Dynamic Pricing for Urban Parking Lots - Project Report

1. Project Overview

Urban parking spaces are limited and highly demanded, yet static pricing models lead to inefficiencies such as overcrowding or underutilization. This project builds a dynamic, real-time pricing engine for 14 urban parking lots. By leveraging real-time data, ML-inspired demand modeling, and Pathway's data streaming, this solution dynamically adjusts prices to match demand while ensuring smooth and explainable pricing behavior.

2. Technologies Used

- Language: Python 3
- Data Manipulation: Pandas, Numpy
- Real-Time Data Pipeline: Pathway
- Visualization: Bokeh, Panel
- Development Environment: Google Colab
- Version Control: GitHub

3. Data Pipeline and Architecture

The pipeline begins with a CSV file simulating real-time parking data, streamed using Pathway. It includes attributes like timestamp, occupancy, queue length, vehicle type, traffic level, and special day indicator. After preprocessing and encoding categorical variables, two pricing models are implemented using windowed aggregation and applied pricing logic. Results are visualized using Bokeh plots per lot.

Architecture:
1. CSV Ingestion (Pathway Replay)
2. Data Cleaning & Feature Engineering
3. Model 1: Baseline Linear Pricing
4. Model 2: Demand-Based Pricing
5. Visualization: Bokeh Plots Per Lot

4. Model 1: Baseline Pricing

Model 1 is a simple linear model using only occupancy and capacity:

```
price = base_price + alpha * (occupancy / capacity)
```

- Base price: $10
- Alpha (scaling factor): 5
- Price is clipped between $5 and $20
- Used as a control model for evaluating improvements in Model 2

5. Model 2: Demand-Based Pricing

Model 2 incorporates multiple features into a demand function and adjusts price accordingly:

Demand Function:

```
demand = 0.35*(occupancy/capacity) + 0.20*(queue/5) + 0.15*(traffic/2) + 0.20*vehicle_weight + 0.10*special_day
```

Pricing Function:

```
price = base_price + lambda * demand
```

- Lambda: 10
- Prices are bounded between $5 and $20
- Enables responsiveness to changing external conditions

6. Visualizations

Each parking lot has an individual Bokeh line plot visualizing pricing behavior over time. Due to Colab limitations, static snapshots of price evolution were extracted using Pathway's `to_pandas()` method and plotted using Bokeh. Graphs clearly show the impact of occupancy and demand features on final prices.

7. Assumptions

- Occupancy ratio is a reliable base indicator of demand
- Queue length is capped at 5, traffic at 2 (for normalization)
- Truck = 1.0, Car = 0.75, Bike = 0.5, Cycle = 0.25 (Vehicle Weights)
- Special days are binary flags (0 or 1)
- Daily tumbling windows with Pathway used for real-time grouping

8. Conclusion

This project demonstrates the effectiveness of real-time data streaming combined with pricing intelligence. Model 1 offers a simple, explainable baseline, while Model 2 introduces realistic dynamic adjustments. Visual plots affirm that pricing adapts smoothly and predictably with demand. This pipeline is deployable with minimal dependencies and can be further extended with competitive pricing logic or user routing suggestions.