F1 Pitstop Strategies Report

A. Project Overview

- **Goal**: To predict tyre degradation and optimal pit stop strategies for the 2025 Shanghai Grand Prix.
- **Dataset**: Formula One data for the 2025 Shanghai Grand Prix, retrieved using the FastF1 Python module. The dataset includes columns like Driver, Lap number, Stint, Pit-in/Pit-out times, Compound, Laptime, and environmental factors (track temperature, air temperature, humidity, wind speed). The dataset is available in Shanghai2025.csv.

B. Data Processing

Data is loaded into Rust by reading the Shanghai2025.csv file using the csv crate and deserializing each record into a RawLapData struct.

Cleaning and transformations applied:

- Filtering out invalid or nonsensical data points (e.g., negative track temperature).
- Standardizing compound names to uppercase.
- Converting relevant fields to appropriate Rust types (e.g., lap number, tyre life to u32).
- Grouping laps by driver using a HashMap.
- Sort laps for each driver chronologically by lap number.
- Calculating the time_delta for each lap relative to the driver's fastest non-pit lap (laptime_seconds - min_laptime).
- Identifying tyre stints based on pit-in/pit-out laps and compound changes.
- Calculating the average length of stints for Medium and Hard compounds.

C. Code Structure

- **Modules**:
    - data.rs: Responsible for all data input, cleaning, processing, and calculation of average stint lengths. Organized separately to encapsulate data handling logic.
    - model.rs: Focuses solely on building the tyre degradation model. Separated to keep modeling concerns distinct from data processing and strategy simulation.
    - strategy.rs: Handles the simulation and comparison of different race strategies. Separated to apply the results from the data and model modules.
    - main.rs: Orchestrates the execution by calling functions from the other modules and handling errors. Kept simple to manage the overall program flow.
- **Key Functions & Types**:
    - DataProcessor (struct in data.rs): Manages the data loading and processing workflow.
    - RawLapData (struct in data.rs): Represents initial data structure from CSV.
    - ProcessedLapData (struct in data.rs): Represents cleaned and processed lap data, including time_delta. Used as input for modeling and strategy.
    - calculate_average_stint_lengths (function in data.rs): Determines average stint durations.
    - DegradationModel (struct in model.rs): Holds the fitted models for each compound.
    - build_model (function in model.rs): Fits a linear regression model for a given

compound. Purpose: To create a predictive model for tyre degradation. Inputs: Slice of ProcessedLapData, compound string. Outputs: Option<FittedLinearRegression>. Core Logic: Uses linfa crate, prepares feature matrix (tyre life, temp, tyre life squared) and target vector (time delta), performs linear regression fitting.

  - predict_degradation (function in model.rs): Predicts time delta for a specific lap/temp/compound. Purpose: To use the trained model to estimate degradation. Inputs: Tyre lap, temperature, compound. Outputs: Predicted time delta (f64). Core Logic: Uses the appropriate fitted model and the predict method.
  - Evaluate_model_accuracy (function in data.rs): calculate the mean absolute error
  - simulate_and_print (function in strategy.rs): Runs simulations for different strategies and outputs results. Purpose: To evaluate and compare potential race strategies. Inputs: DegradationModel, average medium stint length, average hard stint length. Outputs: Result<(), Box<dyn Error>>. Core Logic: Defines strategies, loops through stints/laps, calculates cumulative time loss using model.predict_degradation, adds pit stop time loss, prints/visualizes results.

- **Main Workflow**:
  1. main.rs calls DataProcessor::new to load and process the data.
  2. main.rs calls calculate_average_stint_lengths using the processed data.
  3. main.rs calls DegradationModel::new using the processed data to train the degradation model.
  4. main.rs calls evaluate_model_accuracy to display accuracy
  5. main.rs calls simulate_and_print with the trained model and average stint lengths.
  6. simulate_and_print calculates time loss for predefined strategies using the model and prints/visualizes the outcomes.

