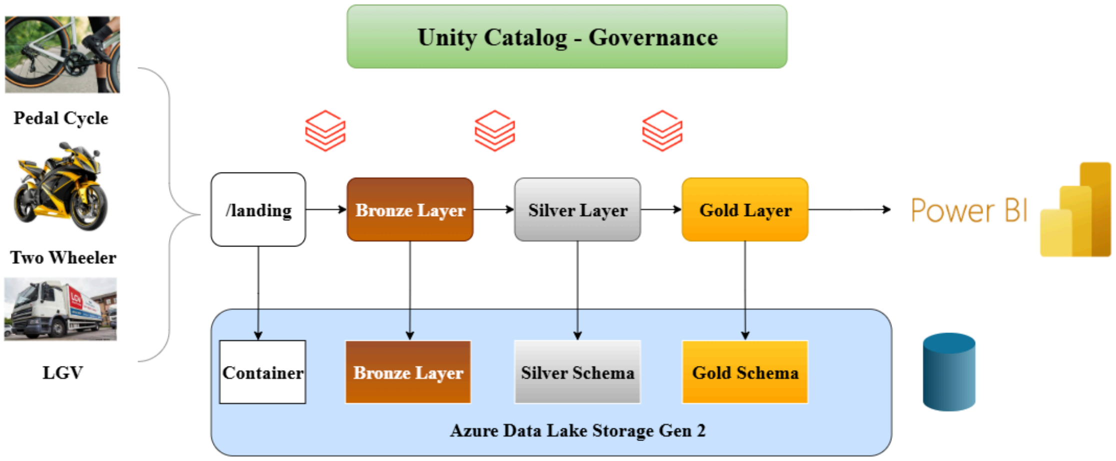


End-to-End Azure Databricks Lakehouse – Traffic & Roads Analytics

Tech Stack	ADLS Gen2 Azure Databricks Power BI Desktop & Service Python Unity Catalog
Brief Summary	**Built an end-to-end Azure Databricks lakehouse** on ADLS with **Landing→Bronze→Silver→Gold Delta tables**, using **incremental ingestion** and **new-record-only** transforms → **Result:** single source of truth & **Gold** ready for reporting/data science.
Link	https://github.com/khanhmdinh/khanhmdinh.github.io/tree/main/01_End-to-End%20Azure%20Databricks%20Lakehouse%20%E2%80%93%20Traffic%20%26%20Roads%20Analyt

Navigation bar

Summary

Scope of Work

- **Datasets:** `traffic`, `roads`.
- **Storage:** Raw files staged in **ADLS Gen2 Landing** (manual drop to simulate ETL).
- **Processing: Databricks notebooks** (PySpark) implement **incremental ingestion** and transformations.
- **Medallion: Landing → Bronze → Silver → Gold** (all **Delta** tables).
- **Governance: Unity Catalog** for catalogs/schemas/tables and permissions.
- **Consumption: Power BI Service** report on Gold.
- **Mode:** Batch project that leverages **Structured Streaming/Auto Loader concepts** for **incremental** behavior (still run in batch for this course).

Deliverables

- **Delta tables:** `bronze.*`, `silver.*`, `gold.*` for **traffic** and **roads**.
- **Databricks notebooks:** for incremental ingestion and Silver/Gold transformations.
- **Power BI report:** built on **Gold** datasets.
- **Unity Catalog artifacts:** catalog/schema/table definitions and permissions.

Key Behaviors & Principles

- **Incremental by design:** Only new files/records move forward each run; **no full reloads**.
- **Idempotent transforms:** Silver logic re-runnable without duplication.
- **Separation of concerns:** Bronze = raw truth, Silver = cleaned/business logic, Gold = serve.

Table of Contents

Summary
Table of Contents
Data Assessment
- **Dataset Information**

I. Project Architecture
II. Landing to Bronze Layer with Auto Loader
- 1. Overview
- 2. What I built
- 3. Key Design Decisions
- 4. Implementation Sketch
- 5. What I validated
- 6. How it works
- 7. Operationalization
- 8. Outputs

III. Bronze to Silver Layer with Incremental DQ & Business Transforms
- 1. Objective
- 2. What I built
- 3. Design Highlights
- 4. Implementation Sketch
- 5. Data Quality
- 6. Business Transformations
- 7. Outputs

