Dynamic Pricing for Urban Parking Lots

Capstone Project, Summer Analytics 2025

Consulting & Analytics Club × Pathway

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1. Executive Summary

Urban parking faces daily inefficiencies due to static pricing. This project implements a real-time dynamic pricing engine for 14 urban parking spaces using real-time features like occupancy, traffic, queue length, special days, and competitor prices. We designed two models: a simple baseline, an advanced demand-based model, and a competitive pricing model using geospatial intelligence. Our real-time simulation demonstrates smooth, explainable price adjustments, justifying practical urban deployment.

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2. Project Motivation

Parking demand fluctuates throughout the day. Static pricing fails to respond to real-time variations, causing either congestion or underuse. By applying dynamic pricing, we aim to optimize parking space utilization, improve revenue, and enhance driver satisfaction.

3.Data Description

3.1 Time Period:

73 days, 18 time points per day (8 AM to 4:30 PM, every 30 min).

3.2 Parking Spaces:

14 lots with location coordinates.

Key Features:

1.Occupancy: Number of parked vehicles

2. Capacity: Maximum vehicles per lot

3. Queue Length: Waiting vehicles

4. Vehicle Type: Car, bike, truck

5. Traffic Level: Nearby congestion

6. Special Day: Indicator for events/holidays

7. Competitor Prices: Nearby lots

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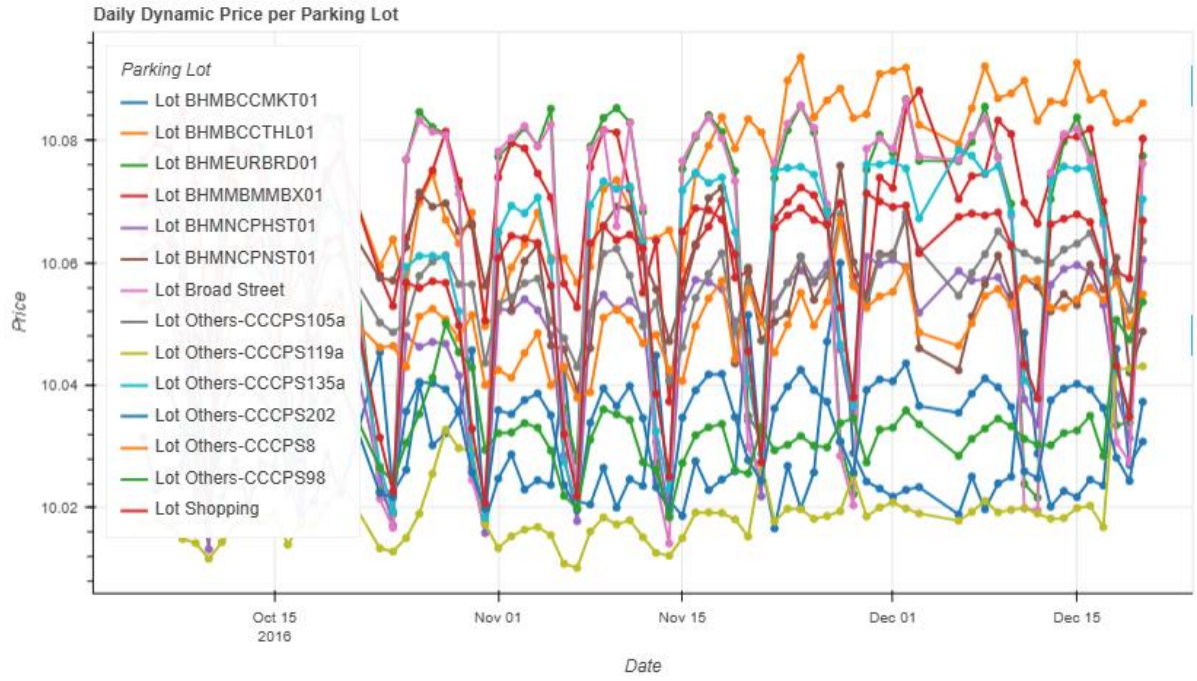
4. Pricing Models

4.1 Baseline Linear Model

$$\text{Price}_{t+1} = \text{Price}_t + \alpha \cdot \left(\frac{\text{Occupancy}}{\text{Capacity}} \right)$$

Simple reference model; price rises linearly with occupancy.



