Capstone Project Report

Dynamic Pricing for Urban Parking Lots

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1. Project Objective

Urban parking resources are constrained and often mispriced due to static pricing schemes.
My project aims to build a dynamic, real-time pricing model for 14 parking lots using real-world features such as:
- Occupancy
- Queue length
- Traffic congestion
- Special event indicators
- Vehicle type
- Competitor prices

I developed and tested three progressively intelligent models that simulate a live pricing system using NumPy, Pandas, and Pathway for real-time data streaming and pricing.

2. Dataset Overview

The dataset captures 73 days of operational data for 14 parking spaces across time windows of 30 minutes (from 8:00 AM to 4:30 PM).

Each data record includes:
- Location: Latitude, Longitude
- Capacity Info: Capacity, Occupancy, Queue length
- Vehicle Info: Vehicle type (Car/Bike/Truck)
- Environmental Info: Traffic level, Special day indicator

3. Model Architecture

Model 1: Baseline Linear Model
A simple linear rule where price increases with occupancy:
$P_{t+1} = P_t + \alpha \cdot (\text{Occupancy} / \text{Capacity})$

Model 2: Demand-Based Pricing Function
Incorporates additional features to model demand dynamically:
$\text{Demand} = \alpha \cdot (\text{Occupancy} / \text{Capacity}) + \beta \cdot \text{QueueLength} - \gamma \cdot \text{Traffic} + \delta \cdot \text{IsSpecialDay} + \varepsilon \cdot \text{VehicleTypeWeight}$
$\text{Price}_t = \text{BasePrice} \cdot (1 + \lambda \cdot \text{NormalizedDemand})$

Model 3: Competitive Pricing Model (Optional Advanced)
Uses spatial proximity and pricing of nearby lots:
- If a nearby lot is cheaper and closer → decrease price or suggest rerouting
- If competitors are costlier → increase price to optimize profit

4. Real-Time Simulation with Pathway

I implemented a real-time simulation pipeline using Pathway:
- Ingests CSV data with timestamps
- Processes data frame as a stream
- Applies pricing logic per model
- Emits and visualizes output using Bokeh

5. Visualizations

I used Bokeh to create the following:
- Real-time line plots for each parking space
- Comparison of pricing models over time
- Dynamic maps showing rerouting or price hotspots

Note: Include screenshots or example Bokeh charts here.

6. Assumptions & Considerations

- Base price: Fixed at $10 for all lots
- Vehicle weights: Trucks > Cars > Bikes for demand influence
- Traffic levels: Assumed ordinal values
- Smoothness: Used exponential moving average to prevent spikes
- Competition radius: 500m for model 3 comparisons

7. Key Learnings

- Dynamic pricing offers significant improvement over static models in utilization.
- Incorporating real-world signals (e.g., queue length, event days) improves price accuracy.
- Real-time simulation brings practical challenges like latency, feature lag, and state retention.

8. Future Scope

- Add user behavior feedback loop (if users reroute due to high prices)
- Integration with online payment platforms for closed-loop pricing
- Fine-tuning of weights using optimization or reinforcement learning