D. Tests

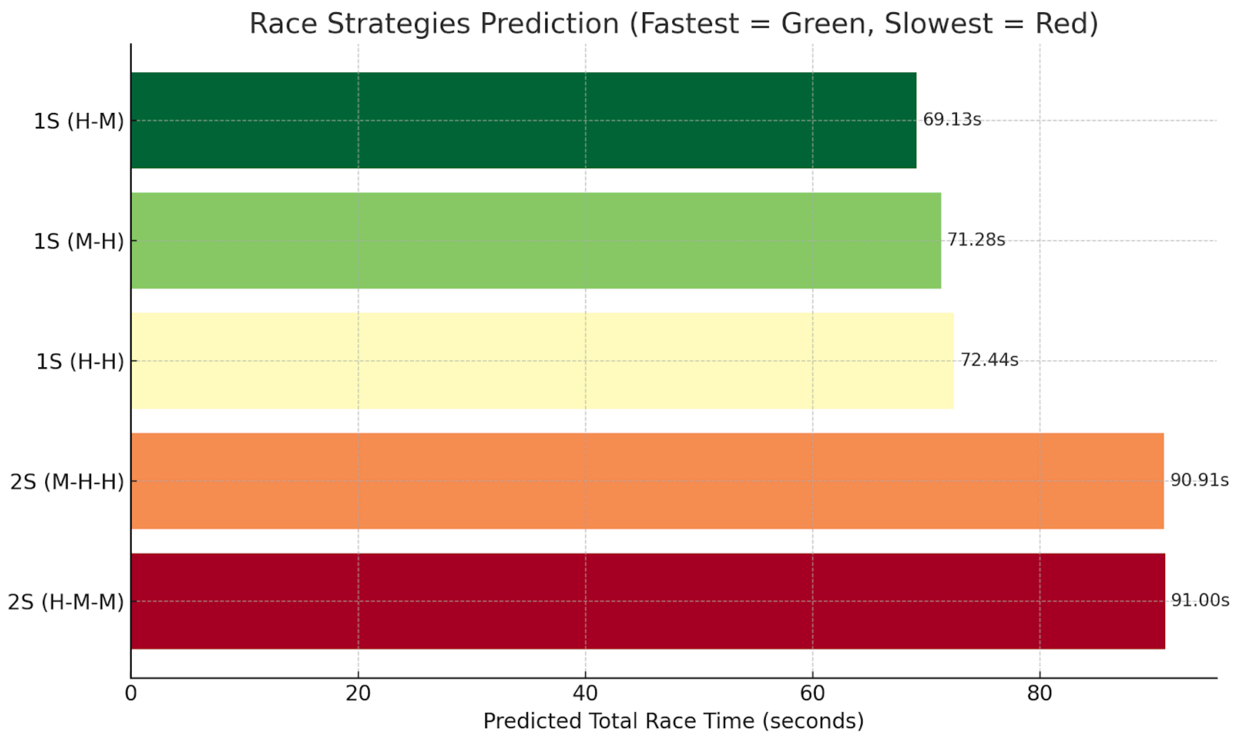
```
running 1 test
test data::stint_length_tests::test_average_stint_length_calculation ... ok
test result: ok. 1 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out; finished in 0.00s
```

- test_average_stint_length_calculation: This test manually sets up processed lap data for two drivers with predefined stints (Driver 1: 5-lap MEDIUM, 4-lap HARD; Driver 2: 6-lap MEDIUM, 5-lap HARD). It then calls calculate_average_stint_lengths with this data and asserts that the calculated average stint lengths match the expected values ((5+6)/2 = 5.5 for Medium, (4+5)/2 = 4.5 for Hard). This test matters because correctly identifying stints and calculating their average length is crucial for defining realistic strategies in the strategy.rs module.