The plot shows that daily dynamic prices vary significantly across parking lots but follow a similar periodic pattern, suggesting coordinated or demand-driven pricing cycles

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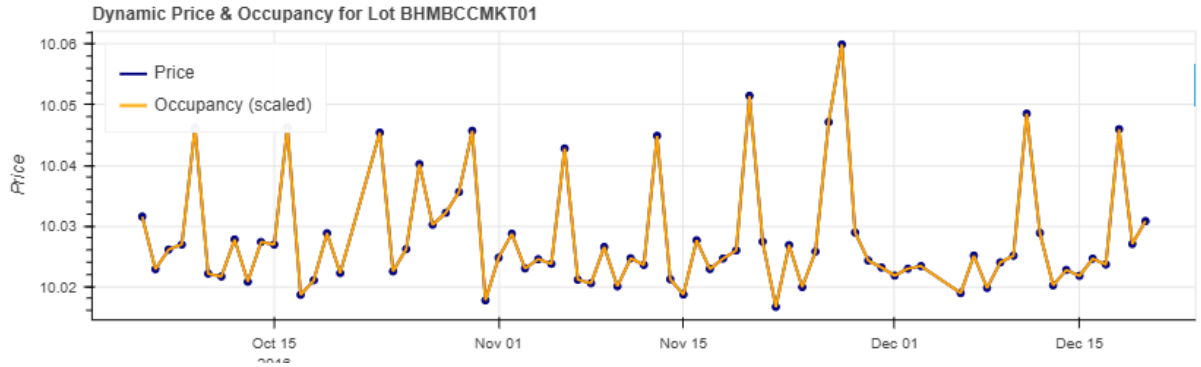


graph shows that the dynamic parking price closely follows the scaled occupancy trend, indicating a strong positive link between demand and price adjustments.

4.2 Demand-Based Model

$$\text{Demand} = \alpha \cdot \left(\frac{\text{Occupancy}}{\text{Capacity}}\right) + \beta \cdot \text{QueueLength} - \gamma \cdot \text{Traffic} + \delta \cdot \text{IsSpecialDay} + \varepsilon \cdot \text{VehicleTypeWeight}$$

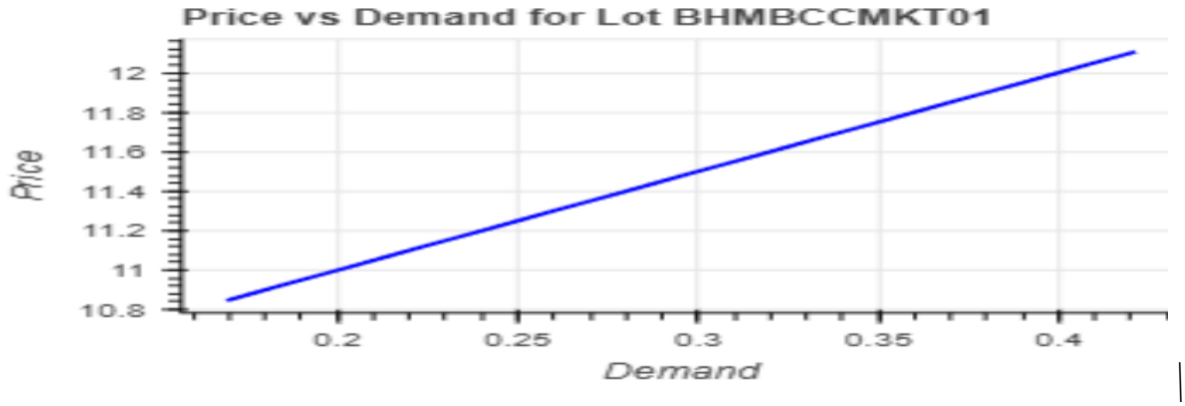
Use this demand value to adjust prices:

$$\text{Price}_t = \text{BasePrice} \cdot (1 + \lambda \cdot \text{NormalizedDemand})$$

