# Predicting Podcast Listening Time with Machine Learning: A CRISP-DM Study

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***Abstract*—Podcasts have become a mainstream medium, yet producers still lack robust, data-driven tools to anticipate audience engagement. The aim of this study is to *predict listening time* (*minutes listened*) using episode- and context-level features (e.g., duration, ad load, publication time, genre, popularity signals). The project, developed as a course assignment, adheres to CRISP-DM: (i) Data Understanding and Data Exploration, (ii) Data Preparation and Feature Engineering, (iii) Model Training and Evaluation, and (iv) Interpretation of Results and Insights. The contribution is a transparent, leakage-safe pipeline and a compact feature set that balances accuracy and interpretability. A tuned Random Forest delivers the best generalization among the tested models.**

***Index Terms*—Podcast analytics, listening time, machine learning, feature engineering, advertising, engagement prediction.**

## I. Introduction

Podcasts have become a mainstream medium, yet producers still lack robust, data-driven tools to anticipate audience engagement. The objective is to *predict listening time* (*minutes listened*) from episode- and context-level information (e.g., duration, ad load, publication time, genre, popularity signals). The work follows CRISP-DM end-to-end: (i) Data Understanding and Data Exploration, (ii) Data Preparation and Feature Engineering, (iii) Model Training and Evaluation, and (iv) Interpretation of Results and Insights. The pipeline is designed to minimize leakage and to remain interpretable, while a tuned Random Forest achieves the strongest generalization among the considered models.

## II. Related Work

Podcast research has investigated the role of advertising, message framing, and host influence in shaping engagement and ad effectiveness. Experimental evidence indicates that ad type and placement significantly affect listener attitudes [1], [2]. Large-sample surveys have measured podcast-listening habits, preferred formats, and attention dynamics across heterogeneous audiences [4], [3]. From a marketing perspective, the strength of the relationship between listener and podcast predicts loyalty and listening duration [5].

From a methodological perspective, predicting user engagement through listening or watch-time metrics parallels research in online video analytics. Studies on YouTube and other platforms highlight the value of time-based objectives and nonlinear models for understanding consumption patterns [6], [7], [8]. These works motivate the use of listening time as a regression target and justify the inclusion of nonlinear ensemble models such as Random Forests to capture richer feature interactions.

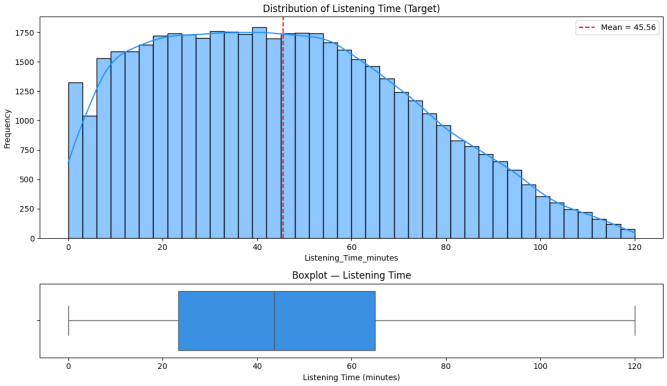

Fig. 1. Distribution and boxplot of *Listening Time (minutes)* after cleaning. Right-skewed shape motivates MAE as primary selection metric.

## III. Data Understanding and Data Exploration

### A. Dataset Overview

The dataset comprises podcast *episodes* as observational units. Each row contains episode-level descriptors and contextual metadata, including absolute duration (*Episode_Length_minutes*), content category (*Genre*), publication context (*Publication_Day*, *Publication_Time*), advertising load (*Number_of_Ads*), and popularity signals for hosts and guests (*Host_Popularity_percentage*, *Guest_Popularity_percentage*). The prediction target is *Listening_Time_minutes*. The granularity is content-instance level rather than show-level aggregates, allowing examination of within-show variance and contextual effects.

