Alexandria University

Faculty of Computers and Data Science
Department: Computing and Data Science
Course Title: Big Data Analytics 2025-2026

Weather Impact on Urban Traffic Analysis

In

Big Data Analytics

Course Code: 02-24-01401

Name:- *Mazen Shaban Jomaa* ID:- *22010201*

Name:- *Osama Mohamed Abd-Elshafy* ID:- *22010047*

Name:- *Omar Yahia Ibrahim* ID:- *22010174*

Name:- *Fouad Ramzy Fouad* ID:- *22010180*

Introduction

This project is about urban traffic analytics under weather conditions aims to design and implement a modern predictive data lake system to analyze how weather conditions affect urban traffic patterns using:

- synthetic data
- MinIO (Bronze / Silver / Gold layers)
- HDFS (as an additional distributed storage layer)
- Python for data processing
- Monte Carlo simulation
- Factor Analysis

It takes a smart city in Lonon, wants to understand how weather conditions (rain, temperature extremes, humidity, wind, visibility) influence traffic behavior and congestion levels, as its scenario. It applies that through 7 phases as follows.

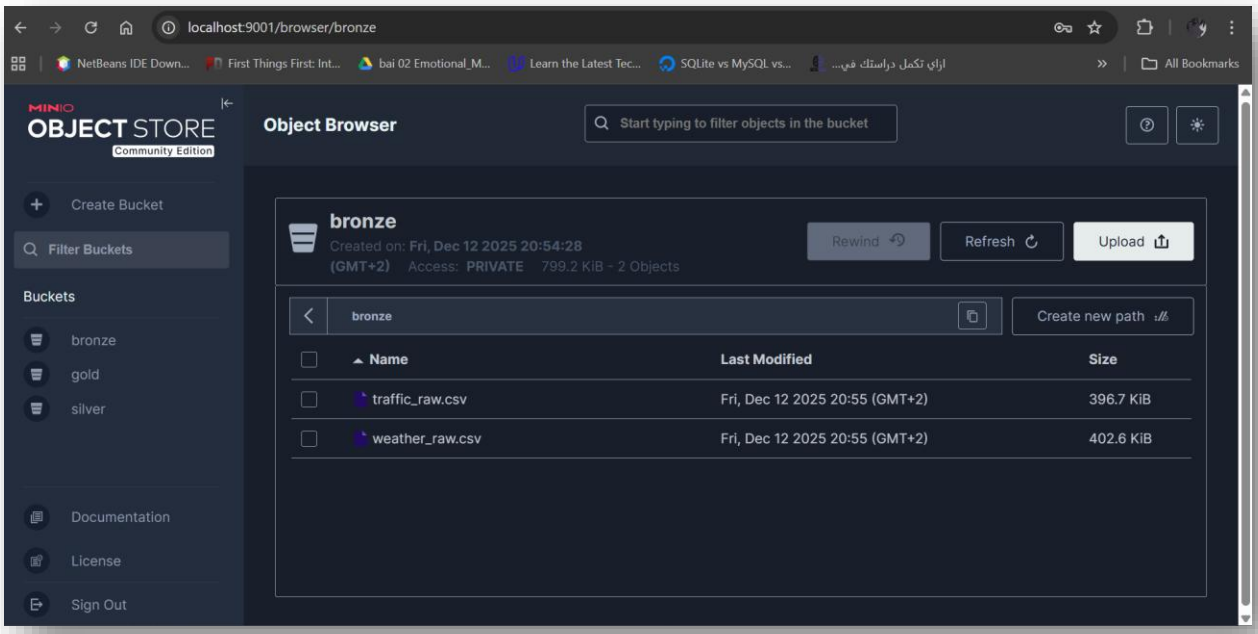
Phase 1: *Infrastructure & Data Ingestion (Bronze Layer)*

Included writing two Python scripts to generate the two synthetic datasets, weather and traffic, such that keeping the dependencies between columns there to mimic the real-life datasets.

Also, a *docker-compose.yml* was created to start MinIO server and create three MinIO buckets:

ii) bronze → raw data
iii) silver → cleaned data
iv)gold → final results

The two generated raw datasets uploaded, then, to the bronze layer through the browser console of MinIO on the local host.



