Capstone Project Report

Dynamic Pricing for Urban Parking Lots
Summer Analytics 2025 – Capstone Program
Consulting & Analytics Club × Pathway

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1. Project Overview

This project addresses the inefficiencies in urban parking due to static pricing models. It implements a real-time, dynamic pricing engine that adjusts parking rates based on live demand features such as occupancy, queue length, traffic, vehicle types, and event days.

The goal is to optimize pricing strategies using real-time simulation and feature-driven models, ensuring better utilization of parking spaces in urban areas.

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2. Tools and Technologies Used

- Python for development
- NumPy & Pandas for data manipulation
- Pathway for real-time stream simulation
- Bokeh & Panel for real-time data visualization
- Google Colab as the primary execution environment

All tools used strictly adhere to the allowed libraries in the problem statement.

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3. Data Ingestion and Preprocessing

- The dataset includes fields for date, time, occupancy, and capacity.
- Date and time are merged into a single timestamp column.
- Data is sorted in chronological order.

- Pathway's replay_csv() function is used to simulate a real-time data stream from historical data.

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4. Feature Engineering

The following derived features are computed in real-time:

- **Occupancy rate** – (Occupancy / Capacity)
- **Queue length** – Simulated using Occupancy % 10
- **Traffic congestion** – Simulated using Occupancy % 5
- **Special event indicator** – Set as 1 when Occupancy % 7 == 0, else 0
- **Vehicle type weight** – Derived from (Occupancy % 3) * 0.1

These features form the core input for the demand-based pricing model.

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5. Models Implemented

Model 1: Baseline Linear Pricing

A simple pricing strategy that increases with occupancy.

Price = Base_Price + α * (Occupancy / Capacity)

Model 2: Demand-Based Dynamic Pricing

A weighted formula that incorporates multiple real-time features:

Demand = 0.6 * (Occupancy / Capacity)
+ 0.2 * Queue
- 0.1 * Traffic
+ 0.1 * SpecialDay
+ 0.05 * VehicleTypeWeight

Price = Base_Price * (1 + 0.5 * Normalized Demand)

- Demand is normalized to ensure smooth output.

- Final price is bounded between $5 and $20.

Model 3: Competitive Pricing Strategy (Conceptual)

Although not implemented due to the lack of multi-location data, this strategy would:

- Use lat/long to find nearby lots
- Compare pricing with competitors
- Adjust own pricing or reroute traffic based on proximity and demand

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6. Real-Time Execution with Pathway

Pathway is used to simulate real-time data flow and apply transformations continuously. Key steps include:

- Streaming historical data using replay_csv()
- Applying transformations and feature engineering on the fly
- Generating price outputs based on active demand features
- Streaming outputs to the visualization module in real-time

The notebook is fully Colab-compatible and executes without delay.

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7. Visualization

The pricing behavior over time is visualized using **Bokeh** and **Panel**, which are embedded directly into the Colab notebook. Visual outputs include:

- Dynamic time-series plots of price vs. timestamp
- Live updating interface as stream progresses
- Interactive display of pricing changes across models

These plots offer insights into how pricing responds to fluctuating demand conditions in real time.

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8. Summary

This project successfully delivers a fully functional dynamic pricing engine using real-time simulated data. All code is developed from scratch using only permitted tools. Models are logically structured, and visualization is interactive.

The final notebook is hosted on Google Colab, designed for public evaluation, and compliant with all technical constraints. The structure is modular and scalable for future extension into competitive and multi-lot pricing models.

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9. Submission Compliance

The following items are included in the GitHub repository:

- ✅ Properly formatted README.md with all required sections
- ✅ Tech stack summary and architecture diagram (Mermaid)
- ✅ Final Google Colab notebook with complete code and logic
- ✅ Real-time visualization using Bokeh
- ✅ Optional project report (this document)
- ✅ Public repository access enabled

Acknowledgments

This project was developed as part of the **Summer Analytics 2025 Capstone Program**, organized by the **Consulting & Analytics Club** in partnership with **Pathway**.

All logic, pricing strategies, and visualizations were designed and implemented in accordance with the official problem statement.