Project II: Manufacturing & Product Distribution

VLBA II – System Architectures

Magdeburg Research and Competence Cluster
Workgroup Business Informatics I

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AGENDA

- Introduction
- Detailed Tasks
- Our Approach
- Tools and Technologies Used
- Data Exploration and Cleaning
- Clustering Based on Geographical Location
- Forecasting Product Sales and Materials Required
- Interpretation and Implications of Results

INTRODUCTION

- MWW serves multiple markets with different demands.
- For the future production planning and sales strategy, the profits of the manufactured goods in the past and for the future need to be analyzed.
- Due to potential regional deviations, the forecasts are expected to be presented specifically for each operated market.
- Moreover, the board values rich visualizations of the results.

DETAILED TASKS

- Because of potential regional differences, the existing customer markets need to be clustered based on their geographical location with the help of a machine learning algorithm. Use visualization technologies of the Google Cloud for the presentation of the clusters

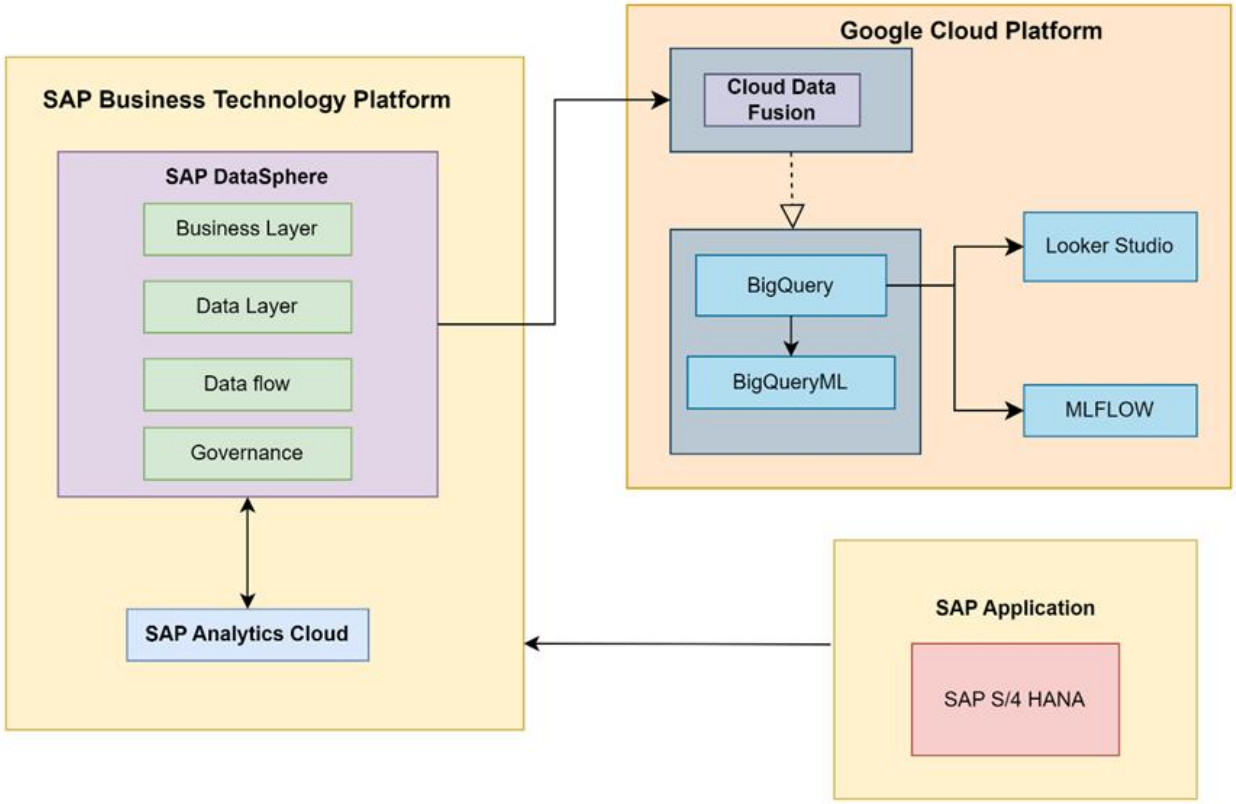
DETAILED TASKS

- Based on the identified clusters, select one sensible market and use data analytics and machine learning models to forecast product sales and required materials to assist management in decision-making for production planning, procurement, and marketing. Use MLflow to orchestrate the Data Science lifecycle
- Interpret and summarize the findings and implications for the business in the form of a dashboard and/or report.

