Azure Spark-Based Taxi Route Analysis

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Introduction

This technical report details the implementation and analysis of a scalable and fault-tolerant system for processing extensive taxi route data in New York City. Leveraging Microsoft Azure's cloud platform, the system utilizes Apache Spark and various Azure services to address complex queries on taxi route data. The report outlines the methodology, tools, and outcomes of this data processing system.

Technicalities

The implementation for each of the questions heavily relies on PySpark, an interface for Apache Spark in Python. The code execution is facilitated using Databricks, with the exception of Question 4, where a Function App was employed. Additionally, Matplotlib was utilized to create some of the graphs, while Power BI played a pivotal role in addressing Question 6.

The data handling approach involved saving datasets as blobs in a storage account. Blob storage, a cloud-based storage service, was chosen due to its capability to efficiently store and manage large volumes of unstructured data.

Apache Spark, a multi-language engine for data engineering, data science, and machine learning, was preferred for its scalability. The system can be scaled horizontally by utilizing more machines or clusters, enhancing the computational resources for larger datasets. Additionally, serverless functions employed in the project exhibit similar scalability. Azure Function app was chosen for its flexibility, ability to execute code without managing the underlying infrastructure, and automatic scaling of resources based on increased load.

Regarding scalability, the blob size can be increased to store more data in a single blob beyond the default 4 MiB. Apache Spark's horizontal scaling and the scalability of serverless functions provide flexibility in handling larger datasets efficiently.

In terms of fault tolerance, Azure's Blob Storage ensures high availability by replicating blobs across multiple machines. Apache Spark achieves fault tolerance through Resilient Distributed Datasets (RDDs), using an immutable graph of operations. In case of failure, operations can be retried by following the links to parent nodes in the graph. Serverless functions benefit from the fault tolerance mechanisms provided by the Azure cloud platform. Functions are designed to be retried in case of failure, ensuring adaptability to potential errors. Also, executing functions in parallel reduces the risk of delays due to failure in a single function.

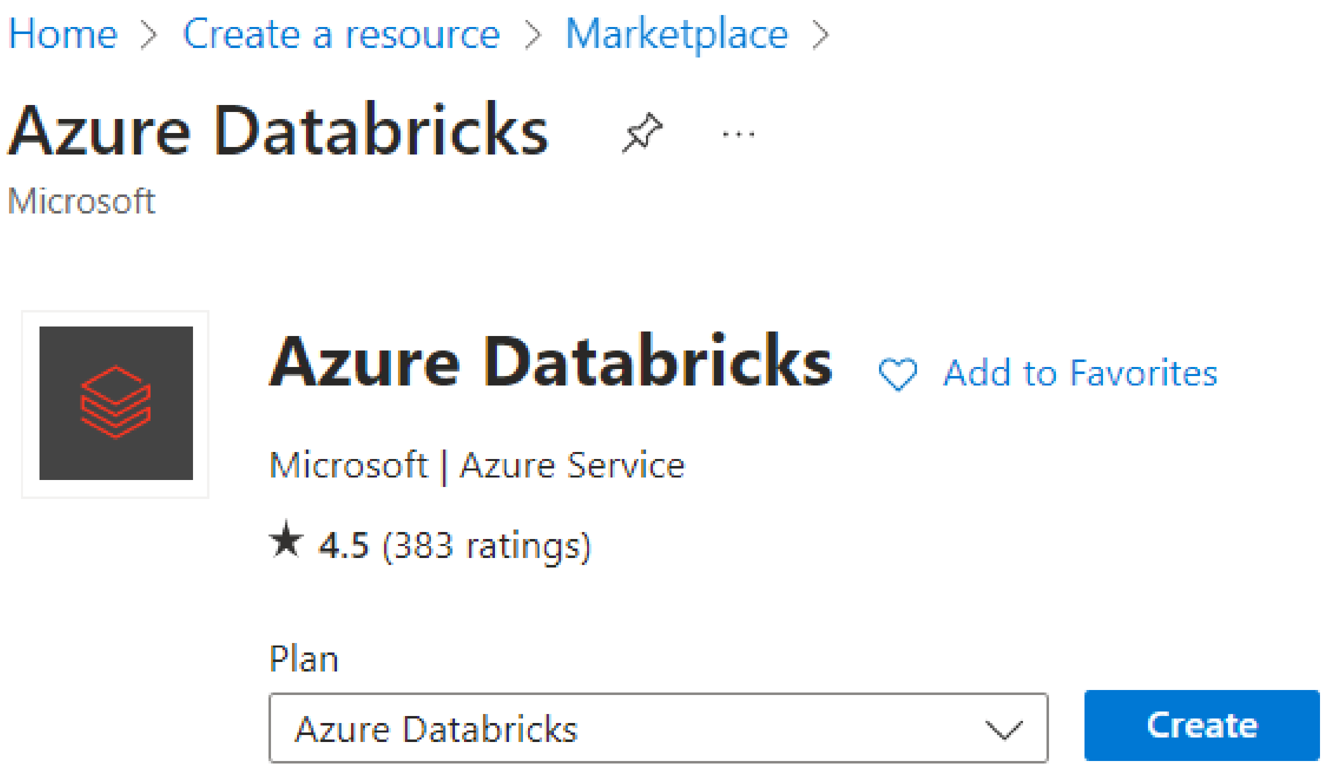
Databricks Configuration

To configure Databricks, we followed the steps outlined in this guide.