IV. Gold Layer: Transformations & Curated Tables
- 1. Objective
- 2. Inputs
- 3. Gold transforms (minimal, transcript-aligned)
- 4. Implementation Sketch
- 5. Outputs

V. Orchestration with Azure Databricks Workflows
- 1. Goal
- 2. What I orchestrated
- 3. Key design choices
- 4. DAG Screenshot
- 5. Outputs

Insights & Actions
- 1) Network Pressure → Hotspot Playbook
- 2) Peak Windows → Time-Aligned Operations
- 3) Investment Targeting → Spend Follows Pressure
- 4) EV Overlay → Charger Placement Where It Matters
- 5) Proven, Auditable Incrementality → Operational Trust

Data Assessment

Dataset Information

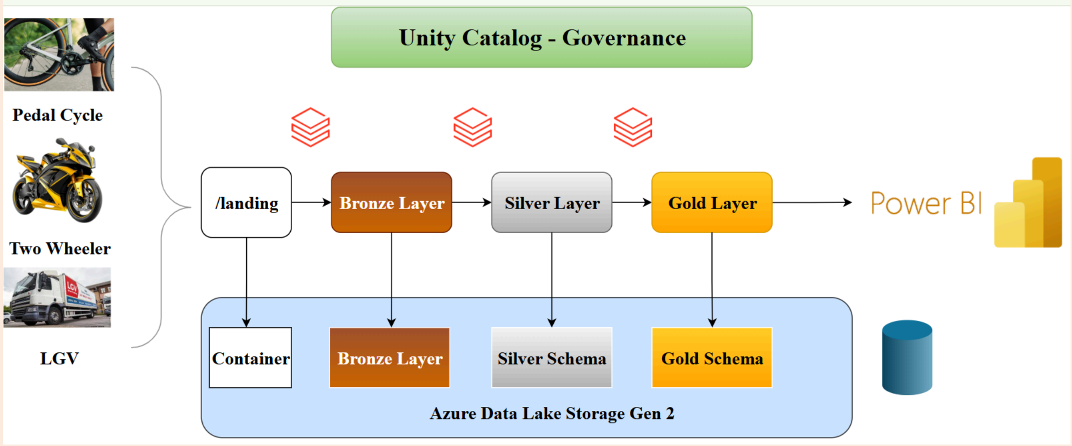
Dataset 1: Raw Traffic counts dataset (count the types of vehicles that flowed past in a given period in day)

Category	Column Name	Description
Vehicle flow point	Record ID	Uniquely identifies a record
	Count Point ID	A unique reference for the road link
	Direction of Travel	Diretion of travel
	Year	Year it happened
	Count Date	The day when the actual count took place
Travel information of vehicle	Hour	Hour 7 represents from 7 AM to 8 AM, and 17 tells from 5 PM to 6 PM
	Region ID	Website region identifier
	Region Name	The name of the Region that travel took place
	Local Authority Name	Local authority that region
	Road Name	This is the road name (for instance M25 or A3)
	Road Category ID	Uniquely identifies road ID
	Start junction Road Name	The road name of the start function of the link
	End junction Road Name	The road name of the end function of the link
	Latitude	Latitude of the Location
	Longtitude	Longtitude of the Location
	Total Link Length (km)	Total length of the nerwork road link
Count of types of vehicles	Pedal Cycles	Counts of pedal cycles
	Two Wheeler Motor Vehicles	Counts of two wheeled motor vehicles
	Car and Taxis	Counts of cars and taxis
	Buses and Coaches	Counts of buses and coaches
	LGV (Large Goods Vehicles)	Counts of LGV Type
	HGV (Heavy Good Vehicles)	Counts of HGV Type
	EV Car	Counts of EV Car
	EV Bike	Counts of EV Bikes

Dataset 2: Raw Roads dataset (the types of roads that got traveled)

Column Name	Description
Road ID	Ordinal number
Road Category ID	Uniquely identifies road ID
Road Category	The type of road
Region ID	Website region identifier
Region Name	The name of the Region that travel took place
Total Link Length (km)	Total length of the nerwork road link (km)
Total Link Length (mile)	Total length of the nerwork road link (mile)
Total Motor Vehicles	Counts the total motor vehicles travelled in the particular road in a year