### B. Target Distribution, Skewness, and Outliers

Figure 1 depicts the empirical distribution of *Listening_Time_minutes* and the dispersion and potential outliers. The distribution is moderately right-skewed: most episodes cluster around mid-range listening, with a long tail of high-consumption cases. Such skewness is common in engagement metrics and implies that (i) MAE better reflects central errors

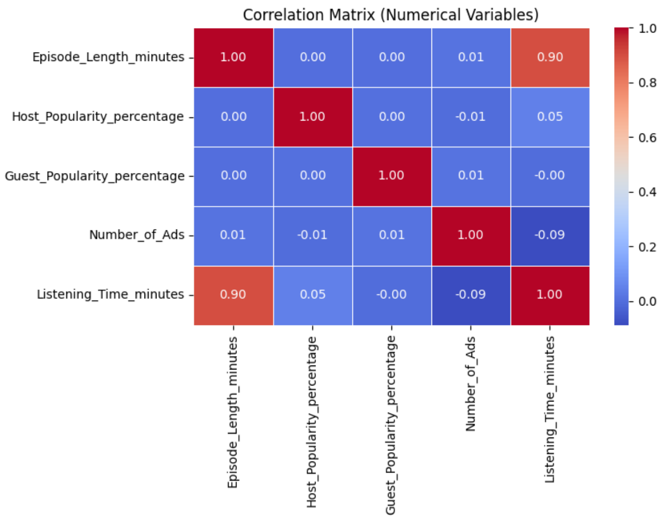

Fig. 2. Correlation matrix among numeric variables. Length shows the only strong marginal correlation with the target; others are weak, motivating engineered features and nonlinear models.

than RMSE (which penalizes extremes), and (ii) variance stabilization benefits linear models only indirectly; the target is therefore kept in natural units for interpretability.

A practical consistency check employs the *listening ratio*, $r = \mathrm{ListeningTime}/\mathrm{EpisodeLength}$. Episodes with $r > 1.2$ are excluded to remove unrealistic or noisy cases (e.g., replays or logging artifacts). Importantly, $r$ is *not* used as a feature to avoid target leakage. Post-filtering, the target retains its right tail but with fewer extreme points, yielding a distribution more representative of single-pass listening behavior.

### C. Correlation Structure and Multicollinearity

Pairwise correlations among numerical variables confirm that *Episode_Length_minutes* is strongly associated with *Listening_Time_minutes* (empirically $r \approx 0.9$), indicating duration as the principal driver of listening. By contrast, popularity percentages and ad counts exhibit weaker marginal correlations with the target. Weak marginal signals may still be relevant when *interacting* with stronger factors or when captured by nonlinear splits.

Because episode length dominates the signal, linear models are susceptible to *coefficient shrinkage* mostly acting on minor features (Lasso), whereas tree ensembles can exploit interaction structure (e.g., different ad effects at different durations). To reduce collinearity in linear baselines without harming ensembles, **Log_Length** is derived to de-skew duration; the raw length is retained for tree models (which are invariant to monotone transformations and remain interpretable in diagnostics).

### D. Duration vs. Listening: Functional Pattern

Figure 3 shows a near-linear trend between *Episode Length* and *Listening Time*. Two nuances are noteworthy:

1) **Heteroscedasticity**: dispersion around the trend grows with duration. Longer episodes span a wider range of actual listening, consistent with partial completion behavior. This supports (i) MAE as a robust metric and (ii) the use of non-linear models that can capture varying slopes or thresholds.
2) **Diminishing returns at extremes**: beyond a certain length, listening increments per additional minute appear to taper for some genres; ensembles can accommodate such curvature more easily than OLS.

