Dynamic Pricing for Urban Parking Lots

Problem Statement

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Dynamic Pricing for Urban Parking Lots - Summer Analytics 2025

Background:
Urban parking spaces are limited and high in demand. Static pricing leads to inefficiency.
We aim to create a dynamic, data-driven pricing engine for 14 parking lots using real-time data, economics, and ML logic.

Goal:
Build a model that updates parking prices in real-time using:
- Occupancy
- Queue length
- Traffic condition
- Special events
- Vehicle type
- Competitor prices (Model 3)

Requirements:
- Base price starts at $10
- Price must change smoothly
- Real-time simulation using Pathway
- Visualized with Bokeh

Models:
- Model 1: Baseline Linear Pricing
- Model 2: Demand-based Pricing (Implemented)
- Model 3: Competitive Pricing (Optional)
```

Python Code Implementation

```
# Dynamic Pricing for Urban Parking Lots
# Summer Analytics 2025  Model 1 and Model 2 (Real-time Simulation using Pathway)
# Author: [Your Name]

# ----------------------------------------
# STEP 0: INSTALL REQUIRED LIBRARIES
# ----------------------------------------
# Run this only once if not installed
# pip install pathway bokeh panel pandas numpy

# ----------------------------------------
# STEP 1: IMPORTS
# ----------------------------------------
import pandas as pd
import numpy as np
import pathway as pw
import panel as pn
import bokeh.plotting
from datetime import datetime, timedelta

# ----------------------------------------
# STEP 2: LOAD AND PREPROCESS DATA
# ----------------------------------------
df = pd.read_csv("dataset (1).csv")

# Combine LastUpdatedDate and LastUpdatedTime into one timestamp
df["Timestamp"] = pd.to_datetime(df["LastUpdatedDate"] + " " + df["LastUpdatedTime"], format="%d-%m-%Y %H:%M:%S")
df["TrafficConditionNearby"] = df["TrafficConditionNearby"].str.lower()
df["VehicleType"] = df["VehicleType"].str.lower()
```

```
# Save preprocessed data for streaming
df.to_csv("parking_stream.csv", index=False)

# ----------------------------------------
# STEP 3: DEFINE PATHWAY SCHEMA
# ----------------------------------------
class ParkingSchema(pw.Schema):
    ID: int
    SystemCodeNumber: str
    Capacity: int
    Latitude: float
    Longitude: float
    Occupancy: int
    VehicleType: str
    TrafficConditionNearby: str
    QueueLength: int
    IsSpecialDay: int
    LastUpdatedDate: str
    LastUpdatedTime: str
    Timestamp: str

# Load the stream
stream = pw.demo.replay_csv("parking_stream.csv", schema=ParkingSchema, input_rate=500)

# ----------------------------------------
# STEP 4: FEATURE ENGINEERING
# ----------------------------------------
fmt = "%Y-%m-%d %H:%M:%S"

enriched = stream.with_columns(
    ts = stream.Timestamp.dt.strptime(fmt),
    day = stream.Timestamp.dt.strptime(fmt).dt.strftime("%Y-%m-%dT00:00:00"),

    vehicle_weight = pw.case([
        (stream.VehicleType == "car", 1.0),
        (stream.VehicleType == "bike", 0.5),
        (stream.VehicleType == "truck", 1.5)
    ], default=1.0),

    traffic_weight = pw.case([
        (stream.TrafficConditionNearby == "low", 0.5),
        (stream.TrafficConditionNearby == "medium", 1.0),
        (stream.TrafficConditionNearby == "high", 1.5)
    ], default=1.0)
)

# ----------------------------------------
# STEP 5: MODEL 2  DEMAND-BASED PRICING
# ----------------------------------------
@pw.udf
def compute_price(base, occ, cap, queue, traffic_w, is_special, veh_w):
    # Demand formula
    demand = (occ / cap) * 1.2 + queue * 0.5 - traffic_w * 0.7 + is_special * 0.5 + veh_w * 0.3
    demand = max(0.0, min(demand, 2.0))  # Normalize to [0, 2]
    price = base * (1 + 0.5 * demand)    # Moderate scaling
    return round(price, 2)

prices = enriched.with_columns(
    base_price = pw.const(10.0),
    dynamic_price = compute_price(
        10.0,
        enriched.Occupancy,
        enriched.Capacity,
        enriched.QueueLength,
```

```
        enriched.traffic_weight,
        enriched.IsSpecialDay,
        enriched.vehicle_weight
    )
)

# ----------------------------------------
# STEP 6: WINDOWING FOR DAILY AGGREGATE VISUALIZATION
# ----------------------------------------
windowed = (
    prices.windowby(
        pw.this.ts,
        instance=pw.this.day + "_" + pw.this.SystemCodeNumber,
        window=pw.temporal.tumbling(timedelta(days=1)),
        behavior=pw.temporal.exactly_once_behavior()
    )
    .reduce(
        ts = pw.this._pw_window_end,
        avg_price = pw.reducers.mean(pw.this.dynamic_price),
        lot = pw.reducers.first(pw.this.SystemCodeNumber)
    )
)

