Project Report

Assignment - EC7205 Cloud Computing
University of Ruhuna

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Project Title:	Analyzing Bike-Sharing System Usage Patterns

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1 Project Introduction

This project aims to identify the most popular Citi Bike stations in New York City based on the frequency of trips originating or ending at each station. Subsequently, it analyzes the busiest hours for these top stations. By leveraging the distributed computing capabilities of Hadoop MapReduce, the project processes large volumes of trip data to determine high demand stations and peak usage times, which can inform urban transportation planning, resource allocation and service optimization.

2 Dataset Introduction

2.1 Source

The dataset used in this project is obtained from the official Citi Bike NYC system data portal: `https://citibikenyc.com/system-data`. This open dataset provides detailed information about individual bike trips taken with Citi Bike, New York City's bike-sharing service.

2.2 Format and Structure

The data is provided in CSV (Comma-Separated Values) format, with each file representing one month of trip data. File names typically follow the format: `YYYYMM-citibike-tripdata.csv`.

2.3 Attributes

Each record in the dataset corresponds to a single trip and includes the following key attributes:

- **ride_id**: Unique identifier assigned to each trip.
- **rideable_type**: Type of bicycle used (e.g., classic_bike, electric_bike).
- **started_at**: Timestamp indicating when the ride began.
- **ended_at**: Timestamp indicating when the ride ended.
- **start_station_name**: Name of the station where the ride originated.
- **start_station_id**: Unique ID of the starting station.
- **end_station_name**: Name of the station where the ride ended.
- **end_station_id**: Unique ID of the destination station.
- **start_lat, start_lng**: Geographic coordinates (latitude and longitude) of the starting station.
- **end_lat, end_lng**: Geographic coordinates of the destination station.
- **member_casual**: Indicates whether the user is a registered member or a casual rider.

2.4 Size and Volume

The dataset is updated monthly, and each file contains a large volume of records, often ranging from hundreds of thousands to millions of rows, depending on the month. This makes it an ideal candidate for processing using distributed computing frameworks such as Hadoop MapReduce. For instance, the dataset from the year 2023 which is used in this project comprises approximately 35,107,070 records, highlighting the scale and suitability of this data for parallel processing.

3 Installation and Setup

3.1 Prerequisites

- Operating System: Ubuntu (WSL)
- Java Development Kit (JDK 8)
- Hadoop (version 3.3.6 - Pseudo-distributed mode configuration)
- Git (for code management)

3.2 Java Installation (JDK 8)

1. Update the package index:

```
sudo apt update
```

2. Install OpenJDK 8:

```
sudo apt install openjdk-8-jdk
```

3. Verify installation:

```
java -version
javac -version
```

4. Configure Passwordless SSH:

```
ssh-keygen -t rsa -P '' -f ~/.ssh/id_rsa
cat ~/.ssh/id_rsa.pub >> ~/.ssh/authorized_keys
chmod 0600 ~/.ssh/authorized_keys
```

3.3 Hadoop Installation and Configuration

1. Download Hadoop binary (e.g., version 3.3.6) and extract

```
cd ~ #
wget https://dlcdn.apache.org/hadoop/common/hadoop-3.3.6/hadoop-3.3.6.tar.gz
tar -xzf hadoop-3.3.6.tar.gz
```

2. Set environment variables (`JAVA_HOME`, `HADOOP_HOME`, `PATH`) in `.bashrc`.

```
nano ~/.bashrc
```

   Add following to .bashrc:

```
# Give actual path where the hadoop is extracted
export HADOOP_HOME=/home/testuser/hadoop-3.3.6
export HADOOP_INSTALL=$HADOOP_HOME
export HADOOP_MAPRED_HOME=$HADOOP_HOME
export HADOOP_COMMON_HOME=$HADOOP_HOME
export HADOOP_HDFS_HOME=$HADOOP_HOME
export YARN_HOME=$HADOOP_HOME
export HADOOP_COMMON_LIB_NATIVE_DIR=$HADOOP_HOME/lib/native
export PATH=$PATH:$HADOOP_HOME/bin:$HADOOP_HOME/sbin
export HADOOP_OPTS="-Djava.library.path=$HADOOP_HOME/lib/native"

# If you didn't set JAVA_HOME system-wide or for this user already:
export JAVA_HOME=/usr/lib/jvm/java-8-openjdk-amd64
export PATH=$PATH:$JAVA_HOME/bin
```

Source the file:

```
source ~/.bashrc
```

3. Configure Hadoop XML files (`core-site.xml`, `hdfs-site.xml`, `mapred-site.xml`, `yarn-site.xml`) for pseudo-distributed mode.

   - `core-site.xml`: Specify `fs.defaultFS`.
     - Edit the file (e.g., using nano):
       `nano $HADOOP_HOME/etc/hadoop/core-site.xml`
     - Add the following content between the `<configuration>` and `</configuration>` tags:

```
<configuration>
    <property>
        <name>fs.defaultFS</name>
        <value>hdfs://localhost:9000</value>
        <description>The name of the default file system. A URI whose
                     scheme and authority determine the FileSystem
                     implementation.</description>
    </property>
</configuration>
```

   - `hdfs-site.xml`: Specify `dfs.replication` (set to 1 for pseudo-distributed) and paths for namenode/datanode directories.
     - Before editing, create directories for NameNode and DataNode data (adjust path for your Hadoop user, e.g., `/home/hadoopuser/hadoop_data/...`):

```
mkdir -p ~/hadoop_data/hdfs/namenode
mkdir -p ~/hadoop_data/hdfs/datanode
```

     - Edit the file:
       `nano $HADOOP_HOME/etc/hadoop/hdfs-site.xml`
     - Add the following content between the `<configuration>` and `</configuration>` tags (adjust paths if you chose different locations):

```
<configuration>
    <property>
        <name>dfs.replication</name>
        <value>1</value>
        <description>Default block replication. The actual number of
                     replications can be specified when the file is
                     created.</description>
    </property>
    <property>
        <name>dfs.namenode.name.dir</name>
        <value>file:/home/testuser/hadoop_data/hdfs/namenode</value>
    </property>
    <property>
```

```
        <name>dfs.datanode.data.dir</name>
        <value>file:/home/testuser/hadoop_data/hdfs/datanode</value>
    </property>
</configuration>
```

