REUSABILITY OF FALCON-9 ROCKETS BY **SPACEX**

By Ramanpreet Singh

12 January 2025

Outline

- Executive summary
- Introduction
- Methodology
- Results
- Conclusion

EXECUTIVE SUMMARY

Methodologies:

- Data collection using web scarapping using BeautifullSoap and API.
- Data Wrangling
- Exploratory data analysis using SQL in SQLlite database.
- Data visualization using Matplotlib and maps by Folium maps.
- Dashboard using Dash by Plotly.
- Machine learning prediction using SKlearn.

EXECUTIVE SUMMARY

Technology used:

- Programming language: Python, SQL
- Operating system: Windows 11
- Web browser: Edge by Microsoft.
- Database: SQL Lite

Introduction

Space X's Falcon-9 are the 2-stage light to medium weight payload career rockets designed to increase its re-usability. Falcon-9 was first launched in 4 June 2010 and by 2020 it has 422 flights and 380 time successfully landed by the end of 2024 that is **90%** rate of success.

This project focuses on factors affecting the successful and unsuccessfull landing of Falcon-9, rate of successful landing and

Methodology

Data Collection:

- Data is gathered from 2 different sources: SpaceX API and Falcon-9 Wikipedia webpage.
- From SpaceX API, data is received using get request method.
- Decoded the data to Pandas DataFrame as it is collected in JSON format using json.normalization() method.
- The data is cleaned and empty values are filled with industrial norms.
- Web scrapping was done from Falcon9 wikipedia page in which the flight tables are converted into Pandas dataFrame for exploratory analysis.

Methodology

Data Collection:

- BeautifulSoap Python library is used for parsing the webpage table data.
- Links:
- Falcon-9 WIkipedia: https://en.wikipedia.org/w/index.php?title=List_of_Falcon_9_and_Falcon_Heavy_launches&oldid=1027686922

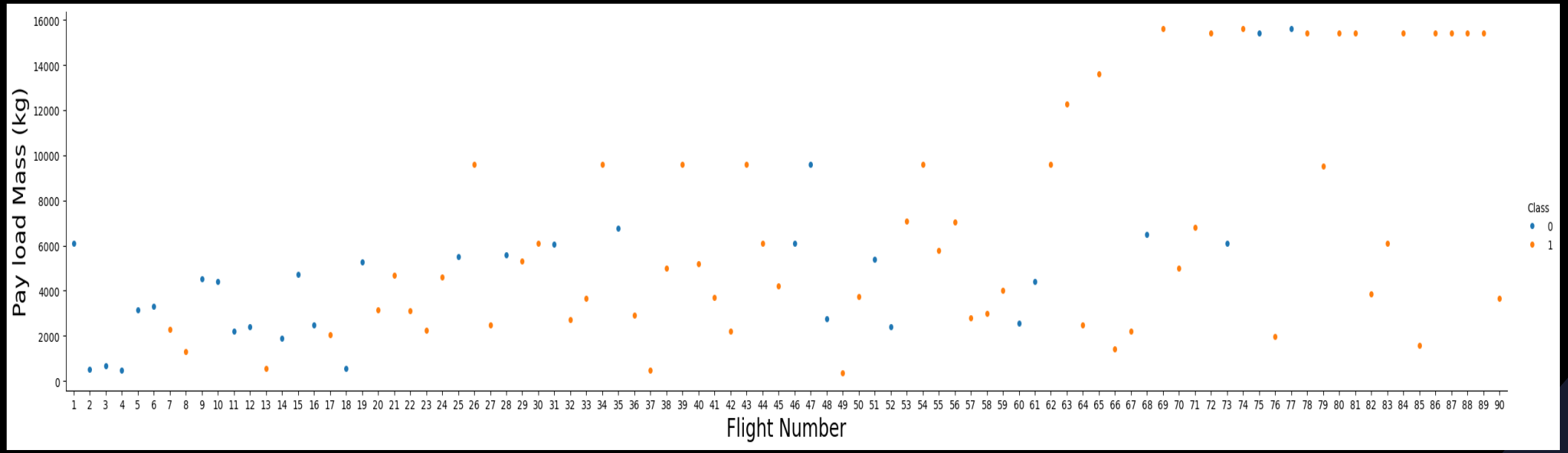
- SpaceX API: https://api.spacexdata.com/v4/rockets/

Data exploration:

Lets explore the data with different visualizations.