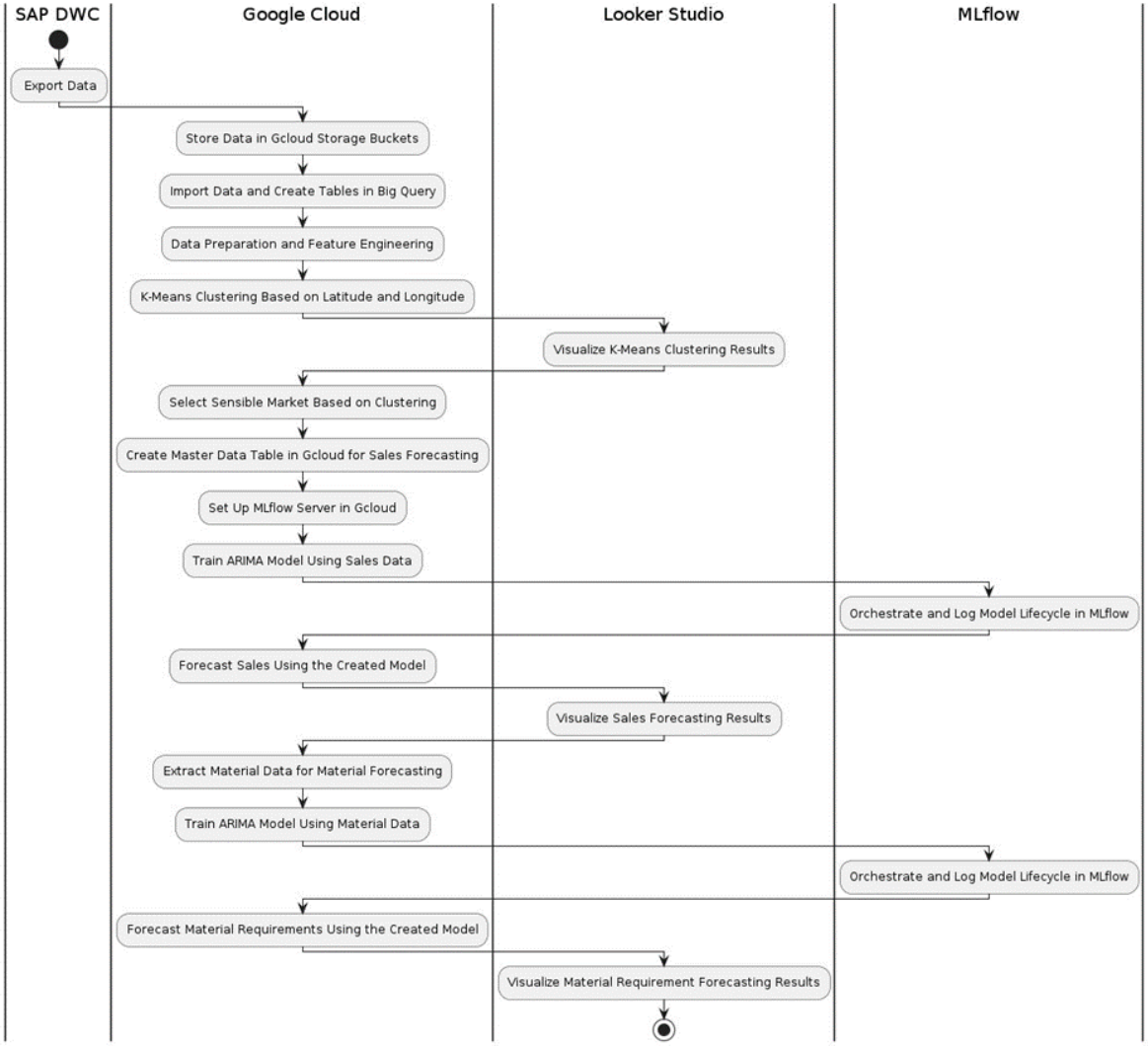
TOOLS AND TECHNOLOGIES USED

- Google Cloud BigQuery
- BigQuery
- BigQuery ML
- MLflow
- Google Cloud Looker Studio

ARCHITECTURE



OUR APPROACH



DATA EXPLORATION AND CLEANING

Given data

- MPD_CustomerAttr: location of customers
- MPD_CustomerText: customer description
- MPD_MaterialAttr: information regarding materials
- MPD_MaterialOrders: past material orders
- MPD_OrderItems: past orders
- MPD_Orders: past orders with customer information
- MPD_ProductAttr: product information
- MPD_ProductMat: required materials for manufacturing
- MPD_ProductText: product names

DATA EXPLORATION AND CLEANING

Data Exploration

- Conducted thorough exploration to understand dataset structure, relationships, and key characteristics.

Data Cleaning

- Imputed mean value for erroneous data in the table MPD-ProductMat for the Amount_Required column

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- Corrected city name in the table ‘MPD-CustomerAttr’ to ensure accurate location-based clustering

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Data Preparation

- Extended the "**MPD_CustomerAttr**" table by adding latitude and longitude columns using the Google Maps Geocoding API for precise geographical analysis.

- The obtained coordinates will be utilized to perform clustering, grouping customers based on geographical proximity for better market segmentation.

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Data Preparation

```
for city in cities:
    geocode_result = gmaps.geocode(city)
    if geocode_result:
        location = geocode_result[0]['geometry']['location']
        results.append({
            'City': city.split(',')[0],
            'Country': city.split(',')[1].strip(),
            'Latitude': location['lat'],
            'Longitude': location['lng']
        })
df = pd.DataFrame(results)
print(df)

df.to_csv('MPD_CustomersAttr_location_Coordinates.csv', index=False)
```

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Data Preparation

```
CREATE OR REPLACE TABLE `vlba-2024-mpd-group-5.MPD_DATA_5.MPD_CustAtt_extended` AS
SELECT
    cust.CustomerId,
    cust.City,
    cust.SalesOrg,
    cust.Country,
    cust.Currency,
    loc.Latitude,
    loc.Longitude,
    ctxt.CustDescr
FROM
    `vlba-2024-mpd-group-5.MPD_DATA_5.MPD-CustomerAttr` AS cust
LEFT JOIN
    `vlba-2024-mpd-group-5.MPD_DATA_5.MPD_CustomersAttr_location_Coordinates` AS loc
ON
    cust.City = loc.City
LEFT JOIN
    `vlba-2024-mpd-group-5.MPD_DATA_5.MPD-CustomerText` AS ctxt
ON
    cust.CustomerId = ctxt.CustomerID;
```

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Clustering

- Algorithm Selection:

  Employed K-Means clustering to segment customer markets based on geographical locations using latitude and longitude coordinates, chosen for its simplicity, efficiency, scalability, and interpretability.

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Clustering

- Implementation:

  Utilized BigQuery ML to execute K-Means clustering with k=4, determined through iterative testing to group customers into four distinct, strategically significant geographical clusters.