Phase 2: *Data Cleaning (Bronze → Silver)*

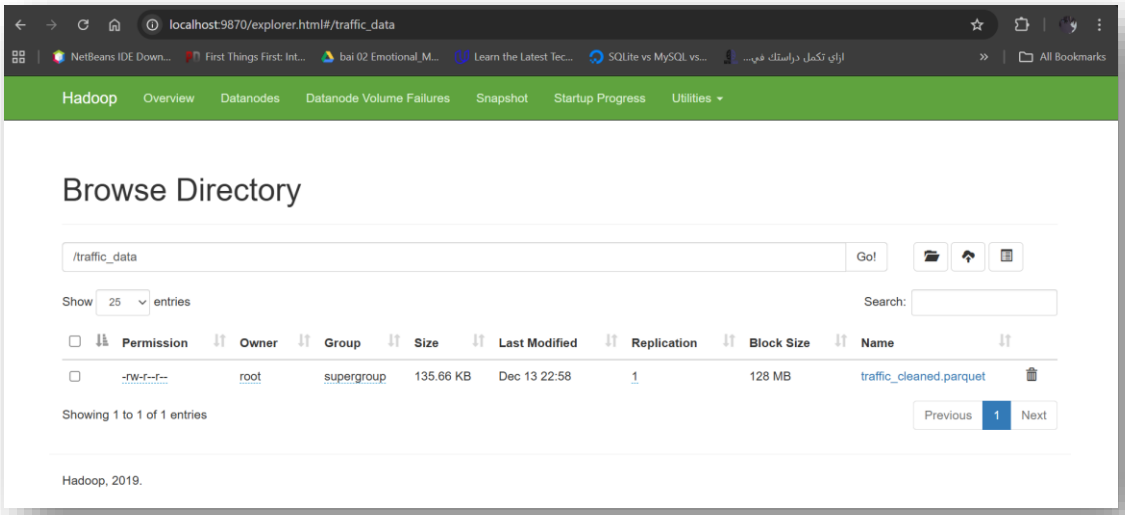
Transformed the messy raw data into clean analytical datasets. For each dataset, the process started by imputing the null values according to the problem with a specific column using pattern-based cleaning, XGBoost, etc. Then, it corrected the wrong format of some columns. After that, checking for duplicates which did not exist because of the imputation in the beginning. It, finally, checked for outliers statistically, using IQR, and graphically, using box plots and histograms to handle.

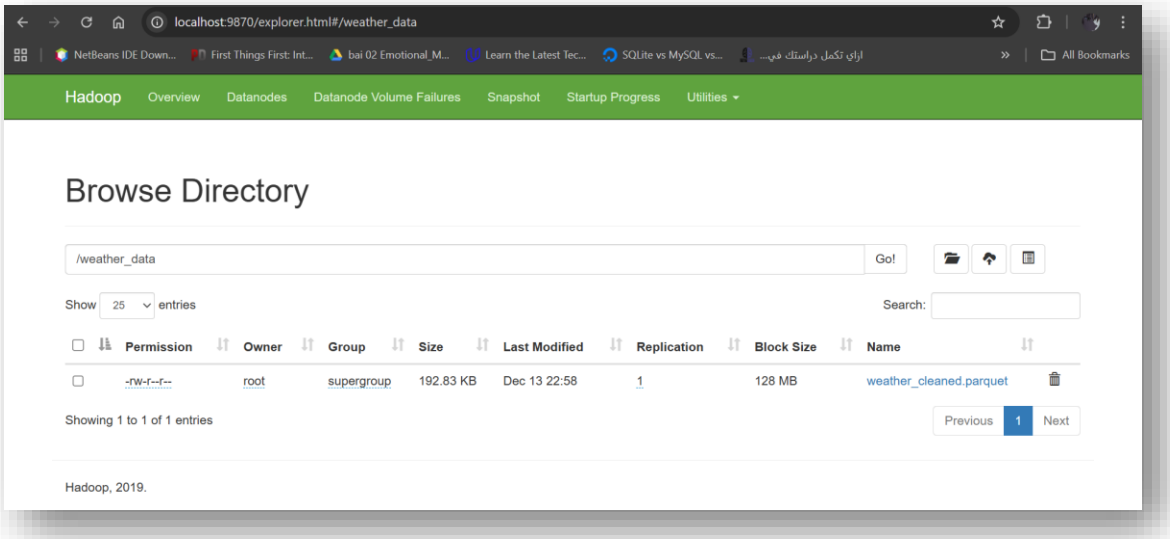
By finishing the cleaning process with no single deleted row, 5250 in 5250 out, both notebooks ended up connecting to the MinIO server to upload the cleaned version of both datasets into the silver bucket of MinIO as parquet files, in addition to saving other copies locally.

More explanation in detail is shown in the notebooks, *big data project E(1) V(2).ipynb* and *big data project traffic data set.ipynb*, themselves as markdown cells interpreting the code flow.

Phase 3: *HDFS Integration (Additional Storage Layer)*

Integrated the Hadoop distributed file system with the data lake using Python script file, *ingest_to_hdfs.py*, which connects to both, the MinIO and the HDFS servers, fetch the data files from the silver bucket, and streams the data (read RAM → write RAM). It opens the MinIO file as a stream and pass it directly to HDFS write storing in the *weather_data* and *traffic_data* folders.





Phase 4: *Dataset Merging*

To create a unified dataset for analysis, it connects, in the *merge_datasets.py* Python script, to the silver layer on the MinIO server and read the cleaned version parquet files to apply inner join between them on the “date_time” and “city” columns.

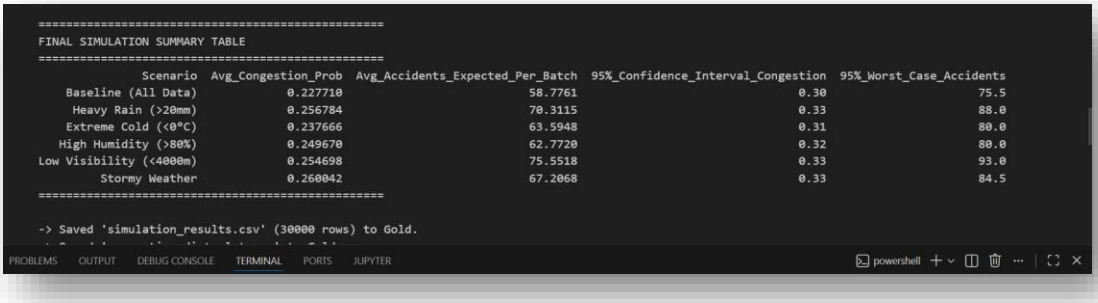
In the end, it uploads the cleaned unified one into the gold bucket on MinIO as a parquet file, as well.

