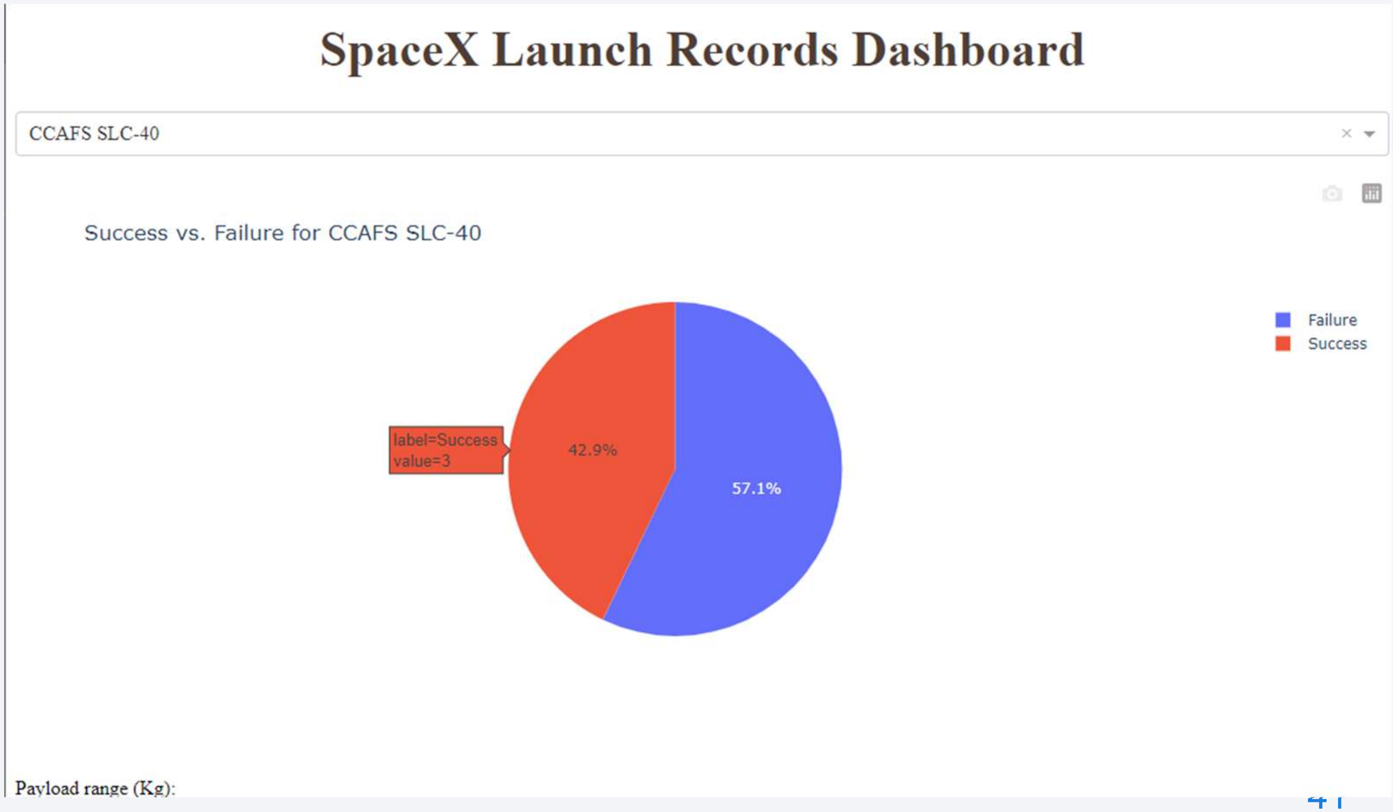


SpaceX Launch Records Dashboard



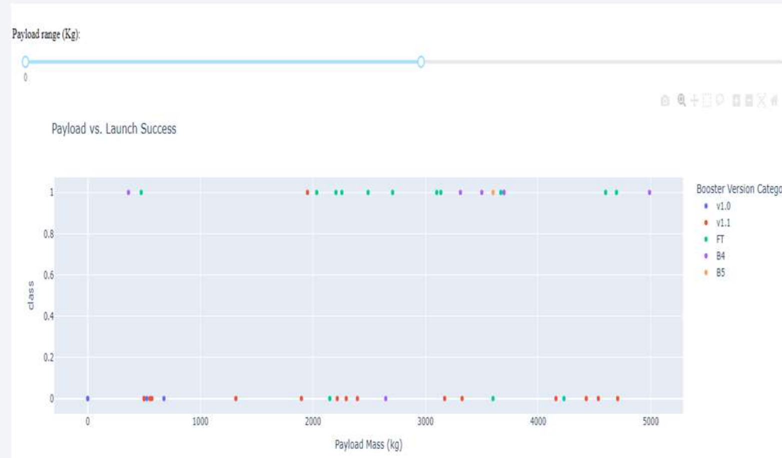
Most Success Launch Rate Site

- CCAFS SLC-40 show the highest success rate with 42,9%
- Even then the rate is lower than 50%



Payload vs. Launch Outcome

- The larger payload mass range show the higher success rate
- FT boost version show the higher successful rates for the most of payload mass range



Section 5

Predictive Analysis (Classification)