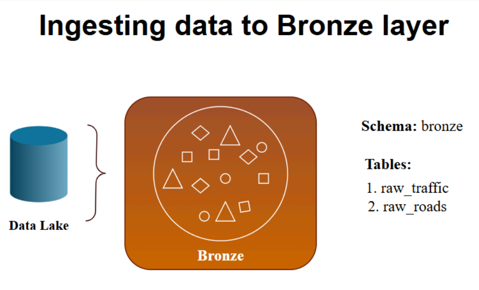
I. Project Architecture



II. Landing to Bronze Layer with Auto Loader

1. Overview

Implemented a **reliable landing-to-Bronze ingestion pattern** on **Azure Databricks** using **Auto Loader (cloudFiles)**. The pipeline reads CSV files from a **Landing** container, enforces an **explicit schema**, adds an `extract_time` lineage column, and writes to **Bronze Delta tables** with proper **checkpointing** and **batch-style triggers** (`availableNow`).



2. What I built

- **Read function** for `raw_traffic` **&** `raw_roads` (Auto Loader, CSV, explicit schema).
- **Write function** to append into `bronze_raw_traffic` & `bronze.raw_roads` (Delta) with `availableNow` trigger.
- Independent **schemaLocation** and **checkpointLocation** to avoid cross-contamination with traffic.
- Added **operational observability** (query names, checkpoints, and run messages).

3. Key Design Decisions

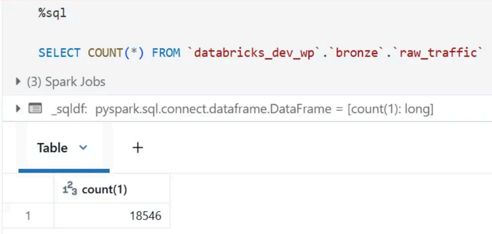
- **Auto Loader (cloudFiles)** for scalable file discovery and schema management.
- **Explicit schema** (StructType) instead of inference for stability and predictable evolution.
- **Separate state for each stream**:
  - Traffic: `<checkpoints>/raw_traffic_load/{schema_info|checkpoint}`
  - Roads: `<checkpoints>/raw_roads_load/{schema_info|checkpoint}`
- **Batch-style execution** with `trigger(availableNow=True)` so the stream **starts → ingests → stops**.
- **Lineage**: `extract_time = current_timestamp()` for auditing and validating incremental behavior.
- **No secrets / no hard-coding**: resolve storage URLs via **Unity Catalog External Locations** or widgets.
- **No extra derived columns** for roads (kept the schema minimal as per requirements).
- **Parameterization**: `env` (dev/test/prod) and UC **External Locations** for URLs (no hard-coding).

4. Implementation Sketch

02+Load+to+Bronze.ipynb

5. What I validated

- **Incremental behavior**: After uploading a new CSV into `landing/raw_traffic`, re-running the notebook (with `trigger(availableNow=True)`) **doubled** the Bronze row count from **18,546 → 37,092.**



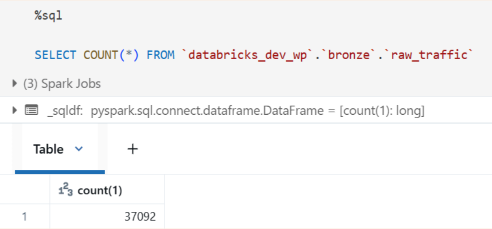
```
%sql

SELECT COUNT(*) FROM `databricks_dev_wp`.`bronze`.`raw_traffic`
```

(3) Spark Jobs

_sqldf: pyspark.sql.connect.dataframe.DataFrame = [count(1): long]

	count(1)
1	18546



```
%sql

SELECT COUNT(*) FROM `databricks_dev_wp`.`bronze`.`raw_traffic`
```

(3) Spark Jobs

_sqldf: pyspark.sql.connect.dataframe.DataFrame = [count(1): long]

	count(1)
1	37092

- **Lineage proof**: The `extract_time` column differs between pre-existing and newly ingested records, proving micro-batch separation.
- **No reprocessing**: Auto Loader consulted the **checkpoint** and skipped previously ingested files—no duplicates.

