Dynamic Pricing for Urban Parking Lots

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Executive Summary

In today's urban environments, static parking pricing leads to inefficient resource allocation and revenue loss. This project implements a real-time dynamic pricing system for urban parking lots, using occupancy data, traffic conditions, and competitive pricing strategies. The solution is built using Python, Pathway, and Bokeh, and deployed in a simulated streaming environment. It includes five progressively smarter pricing models, each adding layers of intelligence and realism, from basic occupancy-based adjustments to full real-time competitive adaptation.

Problem Statement

Parking pricing in urban areas is typically static and fails to reflect real-time demand, congestion, or availability. This results in overpricing during low-demand periods and underpricing during peak times. The objective is to design and simulate a dynamic pricing engine that adjusts parking rates in real time based on multiple data features and is scalable across parking lots.

Methodology

Model 1: Linear Pricing Based on Occupancy

A simple linear formula adjusts prices as occupancy increases:

Price = Base + α × (Occupancy / Capacity)

- Base Price = $10
- α = 1.0
- Price capped between $5 and $20

Model 2: Demand-Based Pricing

Incorporates multiple demand features:

- Occupancy rate
- Queue length
- Nearby traffic
- Special event indicator
- Vehicle type weighting

Final Price = Base × (1 + λ × NormalizedDemand)

- λ = 0.8
- Output is normalized and clipped between $5 and $20

Model 3: Competitive Pricing Adjustment

Adds spatial awareness by comparing nearby parking lots:

- Haversine formula used to calculate distance between lots
- If nearby lots are cheaper ➜ reduce price
- If isolated or underpriced ➜ increase slightly

Only lots within a 1 km radius are considered as competitors.

Model 4: Real-Time Simulation with Pathway

Simulates a real-time stream of parking data using:

- Static mode CSV ingestion
- User-defined function (@pw.udf) to compute live pricing
- Output printed as a simulated stream

Model 5: Bokeh Visualization

Creates an interactive pricing chart for real-time dashboards:

- Visualizes Model 2 pricing across lots
- Built using Bokeh with ColumnDataSource
- Enhances business interpretability

Architecture

graph TD

A [Raw CSV Dataset] --> B [Model 1: Linear Pricing]

B --> C [Model 2: Demand-Based Pricing]

C --> D [Model 3: Competitive Adjustment]

D --> E [Model 4: Pathway Simulation]

E --> F [Model 5: Bokeh Visualization]

Technologies Used

- Python (Pandas, NumPy)
- Pathway (real-time data streaming)
- Matplotlib & Bokeh (data visualization)
- Google Colab (notebook environment)
- GitHub (version control & submission)

Dataset

The dataset includes over 18,000 records with the following key features:

- Occupancy, Capacity
- Latitude, Longitude
- Queue Length
- Traffic Condition Nearby
- Special Day Indicator
- Vehicle Type

A sample of 100 rows was used for real-time simulation.

Outcomes

- Built five pricing models of increasing complexity
- Developed real-time processing logic using Pathway
- Achieved flexible, interpretable pricing structures
- Fulfilled all deliverables: code, README, plots, architecture

GitHub Repository

All project files, models, visuals, and notebook are hosted here:
🔗 https://github.com/M2Z2/Dynamic-Pricing-Urban-Parking

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