- mapred-site.xml: Specify mapreduce.framework.name to yarn.
  - If mapred-site.xml doesn't exist, copy it from the template:

```
cp $HADOOP_HOME/etc/hadoop/mapred-site.xml.template $HADOOP_HOME/etc/
    hadoop/mapred-site.xml
```

  - Edit the file:

```
nano $HADOOP_HOME/etc/hadoop/mapred-site.xml
```

  - Add the following content between the <configuration> and </configuration> tags:

```
<configuration>
    <property>
        <name>mapreduce.framework.name</name>
        <value>yarn</value>
        <description>The runtime framework for executing MapReduce jobs.
                     Can be one of local, classic or yarn.</description>
    </property>
    <property>
        <name>mapreduce.jobhistory.address</name>
        <value>localhost:10020</value>
    </property>
    <property>
        <name>mapreduce.jobhistory.webapp.address</name>
        <value>localhost:19888</value>
    </property>
</configuration>
```

- yarn-site.xml: Configure yarn.nodemanager.aux-services to mapreduce_shuffle and other YARN properties.
  - Edit the file:

```
nano $HADOOP_HOME/etc/hadoop/yarn-site.xml
```

  - Add the following content between the <configuration> and </configuration> tags:

```
<configuration>
    <property>
        <name>yarn.nodemanager.aux-services</name>
        <value>mapreduce_shuffle</value>
        <description>A comma separated list of services that need to be
                     auxiliary to the NodeManager. For example,
                     mapreduce_shuffle.</description>
    </property>
    <property>
        <name>yarn.resourcemanager.hostname</name>
        <value>localhost</value>
    </property>
    <property>
        <name>yarn.nodemanager.resource.memory-mb</name>
        <value>2048</value> <!-- Adjust based on your system's RAM -->
    </property>
    <property>
        <name>yarn.scheduler.minimum-allocation-mb</name>
        <value>256</value> <!-- Minimum allocation for a container -->
    </property>
    <property>
        <name>yarn.scheduler.maximum-allocation-mb</name>
        <value>1024</value> <!-- Maximum allocation for a container -->
    </property>
    <property>
```

```
            <name>yarn.nodemanager.vmem-pmem-ratio</name>
            <value>2.1</value>
        </property>
    </configuration>
```

4. Format the HDFS NameNode:

   - Navigate to your Hadoop installation directory and execute the format command:

     ```
     cd $HADOOP_HOME
     hdfs namenode -format
     ```

3.4 Starting and Verifying Hadoop Services

1. Navigate to Hadoop's `sbin` directory and start services:

   ```
   cd $HADOOP_HOME/sbin
   ./start-dfs.sh
   ./start-yarn.sh
   ```

   (Or use `./start-all.sh` if preferred, though it's often recommended to start DFS and YARN separately).

2. Verify the services using `jps` (Java Virtual Machine Process Status Tool). You should see processes like NameNode, DataNode, ResourceManager, NodeManager.

   ```
   jps
   ```

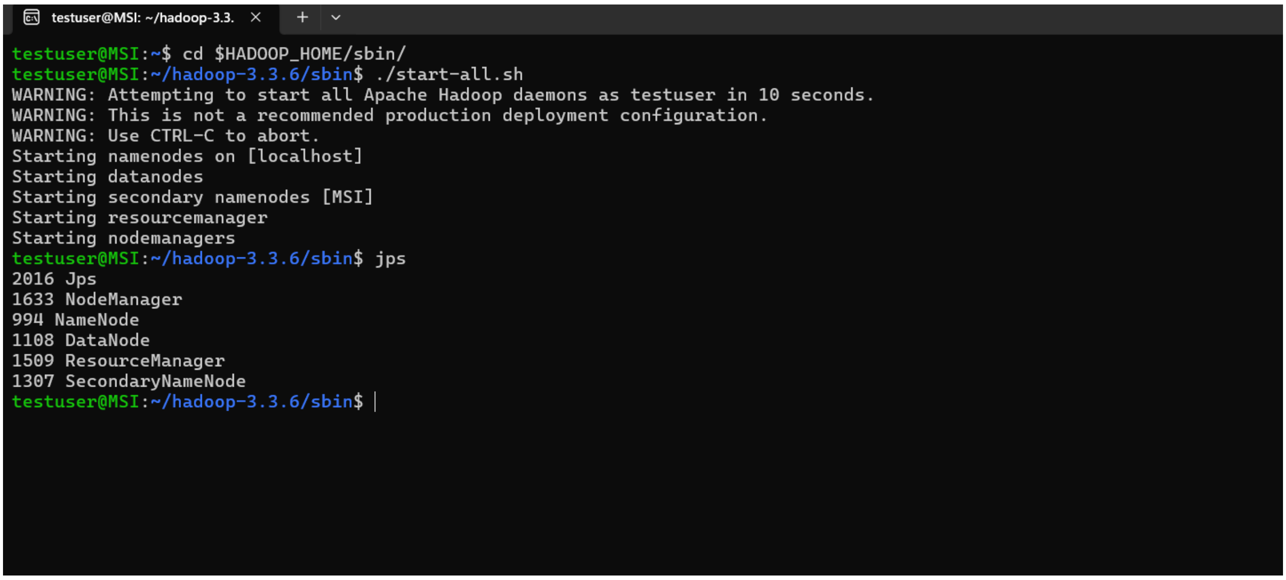


Figure 1: Output of `jps` showing running Hadoop daemons.