Phase 5: *Monte Carlo Simulation (Traffic Risk Prediction)*

Simulates the traffic behavior under different weather conditions. It included:

v) Heavy rain
vi)Temperature extremes
vii) High humidity
viii) Low visibility
ix)Strong winds

Its output contained the probabilities of each of
“avg_congestion_probability”,
“Avg_Accidents_Expected_Per_Batch”,
“95%_Confidence_Interval_Congestion”, and
“95%_Worst_Case_Accidents” for each of the scenarios above aside with the normal state.

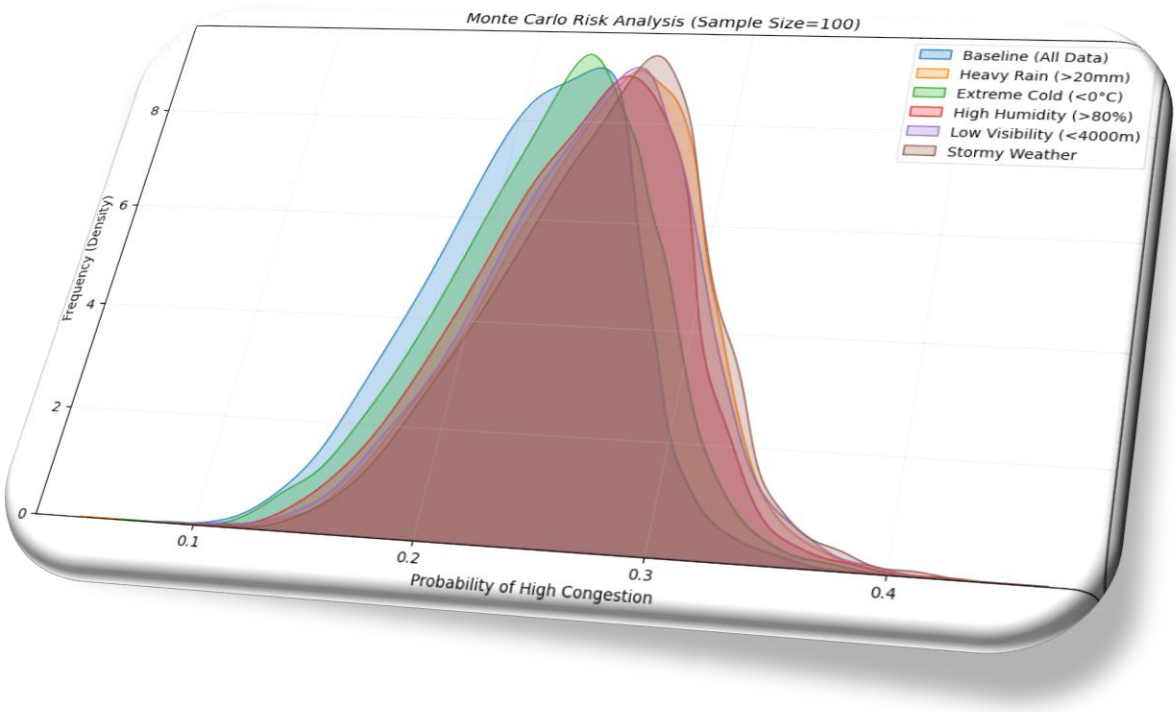


```
================================================
FINAL SIMULATION SUMMARY TABLE
================================================
              Scenario  Avg_Congestion_Prob  Avg_Accidents_Expected_Per_Batch  95%_Confidence_Interval_Congestion  95%_Worst_Case_Accidents
    Baseline (All Data)             0.227710                           58.7761                                0.30                      75.5
     Heavy Rain (>20mm)             0.256784                           70.3115                                0.33                      88.0
    Extreme Cold (<0°C)             0.237666                           63.5948                                0.31                      80.0
   High Humidity (>80%)             0.249670                           62.7720                                0.32                      80.0
Low Visibility (<4000m)             0.254698                           75.5518                                0.33                      93.0
         Stormy Weather             0.260042                           67.2068                                0.33                      84.5
================================================

-> Saved 'simulation_results.csv' (30000 rows) to Gold.
```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS JUPYTER powershell

Also, it uploads the dataset resulting in simulation into the gold layer on MinIO as well as the congestion probability distribution plot shown in the figure below.



Phase 6: *Factor Analysis (Weather Impact Detection)*

a) Checking factor analysis assumptions:

i) No outliers in the data set → Done ☑ [in phase (2)]

ii) Data set size (number of rows) > Number of factors → Done ☑ (as required number of factors is from 1 to 3 while data set size is 5250)

iii) Checking whether there is perfect collinearity between features or not → Done ☑ [no perfect collinearity], checked in Factor Analysis.ipynb file [and there wasn't perfect collinearity]

iv) Homoscedasticity between data set features:

- first it wasn't satisfied, there was heteroscedasticity.