6. How it works

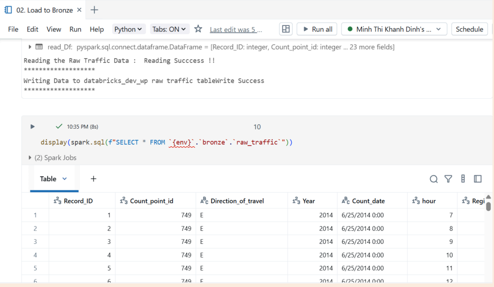
- **Discovery & schema:** `readStream.format("cloudFiles").option("cloudFiles.format","csv").option("cloudFiles.schemaLocation", ...)`
- **State management:** `checkpointLocation` stores progress (last processed file offset), enabling **exactly-once** semantics on retries.
- **Batch-style runs:** `trigger(availableNow=True)` reads the current backlog, **ingests, then stops**—ideal for scheduled daily/bi-daily loads.
- **Audit:** `extract_time = current_timestamp()` stamped at ingestion to verify run boundaries and support operational forensics.

7. Operationalization

- **Scheduling**: Use Databricks Jobs or an external orchestrator (e.g., ADF) to run at **08:00 / 20:00** or **file-arrival triggers**.
- **Monitoring**: Observe `queryName` in Spark UI; track row deltas and distinct `extract_time` values post-run.
- **Recovery**: On cluster restarts, **re-initialize** external-location variables; checkpoint ensures idempotent continuation.

8. Outputs

- **Both** Bronze tables populated: `bronze.raw_traffic` and `bronze.raw_roads`.


02. Load to Bronze
File Edit View Run Help Python Tabs: ON Last edit was 5 ... Run all Minh Thi Khanh Dinh's ... Schedule
Table

read_Df: pyspark.sql.connect.dataframe.DataFrame = [Record_ID: integer, Count_point_id: integer ... 23 more fields]

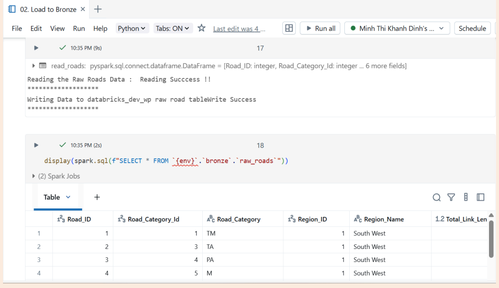
```
Reading the Raw Traffic Data :  Reading Succcess !!
******************
Writing Data to databricks_dev_wp raw traffic tableWrite Success
******************
```

10:35 PM (8s) 10

```
display(spark.sql(f"SELECT * FROM `{env}`.`bronze`.`raw_traffic`"))
```

(2) Spark Jobs

	Record_ID	Count_point_id	Direction_of_travel	Year	Count_date	hour	Regi
1	1	749	E	2014	6/25/2014 0:00	7	
2	2	749	E	2014	6/25/2014 0:00	8	
3	3	749	E	2014	6/25/2014 0:00	9	
4	4	749	E	2014	6/25/2014 0:00	10	
5	5	749	E	2014	6/25/2014 0:00	11	
6	6	749	E	2014	6/25/2014 0:00	12	


02. Load to Bronze
File Edit View Run Help Python Tabs: ON Last edit was 4 ... Run all Minh Thi Khanh Dinh's ... Schedule
Table

10:35 PM (9s) 17

read_roads: pyspark.sql.connect.dataframe.DataFrame = [Road_ID: integer, Road_Category_Id: integer ... 6 more fields]

```
Reading the Raw Roads Data :  Reading Succcess !!
******************
Writing Data to databricks_dev_wp raw road tableWrite Success
******************
```

10:35 PM (2s) 18

```
display(spark.sql(f"SELECT * FROM `{env}`.`bronze`.`raw_roads`"))
```

(2) Spark Jobs

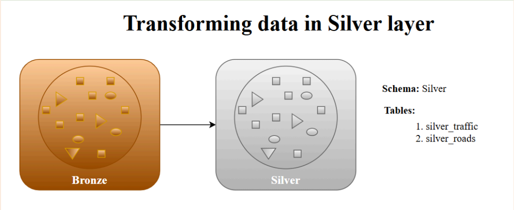
	Road_ID	Road_Category_Id	Road_Category	Region_ID	Region_Name	Total_Link_Len
1	1	1	TM	1	South West	
2	2	3	TA	1	South West	
3	3	4	PA	1	South West	
4	4	5	M	1	South West	

- **Zero custom incremental logic**—Auto Loader + checkpoints delivered **reliable, incremental Bronze loads**.
- **Auditable runs** via `extract_time`; easy to prove what arrived when.
- Ready for **Bronze → Silver** quality rules and downstream modeling.