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Clustering

```
1  CREATE OR REPLACE MODEL `vlba-2024-mpd-group-5.MPD_DATA_5.Cust_Markt_clustering`
2  OPTIONS(
3    model_type='kmeans',
4    num_clusters=4,
5    standardize_features=true
6  ) AS
7  SELECT
8    SAFE_CAST(Latitude AS FLOAT64) AS Latitude,
9    SAFE_CAST(Longitude AS FLOAT64) AS Longitude
10 FROM
11   `vlba-2024-mpd-group-5.MPD_DATA_5.MPD_CustAtt_extended`;
12
```

CLUSTERING BASED ON GEOGRAPHICAL LOCATION

Visualization in Looker Studio

Geographical Customer Segmentation

REGION BASED CLUSTERS

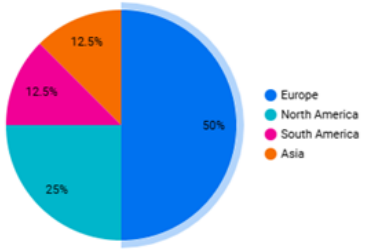
Cluster_name Asia North America South America Europe

CUSTOMER COUNT

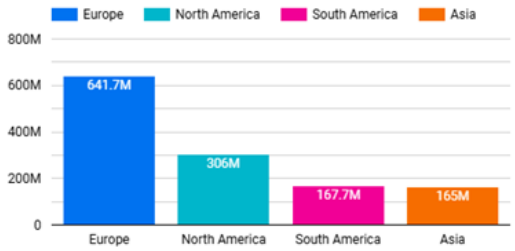
Record Count

24

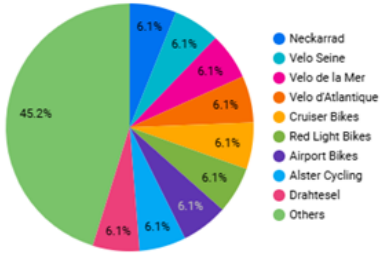
REGION BASED CUSTOMER SEGMENTATION



REVENUE PER REGION



REVENUE SHARE PER CUSTOMER



FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Sensible Market Selection

- Data-driven approach that considers two metrics:
  - Customer Reach
  - Revenue Potential

- Custom queries to calculate the metrics

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Sensible Market Selection

- Customer Reach

Query results

JOB INFORMATION | RESULTS | CHART | JSON | EXECUTION DETAILS

Row	Region	TotalCustomers
1	South America	3
2	Asia	3
3	Europe	12
4	North America	6

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Sensible Market Selection

- Revenue Potential

JOB INFORMATION | RESULTS | CHART | JSON

Row	Region	TotalRevenue
1	South America	167685012.9099...
2	Asia	165033634.1300...
3	Europe	641657746.1000...
4	North America	306039037.1

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Sensible Market Selection

- Based on the results of our analysis, we selected the **Europe** cluster as it had the highest number of customers and generated the highest revenue.

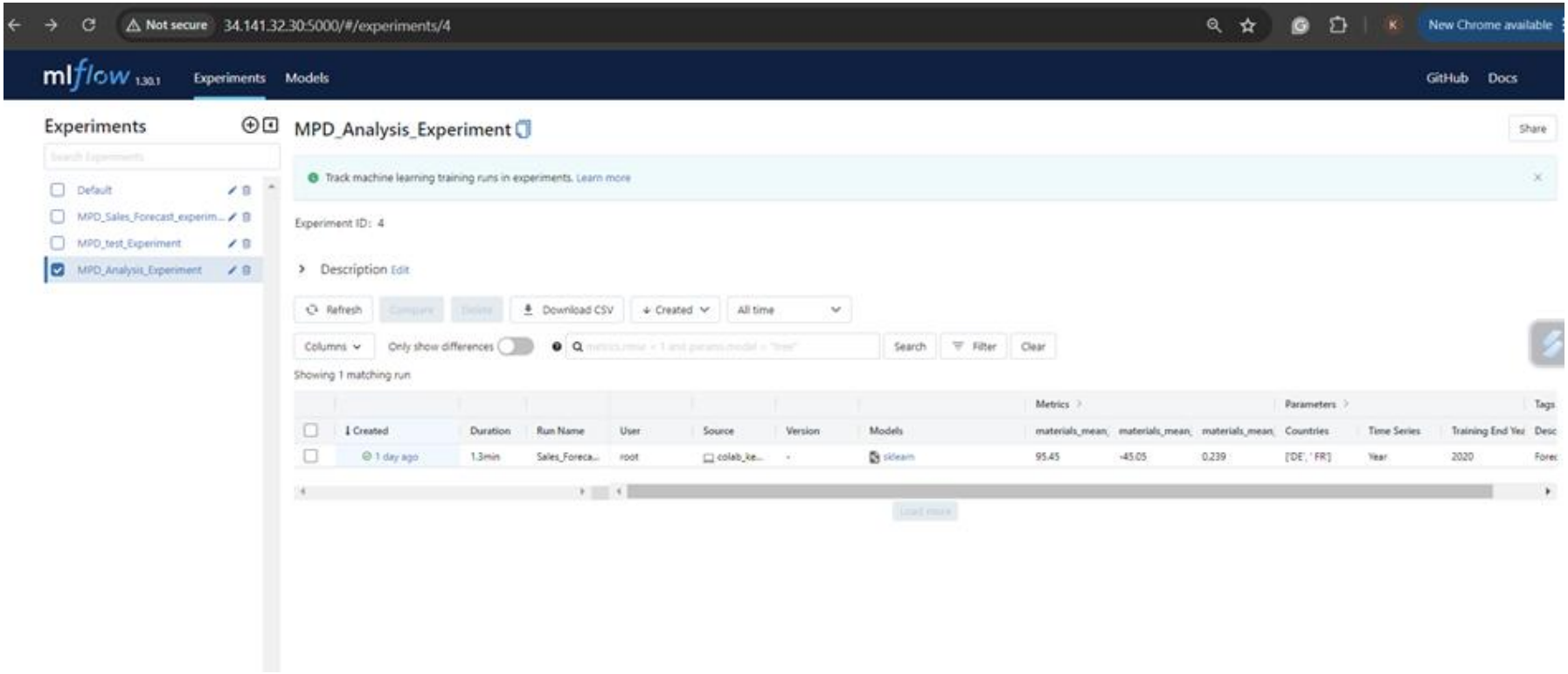
FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

MLflow Orchestration

- Set Up MLflow Server with SQLite backend store
- Logging and Tracking of
  - Model
  - Model Parameters
  - Metrics
  - Forecasted Values

