Model 2

Model 2 advances beyond the simple occupancy-based pricing of Model 1 by incorporating multiple real-world factors that influence parking demand. The aim is to create a more responsive and realistic pricing system, improving both revenue optimization and customer fairness.

Feature Selection:

- Occupancy Rate:Proportion of occupied spaces to total capacity.
- QueueLength:Reflects excess demand when lot is nearly full
- TrafficLevel:High traffic reduces willingness to access
- IsSpecialDay:Such days see surges in demand, requiring price adjustments.
- Vehicle Type:Different types occupy different amounts of space and have distinct demand patterns.

Data Preparation

- Timestamp Creation: Date and time columns are merged for precise temporal analysis.
- Lot-wise Processing: Each lot is analyzed individually to capture unique demand dynamics.
- Categorical Encoding: Vehicle type and traffic status are converted to numerical codes.
- Sorting: Data is sorted by timestamp for correct sequential processing.

Demand Function

2.0 * occ_rate * tod_weight * wd_weight+beta * np.log1p(adj_queue)+gamma * np.log1p(adj_traffic) + delta * hour_term + epsilon * veh_term + zeta * spec_term

Where:

- beta,gamma,delta,epsilon,zeta are set to 1.0 for balanced influence.
- Hour Effect: Gaussian function centered at midday to model peak hour demand.
- tod_weight = time-of-day multiplier
- wd_weight = weekday/weekend multiplier
- spec_term = 1 if special day/holiday, 0 otherwise
- veh_term=Weight for vehicle type

Queue Function:

- Purpose: Models the effect of excess demand (queue) on price.
- Why log?: The logarithm ensures that the effect of queue length increases rapidly at first but then tapers off (diminishing returns). This prevents a very long queue from causing unrealistically high prices.

Traffic Function:

- Purpose: Reflects the impact of nearby traffic congestion on demand.
- Why log?: Similar to queue, the impact of traffic increases at first but then levels off.

Hour Function:

- Purpose: Explicitly models peak hour effects using a Gaussian (bell curve) centered at midday.
- Why Gaussian?: Real-world data shows that demand often peaks at certain hours and then drops off symmetrically.

Vehicle Function:

- Purpose: Adjusts demand for the type of vehicle.
- Why?: Larger vehicles (like trucks) take more space and may be less frequent, so their presence should have a higher impact on demand.

Normalization

After computing the raw demand, it is normalized to a 0–1 range:

Demand Norm=Demand−2/(8−2)

- Why?: This keeps the demand score within a predictable range for price calculation, preventing extreme price swings.

