Dynamic Pricing for Urban Parking Lots

Capstone Project - Summer Analytics 2025
Consulting & Analytics Club × Pathway

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1. Background and Motivation

Urban parking spaces are a scarce resource in high demand. Static pricing strategies lead to inefficiencies such as overcrowding or underutilization. This project explores dynamic pricing as a mechanism to better manage parking lot resources based on real-time demand and competitive context.

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2. Project Objective

This project aims to build a real-time pricing engine for 14 urban parking spaces, adjusting prices based on occupancy, queue length, nearby traffic, special days, vehicle type, and competitor pricing. Starting from a base price of $10, the model ensures smooth and explainable price variations. If a lot is full, it can also suggest rerouting vehicles. The pricing logic begins with Model 1, a simple linear rule based on occupancy, and advances to Model 2, which incorporates a demand function using multiple real-time features.

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3. Data Description

The dataset covers 14 parking lots over 73 days, sampled 18 times daily between 8:00 AM and 4:30 PM. Each record captures the real-time state of a parking lot along with features that influence pricing.

Key data elements include:

- Location: Latitude and longitude for proximity and competition.
- Lot Features: Capacity, current occupancy, and queue length.
- Vehicle Type: Car, bike, truck, or cycle.
- Environment: Nearby traffic conditions and special day indicators (e.g., holidays).

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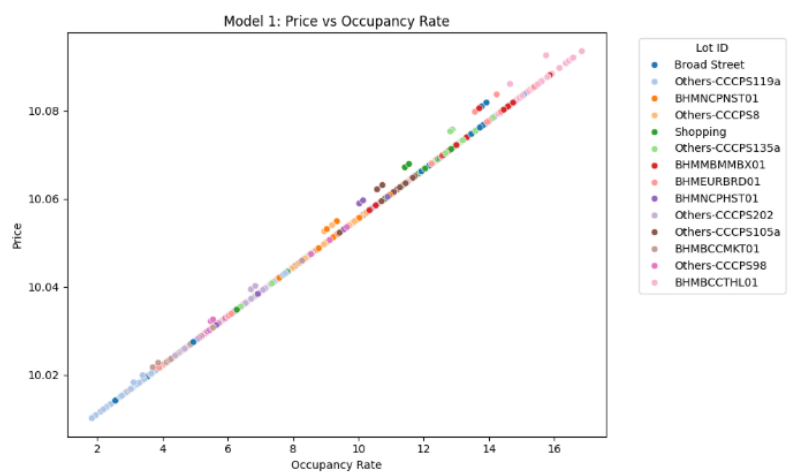
4. Methodology

Used Pathway to stream historical data in real time, maintaining timestamp order and processing live inputs for continuous pricing updates.

4.1. Model 1: Baseline Linear Model

- **Pricing Formula**:

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



This model directly links occupancy to price, ensuring higher prices during peak usage and lower prices during off-peak times. It maintains smooth transitions using a 30-minute tumbling window in Pathway.

4.2. Model 2: Demand-Based Model

- **Demand Function**:

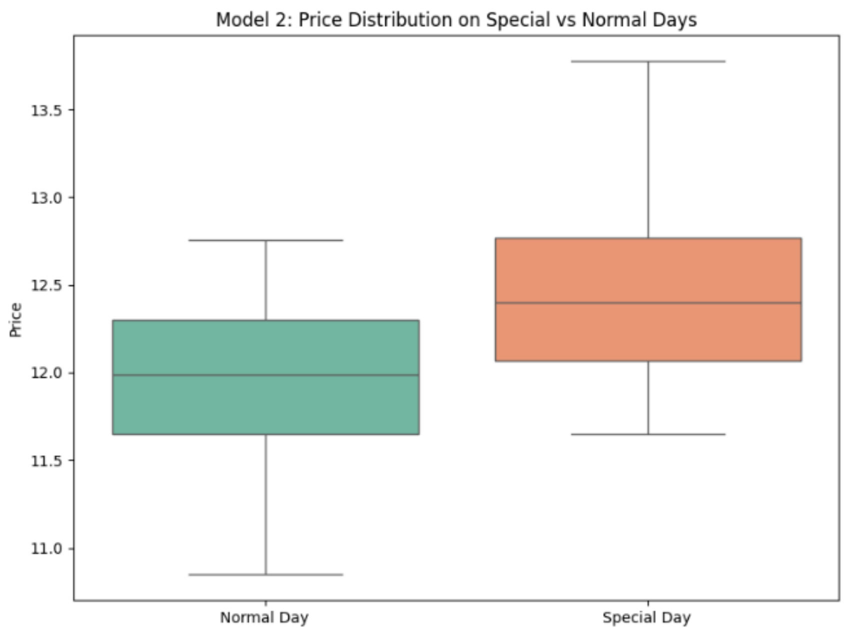
$$\text{Demand} = \alpha \cdot \left(\frac{\text{Occupancy}}{\text{Capacity}}\right) + \beta \cdot \text{QueueLength} - \gamma \cdot \text{TrafficLevel} + \delta \cdot \text{IsSpecialDay} + \varepsilon \cdot \text{VehicleWeight}$$

- Weights used for vehicle types (car: 1.5, bike: 1.0, truck: 2.0, cycle: 0.5)

Dynamic Pricing Formula:

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

- Price bound: [0.5x, 2x] of base price
- **Rationale**: The price increases with higher demand and longer queues, decreases during heavy traffic to reflect congestion, and gets a boost on special days or for heavier vehicle types.



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5. Real-Time Visualization

- Used Bokeh + Panel for real-time, interactive plots
- ColumnDataSource and HoverTool enabled smooth updates
- Simulated live data using replay_csv() from Pathway

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6. Assumptions & Considerations

- Demand function coefficients (α, β, γ, etc.) chosen via trial to reflect real-world influence of features
- Base price (₹10)
- Traffic and vehicle weights modelled as numeric proxies (e.g., bike = 1.0, truck = 2.0)
- Demand is normalized between 0 and 1 for price stability
- Geo-expansion logic assumes Lat-Long clusters for new lots

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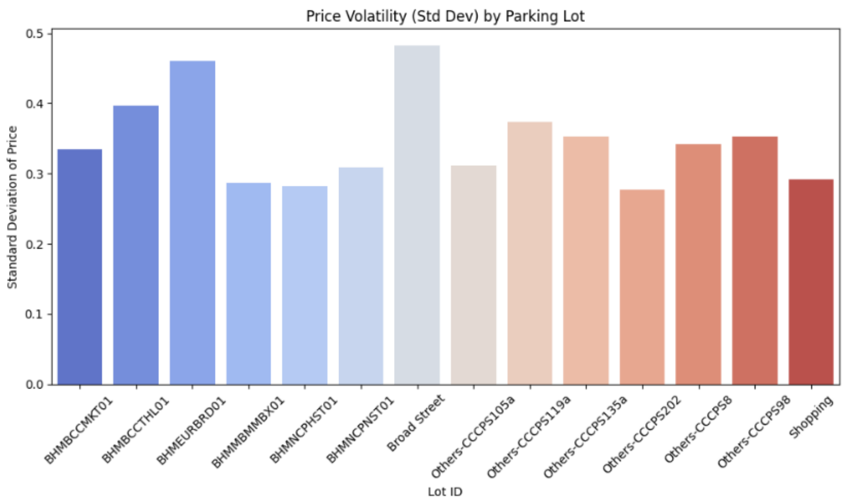
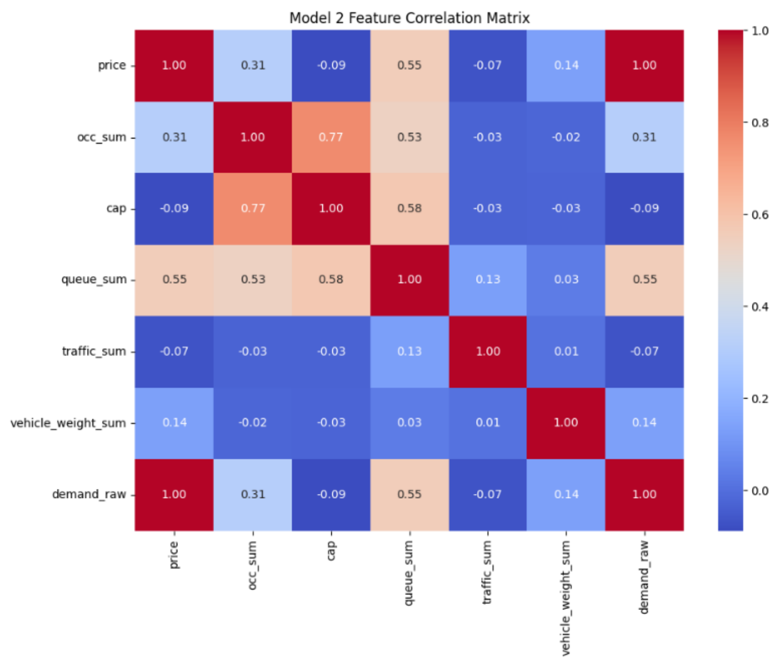
7. Insights