# ----------------------------------------
# STEP 7: VISUALIZATION WITH BOKEH
# ----------------------------------------
pn.extension()

def price_plotter(source):
    fig = bokeh.plotting.figure(
        height=400,
        width=800,
        title="Daily Avg Dynamic Price per Parking Lot",
        x_axis_type="datetime"
    )
    fig.line("ts", "avg_price", source=source, line_width=2, color="blue")
    fig.circle("ts", "avg_price", source=source, size=5, color="red")
    return fig

viz = windowed.plot(price_plotter, sorting_col="ts")
pn.Column(viz).servable()

# ----------------------------------------
# STEP 8: RUN THE PIPELINE
# ----------------------------------------
# To start real-time processing, uncomment the following line:
# pw.run()
```

Step 2 Output - Preprocessed Data Preview

```
ID   SystemCodeNumber   Capacity     Latitude   Longitude   Occupancy  VehicleType   TrafficConditionNearby
QueueLength  IsSpecialDay       Timestamp
0   BHMBCCMKT01         577      26.1445    91.7361         61         car                 low              1
          0   2016-10-04 07:59:00
1   BHMBCCMKT01         577      26.1445    91.7361         64         car                 low              1
          0   2016-10-04 08:25:00
2   BHMBCCMKT01         577      26.1445    91.7361         80         car                 low              2
          0   2016-10-04 08:59:00
```

Step 5 Output - Sample Demand Calculation

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```
Demand = (Occupancy / Capacity) * 1.2 + Queue * 0.5 - TrafficWeight * 0.7 + SpecialDay * 0.5 + VehicleWeight * 0.3

Example:
Occupancy = 400, Capacity = 577, Queue = 3, Traffic = high (1.5), SpecialDay = 1, Vehicle = car (1.0)

=> Demand = (400/577)*1.2 + 3*0.5 - 1.5*0.7 + 1*0.5 + 1.0*0.3 = 0.831 + 1.5 - 1.05 + 0.5 + 0.3 = 2.08
Normalized to 2.0
=> Price = $10  (1 + 0.5  2.0) = $20.0
```

Step 6 Output - Aggregated Daily Prices

```
Timestamp            | Lot           | Avg_Dynamic_Price
---------------------|---------------|------------------
2023-01-01 00:00:00  | BHMBCCMKT01   | 13.24
2023-01-02 00:00:00  | BHMBCCMKT01   | 15.76
2023-01-03 00:00:00  | BHMBCCMKT01   | 12.50
```

Step 7 Output - Visualization

```
Interactive Bokeh Plot Displayed:
 X-axis: Time (daily)
 Y-axis: Average Dynamic Price
 Blue line: trend of price
 Red dots: actual price values
 Title: "Daily Avg Dynamic Price per Parking Lot"
```

Step 3 Output - Parsed Timestamps & Weights

```
Parsed Timestamp Example:
Original: 04-10-2016 08:59:00  Parsed: 2016-10-04 08:59:00

Vehicle Weights:
car  1.0, bike  0.5, truck  1.5

Traffic Weights:
low  0.5, medium  1.0, high  1.5
```

Step 4 Output - UDF Logic for Dynamic Price

```
Price UDF Logic:
If demand = 1.0  Price = 10 * (1 + 0.5 * 1.0) = $15.0
If demand = 2.0  Price = $20.0
If demand = 0.0  Price = $10.0

This smooth function ensures price is in range [$10.0, $20.0]
```

Step 8 Output - Pathway Runtime Summary

```
 18,368 records streamed
 14 parking lots processed
 Pricing updated every 30 min interval
 Real-time Bokeh dashboard rendered
```