3. Verify NameNode UI (Browse http://localhost:9870/)

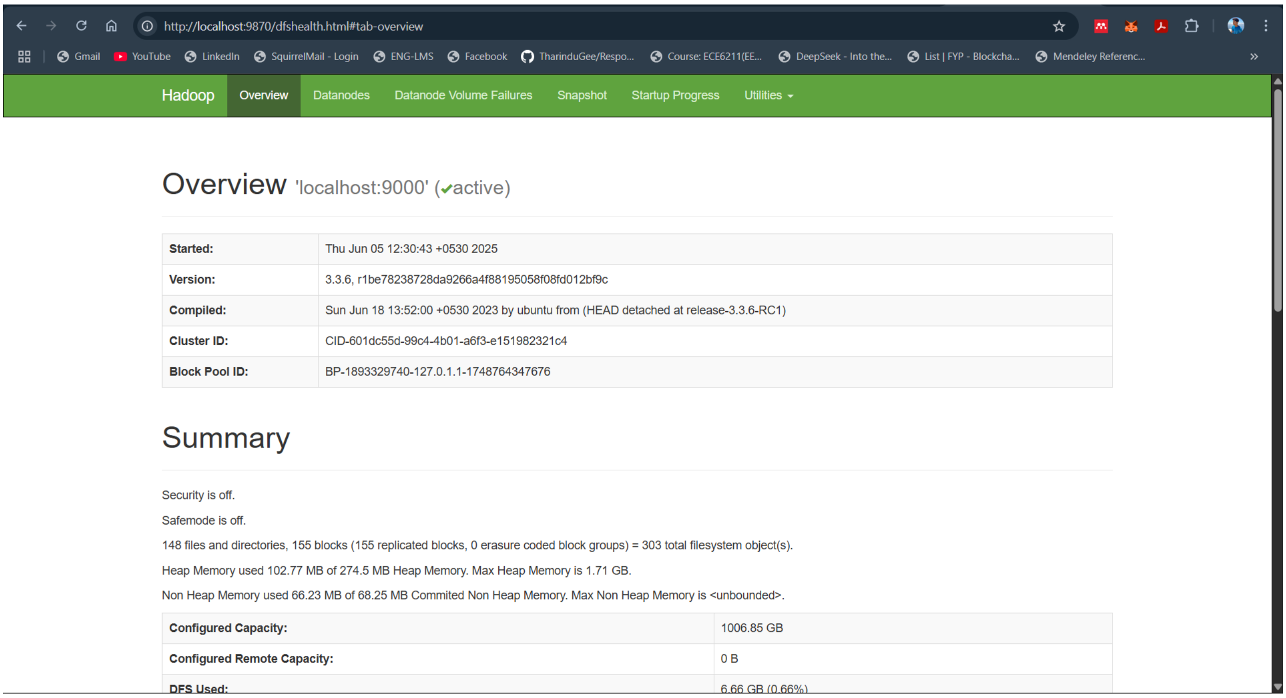


Figure 2: HDFS NameNode UI

3.5 Dataset Preparation on HDFS

1. Download the 2023 Citi Bike dataset from `https://s3.amazonaws.com/tripdata/index.html`.
2. Extract all monthly CSV files from their zipped archives into a single local directory.

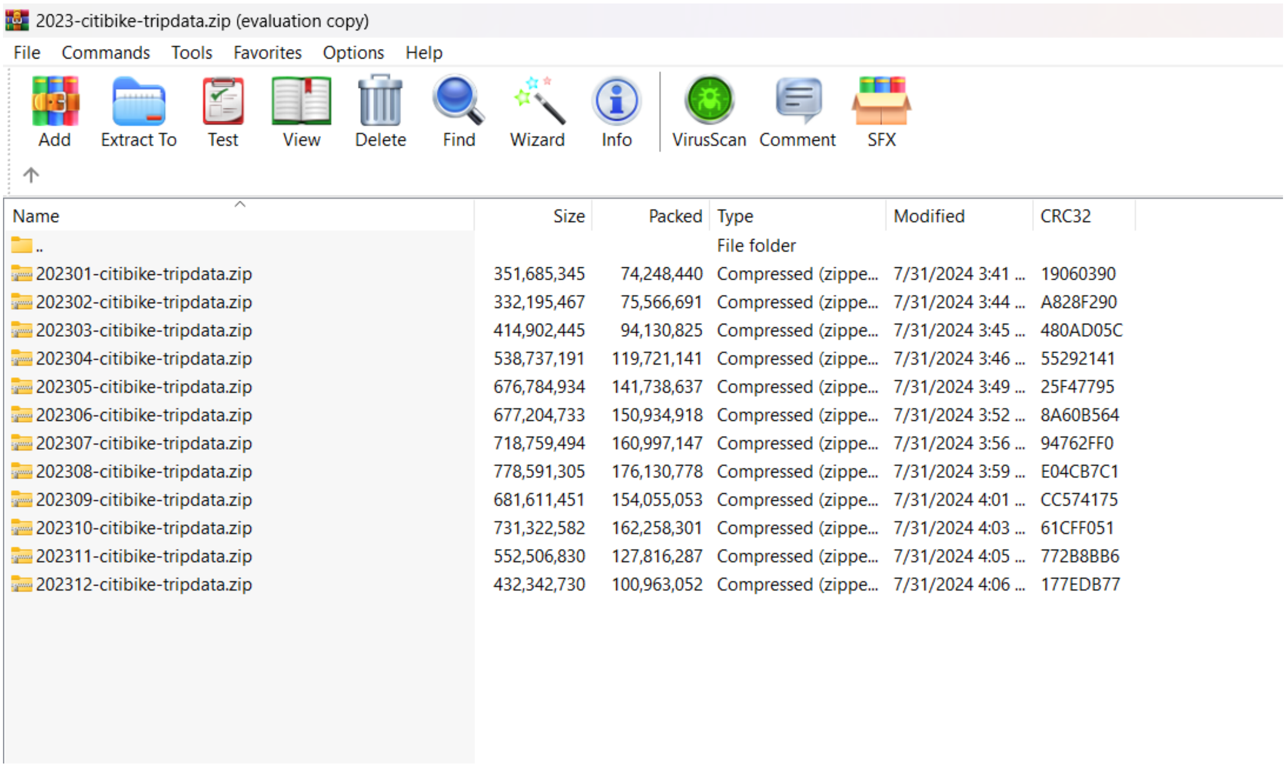


Figure 3: View of zipped monthly data files.

