# Car Sales Forecasting Model Performance Report

## 1. Executive Summary

* **Objective:** Predict used car sale price ($) using dealer, customer, vehicle, and temporal features.
* **Final Model:** Random Forest Regressor (optimized via GridSearchCV)
* **Key Performance (Test set):**
  + R² = 0.9973
  + MAE = 0.0147 (in normalized units)
  + RMSE = 0.0519
  + MAPE = 5.88%
* **Business Impact:** Predict prices within ~6% error, enabling dynamic pricing and inventory valuation.

## 2. Data Overview

* **Rows:** 23,089
* **Features (post‑engineering):** 27 numeric and datetime-derived columns, e.g.:
  + Customer: Annual Income, Income\_Bracket, Price\_to\_Income
  + Vehicle: Company\_Strength, model, Engine\_to\_Model, PI\_plus\_model
  + Temporal: Year, Month, DayOfWeek, Seasonal\_Price\_Index
* **Target:** Price ($) (normalized)

## 3. Feature Engineering

| **Feature** | **Description** | **Corr. with Price** |
| --- | --- | --- |
| Price\_to\_Income | Price ÷ Annual Income | 0.63 |
| Income\_Bracket | Quartile bucket of income | 0.65 |
| Company\_Strength | Mean price per company | 0.61 |
| PI\_plus\_model | Price\_to\_Income + model code | 0.49 |
| Seasonal\_Price\_Index | Mean price per season | 0.42 |
| Year\_Month | Numeric trend (Year\*100 + Month) | 0.99 |

**Decisions:** Retained features with |corr| > 0.2; dropped low-correlation ones.

## 4. Modeling Approach

1. **Baseline Models:** Linear Regression, Decision Tree.
2. **Ensemble Models:** Random Forest, Gradient Boosting, XGBoost.
3. **Validation:** 80/20 train/test split + 5‑fold cross‑validation on training set.
4. **Hyperparameter Tuning:** GridSearchCV on Random Forest:
   * n\_estimators: [100,200]
   * max\_depth: [None,10,20]
   * min\_samples\_split: [2,5]
   * min\_samples\_leaf: [1,2]
   * max\_features: ['auto','sqrt']
   * Scoring: neg\_mean\_absolute\_error

## 5. Performance Comparison

| **Model** | **R² Test** | **MAE Test** | **RMSE Test** | **MAPE Test** | **CV MAE** | **Train Time (s)** | **Verdict** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Random Forest | 0.9973 | 0.0147 | 0.0519 | 5.88% | 0.0147 | 105.9 | **Best overall accuracy** |
| Gradient Boosting | 0.9973 | 0.0300 | 0.0485 | 18.32% | 0.0300 | 28.4 | Speed/accuracy trade‑off |
| XGBoost | 0.9959 | 0.0336 | 0.0641 | 19.99% | 0.0341 | 3.3 | Good speed, tune further |
| Decision Tree | 0.9821 | 0.0524 | 0.1345 | 17.53% | 0.0279 | 1.1 | Under‑generalizes |

## 6. Final Model Selection

* **Selected:** Random Forest Regressor (GridSearchCV best estimator)
* **Hyperparameters:**
  + n\_estimators: 200
  + max\_depth: None
  + min\_samples\_split: 2
  + min\_samples\_leaf: 1
  + max\_features: 'sqrt'
* **Rationale:** Highest test R², lowest MAE/MAPE, stable CV performance.

## 7. Diagnostics

* **Residual Plot:** showed no obvious bias across predicted range.
* **Learning Curve:** converged, low variance between train/val scores.
* **Feature Importance:** top 5 — Year\_Month, Price\_to\_Income, Income\_Bracket, Company\_Strength, PI\_plus\_model.

End of Report