Resource Creation

Initially, we initiated the setup by generating a new Databricks resource through the Azure portal.

Databricks Resource



Home > Create a resource > Marketplace >

Azure Databricks

Microsoft

Azure Databricks

Microsoft | Azure Service

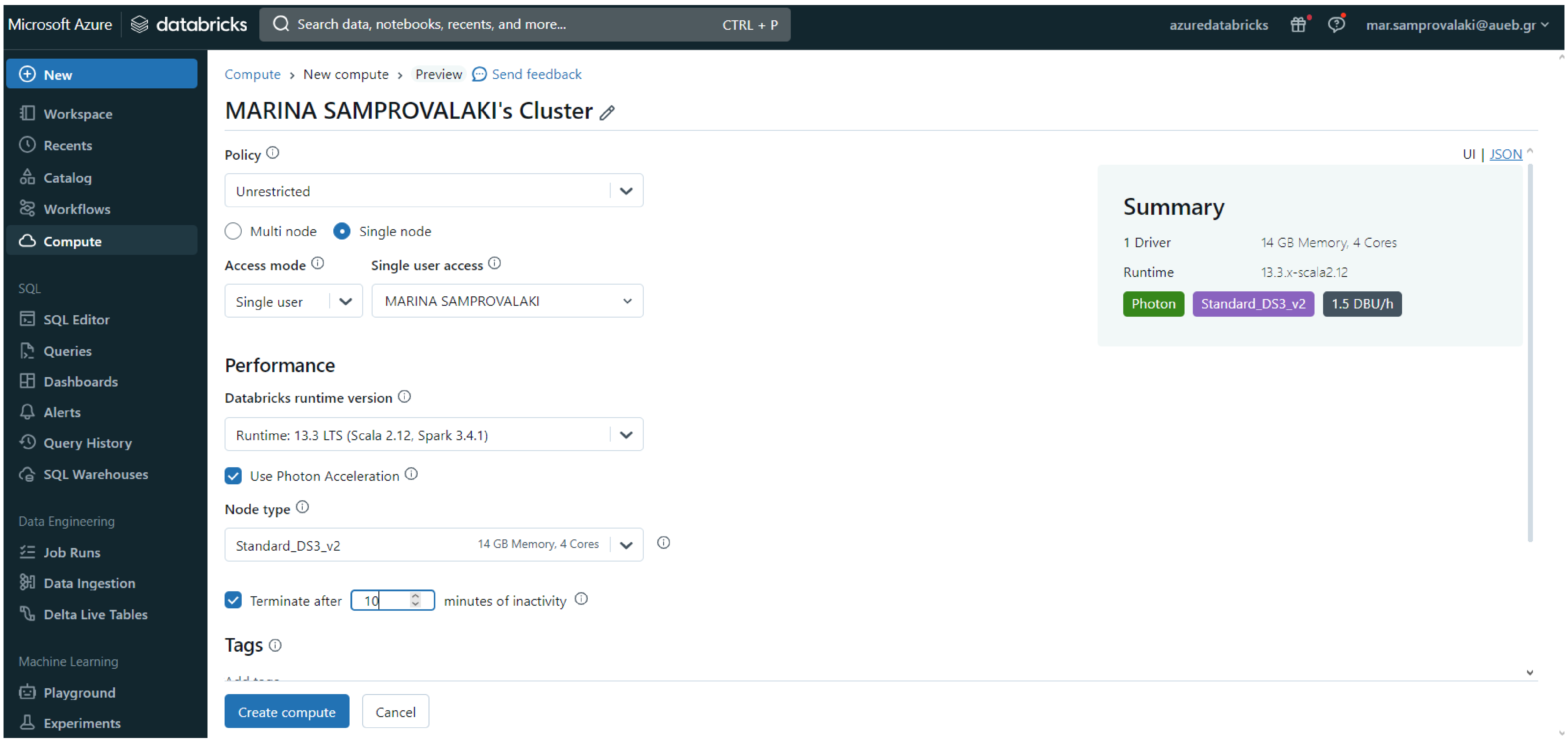
★ 4.5 (383 ratings)

Plan: Azure Databricks

Cluster Setup

Following the resource creation, the subsequent step involved configuring a new cluster within Databricks. A decision point arose concerning whether to opt for a single-user or multi-user cluster. Attempting to create a multi-user cluster raised concerns about resource quotas, leading us to opt for a single-user cluster, as illustrated in the screenshot below.