- After applying standardization, it is satisfied ✅

b) **Stating factor analysis test hypothesis:**

i) H_0 (Null Hypothesis): The variables in the dataset are uncorrelated = The correlation matrix is an identity matrix

ii) H_a (Alternative Hypothesis): The variables are correlated and suitable for factor analysis

c) Testing data set adequacy for factor analysis

i) It passed Barlett's sphericity test ✅

ii) It failed KMO (Kaiser-Meyer-Olkin) test ❌

➢ We should have stopped Factor analysis but in order to apply phase 7 (Visualization dashboard for factor analysis results & Monte Carlo results) we will continue

d) Determining suitable number of factors for the factor analysis

i) Using Kaiser criterion approach (statistical approach)
→ Number of factors=3

ii) Using scree plot approach (graphical approach)
→ Number of factors=3

e) Factor analysis implementation

i) Using PROMAX Rotation (Oblique rotation):

➢ Factor Loadings values table:

a) FACTOR LOADINGS TABLE:

	Factor1	Factor2	Factor3
temperature_c	0.0161	-0.2799	0.3639
humidity	-0.0401	0.3426	-0.0295
rain_mm	-0.0800	0.7766	0.3350
wind_speed_kmh	0.0097	0.0253	0.1127
visibility_weather	0.0207	-0.3122	-0.1181
air_pressure_hpa	-0.0057	-0.1112	-0.4556
vehicle_count	0.9365	-0.1354	0.0289
avg_speed_kmh	-0.5695	-0.0415	-0.0605
accident_count	0.0385	0.0809	-0.0209

- Communalities values table & average communality value:

```
b) COMMUNALITIES:
----------------------------------------
         Variable  Communality
    temperature_c     0.210976
         humidity     0.119881
          rain_mm     0.721686
   wind_speed_kmh     0.013422
visibility_weather     0.111837
  air_pressure_hpa     0.219937
     vehicle_count     0.896248
     avg_speed_kmh     0.329754
    accident_count     0.008462

Average communality: 0.2925
```

- Factor (1):

  Name: Traffic Density & Speed Factor

  most 2 affecting features/variables: vehicle_count and avg_speed_kmh

- Factor (2):

  Name: Precipitation & Moisture Factor

  most 2 affecting features/variables: humidity and rain_mm

- Factor (3):

  Name: Temperature-Pressure Gradient

  most 2 affecting features/variables: air_pressure_hpa and temperature_c

ii) Using VARIMAX Rotation (Orthogonal rotation):

- Factor Loadings values table:

```
a) FACTOR LOADINGS TABLE:
----------------------------------------
                   Factor1  Factor2  Factor3
temperature_c      -0.0349  -0.2558   0.3407
humidity            0.0105   0.3313  -0.0013
rain_mm             0.0233   0.7725   0.3979
wind_speed_kmh      0.0100   0.0318   0.1142
visibility_weather -0.0211  -0.3112  -0.1431
air_pressure_hpa   -0.0087  -0.1332  -0.4635
vehicle_count       0.9081  -0.0122  -0.0067
avg_speed_kmh      -0.5689  -0.1169  -0.0486
accident_count      0.0505   0.0837  -0.0155
```

- Communalities values table & average communality value:

```
b) COMMUNALITIES:
----------------------------------------
          Variable  Communality
     temperature_c     0.182709
          humidity     0.109899
           rain_mm     0.755677
    wind_speed_kmh     0.014154
visibility_weather     0.117764
  air_pressure_hpa     0.232602
     vehicle_count     0.824858
     avg_speed_kmh     0.339681
    accident_count     0.009787

Average communality: 0.2875
```

- Factor (1)

  Name: Traffic Density & Speed Factor

  most 2 affecting features/variables: vehicle_count and avg_speed_kmh

- Factor (2):

  Name: Precipitation & Moisture Factor

  most 2 affecting features/variables: humidity and rain_mm

- Factor (3):

  Name: Precipitation-Pressure Factor

  most 2 affecting features/variables: air_pressure_hpa and rain_mm

ii) Using QUARTIMAX Rotation (Orthogonal rotation):

- Factor Loadings values table:

a) FACTOR LOADINGS TABLE:

	Factor1	Factor2	Factor3
temperature_c	-0.0346	-0.0714	-0.4200
humidity	0.0094	0.2940	0.1529
rain_mm	0.0201	0.8691	0.0001
wind_speed_kmh	0.0097	0.0806	-0.0870
visibility_weather	-0.0199	-0.3422	-0.0153
air_pressure_hpa	-0.0075	-0.3307	0.3510
vehicle_count	0.9082	-0.0105	0.0005
avg_speed_kmh	-0.5684	-0.1283	-0.0104
accident_count	0.0502	0.0675	0.0521

- Communalities values table & average communality value:

b) COMMUNALITIES:

Variable	Communality
temperature_c	0.182709
humidity	0.109899
rain_mm	0.755677
wind_speed_kmh	0.014154
visibility_weather	0.117764
air_pressure_hpa	0.232602
vehicle_count	0.824858
avg_speed_kmh	0.339681
accident_count	0.009787

Average communality: 0.2875

- Factor (1)
  Name: Traffic Density & Speed Factor most 2 affecting features/variables: vehicle_count and avg_speed_kmh

- Factor (2):
  Name: Low-Visibility Rain Factor most 2 affecting features/variables: visibility_weather and rain_mm

- Factor (3):

