Formula 1 Racing Challenge: 2024 Strategy Analysis

"Okay, Lewis…. it's hammer time."

- Peter 'Bono' Bonnington

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1. Introduction

Formula 1, known for its high-stakes, precision-driven environment, relies heavily on strategic decisions that can make or break a race outcome. This analysis focuses on exploring relationships between critical variables such as lap times, tire compounds, stint lengths, pit stop timings, and race positions. By systematically examining these factors, we aim to identify patterns and relationships that can provide deeper insights into the strategic decisions made during races, and how these decisions can be improved.

Using detailed lap-by-lap data, we aim to uncover patterns and relationships that influence race outcomes. Through Exploratory Data Analysis (EDA) and exploration of correlations between key variables, this report highlights the strategic decisions related to pit stops, tire choices, and race management made by teams and drivers and how these decisions impact their race results for the 2024 season. In addition to a detailed exploration of the dataset and key results, we explore patterns in races, such as the frequency of pit stops, the choice of tire compounds, and their impact on race strategy, helping to highlight any trends that emerge between races. The analysis focuses on breaking down complex race data into visualizations and tables that clearly show how drivers and teams perform under different conditions.

Ultimately, the report showcases a clear, engaging story that reveals the strategies that teams employ to gain an edge, and how different factors play a role in shaping the results. The findings will contribute to a broader understanding of race strategy in Formula 1, offering valuable lessons for teams, analysts, and enthusiasts alike. Whether you're a die-hard F1 fan or just curious about the sport's intricacies, this analysis provides a data-driven glimpse into the strategic decisions that happen behind the scenes during a race.

2. Key Findings

The 2024 Formula 1 season offers a unique opportunity for analysis due to several compelling factors. Firstly, the introduction of new regulations aimed at enhancing competition has led to varied performance among teams, making it an exciting year to examine how these changes affect race strategies and outcomes. The close battles between teams, particularly in the mid-field, have resulted in unpredictable race results, providing rich data for analysis. Additionally, the availability of comprehensive telemetry data, including lap times, tire choices, and pit strategies, enables a granular analysis of race performance. The 2024 season also includes notable events such as the return of classic tracks and the introduction of new venues, further enriching the dataset.

The report starts with exploration of data variables and their probable use cases, helping us to understand races and get insights into each specific Grand Prix and the characteristics of drivers and teams.

Total Number of Pit Stops: Teams using aggressive strategies tended to pit more frequently, especially during safety car periods or when track conditions changed. Fewer, well-timed pit stops often correlated with better race outcomes. Teams with optimized pit strategies (minimizing time loss while maximizing tire performance) generally achieved higher rankings.
Tire Compounds Used During the Race: Drivers and teams employed different tire strategies based on the race conditions (e.g., wet tracks favored intermediate or wet tires). Teams like Mercedes and Red Bull showed greater variability in compound choices, adapting quickly to changing track conditions. Tire compound choices were critical to maintaining optimal race pace, especially in response to weather or track temperature changes.
Number of Laps Completed on Each Tire Compound: As lap numbers increased, lap times for soft, intermediate, and medium tires showed a more significant rise compared to hard tires, suggesting that soft and medium compounds wear out faster and lose performance more rapidly. Lap times tended to decrease as the stint progressed, indicating effective tire warm-up and optimization strategies. The soft and medium compounds experienced steeper increases in lap times towards the end of their life compared to hard tires.
Average Lap Time per Stint and Delta Time per Tire Compound: Lap times tend to decrease as the race progresses, indicating that his performance may improve after the first stint (e.g., lower fuel load, tire strategy). For delta times, teams with positive delta times across various compounds might be struggling to find effective tire strategies. For instance, Haas F1 Team has mixed results, showing a positive delta on hard tires and a negative on intermediate, indicating variability in performance depending on the tire choice. However, Aston Martin and Mercedes show significant negative values on intermediate tires (-42.01 and -44.26 seconds, respectively), indicating they excelled with that compound.
Time Spent in Pits: The average time spent in the pits across all teams is 24.54 seconds. Notably, McLaren recorded the shortest average pit stop time at 23.22 seconds, while Sauber had the longest average at 27.19 seconds.
Pit Stop Timing and Race Outcomes: Drivers who pitted earlier during yellow flag conditions often gained a competitive advantage, while those with late pit stops under green flag conditions generally lost time. Consistent and well-timed pit stops were a common feature of race winners. Teams with better predictive strategies around pit stops, particularly during race interruptions, maintained higher positions and better results overall.

Relationship 1: Tire Compound Choice vs Lap Time

Tire Compound Performance

- Soft Compound: Significantly reduces lap times across all models, providing the fastest lap times. The consistent negative effect indicates superior performance compared to other compounds.
- Medium Compound: Also reduces lap times but to a lesser extent than the soft compound. It strikes a balance between speed and durability.
- Hard Compound: While it reduces lap times, its impact is weaker than that of soft and medium compounds, particularly in later models.
- Intermediate and Wet Compounds: Both significantly increase lap times, with wet tires exhibiting the most considerable slowdown due to their use in adverse conditions.

Impact of Race Phase and Stint

- Race Phase: Shows a significant negative correlation with lap times, indicating that as the race progresses, lap times generally get faster. This may be due to factors like lighter fuel loads and improved racing lines.
- Stint: Also negatively affects lap times, suggesting that lap times decrease slightly as drivers go deeper into a stint. This could be attributed to driver adaptation to tire degradation and track evolution over time.
- Tire selection is crucial for optimizing lap times, and effective race strategy (considering race phase and stint) plays a significant role in performance during a Grand Prix.