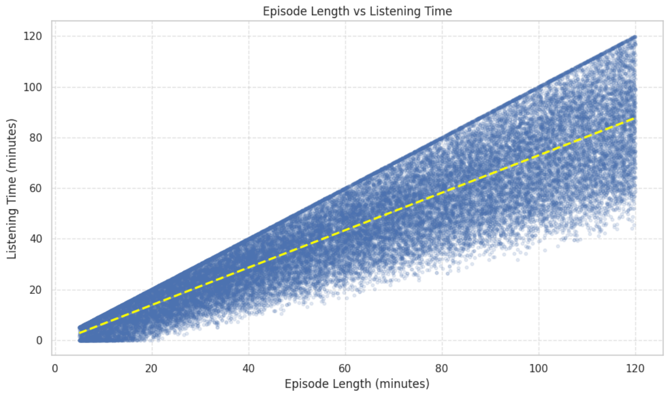

Fig. 3. Episode length vs. listening time. Near-linear trend with heteroscedasticity and diminishing returns at extremes.

### E. Advertising Effects: Level vs. Density

Raw ad counts provide an incomplete view because a fixed number of ads has different salience in short vs. long episodes. A normalized intensity measure, **Ads_per_Minute**, is therefore introduced. Exploratory analysis indicates a *negative* association between ad density and listening, consistent with the intuition that interruptions discourage completion. The binary **Has_Ads** further captures the extensive margin (presence/absence). In practice, **Ads_per_Minute** carries more information than raw counts, while **Has_Ads** helps the model establish a baseline shift when any ads are present.

### F. Popularity Signals and Interaction

Host and guest popularity, measured as percentages, show limited marginal correlation with listening time, yet asymmetric effects emerge: guest popularity matters more when host popularity is already high, suggesting complementary social appeal. To encode such synergy parsimoniously, **Pop_Interaction** is defined as (host × guest)/10,000. This compact term avoids over-parameterization while allowing linear baselines to capture a joint effect; ensembles can further refine heterogeneous impacts across content categories.

### G. Categorical and Temporal Effects

Categorical analysis (not shown for brevity) suggests that *Genre* alone exhibits small mean differences in listening time once duration is accounted for; genre variance is larger *within* categories than *between* categories. Publication timing shows mild yet consistent patterns: evenings and weekends associate with slightly higher listening, plausibly due to availability effects. **Pub_Time_Enc** (ordinal bins: Morning, Afternoon, Evening, Night) and **Is_Weekend** encode these effects. While not dominant predictors, such variables help resolve ties among episodes with similar structural properties.

### *H. Missingness and Data Quality*

Two numeric fields exhibit missingness at manageable rates (*Guest_Popularity_percentage*, *Episode_Length_minutes*); median imputation preserves robustness under skew. For modeling fairness, imputers are embedded inside the pipeline to avoid train–test contamination. Textual and identifier columns (titles, show names) are excluded from $X$ to prevent leakage and spurious correlations. Finally, a diagnostic **Flag_Inconsistent_Listening** is retained for monitoring (not used as a predictor).

### *I. Grouping Effects and Validation Considerations*

Because episodes are nested within podcasts, outcomes may share unobserved show-level factors (e.g., loyal audiences, style). The primary split is random (80/20), and *Podcast_Name* is preserved as a potential grouping key for future group-aware CV to stress-test generalization across shows. Strong performance under random splits, combined with conservative cleaning (ratio threshold), suggests that results are not dominated by artifacts, while a group-aware CV (e.g., GroupKFold) is left explicitly as future work to stress-test generalization across unseen shows.

## IV. Data Preparation and Feature Engineering

### *A. Data Cleaning and Imputation*

Following exploration, data preparation ensures that the input matrix is complete, consistent, and free from potential target leakage. Records with missing targets (*Listening_Time_minutes*) are removed, as supervised models require ground truth. Remaining numeric variables are examined for missingness and distributional skew.

