Summer Analytics 2025 – Final Project Report

Project Title: Dynamic Pricing for Urban Parking Lots

Objective

The goal of this project is to build a real-time, intelligent pricing system for urban parking spaces that dynamically adjusts based on demand, congestion, vehicle type, and competitor pricing. The project simulates a real-world pricing engine using machine learning principles and real-time data streams.

Dataset Description

- 73 Days of Data across 14 parking lots
- 18 time intervals per day (8:00 AM to 4:30 PM, every 30 minutes)
- Features:
    - Latitude & Longitude
    - Capacity, Occupancy, QueueLength
    - VehicleType: car, bike, truck
    - Traffic level, IsSpecialDay

Project Life Cycle

- Framing & Understanding the Problem
- Loading the Data
- EDA (Exploratory Data Analysis)
- Feature Engineering (Scaling/Normalization)
- Building the Model
- Bokeh Plots
- Real-Time Visualization via Pathway

Model Overview

Model 1: Baseline Linear Model

- Formula: `Price_t+1 = Price_t + α * (Occupancy / Capacity)`

- Assumes direct linear relationship between occupancy and pricing

- Serves as a reference for more advanced models.

Model 2: Demand-Based Pricing

- Formula:
  Demand = α * OccupancyRate + β * QueueLength - γ * Traffic + δ * IsSpecialDay + ε * VehicleWeight
  Price = BasePrice * (1 + λ * NormalizedDemand)

- Captures holistic demand based on multiple variables

- Price is bounded: 0.5x to 2x of base price

Model 3: Competitive Pricing

- Adds spatial intelligence:
    - Uses GeoPy to calculate nearby lots (within 1km)
    - Adjusts price based on average nearby competitor price

    - Increases price if competitors are expensive; decreases if nearby lots are cheaper

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Real-Time Simulation with Pathway

- Used pathway library to stream dataset.csv as real-time time-stamped data
- Defined custom UDF to compute prices on-the-fly
- Continuous output to simulated sinks (e.g., dashboard or logs)
- Bounded and explainable pricing updates

Visualization

- Created interactive Bokeh plots:
    - Model 1: Baseline Pricing Over Time
    - Model 2: Demand-Driven Pricing
    - Model 3: Competitive Adjusted Pricing
- Tooltips allow hover-based insights
- Optional future integration with Bokeh Server or Panel for live dashboards

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Assumptions

- Vehicle types are mapped as: car = 1.0, bike = 0.5, truck = 1.5 and cycle = 0.25
- Base price fixed at $10; adjusted via smooth scaling

- Normalizations are min-max scaled within current dataset window
- No lot exceeds 2x base price to avoid user dissatisfaction
- Rerouting logic can be added if occupancy rate exceeds 90% and nearby lots are cheaper

The following weights were assumed based on the correlation heatmap and other exploratory data analysis

Feature	Symbol	Importance	Weight
Occupancy Rate	α	High	1.2
Queue Length	β	Medium	0.8
Traffic (inverse)	γ	Medium	0.7
IsSpecialDay	δ	Low	0.3
Vehicle Weight	ε	Medium	0.6

Conclusion

- A multi-layered dynamic pricing system was implemented from scratch
- Three pricing strategies were explored from basic to geo-aware competition
- Real-time simulation with pathway ensures deployability in production
- Interactive plots explain pricing behavior clearly