Title:

Dynamic Pricing for Urban Parking Lots

Capstone Project – Summer Analytics 2025

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Project Objective

The goal of this project is to build a dynamic, data-driven pricing engine for 14 urban parking lots. Prices are updated in real-time based on features such as occupancy, queue length, vehicle type, nearby traffic congestion, special events, and competitor pricing.

We build and compare three models of increasing complexity:

- Model 1 – Baseline Linear Pricing
- Model 2 – Demand-Based Pricing
- Model 3 – Competitive-Aware Pricing

Tech Stack

- Python (NumPy, Pandas) – for data manipulation and logic
- Pathway – real-time data stream simulation
- Geopy – distance calculations
- Bokeh / Matplotlib – data visualization
- Google Colab – development and execution environment

Model 1 – Linear Pricing (Baseline)

Formula:
$\text{Price}[t+1] = \text{Price}[t] + \alpha \times (\text{Occupancy} / \text{Capacity})$

- Starts from a base price of $10
- α is a constant (e.g., 2.0)
- Price increases proportionally with occupancy

Use Case:
Acts as a simple benchmark for dynamic pricing logic.

Model 2 – Demand-Based Pricing

Demand Function:

Formula:
Demand = α × (Occupancy / Capacity) + β × QueueLength − γ × Traffic + δ × IsSpecialDay + ε × VehicleTypeWeight

Explanation of Terms:

- Occupancy / Capacity: Measures how full the lot is
- QueueLength: Longer queues imply higher demand
- Traffic: High congestion decreases accessibility (thus lowers demand)
- IsSpecialDay: Events or holidays increase demand
- VehicleTypeWeight: Trucks > Cars > Bikes (weights: 1.5, 1.0, 0.7)

Pricing Formula:

Price = BasePrice × (1 + λ × NormalizedDemand)

- Normalized demand is scaled to [0, 1]
- λ determines sensitivity to demand
- Price is clipped between 0.5× and 2× of base

Assumptions

- Demand function results in smooth, gradual price changes

- All vehicle types have a defined weight
    - Car: 1.0, Bike: 0.7, Truck: 1.5
- Traffic is encoded:
    - Low: 0.5, Medium: 1.0, High: 1.5
- Queue length has linear influence
- Base price is fixed at $10 for all lots

Model 3 – Competitive Pricing Logic

This model adds competitive awareness based on distance and price comparison.

Logic:

- If a nearby lot (within 300 meters) is cheaper and available → suggest rerouting or reduce price
- If nearby lots are full or more expensive → allow price to increase up to 2× base
- Distances are calculated using latitude and longitude via Geopy

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Real-Time Implementation

- Data is streamed using Pathway's engine, preserving timestamps
- Pricing models operate on each time slice (18 slots/day from 8:00 AM to 4:30 PM)
- Visualizations are done in real time using Bokeh or Matplotlib

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Price Behavior Summary

Feature	Price Impact
Higher Occupancy	Increases Price
Longer Queue	Increases Price

Feature	Price Impact
High Traffic	Decreases Price
Special Event Day	Increases Price
Vehicle is a Truck	Increases Price (more than Car/Bike)
Nearby Lot is Cheaper	Triggers Price Reduction or Rerouting

Conclusion

This system provides an efficient, real-time pricing solution for urban parking management. Each model represents an advancement in pricing logic:

- **Model 1** reacts to occupancy alone
- **Model 2** considers multiple demand factors
- **Model 3** incorporates competition and rerouting

The full solution can be deployed with real-time data pipelines using Pathway, enabling smarter city infrastructure.