Databricks Cluster Configuration



Compute › New compute › Preview

MARINA SAMPROVALAKI's Cluster

Policy: Unrestricted

○ Multi node ● Single node

Access mode: Single user

Single user access: MARINA SAMPROVALAKI

Performance

Databricks runtime version: Runtime: 13.3 LTS (Scala 2.12, Spark 3.4.1)

☑ Use Photon Acceleration

Node type: Standard_DS3_v2 14 GB Memory, 4 Cores

☑ Terminate after 10 minutes of inactivity

Tags

Summary

1 Driver	14 GB Memory, 4 Cores
Runtime	13.3.x-scala2.12

Photon · Standard_DS3_v2 · 1.5 DBU/h

Notebook Creation

Subsequently, a crucial component of our setup involved the creation of a notebook to accommodate our code. Opting for Databricks was driven by its user-friendly environment, providing a familiar workspace. The notebook can be accessed here.

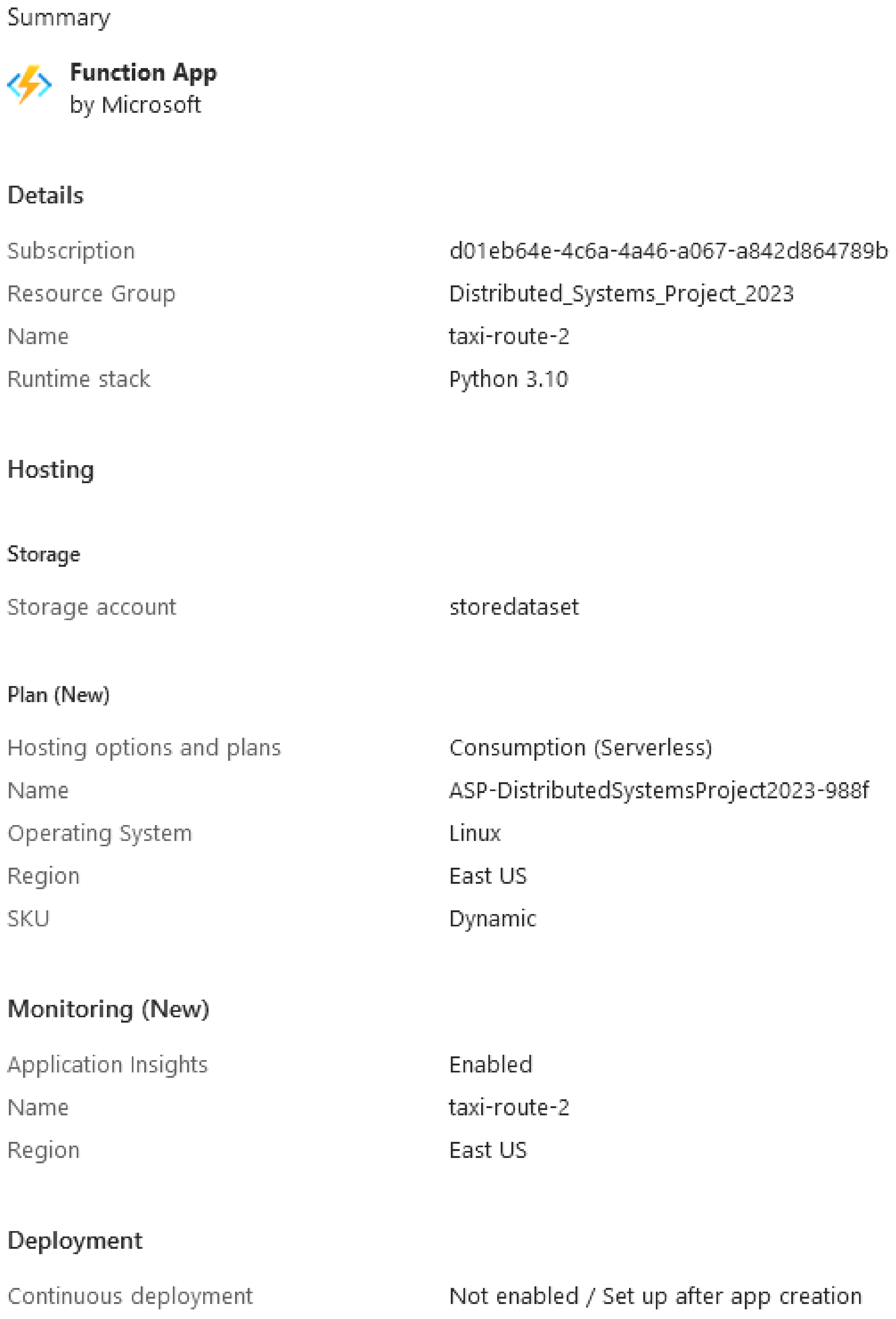
Notebook in HTML form

The hyperlink given requires authentication. If you don't have a Databricks account, you can access the notebook by downloading the HTML file from here.