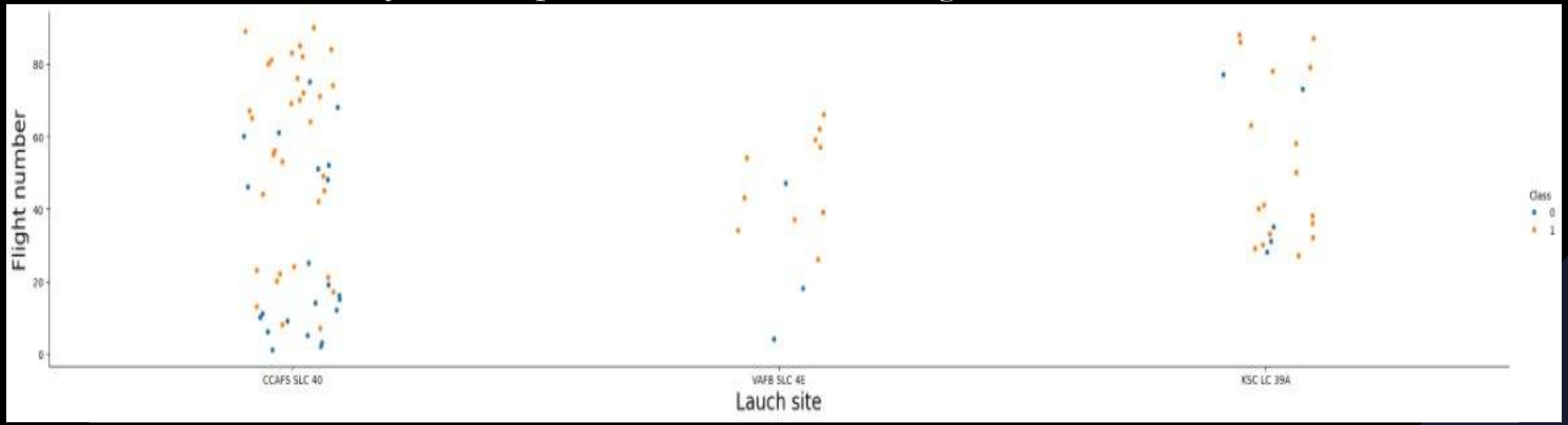
Payload mass vs Flight number:

- As the number of flights increase, the first stage landing tend to increase.
- Payload mass also positively affects the landing as the mass increases, the landing is likely to successful.



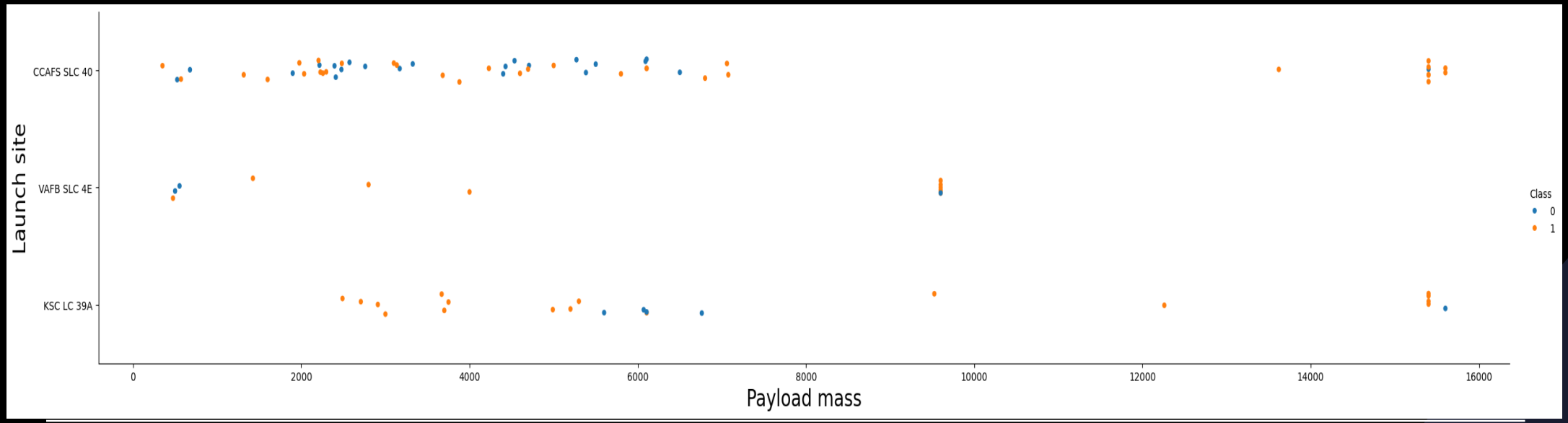
Launch site vs Flight number:

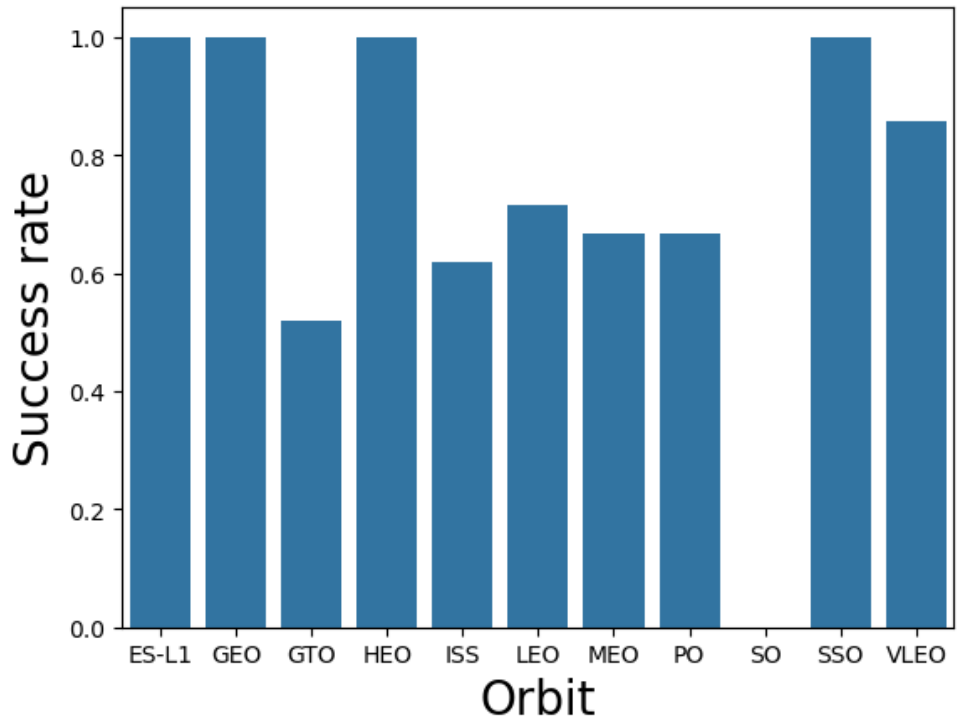
- We can clearly see that CCAFS SLC 40 is the most used launch site with the successful landing being random.
- KSC LC 39A can be seen with most successful in landings with respect to its number of flights while VAFB 5LC 4E is the least used launch site by Space X.
- Launch site have very little impact on successful landing of Falcon-9 rockets.