  Name: Temperature-Pressure Gradient Factor

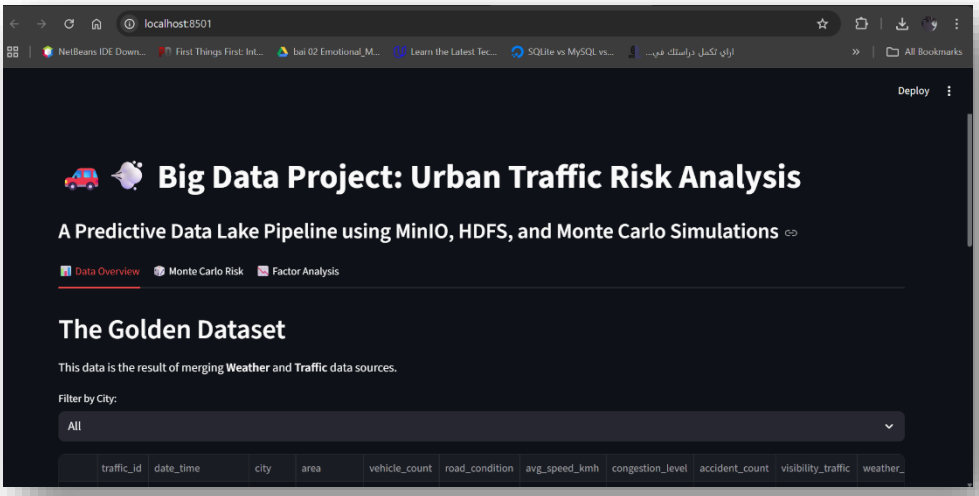
  most 2 affecting features/variables: air_pressure_hpa

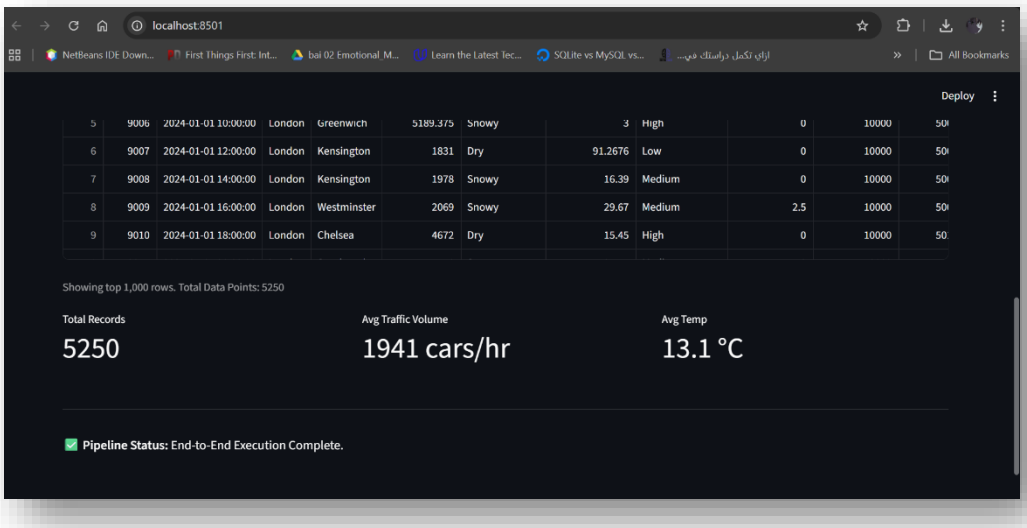
  and temperature_c

Phase 7 (Optional Bonus): *Visualization Dashboard*

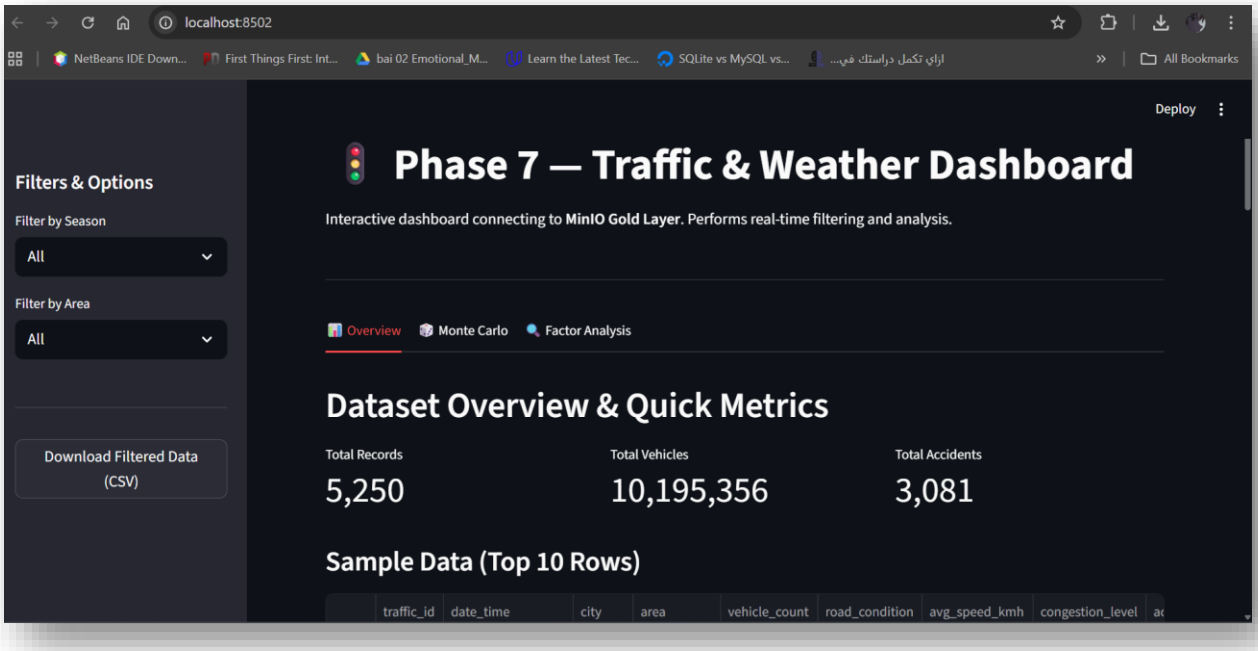
Streamlit has been used to build two simple interactive web dashboards displaying:

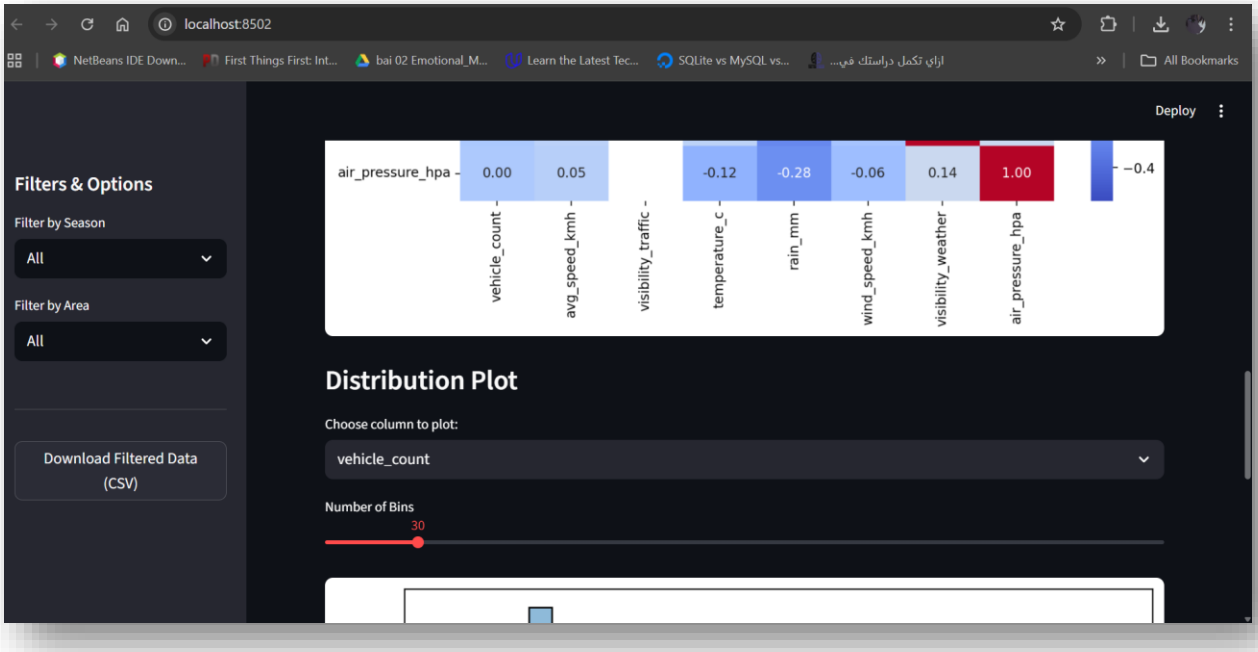
- Cleaned dataset statistics
- Monte Carlo simulation results
- Factor Analysis insights



