Consulting and Analytics Club
IIT Guwahati

"Dynamic Pricing for Urban Parking Lots"

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Project Overview

Objective

To develop an intelligent, data-driven dynamic pricing system for 14 urban parking spaces using real-time data streams and machine learning models built from scratch (using only numpy, pandas, and Pathway). The goal is to optimize parking lot utilization by adjusting prices in response to real-time demand, competition, and environmental factors.

Key Features

- **Real-Time Pricing:**
  Prices are updated dynamically based on historical occupancy, queue length, traffic conditions, special events, vehicle type, and competitor prices.
- **Simulation:**
  The system simulates real-time data ingestion and processing using Pathway, ensuring that pricing decisions are made continuously as new data arrives
- **Smooth Price Adjustments:**
  Pricing changes must be gradual and explainable, starting from a base price of $10 and remaining within reasonable bounds.

Data Description

- **Time Frame:**

  73 days, sampled every 30 minutes from 8:00 AM to 4:30 PM.

- **Features Collected:**
  - Location (latitude, longitude)
  - Lot capacity and current occupancy
  - Queue length
  - Incoming vehicle type (car, bike, truck)
  - Nearby traffic congestion
  - Special day indicators (holidays, events)

Model Development Stages

- **Baseline Linear Model:**

  Price increases linearly with occupancy.

- **Demand-Based Model:**

  Incorporates additional factors (queue, traffic, special days, vehicle type) into a normalized demand function to adjust prices.

- **Competitive Model :**

  Considers geographic proximity and competitor pricing to further refine pricing and suggest rerouting.

Tech Stacks Used

- **Python:**
  Core programming language for all data processing, modeling, and orchestration.
- **Numpy & Pandas:**
  For efficient data manipulation, analysis, and feature engineering.
- **Pathway:**
  Real-time data streaming and processing framework, enabling continuous updates to the pricing model as new data arrives.
- **Bokeh:**
  Interactive data visualization library, used to create real-time dashboards and visual reports.

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Architecture Diagram

Data Sources

- Parking Sensors
- Traffic Feeds
- Event Calendar

Data Ingestion

- Pathway streams
- Preprocessing and Aggregation

Feature Engineering

- Occupancy Rate
- Queue Length
- Traffic Encoding
- Special Days
- Vehicle Type Weights

Pricing Engine

- Baseline Model
- Demand-Based
- Model
- Competitive Model

Visualization

- Bokeh Dashboards
- Analysis
- Conclusion

Workflow

Data Collection & Ingestion

Sources:

- Real-time parking lot sensors (occupancy, queue length, vehicle type)
- Traffic condition feeds near each lot
- Special event and holiday calendars

Ingestion Pipeline:

- All data streams are managed using Pathway, which ensures that new information is processed as soon as it arrives.
- Data is preprocessed to handle missing values, normalize formats, and encode categorical variables.

Feature Engineering

Vehicle Type Weight:

Different vehicle types are assigned weights based on their impact on parking demand & space usage.

Occupancy Rate:

Calculated as the ratio of current occupancy to lot capacity.

Queue Length:

Number of vehicles waiting for a spot, directly affecting demand.

Traffic Encoding:

Traffic conditions near each lot are encoded numerically to quantify their impact on demand.

Special Day Indicator:

Binary feature marking holidays or special events, which typically increase demand.

Pricing Engine

Baseline Linear Model:

- **Logic:**
  Price increases linearly with occupancy.
- **Formula:**
  Price=Base Price+α×Occupancy Rate
- **Purpose:**
  Provides a simple, explainable starting point for dynamic pricing.

Competitive Model:

- **Logic:**
  Considers competitor pricing and geographic proximity.
- **Rerouting:**
  If a lot is full or overpriced, the system can suggest rerouting vehicles to nearby lots with available capacity.
- **Purpose:**
  Maximizes both user satisfaction and revenue.

Demand-Based Model:

- **Logic:**
  Incorporates multiple demand factors. (queue length, traffic, special days, vehicle type)
- **Demand Equation:**
  Demand=α · (CapacityOccupancy)+β · Queue Length−γ · Traffic+δ · IsSpecialDay+ϵ · Vehicle TypeWeight
- **Price Adjustment Formula:**
  Price=BasePrice · (1+λ · NormalizedDemand)
- **Purpose:**
  Enables more responsive pricing that reflect real-world conditions.

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Real-Time Processing

- **Continuous Updates:**
  As new data arrives, the system recalculates prices and updates dashboards.
- **Smooth Adjustments:**
  Pricing changes are constrained to avoid sudden jumps, maintaining user trust and predictability.

Visualization

- **Bokeh Dashboards:**
  Real-time visualizations show pricing trends, occupancy, and comparisons with competitors.

Conclusion

The Competitive Model is the better choice for dynamic pricing in urban parking lots. It delivers the highest adaptability, optimizes both revenue and occupancy, and responds effectively to real-time demand and competition. If implementation resources are limited, the Demand-Based Model is a strong alternative and a significant improvement over the Baseline Linear Model.

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