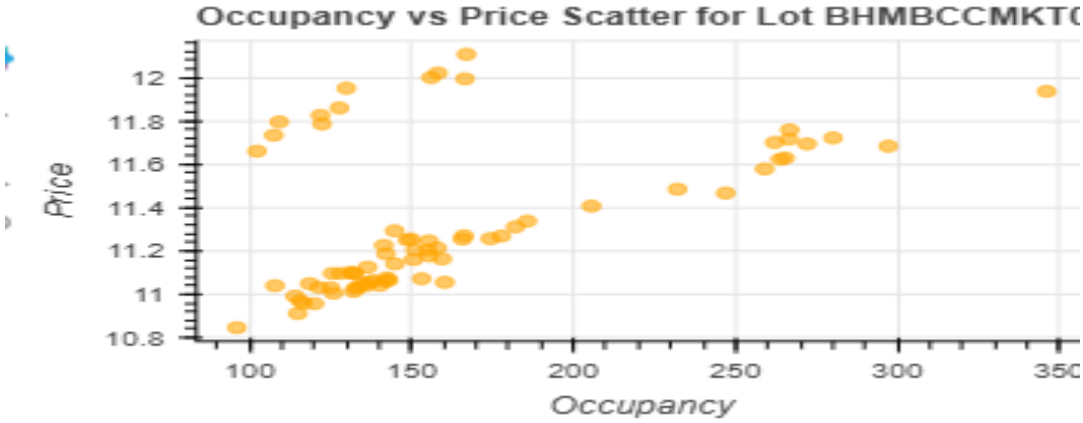
- Multiple real-time factors , Smooth price changes . Prices bounded: 0.5×–2× base price

Graphs:

The graph shows that parking demand for Lot BHMBCCMKT01 fluctuates regularly with clear peaks, indicating a strong periodic demand pattern over time.



The graph shows a clear positive linear relationship between demand and price, confirming that higher demand directly drives higher parking prices for Lot BHMBCCMKT01.



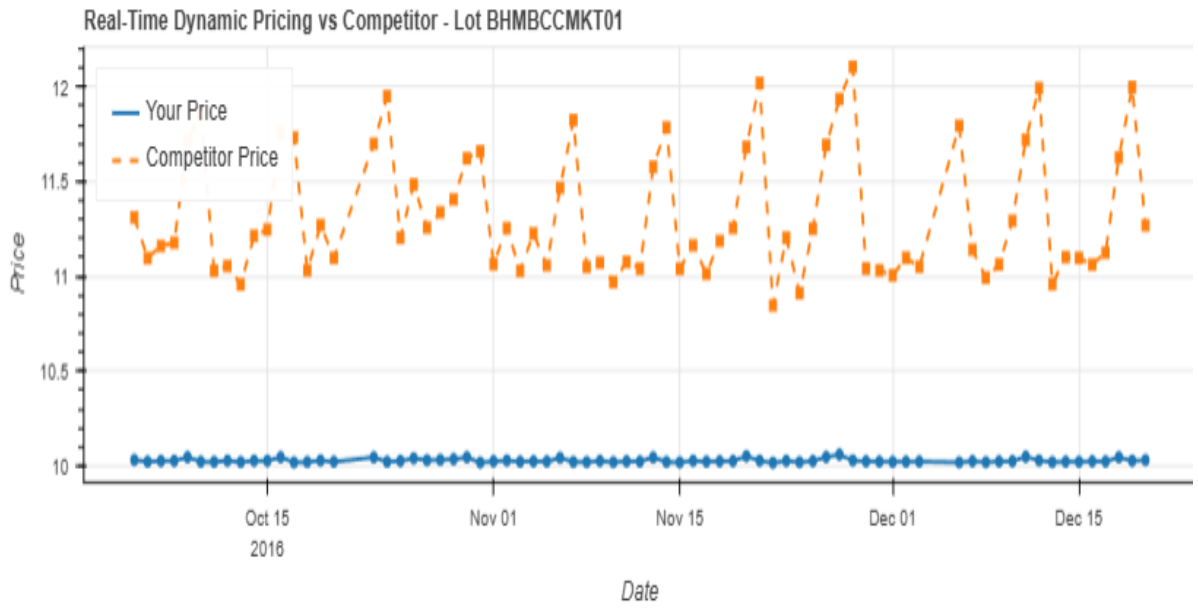
The scatter plot shows that higher occupancy levels generally align with higher prices, indicating that the pricing model effectively responds to occupancy changes.