Two variables show moderate missing rates: *Guest_Popularity_percentage* and *Episode_Length_minutes*. Given right-skewed distributions, **median imputation** is adopted to preserve central tendency while mitigating outlier influence. Categorical fields (e.g., *Publication_Day*, *Publication_Time*, *Genre*) are imputed using the **most frequent category**, avoiding arbitrary placeholders. All imputers are embedded directly in the preprocessing pipeline (scikit-learn `SimpleImputer`), ensuring that imputation parameters are learned only from training folds during cross-validation and preventing information leakage.

### *B. Outlier Detection and Removal*

Engagement data are prone to extreme or inconsistent values. A diagnostic *Listening Ratio* ($r$ = ListeningTime/EpisodeLength) flags episodes with $r > 1.2$ (listening exceeding 120% of episode length), typically corresponding to repeated playback or measurement noise. A single-sided filter removes only those cases beyond this threshold. The process eliminates a small fraction of rows while stabilizing the target variance. A binary variable **Flag_Inconsistent_Listening** is retained to document the number of excluded outliers and to enable future error analysis; it is excluded from modeling to maintain target independence.

### *C. Encoding and Scaling*

The dataset includes both numeric and categorical predictors. A modular preprocessing architecture uses a `ColumnTransformer` combining:

- **Numeric transformer:** median imputation followed by `StandardScaler`, centering variables around zero and scaling to unit variance.
- **Categorical transformer:** most-frequent imputation followed by `OneHotEncoder` with `handle_unknown=ignore`, converting nominal variables into robust binary indicators.

This produces a clean feature matrix $X$ free of missing values and scaled consistently across folds. Embedding preprocessing within each modeling pipeline (Linear, Lasso, Random Forest) guarantees identical handling and prevents discrepancies between model families.

### *D. Feature Construction and Motivation*

Feature engineering balances interpretability and predictive power while remaining faithful to the dataset's behavioral nature. The engineered features include:

- **Log_Length**: $\log(1+\text{EpisodeLength})$ to reduce skewness and capture diminishing returns.
- **Ads_per_Minute**: NumberOfAds/EpisodeLength to reflect ad density independent of total duration.
- **Has_Ads**: a binary indicator distinguishing episodes with and without advertising.
- **Pop_Interaction**: product of host and guest popularity, scaled to $[0, 1]$ by dividing by $10{,}000$.
- **Pub_Time_Enc**: ordinal encoding of publication period (Morning=0, Afternoon=1, Evening=2, Night=3).
- **Is_Weekend**: binary flag for weekend releases.
- **Flag_Inconsistent_Listening**: retained only for diagnostics; excluded from modeling.

The feature set intentionally remains low-dimensional; each variable represents a meaningful behavioral concept (duration, advertising, popularity, timing).

### *E. Feature Integration and Leakage Control*

A strict boundary is maintained between features and the prediction target. Any variable derived directly from *Listening Time* (such as the *Listening Ratio*) is removed prior to modeling. Identifier fields (*Podcast_Name*, *Episode_Title*) and textual descriptions are excluded from $X$ to avoid implicit learning of show-specific popularity. The final matrix comprises the original cleaned variables and the engineered features; all models operate on the same preprocessed input for comparability.

## V. Model Training and Evaluation

### A. Modeling Strategy

The modeling phase follows a progressive, comparative strategy aligned with CRISP-DM: establishing linear baselines, introducing regularization, and finally evaluating nonlinear ensembles. All models are built as end-to-end `Pipeline` objects to guarantee identical preprocessing and to prevent information leakage.

Three regressors are considered:

1) **Linear Regression (OLS)**: interpretable additive baseline over scaled features.
2) **Lasso Regression**: $L_1$-regularized linear model encouraging sparsity and mitigating multicollinearity.
3) **Random Forest Regressor**: ensemble of decision trees with bootstrap sampling and randomized feature selection at splits, suitable for mixed-type behavioral data.

Each model is trained first in a *simple* configuration (no CV tuning), then as a 5-fold CV-tuned variant (Lasso via `GridSearchCV`, Random Forest via `RandomizedSearchCV`).