Function App Creation

To create the Function App, we followed the steps from the following guide.

Function App Configuration



Summary

Details

Subscription	d01eb64e-4c6a-4a46-a067-a842d864789b
Resource Group	Distributed_Systems_Project_2023
Name	taxi-route-2
Runtime stack	Python 3.10

Hosting

Storage

Storage account	storedataset

Plan (New)

Hosting options and plans	Consumption (Serverless)
Name	ASP-DistributedSystemsProject2023-988f
Operating System	Linux
Region	East US
SKU	Dynamic

Monitoring (New)

Application Insights	Enabled
Name	taxi-route-2
Region	East US

Deployment

Continuous deployment	Not enabled / Set up after app creation

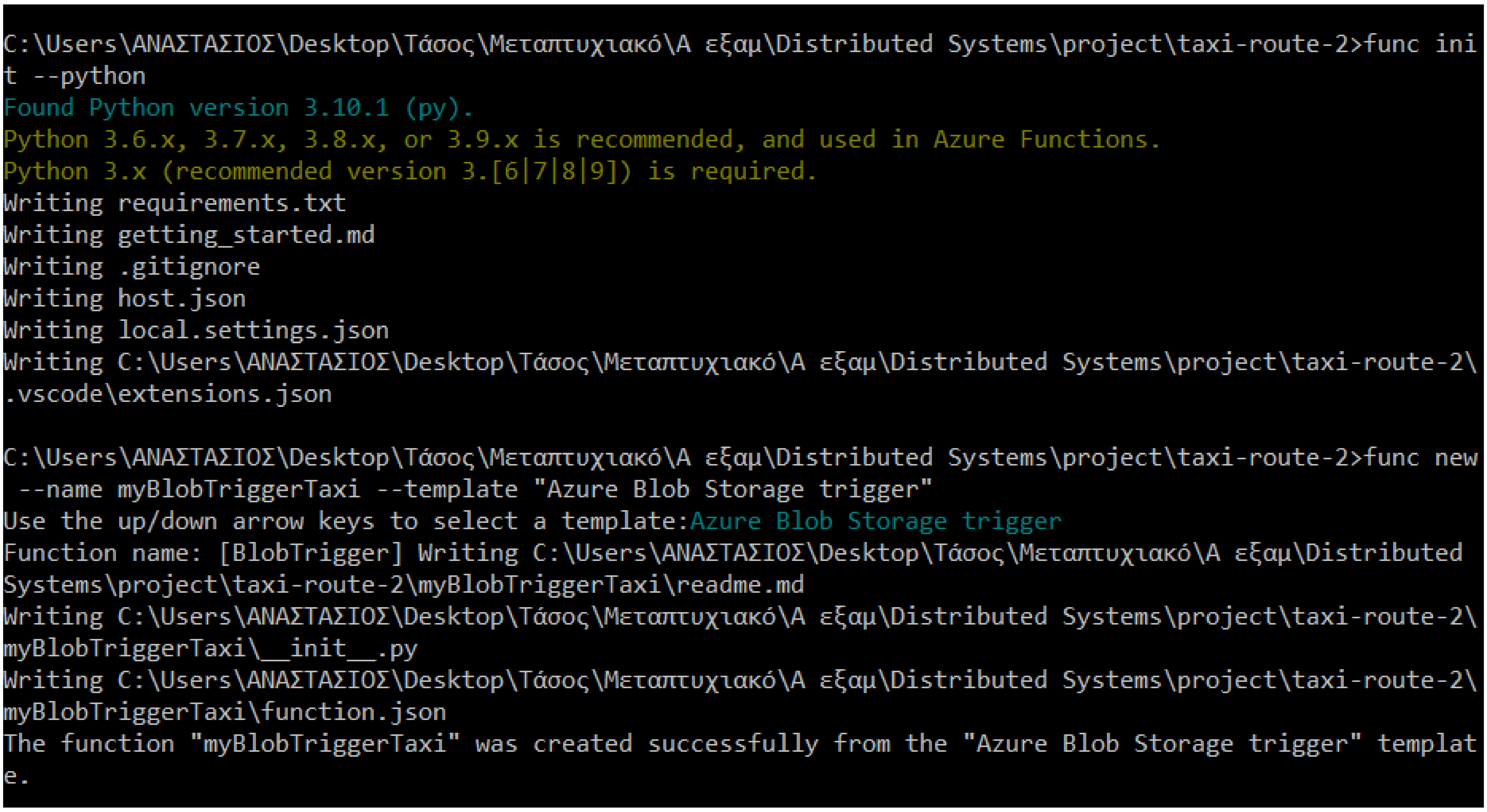
Function App and Blob Trigger Initialization

After we have created the Function App, we choose to create a blob trigger through the command line. To do this, we follow this guide. First, we installed Azure Functions Core Tools according to the previous guide and Azure CLI from the following guide. Then we log in with the *az login* command to our azzount and ran the commands to create the Function App and the Blob Trigger files as indicated here and we used VS Code as our IDE. To find the available Python templates we used the following command as shown here.