Payload mass vs Launch site:

- Here we can see that payload mass have strong positive impact on ladings regardless of which site is used for launchng.
- VAFB is the least used launch site that is only used for light payload mass.





Success rate vs Orbit:

- ES-L1, Geo, HEO and SSO orbits have 100% success rate for landing of Falcon-9
- GTO can be seen with the lowest success rate while SO orbit can be seen to have 0.

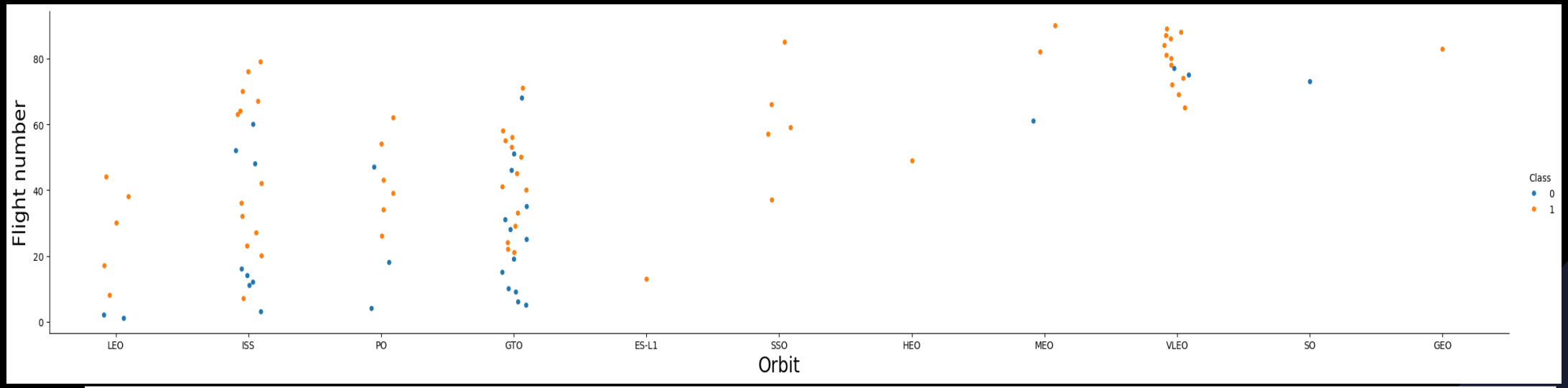
Flight number vs Orbit type:

- GTO orbit have most satalite launches by SpaceX.
- ES-L1, HEO, SO, GEO have only 1 satalite launched by Falcon 9 .
- SSO have the 5 launches all with successful landings while GTO have 50% rate of success.
- Orbit with most success which has more than 1 satalite launch is **VLEO**

	Orbit	orbit	no_of_success	success_rate
0	ES-L1	1	1	1.000000
1	GEO	1	1	1.000000
2	GTO	27	14	0.518519
3	HEO	1	1	1.000000
4	ISS	21	13	0.619048
5	LEO	7	5	0.714286
6	MEO	3	2	0.666667
7	PO	9	6	0.666667
8	SO	1	0	0.000000
9	SSO	5	5	1.000000
10	VLEO	14	12	0.857143