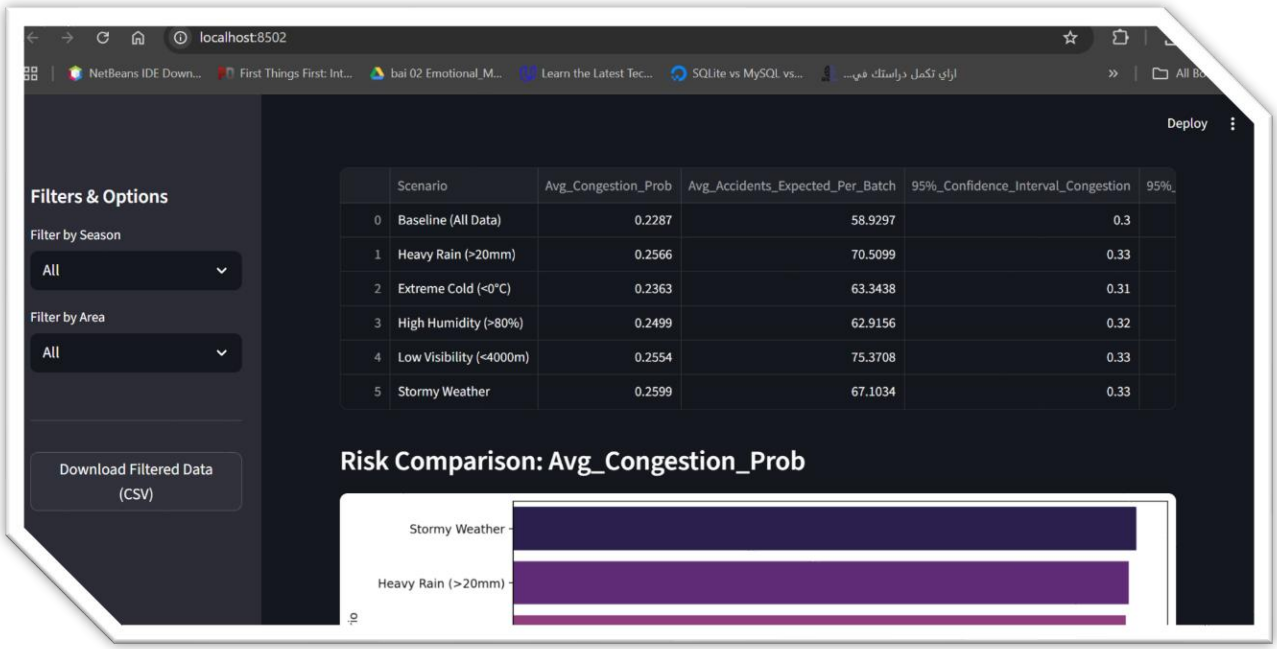


The two figures above show the data overview tab and the overview tab on the other dashboard allows for filtering in case of needing for more specificity about some feature.

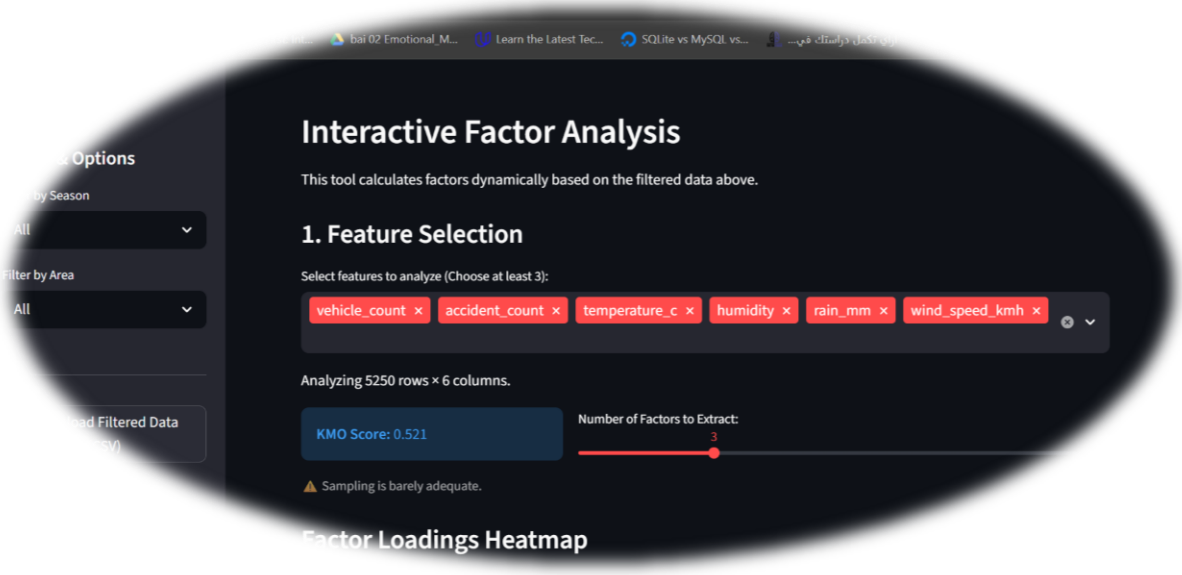




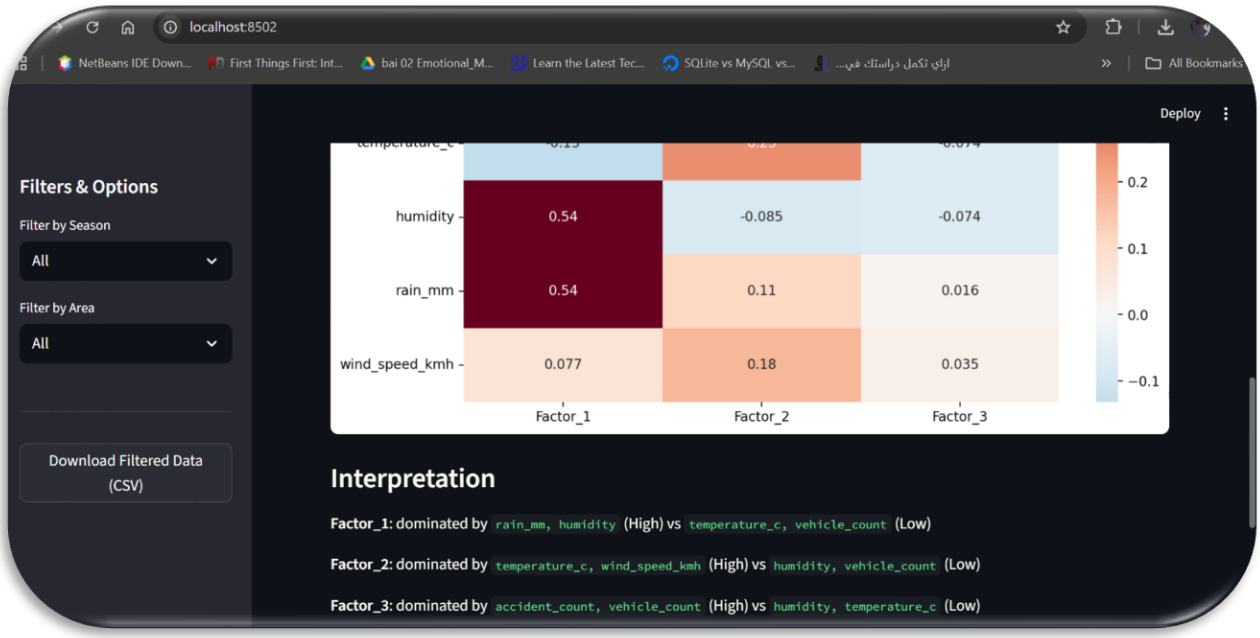
For the Monte Carlo tab, it shows the simulation summary table in addition to a plot for congestion probability in different scenarios.