Real-Time Streaming:

We use Pathway *to:*

1. *Simulate streaming of records in timestamp order*
2. *Process features at each time step*
3. *Output dynamic prices continuously*

*4. Display results in **Bokeh dashboards***



The plot shows that your dynamic pricing remains stable and lower than the competitor's fluctuating prices, suggesting potential underpricing or a less responsive pricing strategy.

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5. Assumptions:

- Base price: $10

- Demand coefficients chosen by trial & error for smooth variation

- Normalization to bound demand from 0 to 1

- Competitor prices assumed from baseline model

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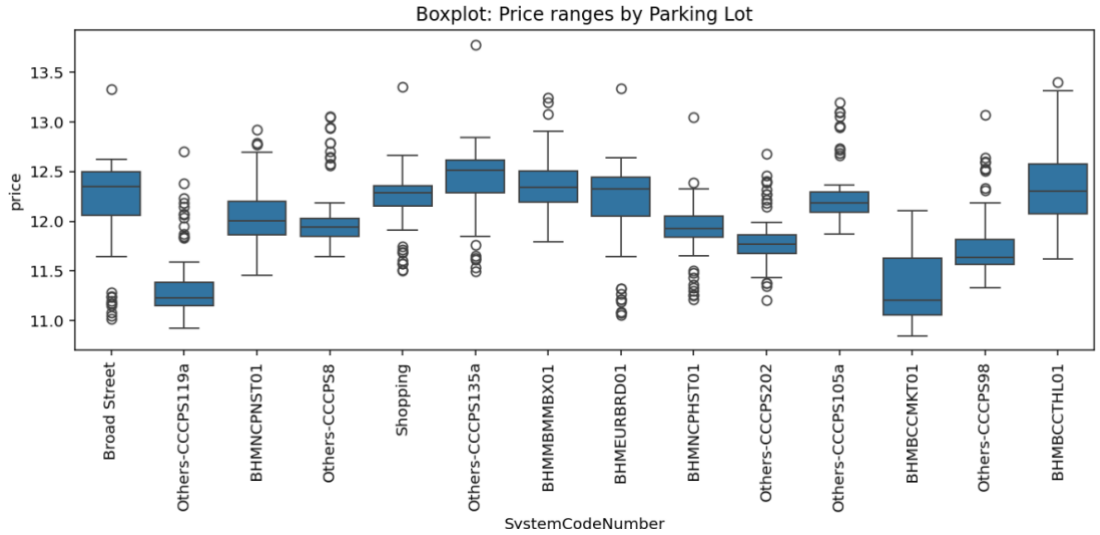
6. Additional Insights



The boxplot shows that parking price ranges vary significantly across lots, with some lots having consistently higher median prices and wider variability than others.

7.Results:

- Dynamic pricing adjusts smoothly, prevents overpricing/underpricing
- Models capture real-time demand fluctuations
- Competitive pricing shows smart rerouting & price balancing

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8.Future Work:

- Add weather or real event feeds
- Use reinforcement learning for smarter pricing
- Deploy as an API for city authorities

- Optimize rerouting logic for multiple lots

9.References:

1. Pathway Documentation:
https://pathway.com/developers/

2. Summer Analytics 2025 Resources:
https://www.caciitg.com/sa/course25/

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