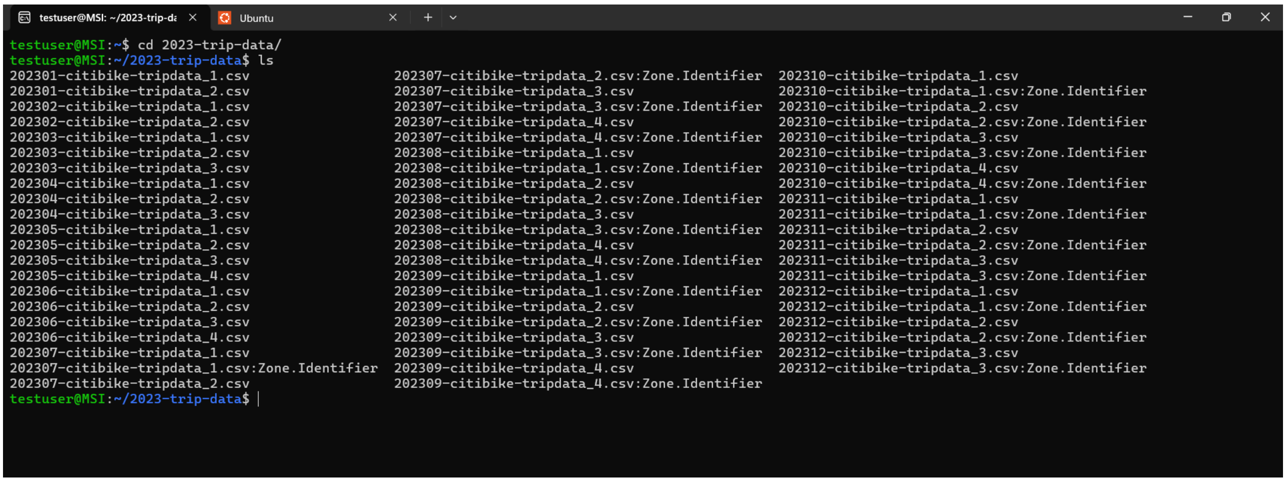


Figure 4: Extracted CSV files for all months of 2023 in a local directory.

3. Create an input directory on HDFS and upload the CSV files:

```
hdfs dfs -mkdir popular_stations_input
hdfs dfs -put path/to/local/citibike_data_2023/*.csv popular_stations_input
hdfs dfs -ls popular_stations_input
```

4 MapReduce Job Implementation and Execution

This section details the process of compiling the Java source code for the MapReduce jobs, packaging them into JAR files, and executing them on the Hadoop cluster.

4.1 Cloning the Project Repository

The Java source code for the MapReduce jobs is available in a Git repository.

```
git clone https://github.com/TharinduGee/Hadoop_MapReduce.git
cd Hadoop_MapReduce
```

It is assumed that the Java source files (e.g., `PopularStationsDriver.java`, `PopularStationsMapper.java`, `PopularStationsReducer.java`, and similarly for `BusiestHour`) are located in the root of this cloned directory.

4.2 Job 1: Identifying Popular Stations

This job processes the trip data to count the usage frequency of each station.

4.2.1 Compiling and Packaging Job 1 (popularStations.jar)

1. Set the Hadoop classpath:

```
export HADOOP_CLASSPATH=$(hadoop classpath)
```

2. Create a directory for compiled class files:

```
mkdir classes_popular_stations
```

3. Compile the Java source files for the Popular Stations job (adjust filenames as necessary):

```
javac -cp $HADOOP_CLASSPATH -d classes_popular_stations \
  PopularStationsDriver.java PopularStationsMapper.java \
  PopularStationsReducer.java
```

4. Create the JAR file `popularStations.jar`:

```
jar -cvf popularStations.jar -C classes_popular_stations .
```

This creates `popularStations.jar` in the current directory (`Hadoop_MapReduce`).

5. (Optional) Verify the JAR contents:

```
jar -tf popularStations.jar
```

Note: If a pre-compiled `popularStations.jar` is already available in the repository, the compilation and packaging steps can be skipped.

4.2.2 Running Job 1 and Retrieving Results

1. Execute the MapReduce job:

```
hadoop jar popularStations.jar PopularStationsDriver \
  popular_stations_input popular_stations_output
```

The input path is `/popular_stations_input` on HDFS and the output will be stored in `/popular_stations_output` on HDFS.

2. View the output files:

```
hdfs dfs -ls popular_stations_output
```

3. Display the contents of the output file (typically `part-r-00000`):

```
hdfs dfs -cat popular_stations_output/part-r-00000
```