III. Bronze to Silver Layer with Incremental DQ & Business Transforms

1. Objective

Promote **Bronze Delta** tables—`raw_traffic` and `raw_roads`—to curated **Silver** tables using **Structured Streaming over Delta**. Process **only newly arrived rows** per run, enforce **data quality**, and apply **dataset-specific business logic** that makes the data analysis-ready.



2. What I built

- Built the **Silver-Traffic** notebook and parameterized it by **environment** (dev/test/prod).
- Implemented **streaming reads from Delta** for incremental transforms (no reprocessing).
- Codified **duplicate removal**, **null handling**, and **dataset-specific features**.
- Wrote clean, append-only **writeStream → Silver** with checkpoints and run observability.

3. Design Highlights

- **Defense-in-depth DQ:**
  - **Duplicates:** `dropDuplicates()` on stream to prevent downstream cardinality issues.
  - **NULL:** Replace **string** nulls with `"Unknown"` and **numeric** nulls with `0` using `fillna`.
  - **Renaming Columns:** replacing with an underscore quoting if the dataset is coming without having any of the underscores
  - **Creating Electric Vehicles Count:** `EV_Bike` → `Electric_Vehicles_Count` / `Motor_Vehicles_Count`
- **Business features:**
  - `electric_vehicles_count = ev_car + ev_bike`
  - `motor_vehicles_count = cars + buses + lgv + hgv + electric_vehicles_count`
  - `transform_time = current_timestamp()` for lineage & auditability.

4. Implementation Sketch

03+Silver+Traffic+Transformations.ipynb

04. Common notebook.ipynb

05+Silver+Road+Transformations.ipynb

5. Data Quality

- **Duplicates:** Remove using `dropDuplicates()` to protect downstream keys/cardinality.
- **Nulls:**
  - String columns → replace with `"Unknown"`
  - Numeric columns → replace with `0`

- **Column hygiene:** Column names use underscores (handled during Bronze ingestion via explicit schemas).
- **Lineage:** Add `transform_time = current_timestamp()` in Silver for auditability.

6. Business Transformations

- **Traffic → Silver**
  - `electric_vehicles_count = ev_car + ev_bike`
  - `motor_vehicles_count = cars + buses + lgv + hgv + electric_vehicles_count`
- **Roads → Silver**
  - `road_category_name` from `road_category` code (e.g., `TO → "Class A Trunk Road"`, `TM → "Class A Trunk Motor"`, `PA → "Class A Principal Road"`, `PM → "Motorway"`, `M → "Class B Road"`, else `NA`)
  - `road_type` from `road_category_name` (`LIKE '%Class A%' → "Major"`, `LIKE '%Class B%' → "Minor"`, else `NA`)

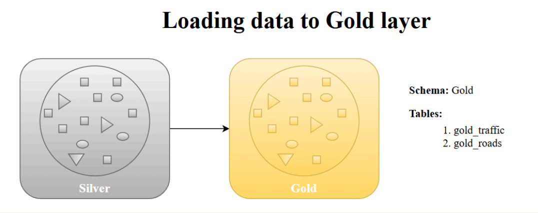
7. Outputs

- **Silver table created:**
  - **`silver.silver_traffic`**: cleaned, deduped, with `electric_vehicles_count`, `motor_vehicles_count`, `transform_time`.
  - **`silver.silver_roads`**: cleaned, deduped, with `road_category_name`, `road_type`, `transform_time`.
- **Incremental by design:** Only new Bronze rows are transformed per run (micro-batches + checkpoints).

IV. Gold Layer: Transformations & Curated Tables

1. Objective

Read curated **Silver** tables, apply **light, business-oriented transforms**, and publish **Gold** tables for reporting. Keep processing **incremental** and **idempotent** using Structured Streaming over Delta with checkpointing.



2. Inputs

- `silver.silver_traffic`: already cleaned, includes `motor_vehicles_count`, `electric_vehicles_count`, `transform_time`.
- `silver.silver_roads`: already cleaned, includes `road_category_name`, `road_type`, `length_km`, `transform_time`.

3. Gold transforms (minimal, transcript-aligned)

- **Traffic:**
  - `vehicle_intensity` (a.k.a. density) = `motor_vehicles_count / length_km`.
  - `load_time = current_timestamp()` (lineage at Gold load).
- **Roads:**
  - No new business calc required here; add `load_time` for lineage.