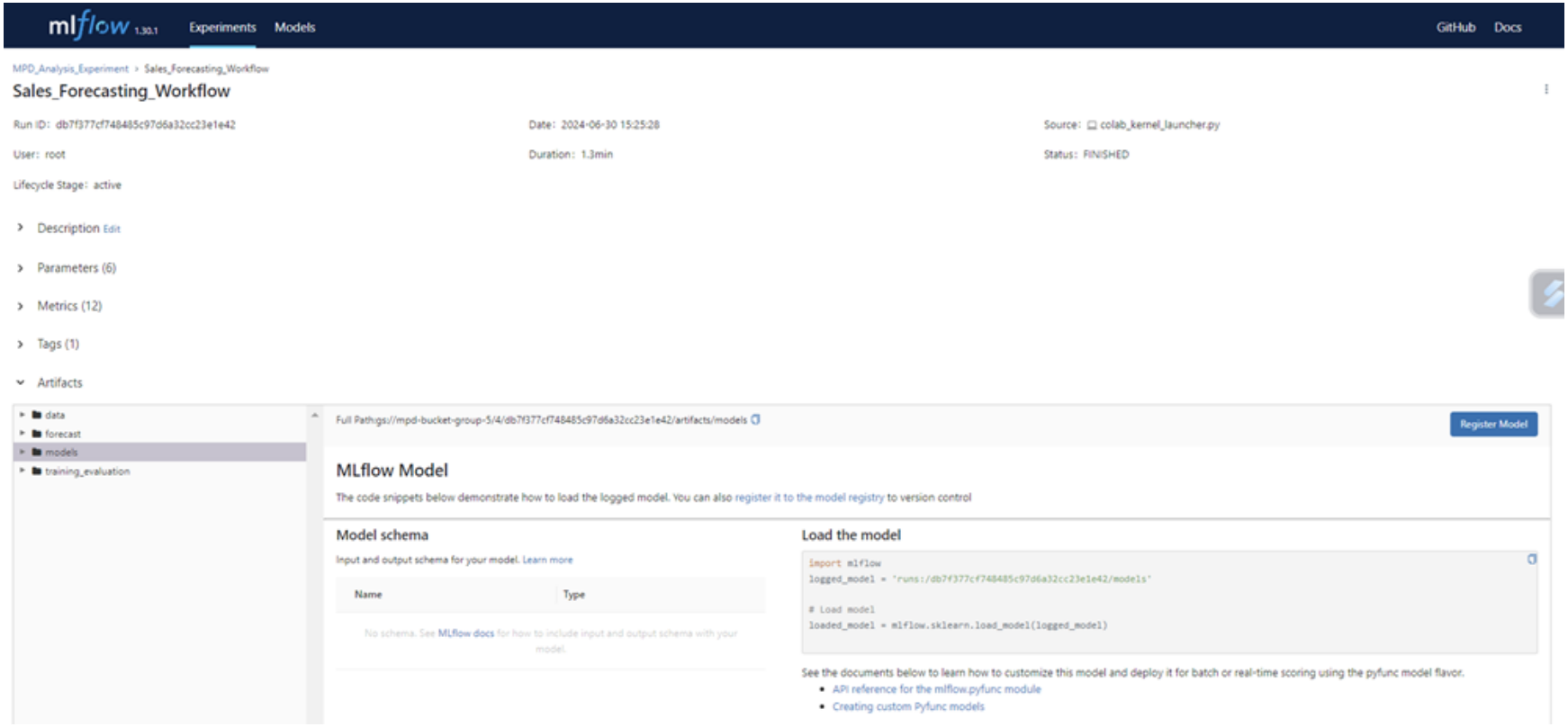
FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

MLflow Orchestration



FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

MLflow Orchestration



FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Data Preparation

- Sales Data Extraction and Joining:

  - Extracted relevant sales data from Google BigQuery.

  - Performed join operations on CustomerAttr, Orders, OrderItems, and ProductText tables based on user-specified countries.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Data Preparation

- Materials Data Preparation:

  - Joined the sales data (sales_table) with the ProductMat table.

  - Created a new attribute total_materials_required by multiplying Lot_size and Amount_Required.

- Utilized MLflow for centralized management and reproducibility of prepared data artifacts.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Model Training and Evaluation

- Used ARIMA PLUS for product and materials forecast
- Chosen for its ability to capture and forecast time-series patterns like seasonality and trends in sales and materials consumption data.
- Used Google BigQuery ML for scalable and efficient data processing, ensuring accurate and timely forecasts.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Model Training and Evaluation

- Models are trained on the previously prepared data for both Sales Forecast and Material Forecast

```
def train_model_sales(countries, start_year, end_year):
    countries_str = ', '.join(f"'{country}'" for country in countries)
    bq_query = f"""
    CREATE OR REPLACE MODEL `vlba-2024-mpd-group-5.MPD_DATA_5.MPD_Product_Sales_Forecast1`
OPTIONS(
  model_type='ARIMA_PLUS',
  auto_arima=True,
  time_series_data_col='total_sales',
  time_series_timestamp_col='Year',
  time_series_id_col='ProdDescr'
) AS
WITH sales_data AS (
  SELECT
    DATE_TRUNC(Date, YEAR) AS Year,
    SUM(SalesQuantity) AS total_sales,
    ProdDescr
  FROM
    `vlba-2024-mpd-group-5.MPD_DATA_5.TASK2_MPD_DATA_FOR_SALES_FORECAST`
```

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Model Training and Evaluation

- Models are trained on the previously prepared data for both Sales Forecast and Material Forecast

```
def train_model_mat(countries, start_year, end_year):

    countries_str = ', '.join(f"'{country}'" for country in countries)

    bq_query1 = f"""CREATE OR REPLACE MODEL `vlba-2024-mpd-group-5.MPD_DATA_5.Material_Forecast`
OPTIONS(
  model_type='ARIMA_PLUS',
  auto_arima=True,
  time_series_data_col='total_materials_required',
  time_series_timestamp_col='Year',
  time_series_id_col='MatId'
) AS
WITH material_data AS (
  SELECT
    DATE_TRUNC(Date, YEAR) AS Year,
    SUM(Total_materials_Required) AS total_materials_required,
    MatId
  FROM
    `vlba-2024-mpd-group-5.MPD_DATA_5.TASK2_MPD_DATA_FOR_MATERIAL_FORECAST`
```