Some lots exhibit steep price changes day-to-day, while others remain stable.

High volatility suggests dynamic demand zones or traffic hotspots.



Occupancy and queue length have the strongest positive influence on pricing.

Traffic conditions show a slight negative correlation — reducing prices in congestion.

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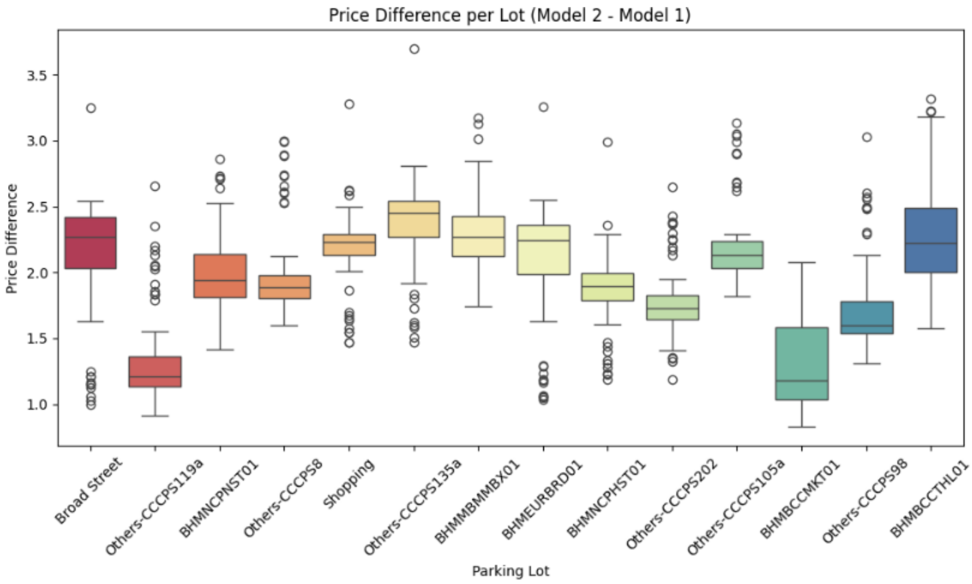
8. Results

- **Model 1**: Price based on occupancy
- **Model 2**: Factors in queue, traffic, vehicle type, special days
- **Model 2** is smoother, more adaptive
- Higher prices on special days, high demand
- Real-time plots show trends and competitor comparison



7. Future Scope

- Real-time dynamic pricing has huge potential for urban infrastructure management
- This project lays the foundation for:
    - Price optimization
    - User rerouting
    - Revenue maximization strategies

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8. Resources

- Pathway Developer Guide: https://pathway.com/developers/user-guide/introduction/first_realtime_app_with_pathway/
- Summer Analytics 2025: https://www.caciitg.com/sa/course25