### B. Cross-Validation and Hyperparameter Optimization

Cross-validation (CV) uses a 5-fold KFold split with shuffling and fixed random seed (42). At each iteration, 80% of data serves as training and 20% as validation, cycling across folds. CV scores report mean validation performance; final models are refit on the entire training set before evaluation on the held-out test set.

For **Lasso**, the regularization parameter $\alpha$ is optimized across a logarithmic grid in $[10^{-4}, 0.3]$ using negative MAE as the selection criterion. For **Random Forest**, `RandomizedSearchCV` samples 20 combinations over:

- `n_estimators` $\in \{200, 300, 400, 600\}$,
- `max_depth` $\in \{8, 12, 16, \text{None}\}$,
- `min_samples_split` $\in \{2, 4, 6\}$,
- `min_samples_leaf` $\in \{1, 2, 4\}$,
- `max_features` $\in \{\text{“sqrt”}, 0.5\}$.

Negative MAE (`scoring='neg_mean_absolute_error'`) is prioritized due to the right-skewed target.

### C. Evaluation Metrics

Performance is reported through three complementary metrics: **MAE** (robust central error), **RMSE** (penalization of large deviations), and $R^2$ (explained variance). Given the target's skewness, MAE is the primary selection criterion; RMSE and $R^2$ provide secondary diagnostics of dispersion and fit.

### D. Results: Baseline vs. Tuned Models

The complete comparison appears in Table I. Linear and Lasso models yield nearly identical performance (MAE $\approx$ 9.5, $R^2 \approx$ 0.785), indicating limited benefits from regularization under the current feature set. The **Random Forest (simple, no CV)** improves over linear baselines (MAE = 9.11, $R^2$ = 0.81), demonstrating the value of non-linear splits and interactions. After tuning, the **Random Forest (CV tuned)** reduces MAE to 8.83 and increases $R^2$ to 0.815; the improvement is consistent across folds and reflects better control over tree depth and node regularization.

TABLE I
Test-set performance (lower is better for MAE/RMSE; higher is better for $R^2$).

| Model | MAE | RMSE | $R^2$ |
|---|---|---|---|
| RandomForest (CV tuned, 5-fold) | 8.83 | 11.47 | 0.815 |
| RandomForest (simple, no CV) | 9.11 | 11.63 | 0.810 |
| Lasso (CV tuned, 5-fold) | 9.52 | 12.37 | 0.785 |
| Lasso (simple, no CV) | 9.52 | 12.36 | 0.785 |
| Linear Regression | 9.54 | 12.36 | 0.785 |

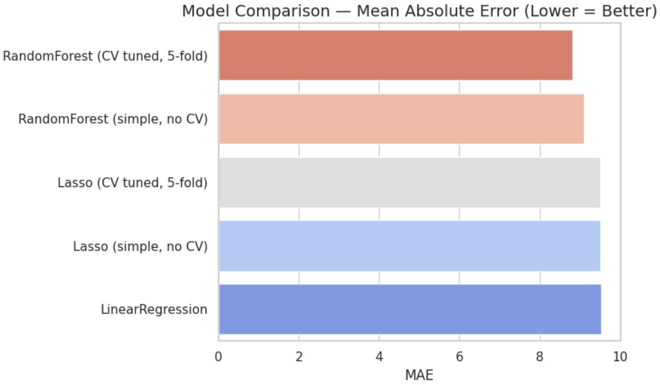

Fig. 4. Model comparison (MAE): simple vs. CV-tuned variants. Cross-validation provides stable, incremental improvements for Lasso and Random Forest.

### E. Residual Analysis and Robustness

Residuals are approximately symmetric around zero, with no strong heteroscedastic patterns, suggesting that preprocessing stabilized feature scales. Small underestimations persist for very long episodes, plausibly reflecting listener fatigue and multitasking contexts rather than systematic model bias. Conditional rules in the Random Forest mitigate this effect more effectively than linear models, explaining higher $R^2$ despite similar MAE values.