4. Implementation Sketch

06+Final+Transformations.ipynb

5. Outputs

- **Created Gold tables:**
  - `${env}.gold.gold_traffic` with `vehicle_intensity` & `load_time`.
  - `${env}.gold.gold_roads` with `load_time`.
- **Operational posture:** Incremental, checkpointed, and environment-aware; ready to power semantic models and BI.

V. Orchestration with Azure Databricks Workflows

1. Goal

Automate the **end-to-end pipeline** (Landing → Bronze → Silver → Gold) by chaining our notebooks in a **dependency-aware** job, parameterized by environment and backed by checkpoints for incremental, idempotent runs.

2. What I orchestrated

Task graph (DAG) — executed in order on success:

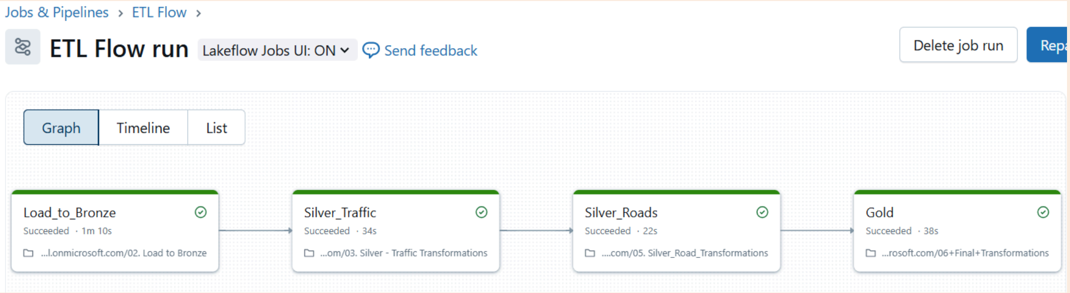
1. **Load to Bronze** — Auto Loader ingests *raw_traffic* and *raw_roads* from Landing → `bronze.*`
2. **Silver: Traffic** — incremental DQ + business transforms → `silver.silver_traffic`
3. **Silver: Roads** — incremental DQ + business transforms → `silver.silver_roads`
4. **Gold: Finalize** — light enrichments → `gold.gold_traffic` , `gold.gold_roads`

> Common / Config notebook is imported at the top of every task to centralize paths, helpers, and conventions:
>
> `%run /Workspace/<path>/common`

3. Key design choices

- **Single-source configuration:** `%run` (same Spark session) exposes **locations** (`landing` , `checkpoints` , `bronze` , `silver` , `gold`) and **utilities (** `remove_dupes` , `handle_nulls`).
- **Environment parameterization:** Each notebook reads `env` via widgets so the Workflow can pass `env=dev|test|prod` .
- **Incremental by default:** Bronze and Silver are **streaming over Delta** with **checkpointed** `writeStream` and `trigger(availableNow=True)` .
- **Failure isolation:** Downstream tasks run **only if predecessors succeed**; failures halt the DAG for fast feedback.

4. DAG Screenshot



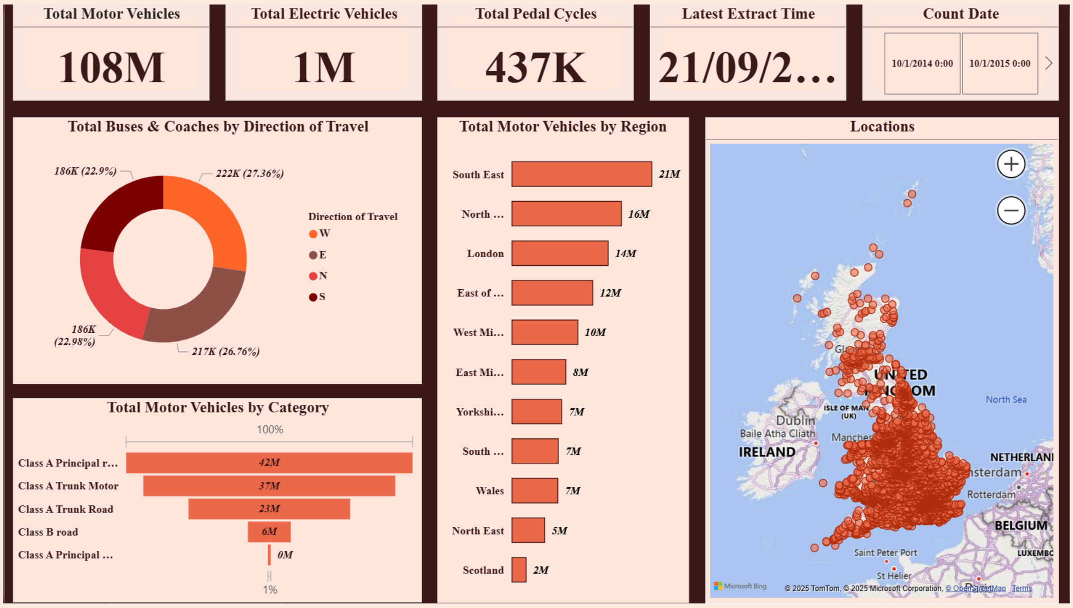
Jobs & Pipelines › ETL Flow ›
ETL Flow run
Lakeflow Jobs UI: ON
Send feedback
Delete job run
Rep
Graph
Timeline
List
Load_to_Bronze
Succeeded · 1m 10s
...l.onmicrosoft.com/02. Load to Bronze
Silver_Traffic
Succeeded · 34s
...om/03. Silver - Traffic Transformations
Silver_Roads
Succeeded · 22s
....com/05. Silver_Road_Transformations
Gold
Succeeded · 38s
...rosoft.com/06+Final+Transformations