Classification Accuracy

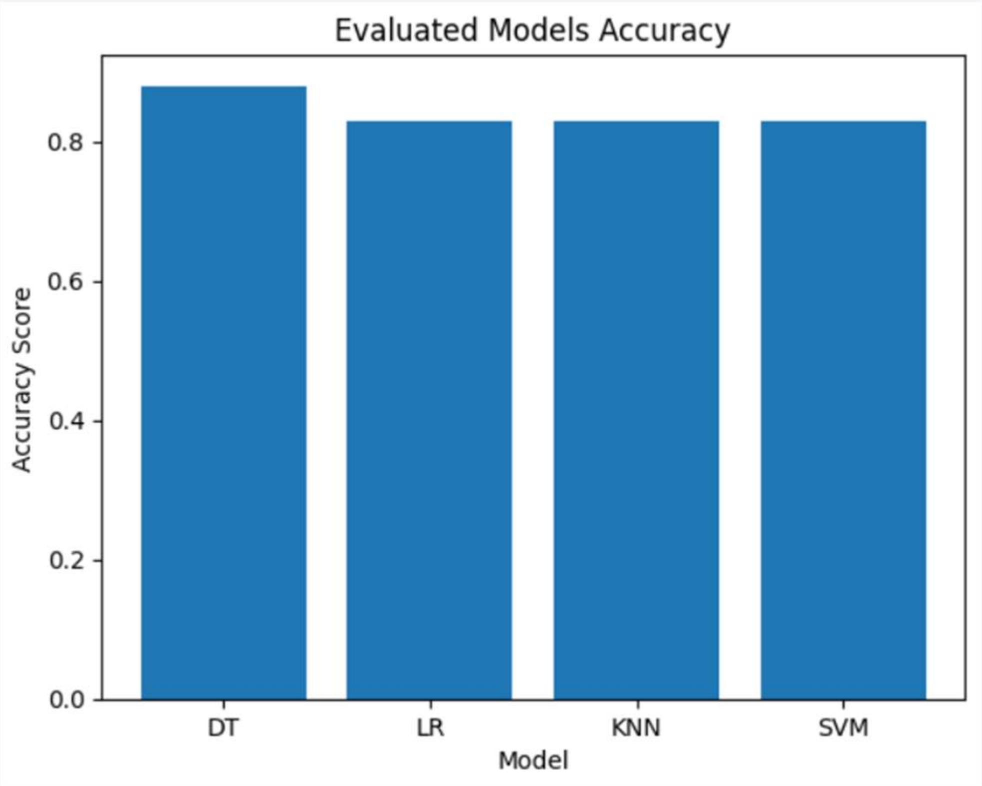
DT = Decision Tree

LR = Logistic Regression

KNN = K-Nearest Neighbor

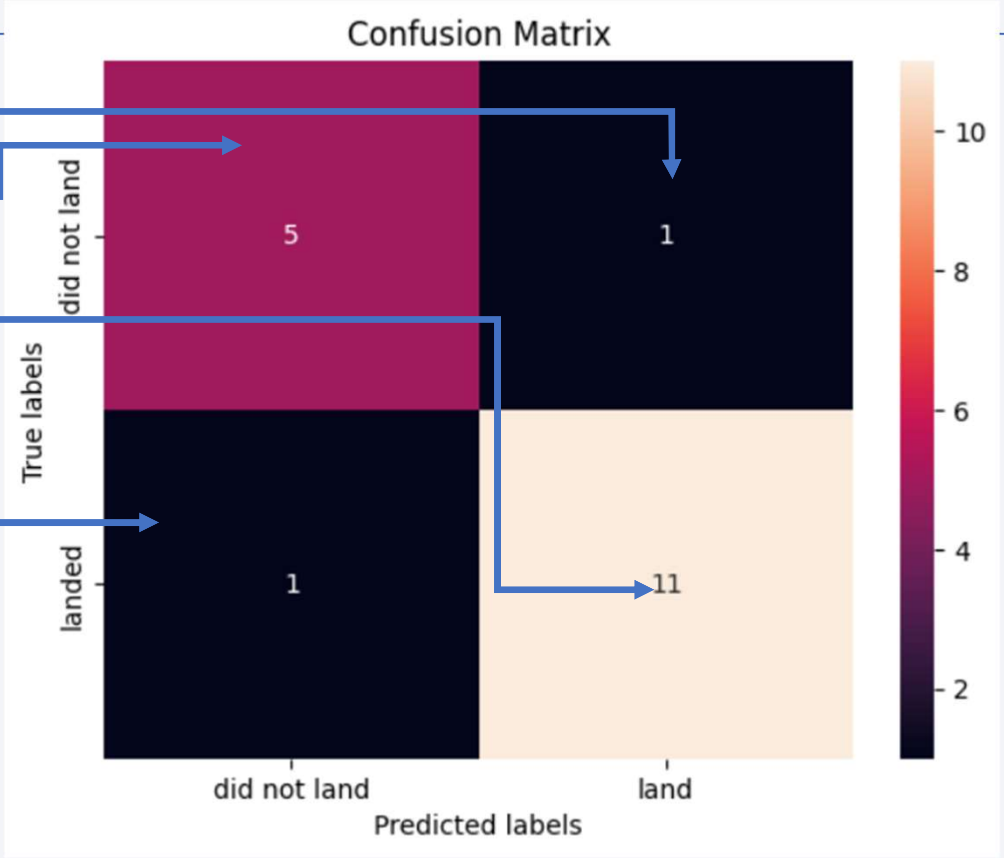
SVM = Support Vector Machine

Decision Tree had highest accuracy with a score of 0.88



Confusion Matrix

- One False Negatives
- Five True Positives
- Eleven True Negatives
- One False Positives