E. Results

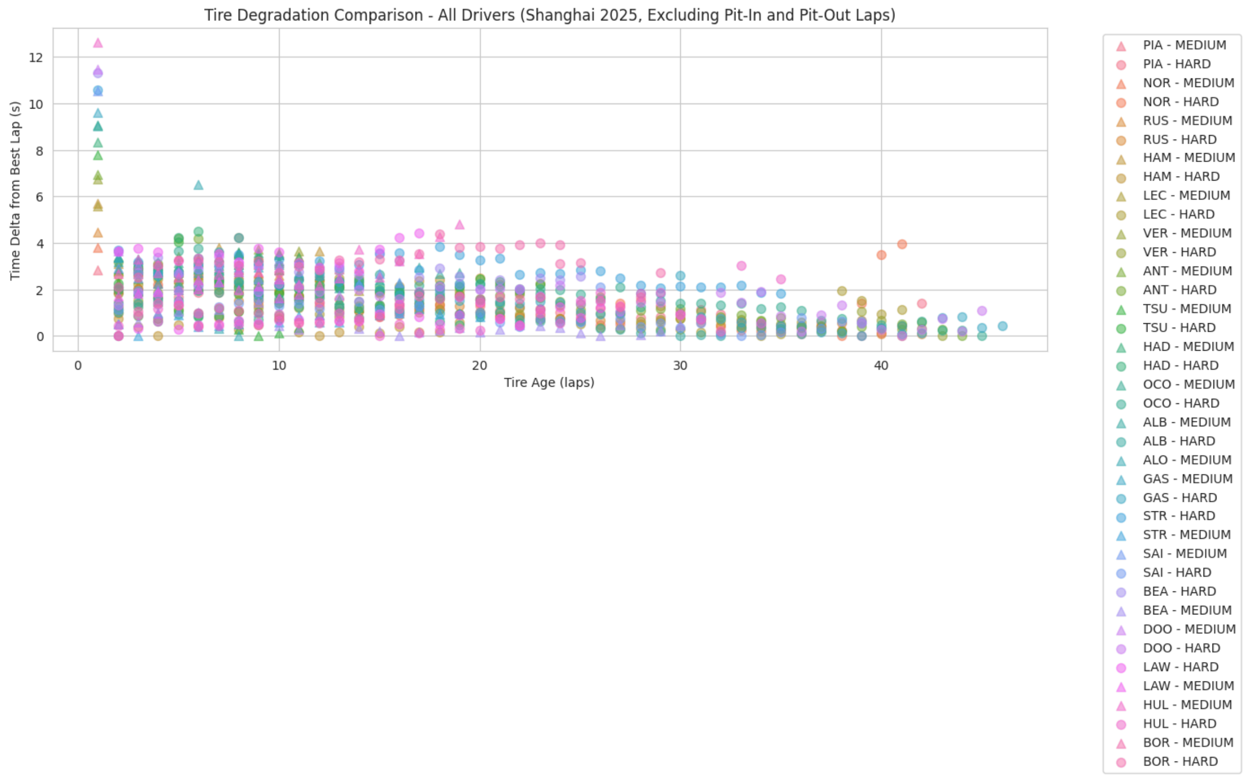
```
Starting Simulation...

Avg Stints - Med: 13.5, Hard: 32.5
```

```
Model Prediction Accuracy (Mean Absolute Error):

- Medium compound: 0.805 seconds per lap

- Hard compound: 0.589 seconds per lap


--- Strategies (Laps: 56, Pit Loss: 21s) ---

- 1S (M-H)   :  71.28s (1 stops)

- 1S (H-M)   :  69.13s (1 stops)

- 1S (H-H)   :  73.44s (1 stops)

- 2S (M-H-H) :  90.91s (2 stops)

- 2S (H-M-M) :  91.00s (2 stops)
```



[Image 1]: Bar chart visualizing the predicted total race time (seconds) for each strategy. 1S (H-M) is shown as fastest (green bar), followed by 1S (M-H), 1S (H-H), 2S (M-H-H), and 2S (H-M-M) as slowest (red bar).

