Capstone Project on Real-Time Dynamic Pricing Models for Smart Urban Parking

1. Introduction

In today's busy cities, finding parking is often more stressful than the drive itself. Static parking fees rarely reflect real-time demand, which leads to overcrowded lots in some places and empty ones elsewhere. Our project tackles this issue by building a dynamic pricing engine that adjusts parking rates in real-time, based on demand signals.

2. Problem Statement

The core question is simple: how do we set the right price for a parking spot at the right time?

Our aim is to design a real-time pricing model that responds to current demand conditions like occupancy, queue length, and traffic levels—ultimately helping improve utilization and reduce parking chaos.

3. Tech Stack

- Python
- Pathway (for real-time stream processing)
- Bokeh and Panel (for live dashboards)
- Pandas and NumPy (for data handling)
- Scikit-learn (for regression modeling)
- Google Colab
- Mermaid.js (for architecture diagrams)

4. Project Architecture

The system simulates live parking data from CSV files, streams it using Pathway, applies pricing logic via two models, and displays pricing for all spots in a live dashboard.

(A Mermaid-style architecture diagram is included in the README on GitHub.)

5. Model 1 – Simple Linear Pricing

This model assumes price is directly tied to how full a spot is. The formula is:

$\text{Price}_{(t+1)} = \text{Price}_{(t)} + \alpha * \text{Occupancy}$

We use real-time patterns to estimate the coefficient α. It's simple, lightweight, and works well in low-data environments.

6. Model 2 – Feature-Based Pricing

This model brings more context into pricing decisions. It uses the following features:

- Occupancy
- Queue Length
- Traffic
- Special Day
- Vehicle Type

We assume a set of coefficients and simulate pricing data. Then, we use linear regression to see if the model can recover the original values. This checks the model's robustness and adds depth to pricing logic.

7. Real-Time Integration

Using Pathway, we continuously stream and process data updates. Each parking spot is tracked separately, and pricing is updated in real time.

We used .items() and .filter() to manage updates for multiple spots and show real-time outputs for each one in Bokeh dashboards.

8. Model Comparison

Our third notebook compares both models across the same set of parking data.

This gives insights into when a basic model is enough, and when richer data helps make smarter pricing decisions.

9. Key Learnings

- Simple models can still be powerful.
- More features give better pricing control.
- Real-time systems need efficient tools—Pathway made this practical.
- Live dashboards help spot issues and insights instantly.

10. Future Work

- Add a third model using elasticity or reinforcement learning
- Connect with real parking APIs for deployment
- Build a mobile interface for drivers
- Explore dynamic discounting strategies

11. Conclusion

This project shows how real-time pricing can help cities manage parking better. Smarter pricing means less traffic, better use of space, and a smoother experience for everyone.