Blob Trigger Creation

To create the Blob Trigger, we altered the __init__.py file, and the function.json file, where we defined the input/output bindings according to the following guide. Also, we had to add Pandas to requirements.txt, as it is used to read the input file.

Initialisation of Function and creation of Blob Trigger



```
C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed Systems\project\taxi-route-2>func ini
t --python
Found Python version 3.10.1 (py).
Python 3.6.x, 3.7.x, 3.8.x, or 3.9.x is recommended, and used in Azure Functions.
Python 3.x (recommended version 3.[6|7|8|9]) is required.
Writing requirements.txt
Writing getting_started.md
Writing .gitignore
Writing host.json
Writing local.settings.json
Writing C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed Systems\project\taxi-route-2\
.vscode\extensions.json

C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed Systems\project\taxi-route-2>func new
 --name myBlobTriggerTaxi --template "Azure Blob Storage trigger"
Use the up/down arrow keys to select a template:Azure Blob Storage trigger
Function name: [BlobTrigger] Writing C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed
Systems\project\taxi-route-2\myBlobTriggerTaxi\readme.md
Writing C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed Systems\project\taxi-route-2\
myBlobTriggerTaxi\__init__.py
Writing C:\Users\ΑΝΑΣΤΑΣΙΟΣ\Desktop\Τάσος\Μεταπτυχιακό\Α εξαμ\Distributed Systems\project\taxi-route-2\
myBlobTriggerTaxi\function.json
The function "myBlobTriggerTaxi" was created successfully from the "Azure Blob Storage trigger" templat
e.
```

Function App Deployment and Code

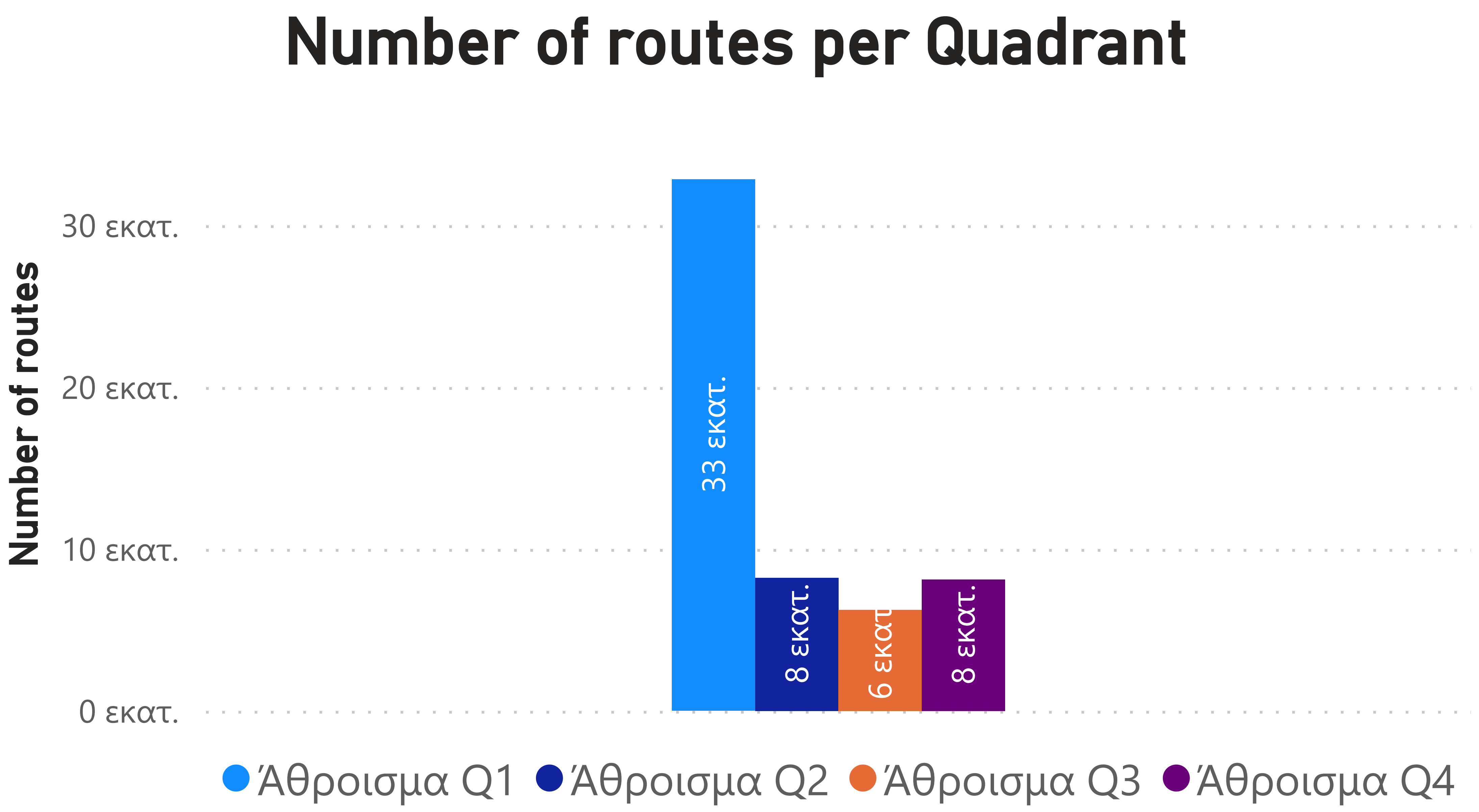
To deploy the Function App, we use the *func azure functionapp publish* command from this guide. The code of the Function App can be found in this link, where the folder contains the __init__.py file, the function.json, and the rquirements.txt.