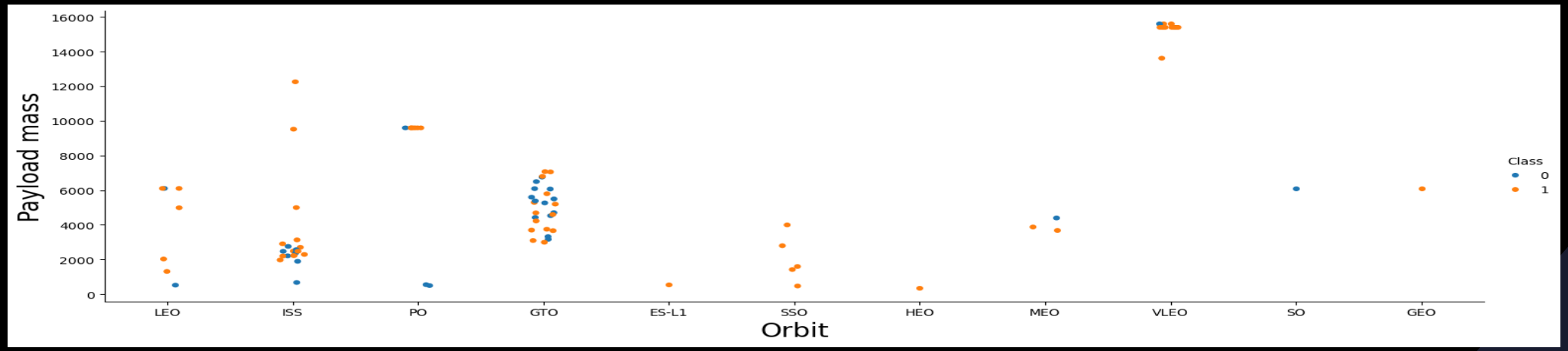
Flight number vs Orbit type: Here is the visualization of all the flights launched in different orbits.

- After few flights, the landings were successful in LEO orbit.
- ISS, PO and GTO have no impact of orbit in successful landings as the landing success is random with flight number.
- SSO with 5 flights all have successful landings.



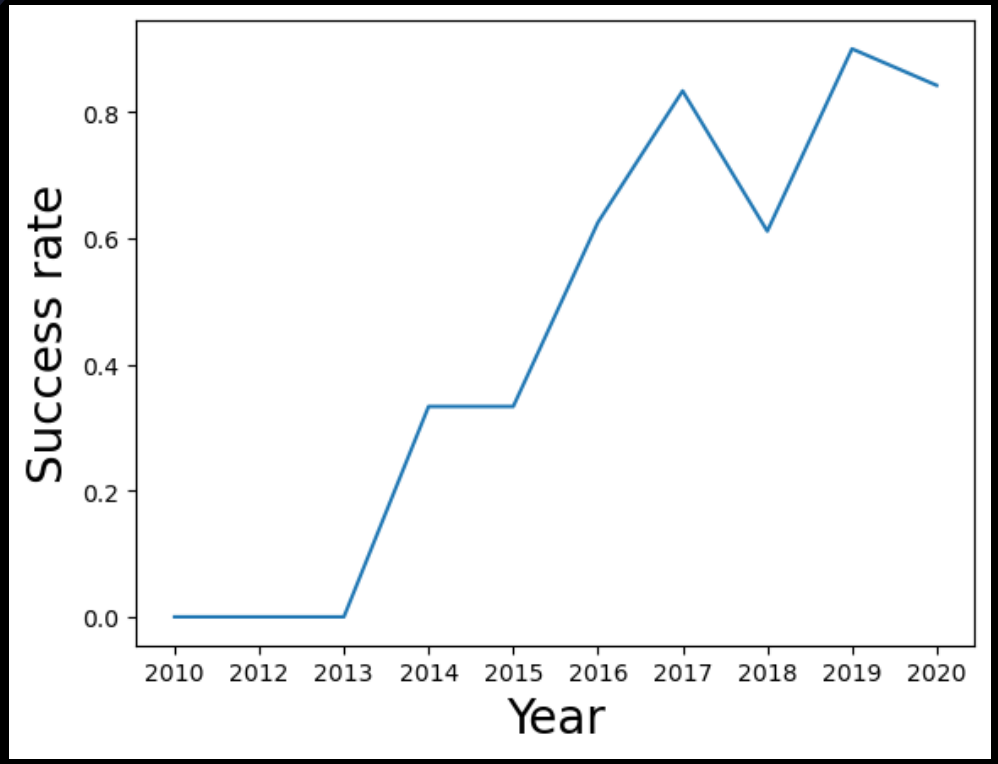
Payload mass vs Orbit type: Payload mass have a direct impact on successful landings.

- VLEO orbit carring last few flights and heaviest payloads can be seen with 12 out of 14 successful landing flights.
- LEO, GTO, ES, SSO, HEO, MEO, SO, GEO was never used for heavy payloads exceeding 8000kg and the rockets landings become successful as the payload mass increase.



Year vs Successful landings:

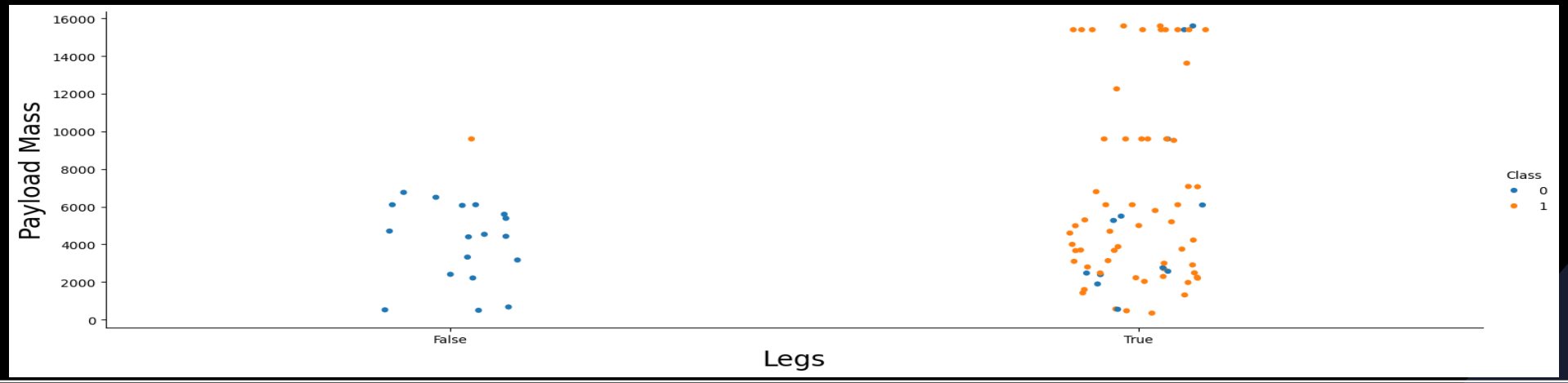
- Landing success rate start to increase after 2013 and had a sharp spike to 2017.
- It had a small dip in 2017-2018 and then reached to the almost 90% from 2018-2020.



Payload mass vs Legs:

We can notice the huge difference in the success rate based on the legs used by the rockets.

- Legs were not used in few flights where payload mass is less than 10000kg in which almost all of them failed to land while rockets landed successfully where legs were used.
- Last rocket was successfully landed without the use of legs at the payload mass of 10000 kg. The rocket was catched in mid-air. There might be few chances to land successfully without legs if the payload mass is more than 10000 kg.



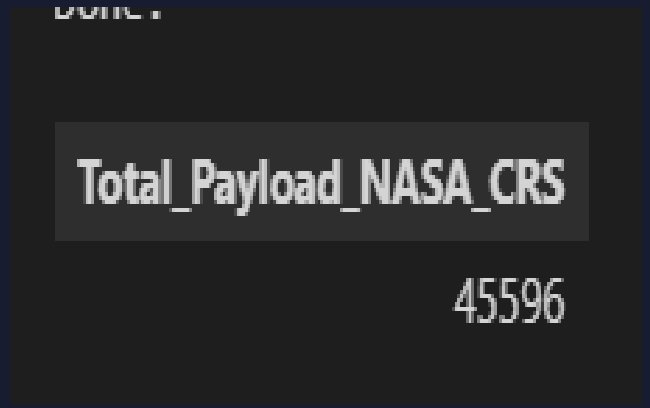
SQL exploration in data

List of 4 launch sites used by SpaceX.

```
%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



Total payload mass by the SpaceX Falcon9 rockets for customer NASA CRS.

5 Records where the Site names begin with name 'CCA'

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

```
%sql SELECT * FROM SPACEXTABLE WHERE "Launch_Site" LIKE 'CCA%' LIMIT 5
```

✓ 0.0s

* sqlite:///my_data1.db
Done.

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

- Average payload mass carried by SapceX Falcon-9 v1.1

```
%sql SELECT AVG(PAYLOAD_MASS__KG_) FROM SPACEXTABLE WHERE "Booster_Version" = 'F9 v1.1'
```

✓ 0.0s

* sqlite:///my_data1.db
Done.

AVG(PAYLOAD_MASS__KG_)
2928.4

First Successful landing by SpaceX Falcon-9 Rocket in 22 December 2015.

```
%%sql
SELECT
MIN("Date") as First_Landing
FROM SPACEXTABLE
WHERE "Landing_Outcome" = "Success (ground pad)";
```

✓ 0.0s

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

First_Landing
2015-12-22

- Average payload mass carried by SapceX Falcon-9 v1.1 is 2928.4 KG

```
%sql SELECT AVG(PAYLOAD_MASS__KG_) FROM SPACEXTABLE WHERE "Booster_Version" = 'F9 v1.1'
```

✓ 0.0s

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

AVG(PAYLOAD_MASS__KG_)
2928.4

Booster versions carrying payload between 4000 and 6000 kg..

```
%%sql
SELECT "Booster_Version"
FROM
SPACEXTABLE
WHERE "Landing_Outcome" = "Success (drone ship)" AND "PAYLOAD_MASS__KG_" > 4000 AND "PAYLOAD_MASS__KG_" < 6000
```

✓ 0.0s

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

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

- Total successful landings.

```
%%sql
SELECT "Mission_Outcome",
COUNT(*)
FROM
SPACEXTABLE
WHERE "Mission_Outcome" IN ("Success", "Failure")
```

✓ 0.0s

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

Mission_Outcome	COUNT(*)
Success	98

Names of Rocket booster versions carrying most payload in Descending order.

```
%%sql
SELECT
"Booster_Version"
FROM SPACEXTABLE
WHERE
"PAYLOAD_MASS__KG_" = (SELECT MAX("PAYLOAD_MASS__KG_") FROM SPACEXTABLE);
```

✓ 0.0s

```
 * 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

List the records failure landing outcomes in drone ship in year 2015.