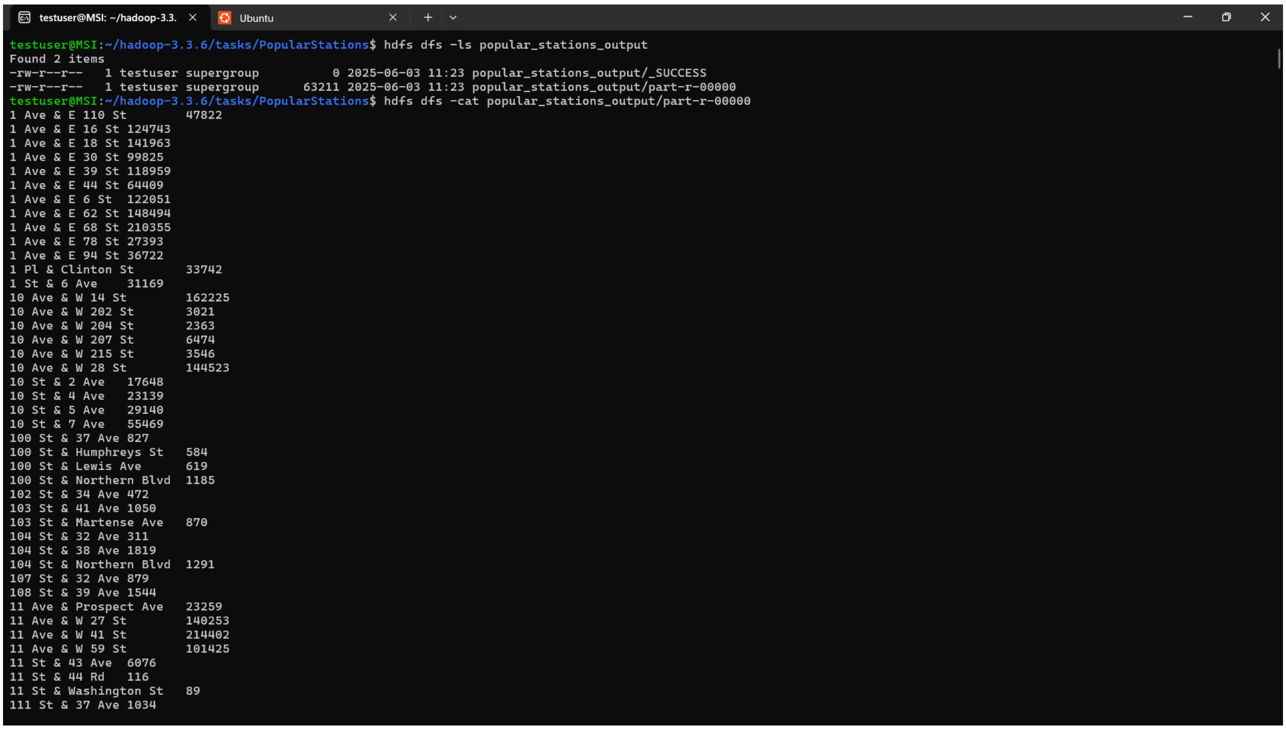


Figure 5: Sample output of Job 1, showing station names and their usage counts.

The first column represents the station name, and the second column represents the total number of trips starting or ending at that station.

4.2.3 Analyzing Job 1 Results

1. Get the count of unique stations processed:

```
hdfs dfs -cat popular_stations_output/part-r-00000 | wc -l
```

2. Get the top 10 most popular stations:

```
hdfs dfs -cat popular_stations_output/part-r-00000 | sort -t$'\t' -k2,2nr | head -n 10
```

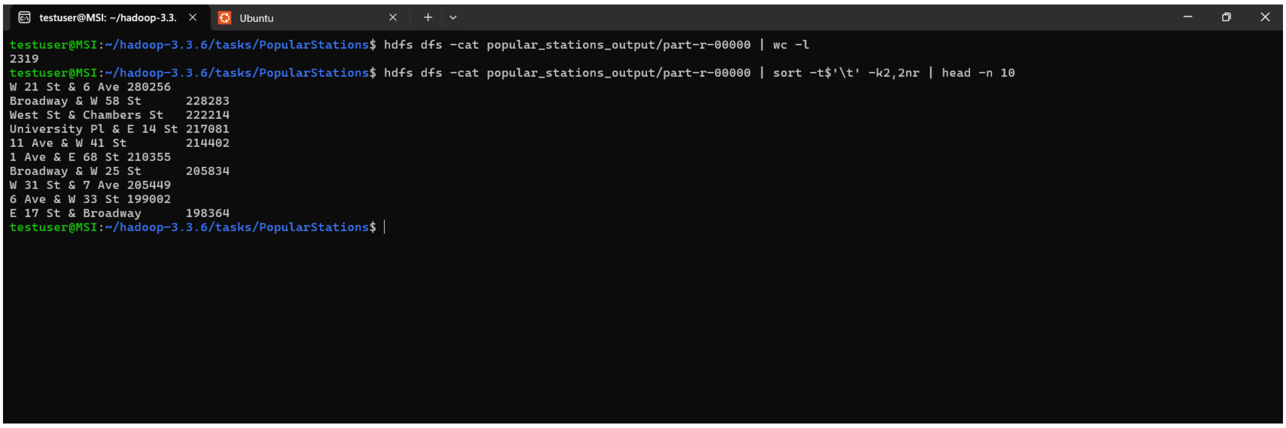


Figure 6: Unique station count and the top 10 most popular stations with their counts.

4.3 Job 2: Finding Busiest Hours for Top Stations

This job identifies the busiest hours for the top 10 most popular stations (determined by Job 1) using Hadoop's Distributed Cache feature.

4.3.1 Preparing Data for Distributed Cache

The list of top 10 popular stations needs to be provided to Job 2 via the Distributed Cache.

1. Create a local file containing the names of the top 10 stations:

```
hdfs dfs -cat popular_stations_output/part-r-00000 | sort -t$'\t' -k2,2nr | \
head -n 10 | awk -F'\t' '{print $1}' > /tmp/top_stations.txt
```

2. Create a directory on HDFS for cache files and upload the station list:

```
hdfs dfs -mkdir -p job2_cache_data
hdfs dfs -put tmp/top_stations.txt job2_cache_data/top_stations.txt
```

4.3.2 Compiling and Packaging Job 2 (busiestHour.jar)

Follow a similar process as for Job 1:

1. Ensure Hadoop classpath is set: `export HADOOP_CLASSPATH=$(hadoop classpath)`
2. Create a directory for compiled class files:

```
mkdir classes_busiest_hour
```

3. Compile the Java source files for the Busiest Hour job (adjust filenames as necessary):

```
javac -cp $HADOOP_CLASSPATH -d classes_busiest_hour \
BusiestHourDriver.java BusiestHourMapper.java BusiestHourReducer.java
```

4. Create the JAR file `busiestHour.jar`:

   ```
   jar -cvf busiestHour.jar -C classes_busiest_hour .
   ```

   This creates `busiestHour.jar` in the current directory (`Hadoop_MapReduce`).

5. (Optional) Verify the JAR contents: `jar -tf busiestHour.jar`

Note: If a pre-compiled `busiestHour.jar` is available, these steps can be skipped.

4.3.3 Running Job 2 and Retrieving Results

1. Execute the MapReduce job, providing the cache file path:

   ```
   hadoop jar busiestHour.jar BusiestHourDriver popular_stations_input \
   busiest_hour_output job2_cache_data/top_stations.txt
   ```

   The input is the same main dataset, output is to `/busiest_hour_output`, and the third argument is the HDFS path to the cached file.