- **Interpretation**: The results predict that a 1-stop strategy is significantly faster than a 2-stop strategy for the 2025 Shanghai Grand Prix, primarily due to the time lost during the extra pit stop (estimated at 21 seconds). The fastest predicted strategy is starting on Hard tyres and switching to Medium (1S H-M), followed closely by starting on Medium and switching to Hard (1S M-H). This suggests that under the simulated conditions (gentle weather, low degradation), minimizing pit stops is key. The model's preference for the H-M strategy over M-H, contrary to real-world common practice for this race, might be attributed to the training data being solely from the formal race session, potentially biasing the model towards conditions favorable to Hard tyres later in stints when track temperatures are higher. The following visualization also supports this interpretation: when tyre age is around 1-2, the time delta is great.



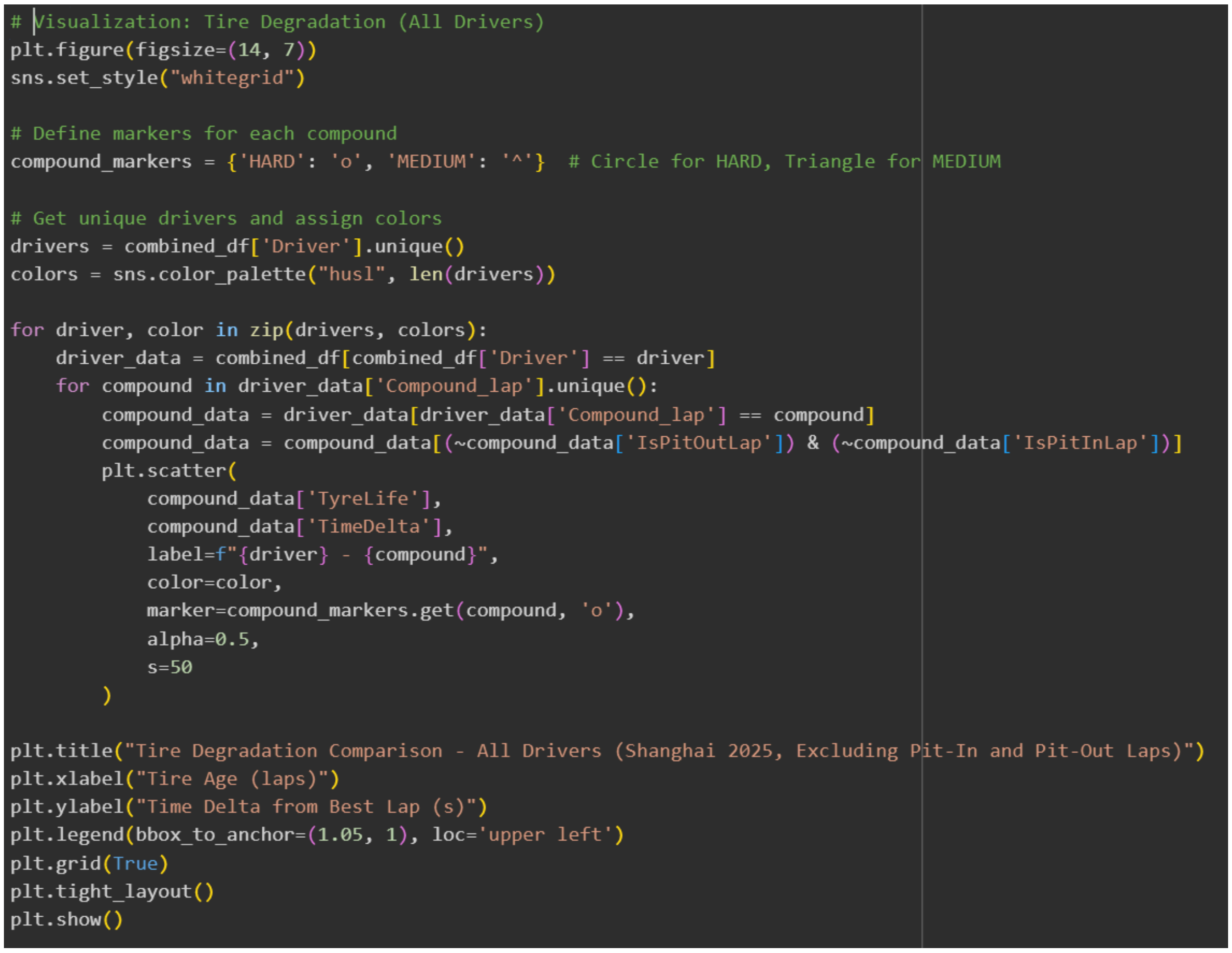
F. Usage Instructions

1. **Build**: Navigate to the project root directory in your terminal and run cargo build.
2. **Run**: Execute the compiled program using cargo run.
3. **Input**: The program reads data from Shanghai2025.csv located in the same directory as the executable. No command-line arguments or user interaction in the terminal is required beyond running the command.
4. **Expected Runtime**: The program compiles in approximately 4-5 seconds and runs almost instantly (finished in 0.00s in the test output), as shown in the cargo run output.

G. AI-Assistance Disclosure and Other Citations

- **AI-Assistance**: ChatGPT was used to generate the first bar chart visualizing the predicted total race times for the strategies (Image 1). *Explanation*: I used ChatGPT to create a visual representation of the numerical results from the simulation. This helped in presenting the comparison of strategies in a clear, graphical format, making the interpretation easier.

- It is also used to conduct this shorten version of the F1_pitstop_strategy pdf.
- **Other Citations**:
    - Piter76. (2020, December). *Saturating, what does it really do, and when is it useful?* The Rust Programming Language Forum. Retrieved April 25, 2025, from https://users.rust-lang.org/t/saturating-what-does-it-really-do-and-when-is-it-useful/52720
        - *Explanation*: This forum post was helpful in understanding the saturating_sub method used in strategy.rs to safely subtract lap numbers when calculating stint lengths, preventing underflow and handling edge cases where calculated lengths might theoretically exceed total laps due to rounding.
    - FastF1 Python Module: Used to retrieve the dataset for the project. (Implicitly cited by mentioning the source).
    - Python code for generating Plot 2 (Tyre age vs Time Delta): Provided below, indicating Python (specifically using Google Colab) was used for this specific visualization outside the main Rust project.



```python
# Visualization: Tire Degradation (All Drivers)
plt.figure(figsize=(14, 7))
sns.set_style("whitegrid")

# Define markers for each compound
compound_markers = {'HARD': 'o', 'MEDIUM': '^'}  # Circle for HARD, Triangle for MEDIUM

# Get unique drivers and assign colors
drivers = combined_df['Driver'].unique()
colors = sns.color_palette("husl", len(drivers))

for driver, color in zip(drivers, colors):
    driver_data = combined_df[combined_df['Driver'] == driver]
    for compound in driver_data['Compound_lap'].unique():
        compound_data = driver_data[driver_data['Compound_lap'] == compound]
        compound_data = compound_data[(~compound_data['IsPitOutLap']) & (~compound_data['IsPitInLap'])]
        plt.scatter(
            compound_data['TyreLife'],
            compound_data['TimeDelta'],
            label=f"{driver} - {compound}",
            color=color,
            marker=compound_markers.get(compound, 'o'),
            alpha=0.5,
            s=50
        )

plt.title("Tire Degradation Comparison - All Drivers (Shanghai 2025, Excluding Pit-In and Pit-Out Laps)")
plt.xlabel("Tire Age (laps)")
plt.ylabel("Time Delta from Best Lap (s)")
plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
plt.grid(True)
plt.tight_layout()
plt.show()
```