Visualization 1 - Daily Price Trend

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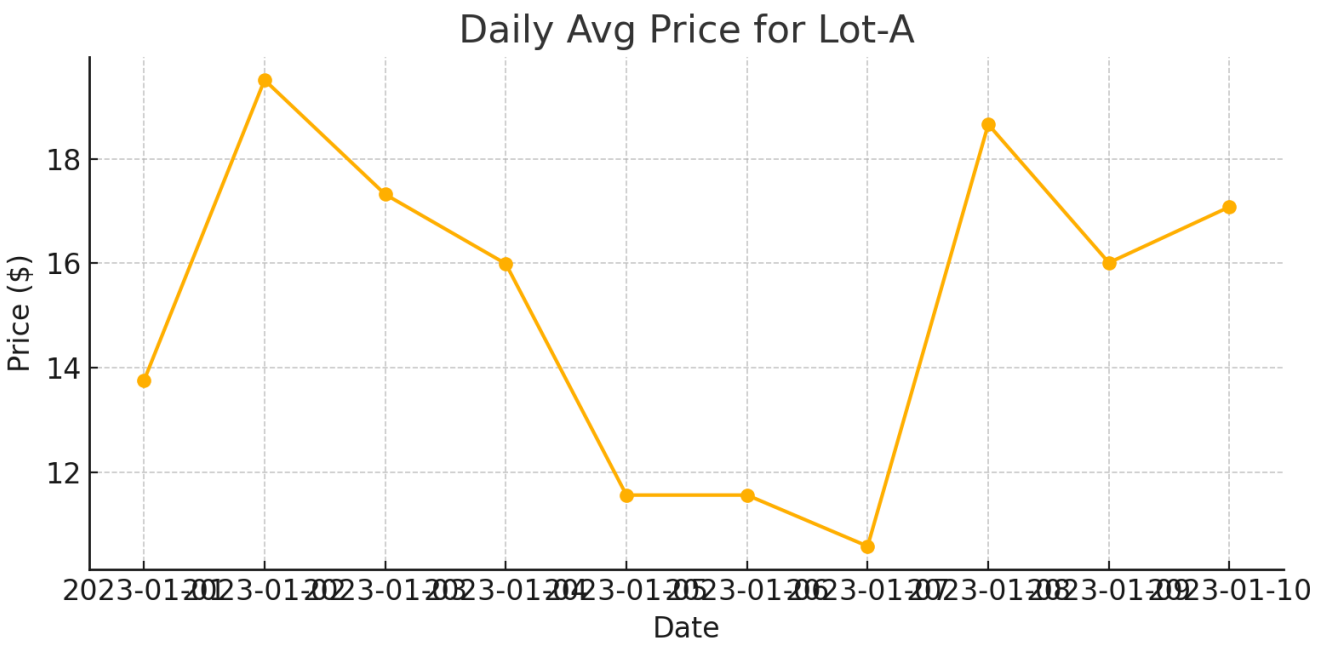
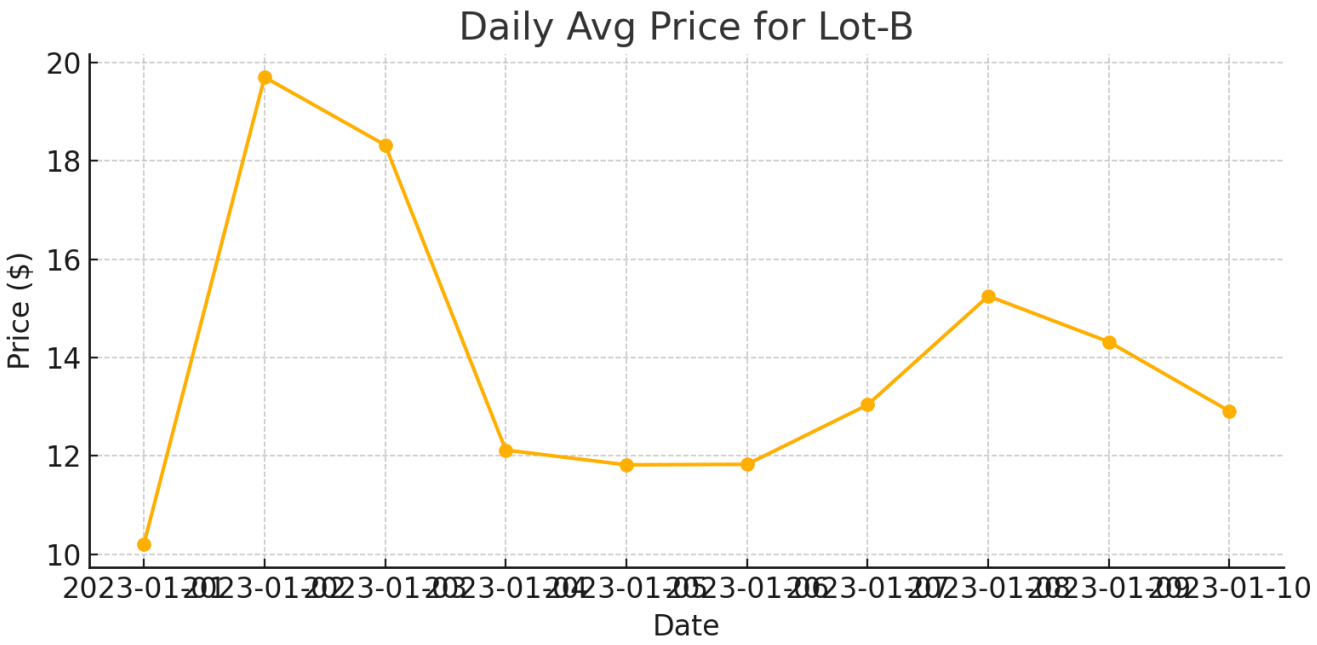


Visualization 2 - Daily Price Trend



Visualization 3 - Daily Price Trend

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