## VI. Interpretation of Results and Insights

### A. Feature Importance and Model Explainability

Interpretation relies on *feature importances* from the tuned Random Forest, computed via mean decrease in impurity (MDI). Figure 5 reports the top-ranked features. **Episode_Length_minutes** and **Log_Length** dominate, indicating duration as the primary determinant of listening behavior. The presence of **Log_Length** suggests a nonlinear saturation effect: listening increases with duration but at a diminishing rate.

### B. Advertising and Engagement Trade-offs

Advertising-related variables occupy the next positions. **Ads_per_Minute** shows a clear negative effect, while **Has_Ads** reinforces the downward shift. These findings align

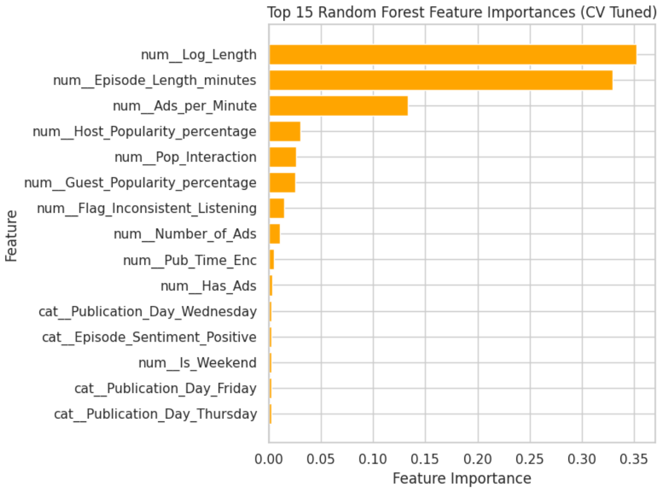

Fig. 5. Top feature importances from the CV-tuned Random Forest. Episode-related and advertising-related variables dominate listening-time prediction.

with evidence that frequent interruptions reduce retention. From an operational standpoint, optimizing *ad density* is preferable to maximizing absolute ad count, preserving audience satisfaction without substantial revenue loss.

### C. Popularity and Social Influence

**Pop_Interaction** (host × guest popularity) exhibits moderate and consistent importance. Individual popularity measures correlate weakly with listening time, whereas their interaction captures social reinforcement: recognized host–guest combinations enhance engagement. Collaborative or crossover episodes between known personalities represent a pragmatic lever to improve attention and listening duration.

### D. Temporal and Contextual Factors

Temporal features (**Pub_Time_Enc**, **Is_Weekend**) contribute smaller but stable effects. Weekend or evening releases tend to achieve slightly higher listening times, consistent with availability patterns. Although secondary to structural and advertising variables, timing provides incremental gains and may inform scheduling strategies.

### E. Nonlinear and Conditional Effects

Tree-based models reveal nonlinear, conditional dependencies. Ad density exerts stronger negative impact on shorter episodes, where each interruption occupies a larger fraction of total duration; the same number of ads in long-format episodes has a smaller marginal effect. Popularity effects intensify for mid-length episodes, where exposure time is sufficient for recognition. Such patterns remain largely invisible to linear models, highlighting the benefit of ensembles for behavioral prediction.

## VII. Conclusions

A 5-fold CV-tuned Random Forest outperforms linear baselines in predicting podcast listening time, achieving $R^2 = 0.815$ with an MAE of 8.83 minutes. The most influential features reflect intuitive mechanisms: episode length (raw/log) and ad load are key drivers, while popularity and timing exert smaller yet consistent effects. Potential extensions include textual/NLP features (titles, descriptions, transcripts), finer-grained modeling of ad placement/dosage, and group-aware validation to test robustness across shows. Results are constrained by metadata availability; richer textual or user-level data could further improve predictive accuracy.

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