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Model Training and Evaluation

Used the in-built ML.EVALUATE() function to assess model performance

```
#3: Model Evaluation
def evaluate_model_sales():
    eval_query1 = """
    Select
     *
    from
      ML.EVALUATE(MODEL `vlba-2024-mpd-group-5.MPD_DATA_5.MPD_Product_Sales_Forecast1`);
    """
    eval_job = client.query(eval_query1)
    eval_result = eval_job.result()
    eval_df = eval_result.to_dataframe()
    eval_df.to_csv('/tmp/sales_training_evaluation.csv', index=False)
    mlflow.log_artifact('/tmp/sales_training_evaluation.csv', artifact_path="training_evaluation")
    return eval_df


def evaluate_model_mat():
    eval_query = """
    Select
     *
    from
      ML.EVALUATE(MODEL `vlba-2024-mpd-group-5.MPD_DATA_5.Material_Forecast`);
    """
    eval_job = client.query(eval_query)
    eval_result = eval_job.result()
    eval_df = eval_result.to_dataframe()
    eval_df.to_csv('/tmp/material_training_evaluation.csv', index=False)
    mlflow.log_artifact('/tmp/material_training_evaluation.csv', artifact_path="training_evaluation")
    return eval_df
```

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Deployment and Monitoring

- BigQuery ML's ARIMA_PLUS model automatically handles hyperparameter tuning.
- Once the ARIMA_PLUS model is trained using BigQuery ML, it is ready for use in forecasting without additional deployment steps.
- Streamlines the process, making it more efficient and user-friendly.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Deployment and Monitoring

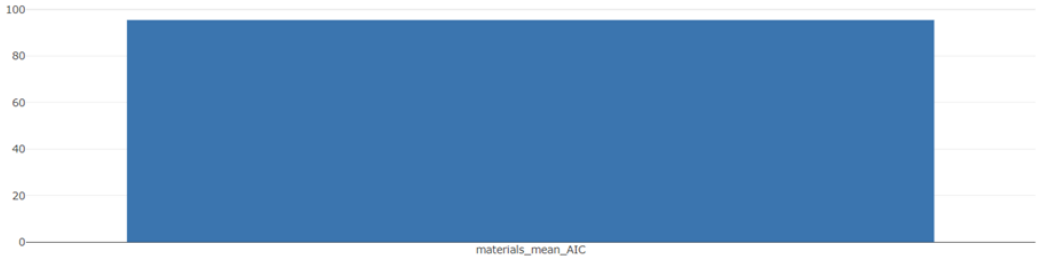
- After training, evaluating the models and validating the forecast results, we registered and logged them to the MLflow server.
- Monitoring with MLflow: Log performance metrics and hyperparameters of ARIMA PLUS models for product sales and materials.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Deployment and Monitoring

Metrics (12)

Name	Value
materials_mean_AIC	95.45
materials_mean_log_likelihood	-45.05
materials_mean_non_seasonal_d	0.239
materials_mean_non_seasonal_p	0.408
materials_mean_non_seasonal_q	0.408
materials_mean_variance	8094198.1
sales_mean_AIC	111.1
sales_mean_log_likelihood	-52.6
sales_mean_non_seasonal_d	0.103
sales_mean_non_seasonal_p	0.655
sales_mean_non_seasonal_q	0.31
sales_mean_variance	4074.3



Metric	Latest	Min	Max
materials_mean_AIC	95.45 (step=0)	95.45 (step=0)	95.45 (step=0)

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Forecasting

Implemented Flexible Forecasting Approaches:

- **Forecast by Period:** Predict values for a user-defined number of years for both Product Sales and Materials.
- **Forecast for a Particular Year**:Predict values for a user-specified year for both Product Sales and Materials.

Results are saved as CSV files and logged as artifacts in MLflow.

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Forecasting

User Inputs

```
Enter countries (comma-separated): DE, FR
Enter training start year: 2010
Enter training end year: 2020
Enter forecast period (in years): 7
Enter a specific year for forecast: 2026
```

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Forecasting

Sales Product Forecast for specific period

ProdDescr	forecast_timestamp	forecast_value
Air Pump	2021-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2022-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2023-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2024-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2025-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2026-01-01 00:00:00+00:00	1893.3000000000002
Air Pump	2027-01-01 00:00:00+00:00	1893.3000000000002

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Forecasting

Materials Forecast for a specific period

Full Path:gs://mpd-bucket-group-5/4/bdd1b82317ab4716a94f22c09945130f/artifacts/forecast/materials_forecast_for_period_7_years.csv
Size: 85.04KB

Previewing the first 500 rows

ProdDescr	MatId	Year	total_materials_required
Air Pump	PLAS1000	2021-01-01 00:00:00+00:00	184437.0
Air Pump	PLAS1000	2022-01-01 00:00:00+00:00	184437.0
Air Pump	PLAS1000	2023-01-01 00:00:00+00:00	184437.0
Air Pump	PLAS1000	2024-01-01 00:00:00+00:00	184437.0
Air Pump	PLAS1000	2025-01-01 00:00:00+00:00	184437.0

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

Forecasting

Sales Product Forecast for a specific year

ProdDescr	forecast_timestamp	forecast_value
Air Pump	2026-01-01 00:00:00+00:00	1893.3000000000002
Alu Scoot	2026-01-01 00:00:00+00:00	1534.4
Deluxe Touring Bike-Black	2026-01-01 00:00:00+00:00	601.8000000000001
Deluxe Touring Bike-Red	2026-01-01 00:00:00+00:00	409.9662039841683
Deluxe Touring Bike-Silver	2026-01-01 00:00:00+00:00	1140.9
E-Bike Tailwind	2026-01-01 00:00:00+00:00	336.44545455982467

FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

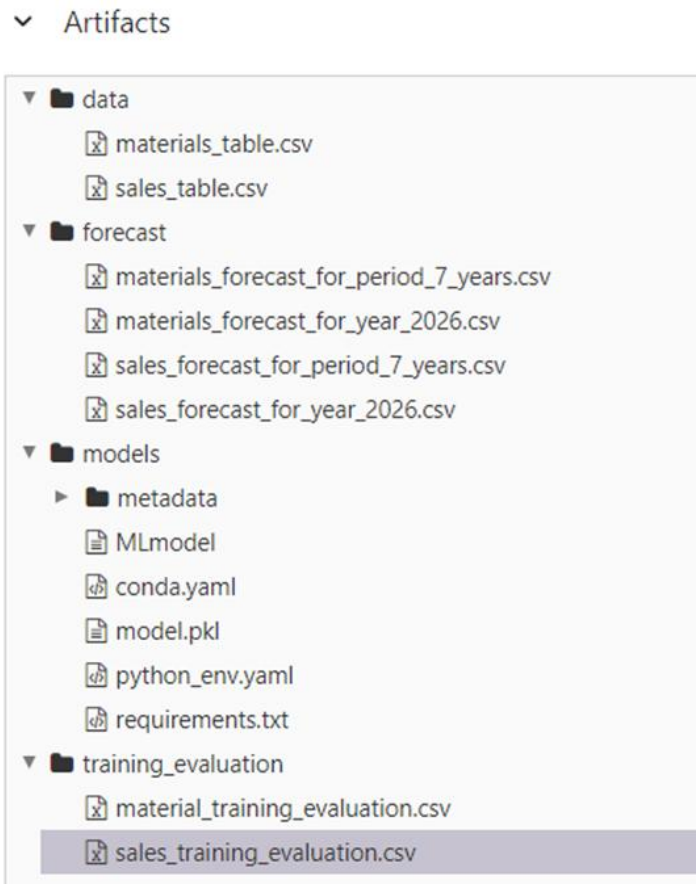
Forecasting

Materials Forecast for a Specific year

ProdDescr	MatId	Year	total_materials_required
Air Pump	PLAS1000	2026-01-01 00:00:00+00:00	184437.0
Air Pump	VENT1000	2026-01-01 00:00:00+00:00	221812.5
Alu Scoot	BATT1000	2026-01-01 00:00:00+00:00	428.2343659026982
Alu Scoot	SCLE1000	2026-01-01 00:00:00+00:00	290.3
Alu Scoot	SCRA1000	2026-01-01 00:00:00+00:00	580.6
Alu Scoot	SSEA1000	2026-01-01 00:00:00+00:00	320.33708557449404