List the landing outcomes between date 2010-06-04 to 2017-03-20

Landing_Outcome	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

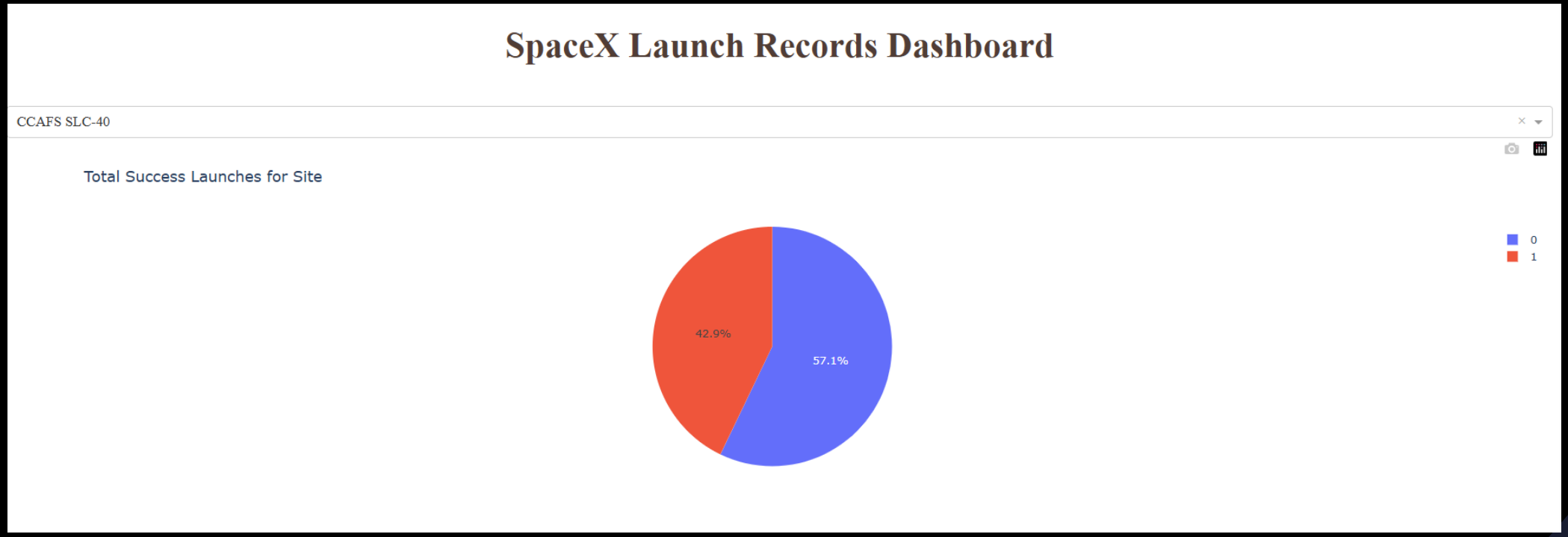
```
%%sql
SELECT
    CASE substr("Date", 6, 2)
        WHEN "01" THEN "January"
        WHEN "02" THEN "February"
        WHEN "03" THEN "March"
        WHEN "04" THEN "April"
        WHEN "05" THEN "May"
        WHEN "06" THEN "June"
        WHEN "07" THEN "July"
        WHEN "08" THEN "August"
        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 SPACEXTABLE
WHERE substr("Date", 0, 5) = "2015"
AND "Landing_Outcome" = "Failure (drone ship)";
```