2. View the output (this may show intermediate logging from the job):

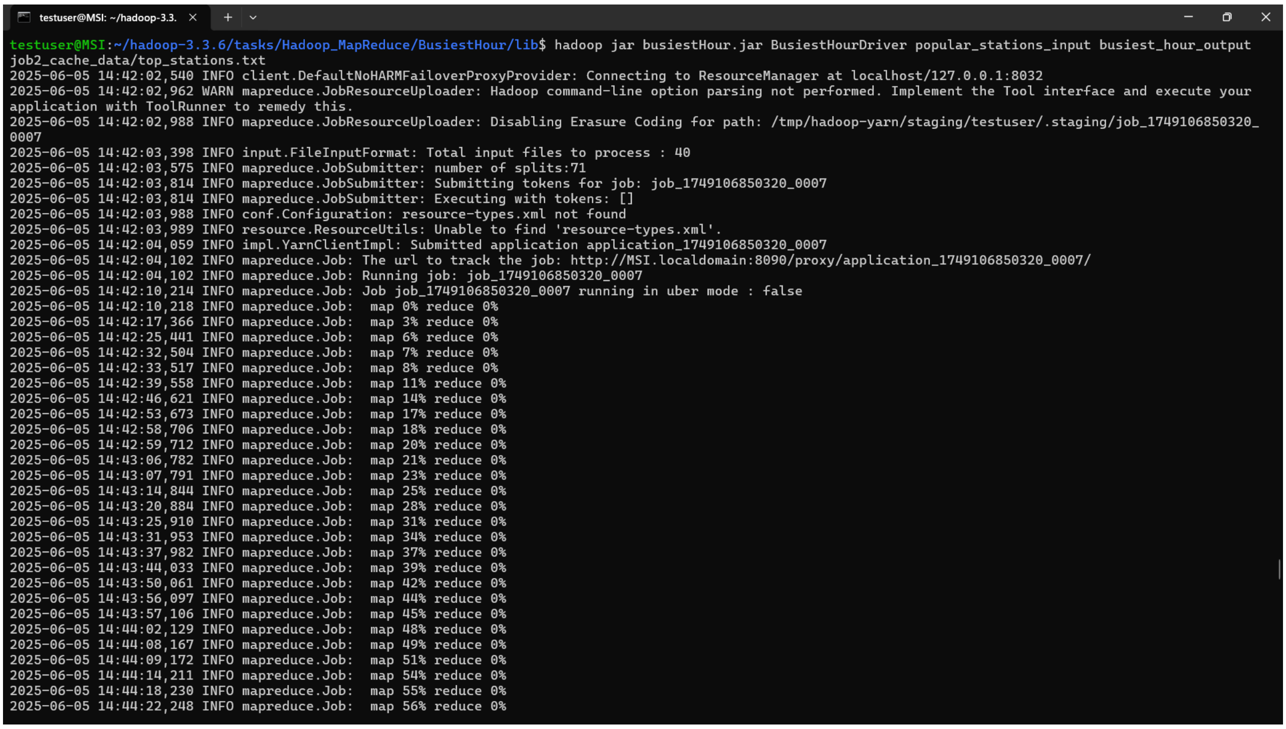
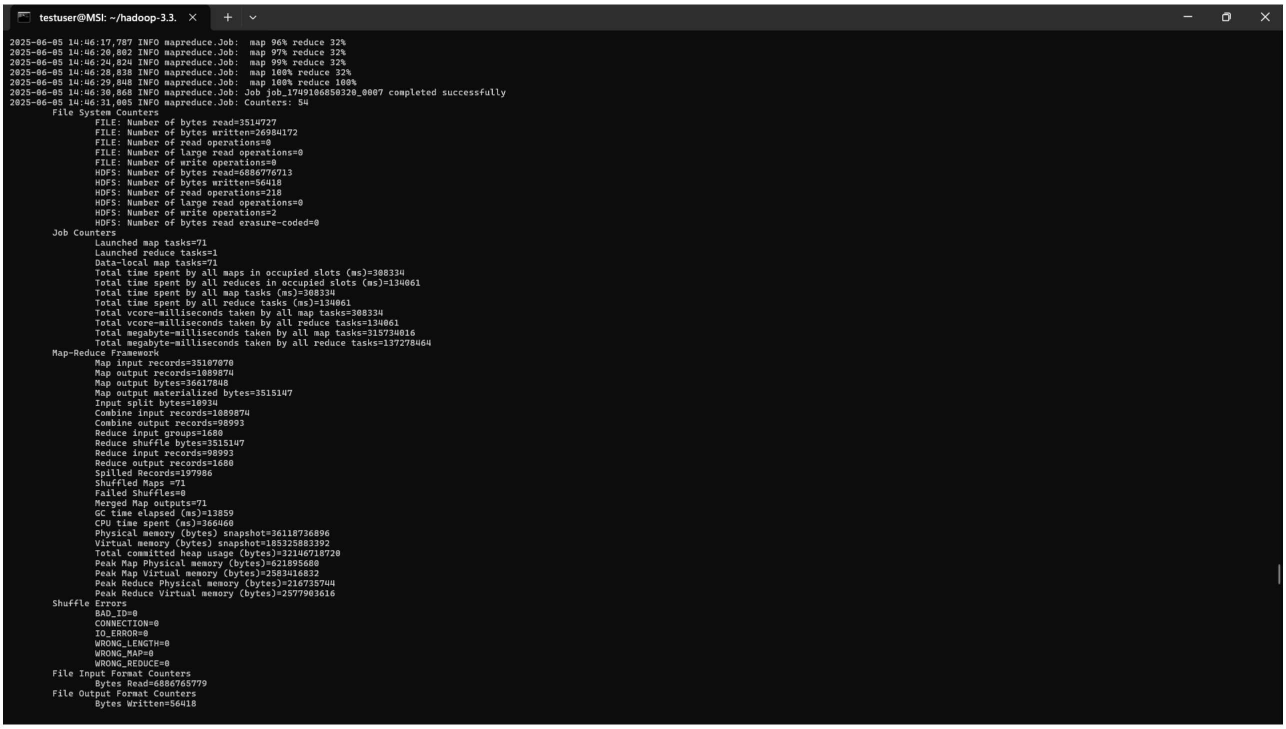


Figure 7: MapReduce job execution log/status for Job 2 (Part 1).