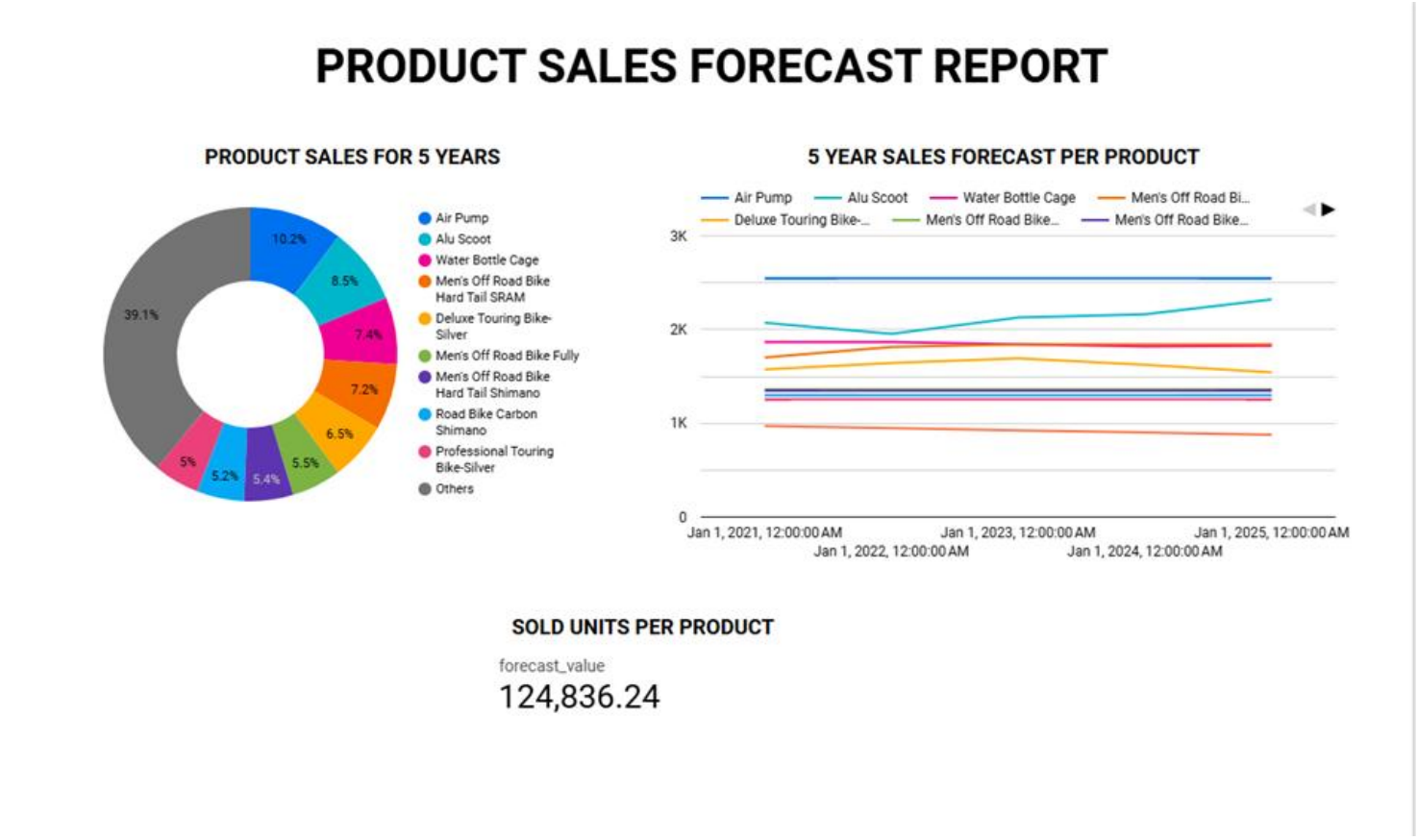
FORECASTING PRODUCT SALES AND MATERIALS REQUIRED

MLflow Logged Artifacts



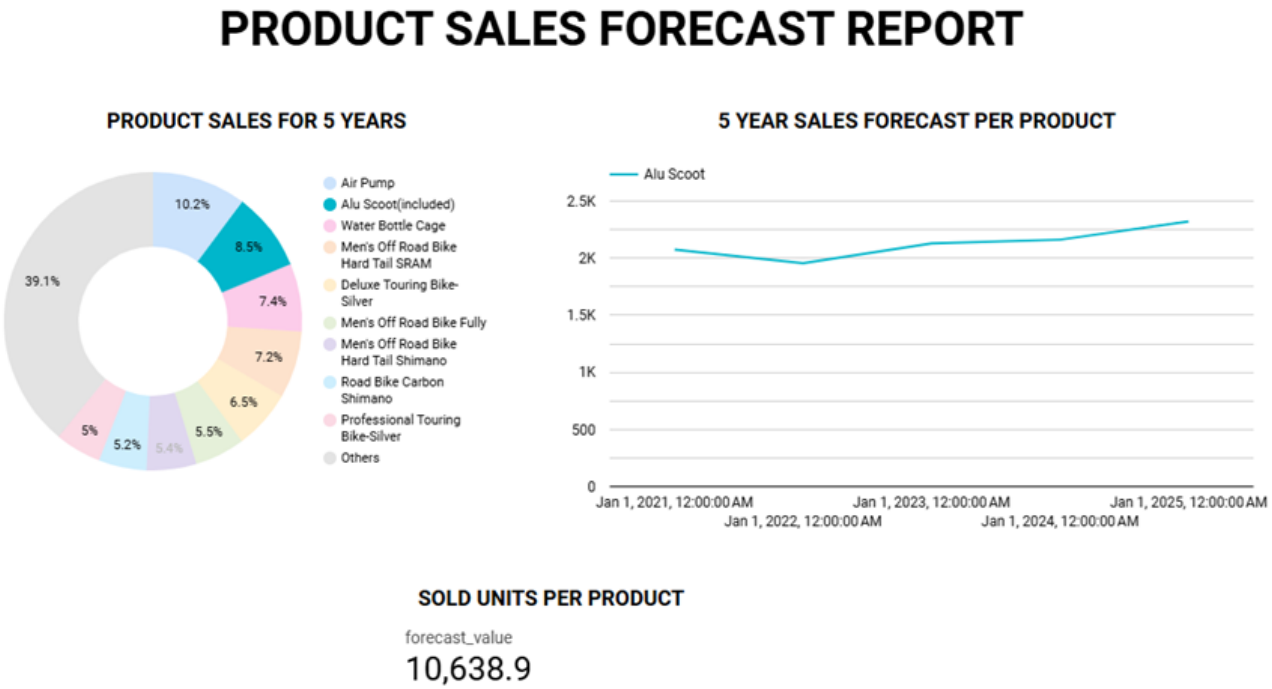
INTERPRETATION AND IMPLICATIONS OF RESULTS

Product Sales Forecast



INTERPRETATION AND IMPLICATIONS OF RESULTS

Product Sales Forecast



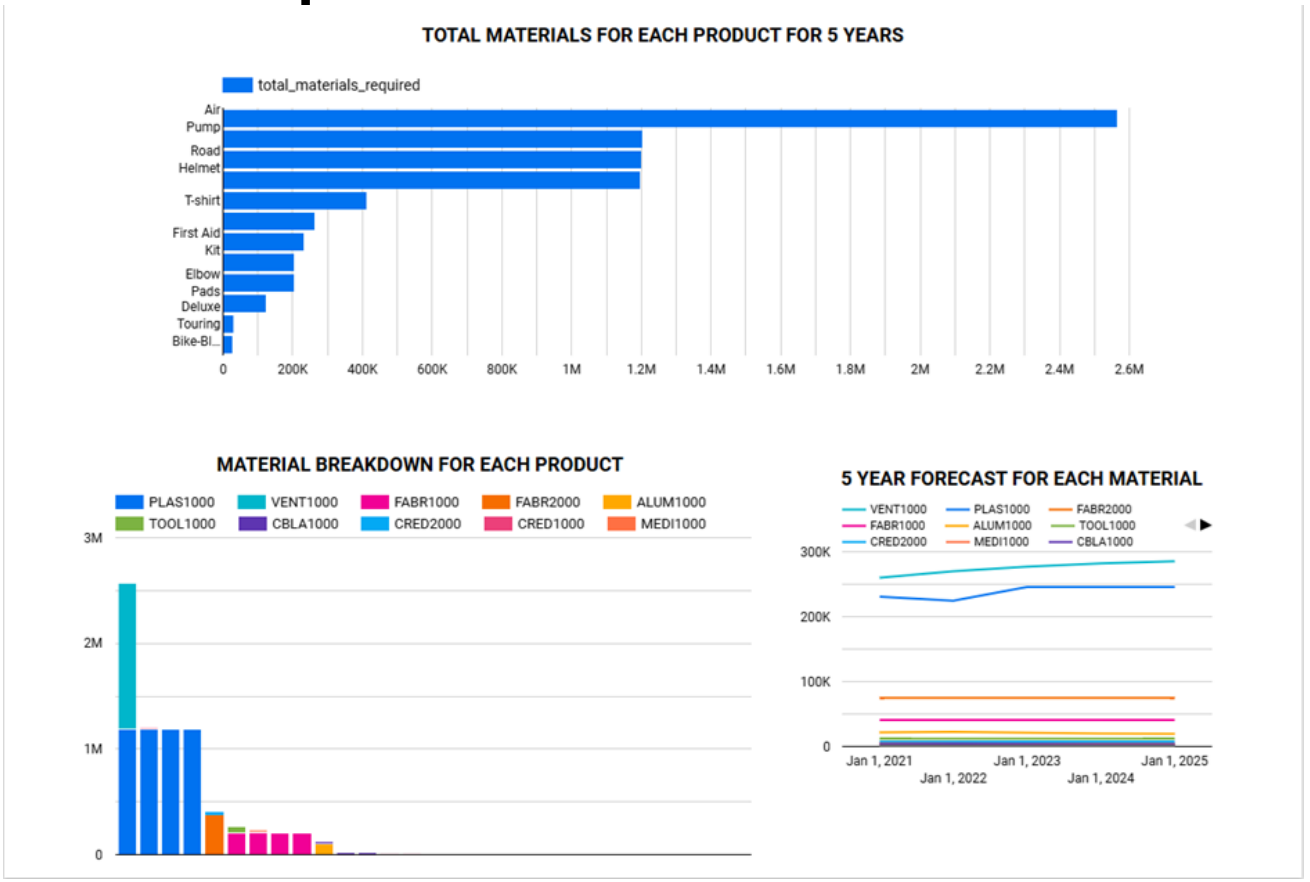
INTERPRETATION AND IMPLICATIONS OF RESULTS

Business Implications

- Product Strategy - With 39.1% of sales in "Others," diversify and innovate continuously.
- Market Demand - Focus on growing products like "Air Pump" and "Alu Scoot"