5. Outputs

- One-click or scheduled workflows execute the entire **Landing → Bronze → Silver → Gold** flow **reliably**, in minutes on dev.
- After a test run (new files uploaded to Landing), **row counts increased across all layers** and Gold tables reflected new **lineage timestamps** (`extract_time` , `transform_time` , `load_time`), demonstrating incremental behavior end-to-end.

Insights & Actions

View the Live Dashboard: https://app.powerbi.com/reportEmbed?reportId=3febcad3-e7d0-4354-b7b5-531a8d428863&autoAuth=true&ctid=dcca8464-f86f-44ac-a6dd-7032f818fe7b



Total Motor Vehicles	Total Electric Vehicles	Total Pedal Cycles	Latest Extract Time	Count Date
108M	1M	437K	21/09/2…	10/1/2014 0:00 10/1/2015 0:00

1) Network Pressure → Hotspot Playbook

- **What we see:** Gold's `vehicle_intensity` highlights the links with the highest load per kilometre—the true pressure points to act on first.
- **Action:** Rank links by `vehicle_intensity`; treat the **top 5–10%** with a **Hotspot Playbook** (signal retiming, lane priority, incident-response rules).
- **Measure:** Track **p95/median** `vehicle_intensity` on treated links before/after using **Gold** snapshots (keyed by `load_time`).

2) Peak Windows → Time-Aligned Operations

- **What we see:** The traffic schema captures **hourly granularity** (e.g., hour 7 = 7–8 AM), enabling precise identification of peak windows by region/corridor.
- **Action:** Align staffing and **signal timing** to local peaks; schedule maintenance in **off-peak** windows per region.
- **Measure:** Reduction in **peak-window** `vehicle_intensity`; improved maintenance timeliness.

3) Investment Targeting → Spend Follows Pressure

- **What we see: Road categories/types** are derived in **Silver** (e.g., `road_type`), allowing intensity to be compared **per km** by class.
- **Action:** Rebalance **CapEx/Opex** toward categories with **persistently higher intensity/km**; defer lower-pressure segments.
- **Measure: Intensity/km** decreases in prioritized categories over successive Gold refreshes.

4) EV Overlay → Charger Placement Where It Matters

- **What we see:** `electric_vehicles_count` and `motor_vehicles_count` are standardized in **Silver**, enabling **EV share** views across corridors.
- **Action:** Pilot charger placement on **high-adoption, high-pressure** corridors to reduce cruising for charge and support growth.

- **Measure: EV share** uplift and **charger utilization** at pilot sites, without raising local intensity.

5) Proven, Auditable Incrementality → Operational Trust

- **What we proved:** A controlled test **doubled Bronze rows from 18,546 → 37,092** after a new CSV drop; distinct `extract_time` stamps and checkpointing prevented re-ingest/duplicates—validating **incremental, exactly-once** flow through Bronze→Silver→Gold.
- **Action:** Set refresh **SLAs** and add "delta since last load" tiles in the report to reassure stakeholders.
- **Measure:** Consistent **row deltas** and lineage timestamps (`extract_time` / `transform_time` / `load_time`) visible per run.

🌟 **Navigation bar**