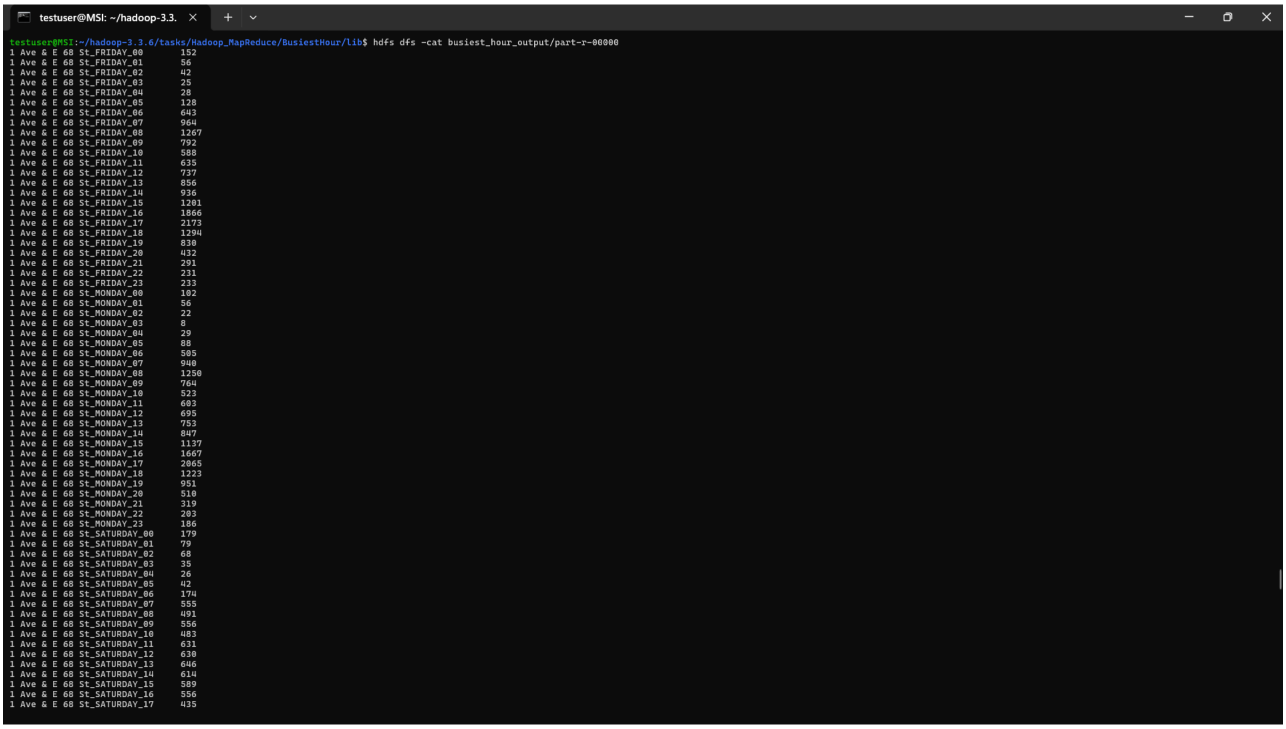


```
2025-06-05 14:46:17,787 INFO mapreduce.Job:  map 96% reduce 32%
2025-06-05 14:46:20,802 INFO mapreduce.Job:  map 97% reduce 32%
2025-06-05 14:46:24,824 INFO mapreduce.Job:  map 99% reduce 32%
2025-06-05 14:46:28,838 INFO mapreduce.Job:  map 100% reduce 32%
2025-06-05 14:46:29,848 INFO mapreduce.Job:  map 100% reduce 100%
2025-06-05 14:46:30,868 INFO mapreduce.Job: Job job_1749106850320_0007 completed successfully
2025-06-05 14:46:31,005 INFO mapreduce.Job: Counters: 54
        File System Counters
                FILE: Number of bytes read=3514727
                FILE: Number of bytes written=26984172
                FILE: Number of read operations=0
                FILE: Number of large read operations=0
                FILE: Number of write operations=0
                HDFS: Number of bytes read=6886776713
                HDFS: Number of bytes written=56418
                HDFS: Number of read operations=218
                HDFS: Number of large read operations=0
                HDFS: Number of write operations=2
                HDFS: Number of bytes read erasure-coded=0
        Job Counters
                Launched map tasks=71
                Launched reduce tasks=1
                Data-local map tasks=71
                Total time spent by all maps in occupied slots (ms)=308334
                Total time spent by all reduces in occupied slots (ms)=134061
                Total time spent by all map tasks (ms)=308334
                Total time spent by all reduce tasks (ms)=134061
                Total vcore-milliseconds taken by all map tasks=308334
                Total vcore-milliseconds taken by all reduce tasks=134061
                Total megabyte-milliseconds taken by all map tasks=315734016
                Total megabyte-milliseconds taken by all reduce tasks=137278464
        Map-Reduce Framework
                Map input records=35107070
                Map output records=1089874
                Map output bytes=36617848
                Map output materialized bytes=3515147
                Input split bytes=10934
                Combine input records=1089874
                Combine output records=98993
                Reduce input groups=1680
                Reduce shuffle bytes=3515147
                Reduce input records=98993
                Reduce output records=1680
                Spilled Records=197986
                Shuffled Maps =71
                Failed Shuffles=0
                Merged Map outputs=71
                GC time elapsed (ms)=13859
                CPU time spent (ms)=366460
                Physical memory (bytes) snapshot=36118736896
                Virtual memory (bytes) snapshot=185325883392
                Total committed heap usage (bytes)=32146718720
                Peak Map Physical memory (bytes)=621895680
                Peak Map Virtual memory (bytes)=2583416832
                Peak Reduce Physical memory (bytes)=216735744
                Peak Reduce Virtual memory (bytes)=2577903616
        Shuffle Errors
                BAD_ID=0
                CONNECTION=0
                IO_ERROR=0
                WRONG_LENGTH=0
                WRONG_MAP=0
                WRONG_REDUCE=0
        File Input Format Counters
                Bytes Read=6886765779
        File Output Format Counters
                Bytes Written=56418
```

Figure 8: MapReduce job execution log/status for Job 2 (Part 2).