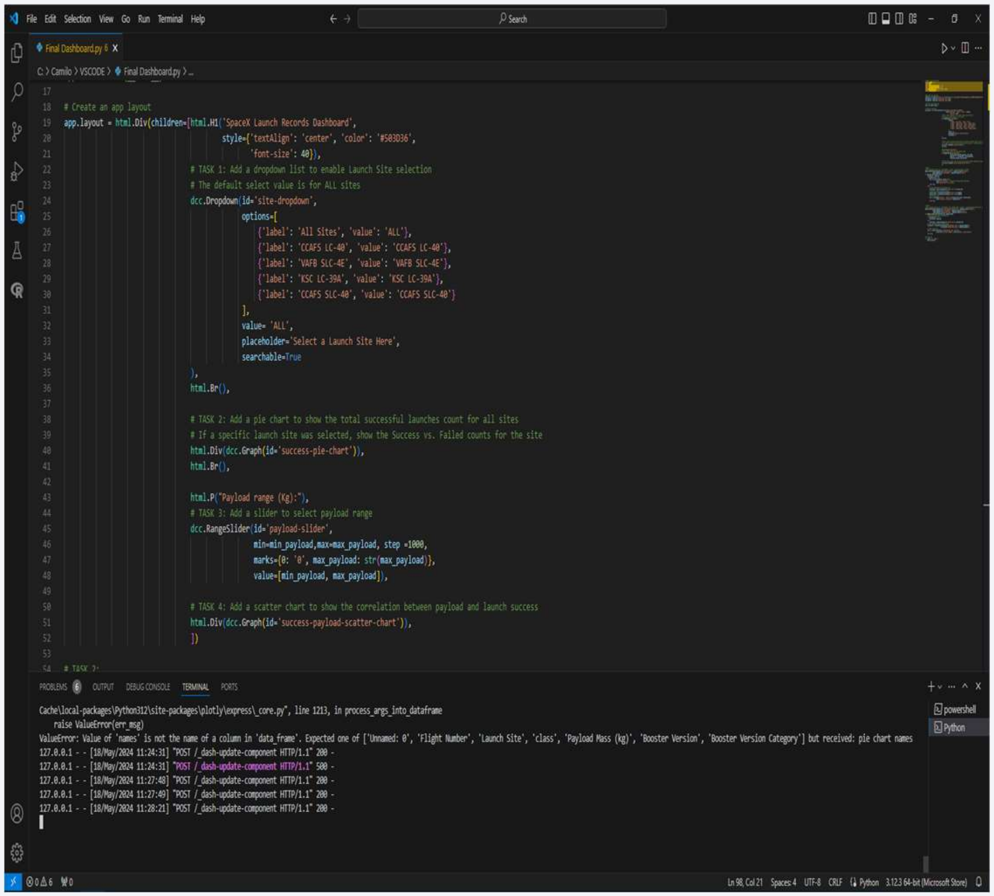


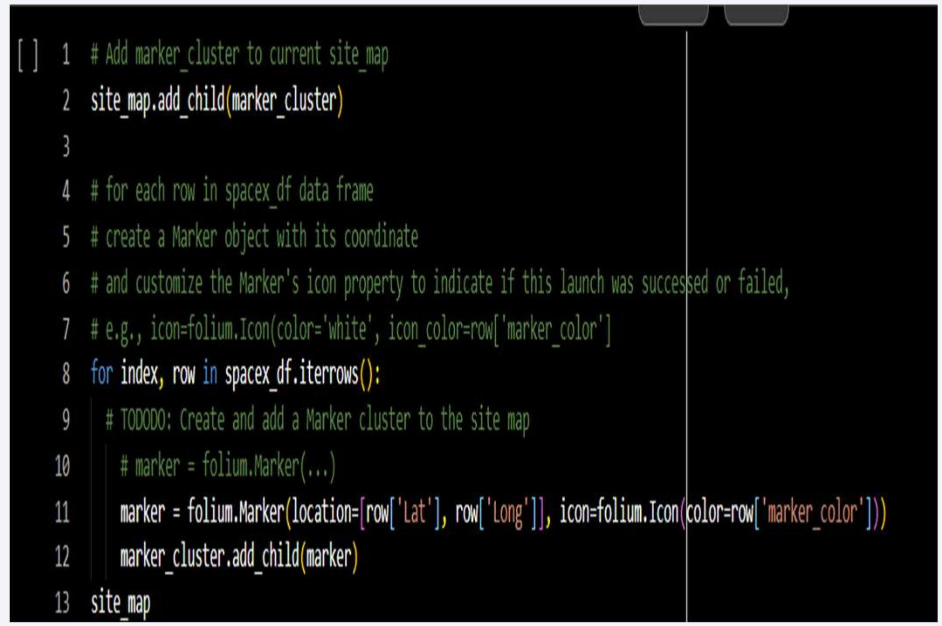
Conclusions

- In order to forecast reusability basen on mission-specific data is recomendend to use Decision Tree Model.
- Is necessarry to implement and iterative process to re-train the model to achieve an enhanced results
  - This must be based on the feedback process with the stakeholder

- The identified model suggests good accuracy, which allows for inferring an appropriate prediction of success in landings and consequently in reusability.