Data Preparation

The analysis initiated by connecting to Azure Blob Storage, where taxi route datasets were stored. After successfully mounting the Blob Storage, four distinct DataFrames (df1, df2, df3, and df4) were created, each based on specific quantiles rather than months. These individual DataFrames were strategically merged into a unified dataset (df) to provide a comprehensive perspective of the taxi route data based on quantile divisions.

1st Question - Geographical Quadrant Analysis

To address the first question, taxi routes were systematically categorized based on their pickup locations within defined geographical quadrants around a central point in the city. PySpark's DataFrame operations were employed to establish quadrant-specific conditions, creating new columns indicating the quadrant of each taxi pickup. Ride counts for each quadrant were aggregated, providing insights into taxi activity in different geographical regions. The processed DataFrame was persisted in the default database for lasting accessibility and query efficiency.

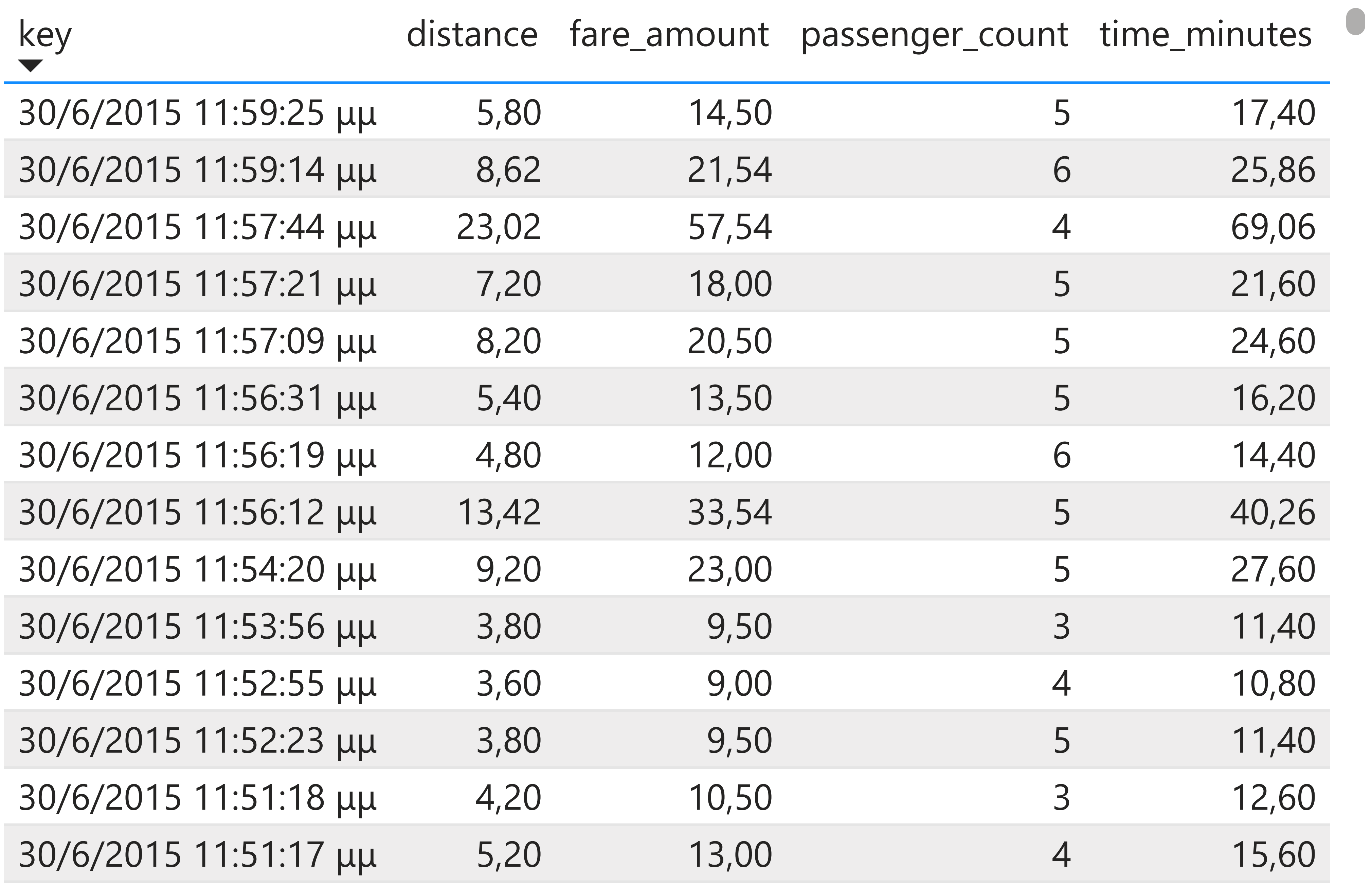


2nd Question - Route Metrics Calculation

For the second question, we identified routes that exceeded one kilometer in distance, lasted more than 10 minutes, and involved more than two passengers.