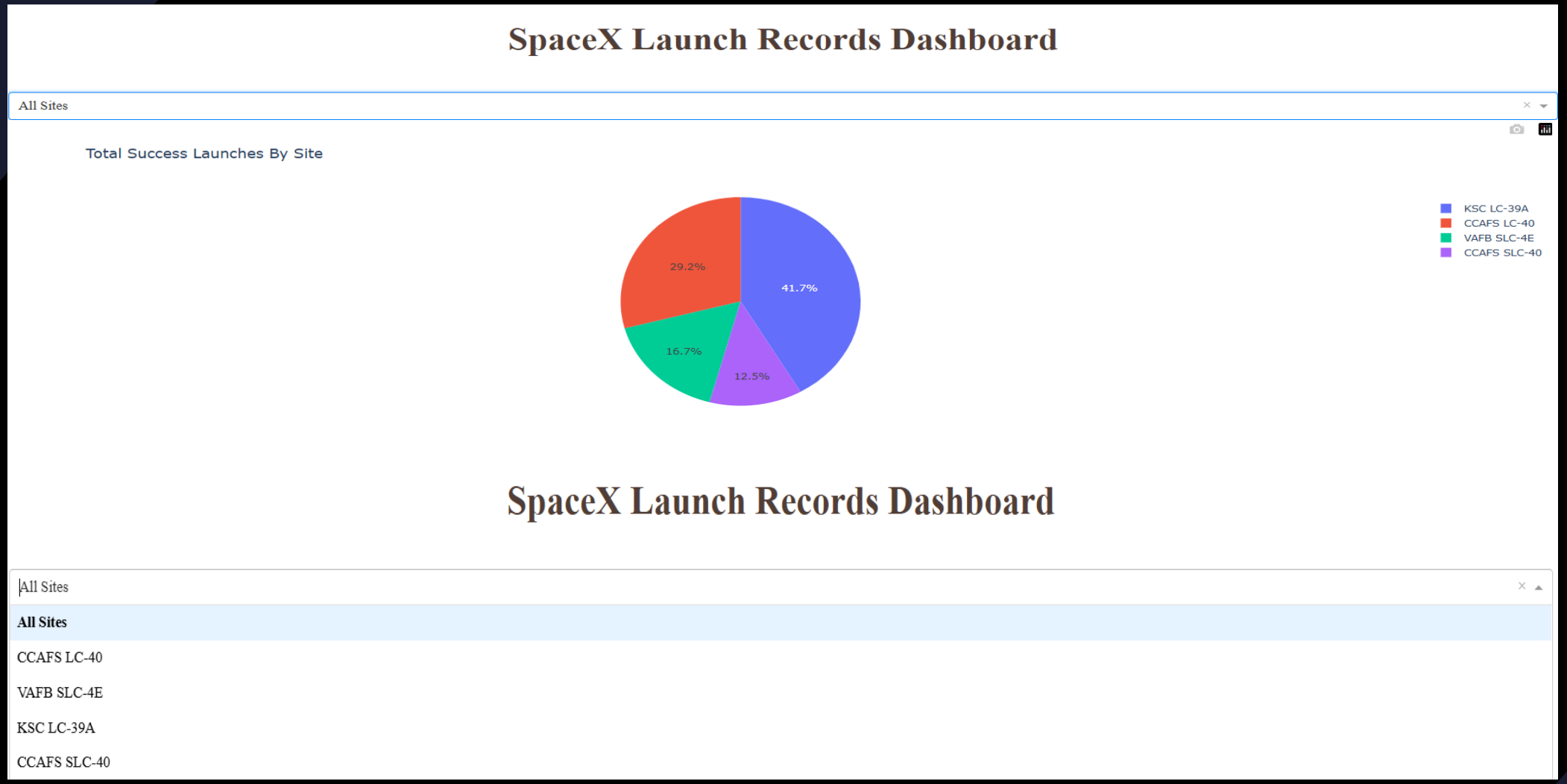
✓ 0.0s

* sqlite:///my_data1.db
Done.

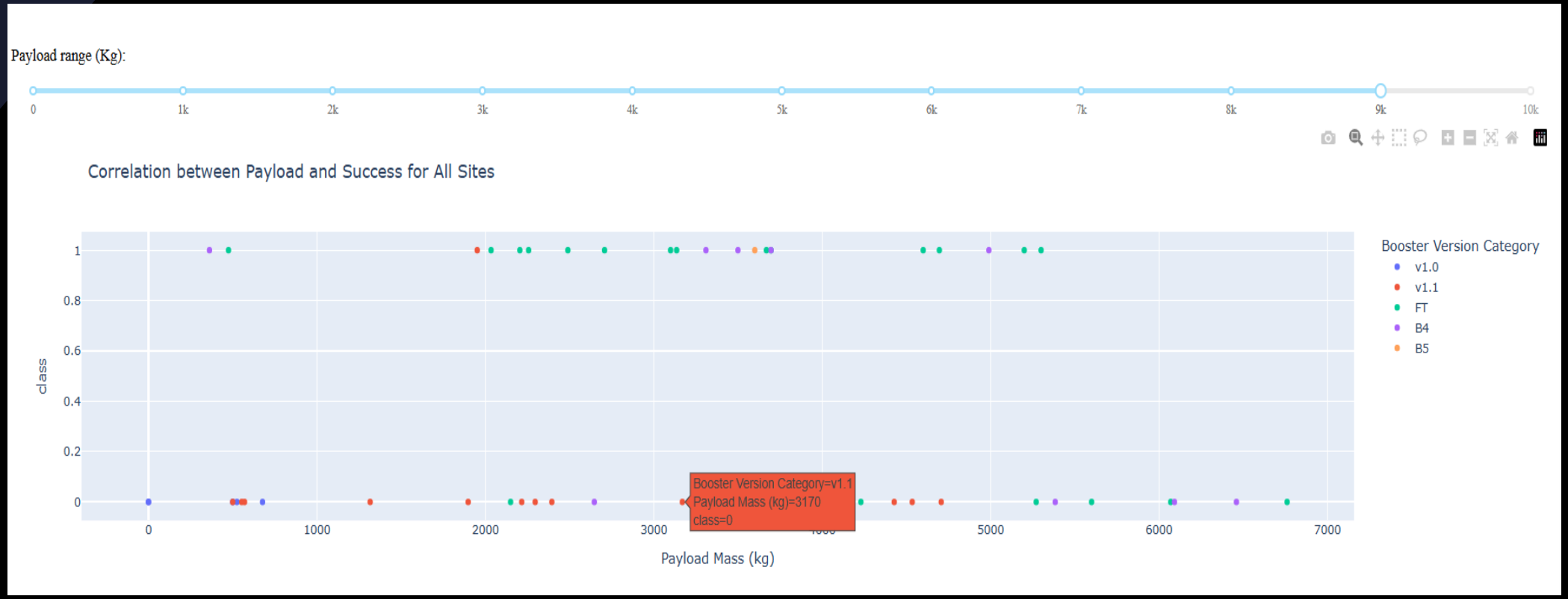
month_name	Landing_Outcome	Booster_Version	Launch_Site
January	Failure (drone ship)	F9 v1.1 B1012	CCAFS LC-40
April	Failure (drone ship)	F9 v1.1 B1015	CCAFS LC-40

Dashboard using Dash





Choose from different launch sites or all sites to update the pie chart for successful landings.



