**Capstone Project Report: Dynamic Pricing for Urban Parking Lots**

**Project Overview:**  
This project simulates a dynamic pricing system for urban parking lots using real-time data. We aim to develop a pricing engine that adapts parking prices based on occupancy, vehicle type, queue length, traffic conditions, special days, and competition. The models were built using Python, pandas, numpy, and Pathway, as per project constraints.

**Data Description:**  
The dataset contains data collected from 14 urban parking lots over 73 days, with 18 time points per day. The dataset includes features like:

* Location: Latitude, Longitude
* Lot Status: Capacity, Occupancy, QueueLength
* Vehicle: Type
* Environment: TrafficConditionNearby, IsSpecialDay

**Step-by-Step Approach:**

**1. Data Preprocessing:**

* Removed missing values.
* Encoded VehicleType to numerical weights: car (1.0), bike (0.5), truck (1.5).
* Normalized OccupancyRate and QueueLength to a 0-1 scale.

**2. Model 1: Baseline Linear Pricing**  
**Formula:**  
Price\_t+1 = Price\_t + α \* (Occupancy / Capacity)

* A simple linear relationship where price increases with occupancy.
* Used as a benchmark model.

**3. Model 2: Demand-Based Pricing Function**  
**Demand Function:**  
Demand = α \* (Occupancy / Capacity) + β \* QueueLengthNorm - γ \* Traffic + δ \* IsSpecialDay + ε \* VehicleTypeWeight

**Pricing Function:**  
Price = BasePrice \* (1 + λ \* NormalizedDemand)

* Demand is normalized to keep pricing within 0.5x to 2x base.
* Smooth, bounded price response.

**4. Model 3: Competitive Model (Optional)**

* Calculated proximity to nearby parking lots using Haversine distance.
* Adjusted price based on competitor prices:
  + If nearby lots are cheaper and less full, lower price or suggest reroute.
  + If competitors are expensive, raise price moderately.

**Real-Time Processing with Pathway:**

* Simulated streaming of CSV using Pathway.
* Real-time calculation of demand and pricing.
* Used pw.apply() for transformations like vehicle type weighting and demand normalization.
* Emitted FinalPrice and selected fields to a real-time output.

**Real-Time Visualization with Bokeh:**

* After generating output with Pathway, real-time visualizations were implemented using Bokeh.
* Plots were created showing how prices evolve over time for different parking spaces.
* Used line plots where X-axis represents time or index and Y-axis shows FinalPrice.
* Top 5 most active parking lots were visualized for clarity.
* This visualization helped justify pricing behavior by clearly illustrating the impact of demand, congestion, and competition on price shifts.

**Demand Function, Assumptions, and Price Behavior:**

**Demand Function Explanation:**

* The demand function combines multiple weighted real-time features:
  + Occupancy rate
  + Normalized queue length
  + Nearby traffic congestion
  + Whether the day is a special day (e.g. holiday)
  + Type of vehicle (cars, bikes, trucks)
* The demand is normalized to a 0-1 range for price scaling.

**Assumptions Made:**

1. Vehicle type reflects willingness to pay (e.g., trucks can be charged more).
2. Heavy traffic nearby reduces willingness to park, so demand drops.
3. Special days lead to increased demand.
4. Demand is assumed to increase monotonically with queue length and occupancy.
5. Distance to competitors is approximated using Haversine distance.

**How Price Changes with Demand and Competition:**

* As demand increases (due to higher occupancy, queues, or events), the normalized demand increases.
* Final price is computed using the formula: FinalPrice = BasePrice \* (1 + λ \* NormalizedDemand).
* Prices are capped within a practical range (0.5x–2x base).
* In the competitive model, prices are adjusted relative to nearby competitors:
  + If cheaper competitors are nearby and available, the price is lowered to remain attractive.
  + If our lot is in higher demand or fewer alternatives are present, the price is maintained or increased slightly.

**Conclusion:**  
Three models of increasing complexity were built:

1. Linear pricing based on occupancy.
2. Smart demand-driven pricing.
3. Competitor-aware pricing.

All models were implemented in real-time simulation using Pathway. Final prices respond dynamically, smoothly, and justifiably based on real-world economic reasoning.

Bokeh visualizations provided live feedback and clear justification of model performance and pricing rationale.