By applying fundamental principles of physics, and considering the determined mean price of $2.5 per kilometer for taxi drives, as well as assuming an average speed of 20 km/h, we computed the distance covered by each taxi route using the formula

$$u = \frac{x}{t}$$

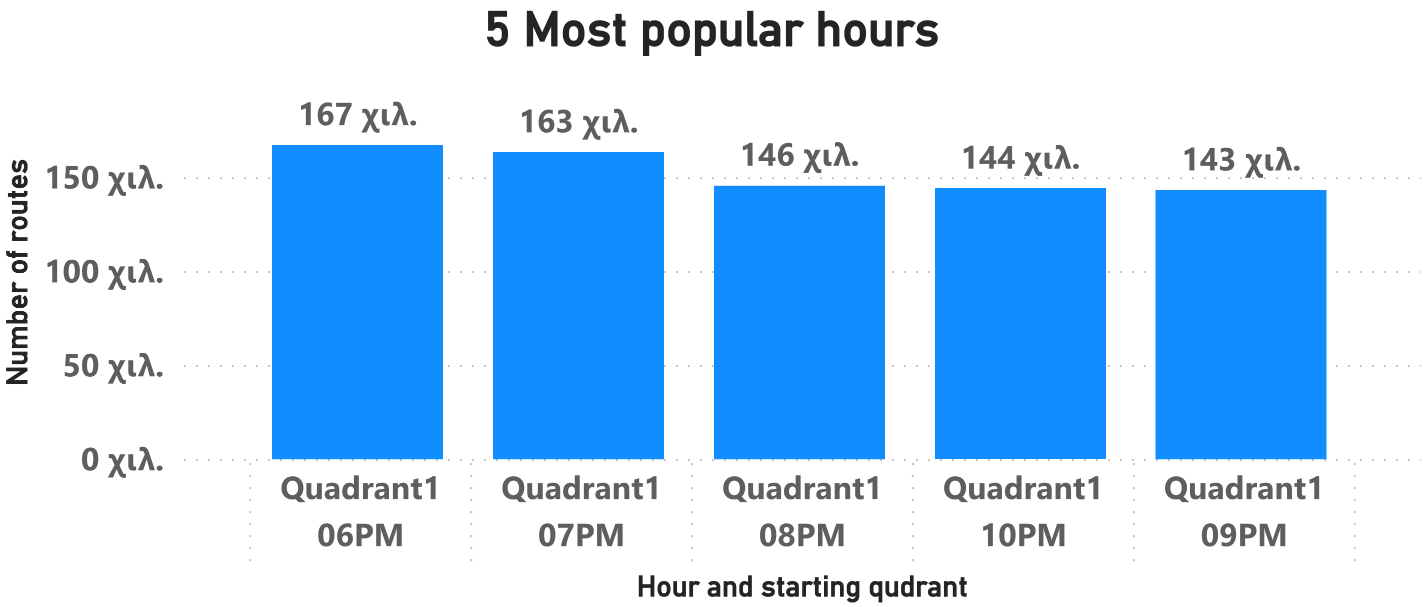
where *u* represents speed, *x* represents distance, and *t* represents time.



key	distance	fare_amount	passenger_count	time_minutes
30/6/2015 11:59:25 μμ	5,80	14,50	5	17,40
30/6/2015 11:59:14 μμ	8,62	21,54	6	25,86
30/6/2015 11:57:44 μμ	23,02	57,54	4	69,06
30/6/2015 11:57:21 μμ	7,20	18,00	5	21,60
30/6/2015 11:57:09 μμ	8,20	20,50	5	24,60
30/6/2015 11:56:31 μμ	5,40	13,50	5	16,20
30/6/2015 11:56:19 μμ	4,80	12,00	6	14,40
30/6/2015 11:56:12 μμ	13,42	33,54	5	40,26
30/6/2015 11:54:20 μμ	9,20	23,00	5	27,60
30/6/2015 11:53:56 μμ	3,80	9,50	3	11,40
30/6/2015 11:52:55 μμ	3,60	9,00	4	10,80
30/6/2015 11:52:23 μμ	3,80	9,50	5	11,40
30/6/2015 11:51:18 μμ	4,20	10,50	3	12,60
30/6/2015 11:51:17 μμ	5,20	13,00	4	15,60

3rd Question - Temporal and Spatial Characteristics

The third question explored the temporal and spatial characteristics of filtered routes. Frequency analysis for each hour of the day identified the top five hours for route commencement. Additionally, spatial analysis determined the most popular quadrants from which these routes originated. The results were presented in tabular format, enhancing understanding of both temporal and spatial dynamics.