This range slider helps to visualize the coorelation between Payload mass and Landing class.

Results:

Models for prediction.

Libraries and models used:

- Python SK Learn library is used here for model training.
- Data is standarized using the StandardScaler from SK Learn.
- 20-80 Split of data is used for testing and training purposes.

```
# students get this
transform = preprocessing.StandardScaler()
```
✓ 0.0s

```
X = transform.fit_transform(X)
```
✓ 0.0s

```
X_train, X_test, Y_train, Y_test = train_test_split(X, Y, test_size=0.2, random_state=2)
Y_test.shape
```
✓ 0.0s

```
(18,)
```

List of models:

- KNN: K Nearest Neighbor
- Decision Tree Classification
- Support Vector Classification
- Logistic regression

	0	1
0	KNN	0.848214
1	Decision Tree	0.875000
2	SVM	0.848214
3	Logistic regression	0.834286

Best model:

- Decision tree classification models has been best for this data as the score is 0.87

```
print("Best model for Falcon 9 prediction is: ", max(models, key=models.get), "With score of: ", models[max(models, key=models.get)])
```

✓ 0.0s

```
Best model for Falcon 9 prediction is:  Decision Tree With score of:  0.875
```

Decision tree confusion matrix:

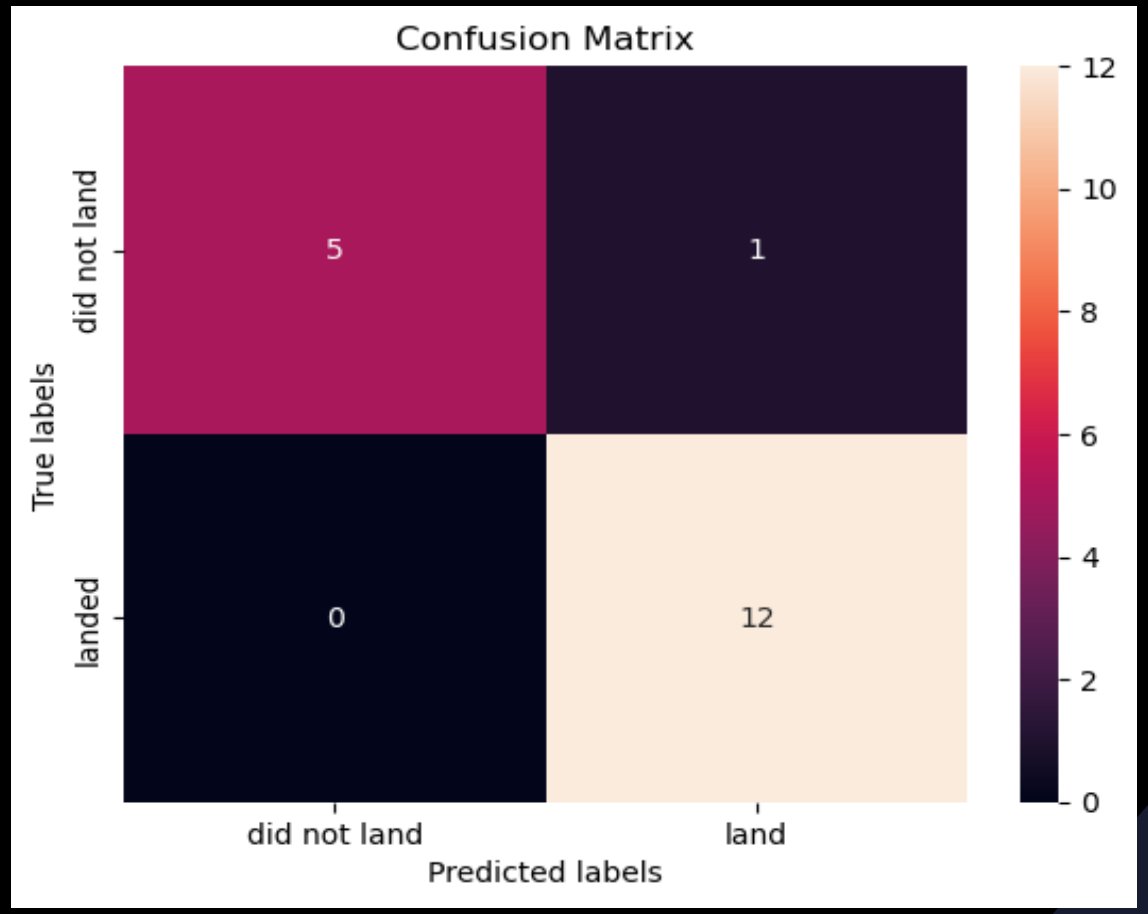
True positive: 12

True negative: 5

False positive: 1

False negative: 0

Model predictied only 1 false neagtive.



Conclusion:

- Decision tree classification have been best for predicting Falcon-9 successful landings.
- ES-L1, Geo, HEO and SSO orbits have 100% success rate for landing of Falcon-9.
- Landing success started after year 2013.