For factor analysis, one dashboard enables users to apply it to some specific features and change the number of extracted factors.

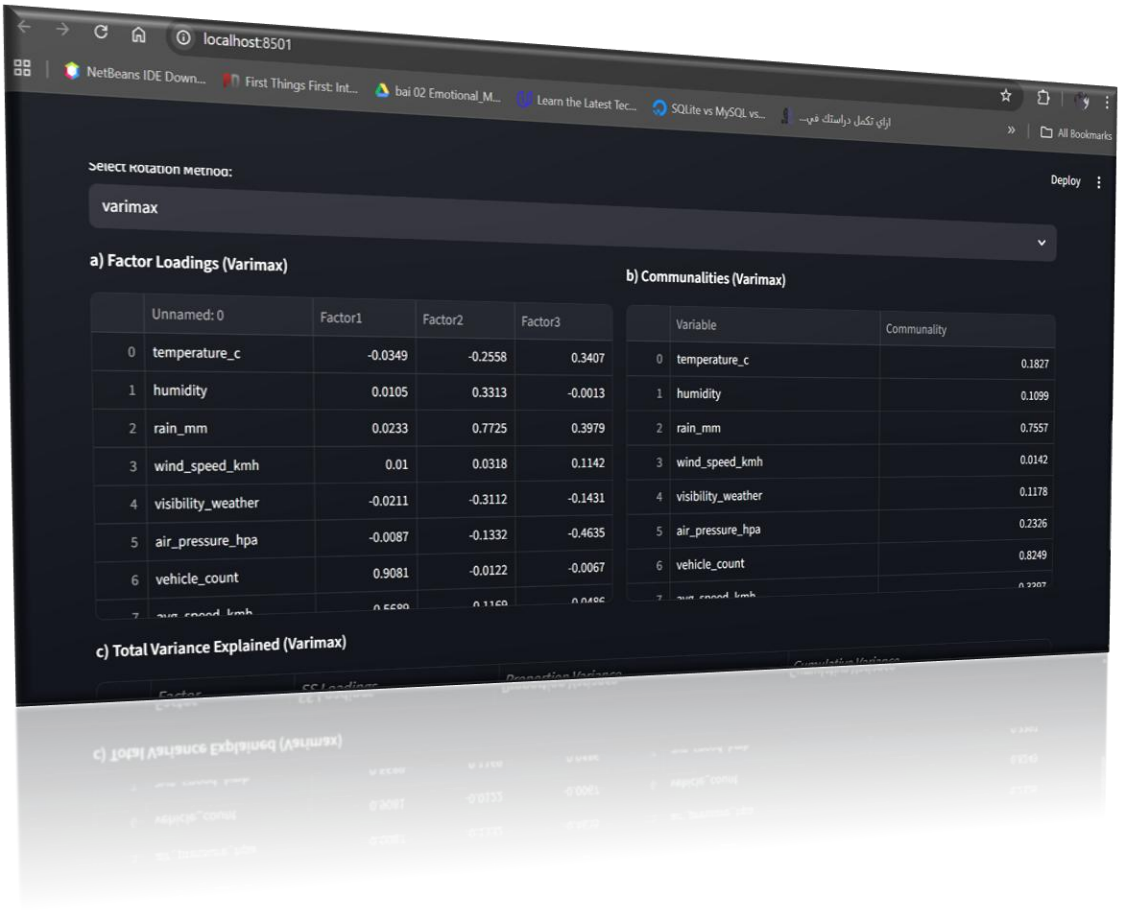


In addition to showing the relationship between each feature and the factors using heatmap as shown below.



The other dashboard clarifies the eigen value table highlighting the highest three values aside with the scree plot that shows that 3 is the number of factors to extract.

Finally, it shows also each of factor loadings, communalities, and total variance explained tables enabling filtering based on the rotation method (Varimax – Promax – Quartimax)



	Unnamed: 0	Factor1	Factor2	Factor3
0	temperature_c	-0.0349	-0.2558	0.3407
1	humidity	0.0105	0.3313	-0.0013
2	rain_mm	0.0233	0.7725	0.3979
3	wind_speed_kmh	0.01	0.0318	0.1142
4	visibility_weather	-0.0211	-0.3112	-0.1431
5	air_pressure_hpa	-0.0087	-0.1332	-0.4635
6	vehicle_count	0.9081	-0.0122	-0.0067

	Variable	Communality
0	temperature_c	0.1827
1	humidity	0.1099
2	rain_mm	0.7557
3	wind_speed_kmh	0.0142
4	visibility_weather	0.1178
5	air_pressure_hpa	0.2326
6	vehicle_count	0.8249

Thank You