3. Display the contents of the output file:

```
hdfs dfs -cat busiest_hour_output/part-r-00000
```



```
testuser@MSI:~/hadoop-3.3.6/tasks/Hadoop_MapReduce/BusiestHour/lib$ hdfs dfs -cat busiest_hour_output/part-r-00000
1 Ave & E 68 St_FRIDAY_00       152
1 Ave & E 68 St_FRIDAY_01       56
1 Ave & E 68 St_FRIDAY_02       42
1 Ave & E 68 St_FRIDAY_03       25
1 Ave & E 68 St_FRIDAY_04       28
1 Ave & E 68 St_FRIDAY_05       128
1 Ave & E 68 St_FRIDAY_06       643
1 Ave & E 68 St_FRIDAY_07       964
1 Ave & E 68 St_FRIDAY_08       1267
1 Ave & E 68 St_FRIDAY_09       792
1 Ave & E 68 St_FRIDAY_10       588
1 Ave & E 68 St_FRIDAY_11       635
1 Ave & E 68 St_FRIDAY_12       737
1 Ave & E 68 St_FRIDAY_13       856
1 Ave & E 68 St_FRIDAY_14       936
1 Ave & E 68 St_FRIDAY_15       1201
1 Ave & E 68 St_FRIDAY_16       1866
1 Ave & E 68 St_FRIDAY_17       2173
1 Ave & E 68 St_FRIDAY_18       1294
1 Ave & E 68 St_FRIDAY_19       830
1 Ave & E 68 St_FRIDAY_20       432
1 Ave & E 68 St_FRIDAY_21       291
1 Ave & E 68 St_FRIDAY_22       231
1 Ave & E 68 St_FRIDAY_23       233
1 Ave & E 68 St_MONDAY_00       102
1 Ave & E 68 St_MONDAY_01       56
1 Ave & E 68 St_MONDAY_02       22
1 Ave & E 68 St_MONDAY_03       8
1 Ave & E 68 St_MONDAY_04       29
1 Ave & E 68 St_MONDAY_05       88
1 Ave & E 68 St_MONDAY_06       505
1 Ave & E 68 St_MONDAY_07       940
1 Ave & E 68 St_MONDAY_08       1250
1 Ave & E 68 St_MONDAY_09       764
1 Ave & E 68 St_MONDAY_10       523
1 Ave & E 68 St_MONDAY_11       603
1 Ave & E 68 St_MONDAY_12       695
1 Ave & E 68 St_MONDAY_13       753
1 Ave & E 68 St_MONDAY_14       847
1 Ave & E 68 St_MONDAY_15       1137
1 Ave & E 68 St_MONDAY_16       1667
1 Ave & E 68 St_MONDAY_17       2065
1 Ave & E 68 St_MONDAY_18       1223
1 Ave & E 68 St_MONDAY_19       951
1 Ave & E 68 St_MONDAY_20       510
1 Ave & E 68 St_MONDAY_21       319
1 Ave & E 68 St_MONDAY_22       203
1 Ave & E 68 St_MONDAY_23       186
1 Ave & E 68 St_SATURDAY_00     179
1 Ave & E 68 St_SATURDAY_01     79
1 Ave & E 68 St_SATURDAY_02     68
1 Ave & E 68 St_SATURDAY_03     35
1 Ave & E 68 St_SATURDAY_04     26
1 Ave & E 68 St_SATURDAY_05     42
1 Ave & E 68 St_SATURDAY_06     174
1 Ave & E 68 St_SATURDAY_07     555
1 Ave & E 68 St_SATURDAY_08     491
1 Ave & E 68 St_SATURDAY_09     556
1 Ave & E 68 St_SATURDAY_10     483
1 Ave & E 68 St_SATURDAY_11     631
1 Ave & E 68 St_SATURDAY_12     630
1 Ave & E 68 St_SATURDAY_13     646
1 Ave & E 68 St_SATURDAY_14     614
1 Ave & E 68 St_SATURDAY_15     589
1 Ave & E 68 St_SATURDAY_16     556
1 Ave & E 68 St_SATURDAY_17     435
```

Figure 9: Sample output of Job 2, showing station-hour combinations and their counts.

4.3.4 Analyzing Job 2 Results

Get the top 10 busiest station-hour combinations:

```
hdfs dfs -cat busiest_hour_output/part-r-00000 | sort -t$'\t' -k2,2nr | head -n 10
```

Figure 10: Top 10 busiest hours for the top 10 popular stations.

5 Expanding the Model

5.1 Dashboard Integration

To visualize the results of MapReduce jobs (e.g., popular stations, busiest times):

1. **Data Serving Layer:** After MapReduce jobs complete, their aggregated output (typically from `part-r-` files in HDFS) should be transferred to a database for dashboard querying.

   The custom script or Apache spark jobs can be used in order to perform above improvement easily.

2. **Visualization Tools:** Show the analytics in the dashboard

   The Power BI, Grafana with Elastic search or custom frontend can be used to show the result.

5.2 Continuous and Autonomous Job Triggering

To keep the analysis up-to-date as new data arrives(e.g., daily or hourly CSV files):

1. **Workflow Orchestration:** Employ a workflow management system to schedule and monitor the data pipeline.

   Simple cron jobs or Apache Airflow can be used to achieve this.

2. **Incremental Data Processing Strategy:** To maintain up-to-date analysis as new data arrives (e.g., daily CSV files), an automated pipeline is essential. This involves structuring raw input data in HDFS by time partitions (e.g. /raw_data/year=YYYY/month=MM/day=DD/) and choosing a processing scope: either full reprocessing of the entire dataset, which is simpler but less efficient, or more complex incremental processing where jobs only act on new data partitions, with results merged into existing aggregates. Regardless of the processing scope, after each scheduled pipeline run, the aggregated results in the serving database must be updated, either by overwriting existing data or by performing update operations for incremental changes.

6 Conclusion

This project successfully demonstrated the use of Hadoop MapReduce for analyzing large-scale bike-sharing data. Job 1 identified the most frequently used Citi Bike stations, providing insights into high-traffic areas. Job 2, utilizing the Distributed Cache, further pinpointed the peak operational hours for these popular stations. The results, such as the top 10 popular stations and their busiest hours, offer valuable information for optimizing bike distribution, station capacity planning, and enhancing user experience in New York City's bike-sharing system. The methodology showcases the power of distributed computing for deriving actionable intelligence from extensive datasets.