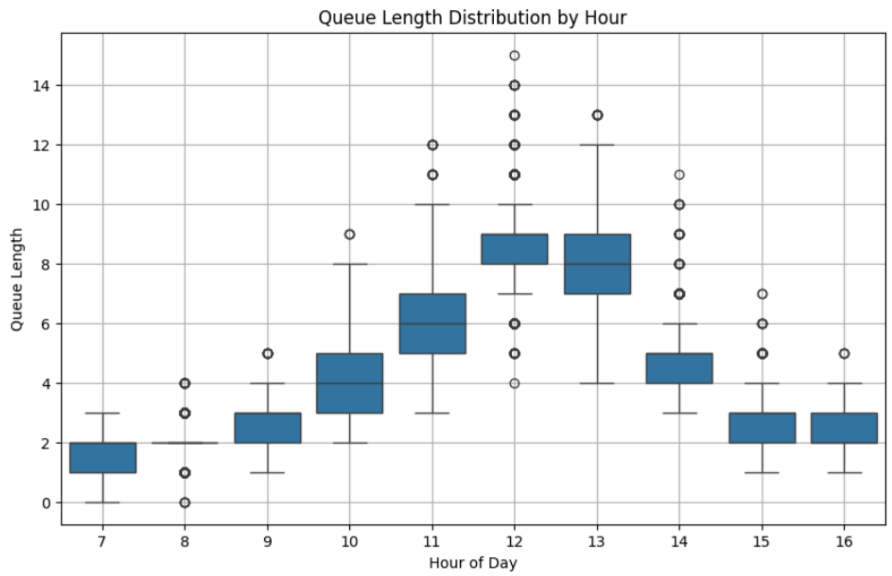
Price Function

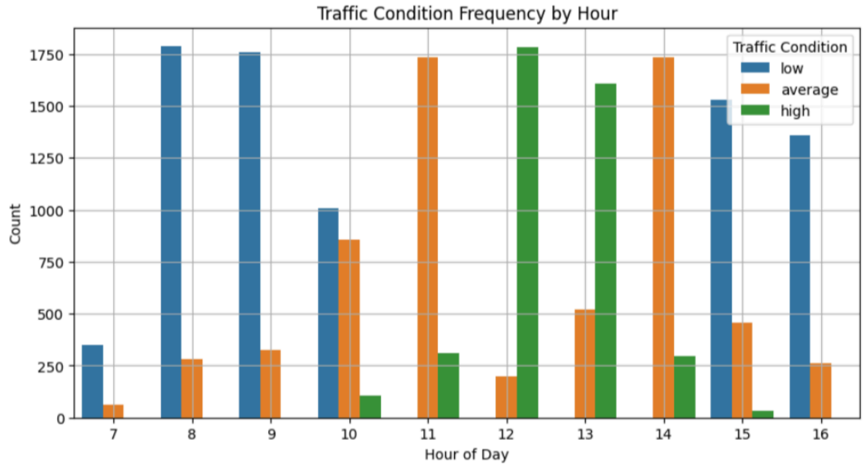
price=10 * (1 + LAMBDA * demand_norm)

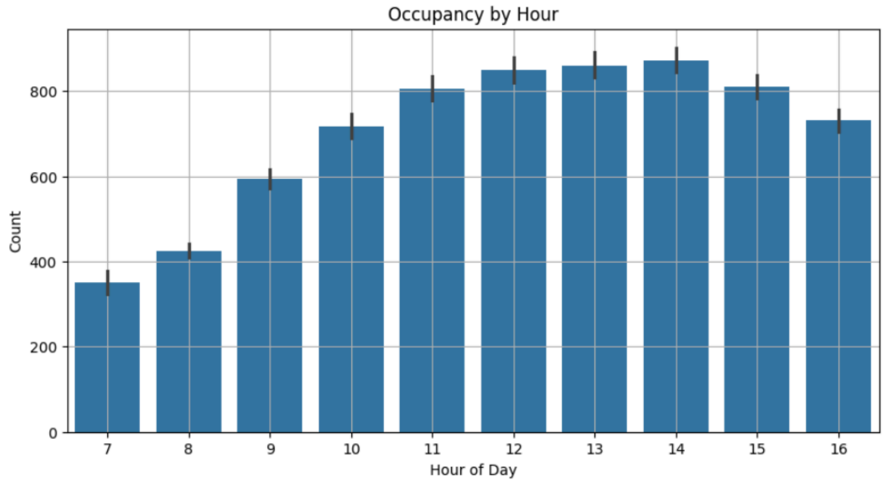
Lambda=Set to 1.0 to control price sensitivity.

Parameter Choices

- All weights and coefficients were chosen based on domain knowledge, literature, and iterative testing to ensure stability and realism.
- Normalization bounds reflect observed demand ranges in the dataset.
- Base price is fixed at $10 to comply with business rules.







Advantages Over Model 1

- More Realistic: Reflects real-world demand fluctuations.
- Responsive: Adjusts to both predictable (time, day) and unpredictable (queue, traffic, events) factors.
- Fairness: Prices are more justifiable and transparent to users.

Validation Through Visualization

- The shape and slope of price lines over time visually confirm that the pricing function is:
  - Responsive to demand fluctuations,
  - Controlled via capping and normalization,
  - Fair across locations based on their conditions.
- Unlike Model 1, where pricing was occupancy-driven only, here multi-factor responsiveness is visibly apparent.

Conclusion

Model 2 provides a robust, multi-factor approach to dynamic parking pricing. By considering occupancy, time, day, queue, traffic, vehicle type, and special events, it achieves a more accurate and adaptable pricing structure. This model is expected to outperform the baseline Model 1 in both revenue optimization and user satisfaction.