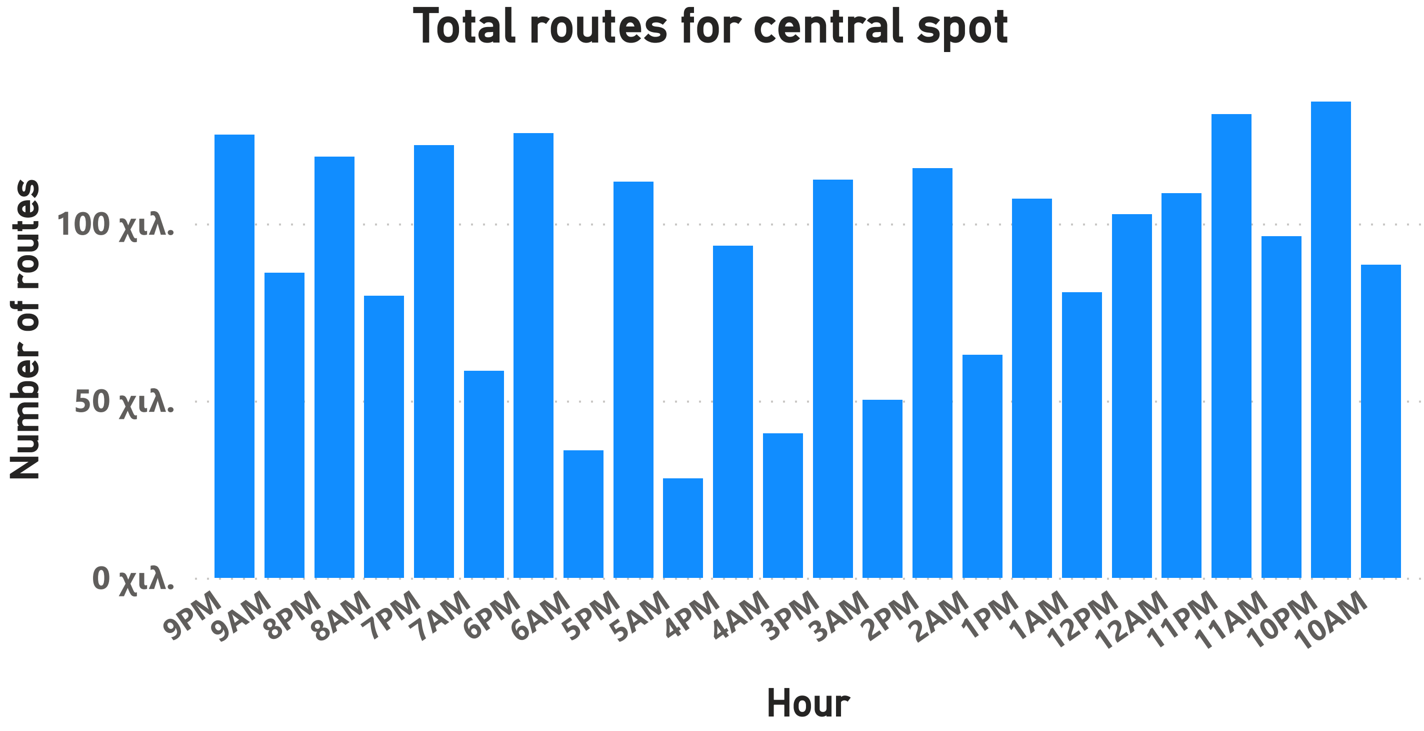


4th Question - Streaming Analysis with Function App

The fourth question involved streaming analysis with a Function App. A blob trigger was employed to continuously check Blob Storage for new data. Upon detecting new blobs, the Function App reads the blob and calculates the routes that have started from each quadrant and then saves the results in a new blob, demonstrating the real-time analytical capabilities of the system.

5th Question - Location-Based Route Analysis

The fifth question assessed taxi routes within a 5 km radius of the location from Question 1. Routes that commenced within this radius and incurred a fare exceeding $10 were identified. Precise PySpark DataFrame operations were implemented, and the results were grouped by the hour of pickup to discern patterns over time.


Total routes for central spot
Number of routes
100 χιλ.
50 χιλ.
0 χιλ.
9PM
9AM
8PM
8AM
7PM
7AM
6PM
6AM
5PM
5AM
4PM
4AM
3PM
3AM
2PM
2AM
1PM
1AM
12PM
12AM
11PM
11AM
10PM
10AM
Hour