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Capstone Project Report

Project Title

Dynamic Pricing for Urban Parking Lots

Program

Summer Analytics 2025 Capstone Project
Conducted by **Consulting & Analytics Club**

Project Overview

This project implements an intelligent **dynamic pricing system** for urban parking lots using **real-time data streams** and multiple pricing models. The goal is to optimize parking space utilization, reduce overcrowding, and maximize revenue by setting data-driven, adaptive prices based on demand, traffic, vehicle type, and competitive factors.

Problem Statement

Urban parking spaces are limited and static pricing often leads to inefficiency — either lots are overcrowded or remain underutilized. The aim is to design and deploy an automated, real-time pricing engine that adjusts parking fees dynamically using live data feeds.

Objectives

- Develop **three pricing models** with increasing complexity.
- Integrate **real-time data processing** with **Pathway**.
- Provide interactive dashboards using **Bokeh**.
- Generate routing suggestions and competitive pricing insights.
- Ensure smooth, explainable, and bounded price variations for users.

Dataset Summary

- **Total Records:** ~18,368
- **Duration:** 73 days

- **Parking Lots Covered:** 14 unique lots
- **Key Features:**
    - `Latitude`, `Longitude` (geo-coordinates)
    - `Capacity`, `Occupancy`, `Queue Length`
    - `Vehicle Type` (car, bike, truck, cycle)
    - `Traffic Condition` (low, average, high)
    - `IsSpecialDay` (binary flag for holidays/events)
    - Timestamps for date and time tracking

Pricing Models Implemented

Model 1: Baseline Linear Pricing

- Formula: `Price = Previous_Price + α × (Occupancy / Capacity)`
- Simple linear adjustment based on occupancy rate.
- Provides a baseline for comparing more advanced models.

Model 2: Demand-Based Pricing

- Factors: Occupancy, queue length, traffic conditions, special days, vehicle type.
- Uses a composite **demand score** normalized with `tanh` to bound price swings.
- Formula:

```
Demand = α×Occupancy_Rate + β×Queue + γ×Traffic + δ×Special_Day +
ε×Vehicle_Weight
Price = Base_Price × (1 + λ×Normalized_Demand) × Vehicle_Weight
```

Model 3: Competitive Pricing

- Adds **geographic competition** using the Haversine formula.
- Suggests rerouting to nearby lots if the current lot is full and competitors have space.
- Adjusts prices dynamically to stay competitive.

Real-Time Implementation

- Integrated **Pathway** for real-time streaming and stateful computation.
- Uses Pathway's `@pw.udf` for row-wise dynamic pricing.
- Stores real-time prices and demand scores in **JSON Lines** files (`streaming_output.jsonl`).
- Final results are analyzed in **Pandas**, with summary statistics generated.

Visualizations

Interactive Bokeh Dashboard includes:

- Real-time price trends by parking lot.

- Scatter plot: **Price vs. Occupancy Rate**.
- Line plot: **Demand Score over Time**.
- Breakdown by **vehicle type** and **traffic condition**.

All visualizations update dynamically based on real streamed results.

Key Findings

Metric	Value
Average Price	~$11–14
Price Range	$5–20
Std Dev	~$3–4

- **Vehicle Type Impact:** Trucks pay ~50% more than cars.
- **Traffic Impact:** High traffic increases average price by ~20%.
- **Demand Sensitivity:** Model 2 provides smoother, more adaptive pricing.
- **Competitive Intelligence:** Model 3 enables dynamic rerouting, optimizing lot utilization across multiple locations.

Final Recommendations

1. **Deploy Model 2** for production, balancing complexity and practical insights.
2. Use **Model 3** selectively for premium lots with high competition.
3. Monitor **demand scores** to detect peak usage and adjust prices preemptively.
4. Provide **real-time routing suggestions** to customers during peak periods.
5. Continuously refine pricing parameters (`α, β, γ, δ, ε`) with historical data.

Deliverables

- `Complete_Dynamic_Pricing_Implementation.ipynb` (notebook with all code, EDA, models).
- `streaming_output.jsonl` (real-time Pathway output).
- Bokeh visualizations and `parking_pricing_analysis.png`.
- `model_comparison.csv`, `pathway_streaming_results.csv`.
- `README.md` for quickstart instructions.

Tools & Libraries

- **Pathway:** Real-time stream processing
- **Bokeh:** Interactive visualizations
- **Pandas, NumPy, Matplotlib:** Data analysis

- **Geospatial:** Haversine formula for distance calculations

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