- Sales Forecasting - Use sales trends to optimize inventory and review declining products like "Deluxe Touring Bike-Silver."

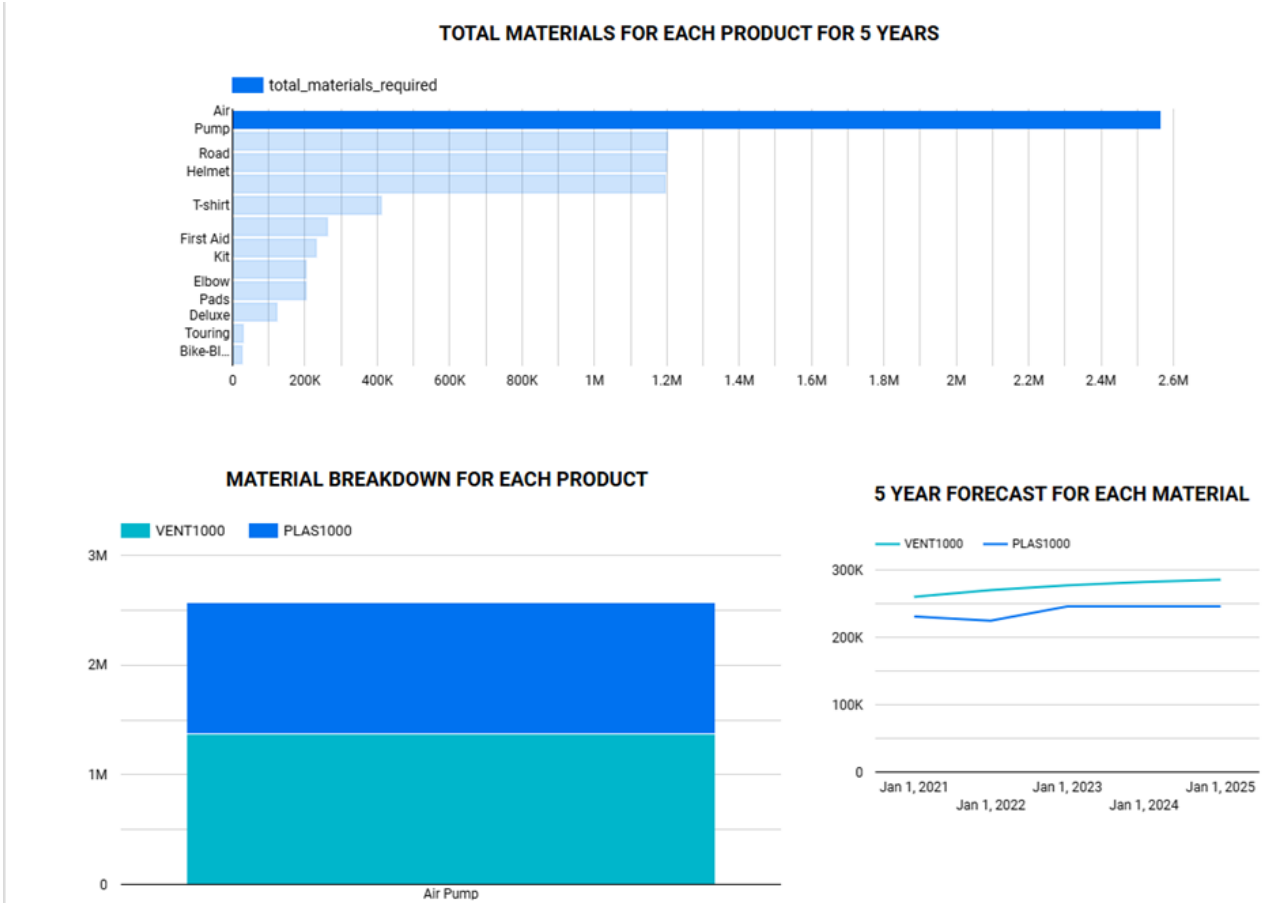
INTERPRETATION AND IMPLICATIONS OF RESULTS

Materials Required Forecast



INTERPRETATION AND IMPLICATIONS OF RESULTS

Materials Required Forecast



INTERPRETATION AND IMPLICATIONS OF RESULTS

Business Implications

- Resource Allocation - Ensure a steady supply of VENT1000 and PLAS1000 for Air Pumps and Road Helmets.
- Cost Forecasting - With increased use of VENT1000, adjust budgets to accommodate rising costs.

THANK YOU