Appendix


File Edit Selection View Go Run Terminal Help
Final Dashboard.py
C: > Camilo > VSCODE > Final Dashboard.py > ...
# Create an app layout
app.layout = html.Div(children=[html.H1('SpaceX Launch Records Dashboard',
style={'textAlign': 'center', 'color': '#503D36',
'font-size': 40}),
TASK 1: Add a dropdown list to enable Launch Site selection
The default select value is for ALL sites
dcc.Dropdown(id='site-dropdown',
options=[
{'label': 'All Sites', 'value': 'ALL'},
{'label': 'CCAFS LC-40', 'value': 'CCAFS LC-40'},
{'label': 'VAFB SLC-4E', 'value': 'VAFB SLC-4E'},
{'label': 'KSC LC-39A', 'value': 'KSC LC-39A'},
{'label': 'CCAFS SLC-40', 'value': 'CCAFS SLC-40'}
],
value= 'ALL',
placeholder='Select a Launch Site Here',
searchable=True
),
html.Br(),
TASK 2: Add a pie chart to show the total successful launches count for all sites
If a specific launch site was selected, show the Success vs. Failed counts for the site
html.Div(dcc.Graph(id='success-pie-chart')),
html.Br(),
html.P("Payload range (Kg):"),
TASK 3: Add a slider to select payload range
dcc.RangeSlider(id='payload-slider',
min=min_payload,max=max_payload, step =1000,
marks={0: '0', max_payload: str(max_payload)},
value=[min_payload, max_payload]),
# TASK 4: Add a scatter chart to show the correlation between payload and launch success
html.Div(dcc.Graph(id='success-payload-scatter-chart')),
])
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
Cache\local-packages\Python312\site-packages\plotly\express_core.py", line 1213, in process_args_into_dataframe
raise ValueError(err_msg)
ValueError: Value of 'names' is not the name of a column in 'data_frame'. Expected one of ['Unnamed: 0', 'Flight Number', 'Launch Site', 'class', 'Payload Mass (kg)', 'Booster Version', 'Booster Version Category'] but received: pie chart names
127.0.0.1 - - [18/May/2024 11:24:31] "POST /_dash-update-component HTTP/1.1" 200 -
127.0.0.1 - - [18/May/2024 11:24:31] "POST /_dash-update-component HTTP/1.1" 500 -
127.0.0.1 - - [18/May/2024 11:27:48] "POST /_dash-update-component HTTP/1.1" 200 -
127.0.0.1 - - [18/May/2024 11:27:49] "POST /_dash-update-component HTTP/1.1" 200 -
127.0.0.1 - - [18/May/2024 11:28:21] "POST /_dash-update-component HTTP/1.1" 200 -
Ln 98, Col 21 Spaces: 4 UTF-8 CRLF Python 3.12.3 64-bit (Microsoft Store)


# Add marker cluster to current site_map
site_map.add_child(marker_cluster)
# for each row in spacex_df data frame
# create a Marker object with its coordinate
# and customize the Marker's icon property to indicate if this launch was successed or failed,
# e.g., icon=folium.Icon(color='white', icon_color=row['marker_color']
for index, row in spacex_df.iterrows():
# TODODO: Create and add a Marker cluster to the site map
# marker = folium.Marker(...)
marker = folium.Marker(location=[row['Lat'], row['Long']], icon=folium.Icon(color=row['marker_color']))
marker_cluster.add_child(marker)
site_map

Thank you!