Relationship 2: Starting Tire Type vs Final Classification

- The choice of starting compound has a minimal impact on a driver's final position in the race.
- Soft Tires: Drivers starting on soft tires tended to finish slightly worse on average, but this difference is not statistically significant, indicating no strong negative impact.
- Medium Tires: Starting on Medium tires had no significant effect on finishing positions, implying neutrality in performance.
- Hard Tires: Similar to Soft tires, starting on Hard tires showed a slight tendency for poorer finishing positions, but again, this was not statistically significant.
- Intermediate and Wet Tires: No significant advantages or disadvantages were found for starting on these tires compared to dry compounds, suggesting that external conditions may have a more significant impact.
- The choice of starting tire compound does not significantly influence final race outcomes.
- The majority of drivers (approximately 65%) start with medium compound tires, followed by 25% with Soft tires and around 10% with Hard tires, reflecting a common strategic preference among teams.

Relationship 3: Number of Laps on a Compound vs Delta Time

- As drivers use a tire for more laps, their lap times tend to get slightly slower.
- Impact of Tire Wear: Lap times increase with tire wear. Specifically, for each additional lap on a tire, lap time increases by approximately 0.04 seconds. While this may seem minor, it compounds over the course of a race, impacting overall performance.

- Initial Performance: Lap times may initially decrease slightly (by about 0.8 seconds) at the beginning of a stint, likely due to the car becoming lighter as fuel is consumed. However, as tires wear out, the trend reverses, leading to slower lap times.

Relationship 4: Number of Stops vs Final Position

- An increase in pit stops is associated with a tendency to finish in a worse position. However, the relationship is not strong.
- Impact of Additional Pit Stops: Each additional pit stop may worsen a driver's final position by about 0.6 places on average. Nonetheless, this effect is not statistically significant, meaning it should be interpreted cautiously.
- Conclusion on Pit Stops: More pit stops are generally associated with slightly worse finishing positions. However, the weak nature of this relationship suggests that pit stops are not the sole factor influencing race outcomes.
- Strategic Considerations: The findings emphasize the importance of a balanced pit stop strategy. While minimizing the number of stops may help improve final positions, teams must also consider tire wear, fuel management, and track conditions to optimize performance.

Relationship 5: Race Length vs Strategy

- Longer races may be associated with fewer pit stops. However, this relationship is very weak and not statistically significant.
- Negligible Impact of Race Length: For each additional lap, the number of pit stops decreases by a minimal amount (-0.0065), reinforcing that race length does not significantly predict the number of pit stops made.
- Minimal Influence on Tire Choice: The number of laps has almost no effect on the type of tires selected by teams.
- Weather Considerations: Changes in weather conditions (e.g., rain) can lead to more pit stops. However, this is a separate consideration from the length of the race.
- Average Lap Times and Pit Stops: As the number of pit stops increases, average lap times tend to increase. Drivers without pit stops have the fastest average lap time (80.31 seconds), while those with four pit stops have the slowest (95.68 seconds). This suggests that frequent pit stops may negatively affect overall performance.
- Optimal Pit Stop Strategy: The analysis indicates an optimal strategy around one pit stop, where average lap times remain competitive (88.21 seconds). This suggests that teams might prioritize minimizing stops to enhance performance.
- Complexity of Strategy: Race length does not significantly influence pit stop frequency or tire choices. Teams consider a multitude of factors when making strategic decisions, indicating that strategy is tailored to specific circumstances rather than being a straightforward response to race length.

Bonus: Monaco Grand Prix

- Significance of Monaco: The Monaco Grand Prix is renowned for its challenging circuit, where strategy—especially tire choice, pit stops, and starting position—is crucial for success.

- Tire Compound Choice vs. Final Classification: Despite of limited overtaking opportunities in Monaco, starting on softer compounds can lead to better finishing positions. Harder compounds are significantly associated with worse outcomes.
- Fresh Soft Compound tires offer the fastest average lap times (78.56 seconds) with low variability, making them ideal for short stints. In contrast, Medium and Hard compounds show high variability in lap times, suggesting that their performance is heavily influenced by external factors.
- Number of Pit Stops vs. Finishing Position: More pit stops generally result in worse finishing positions. Each additional pit stop increases the finishing position by 4.3 places. Minimizing pit stops is critical due to Monaco's limited overtaking opportunities.
- Average Lap Time vs. Tire Compound: Tire choice has a negligible effect on lap time. Most drivers start with harder compounds, reflecting strategic choices.
- Starting Position vs. Final Position: A very strong correlation (0.9734) between grid position and final position underscores the importance of qualifying well. Starting position is a nearly perfect predictor of finishing position.

Conclusions:

- Track Position: The starting position is the most critical factor for success, with strong qualifiers more likely to finish well.
- Pit Stop Strategy: Reducing pit stops is vital, as each pit stop can significantly impact race outcomes.
- Tire Strategy: Tire choice plays a crucial role in overall race strategy, particularly in conjunction with pit stops and race phases.
- These findings highlight that success in the Monaco Grand Prix requires meticulous planning and execution, with a focus on maintaining track position and optimizing tire strategies.

3. Quick Look at the Data[1]

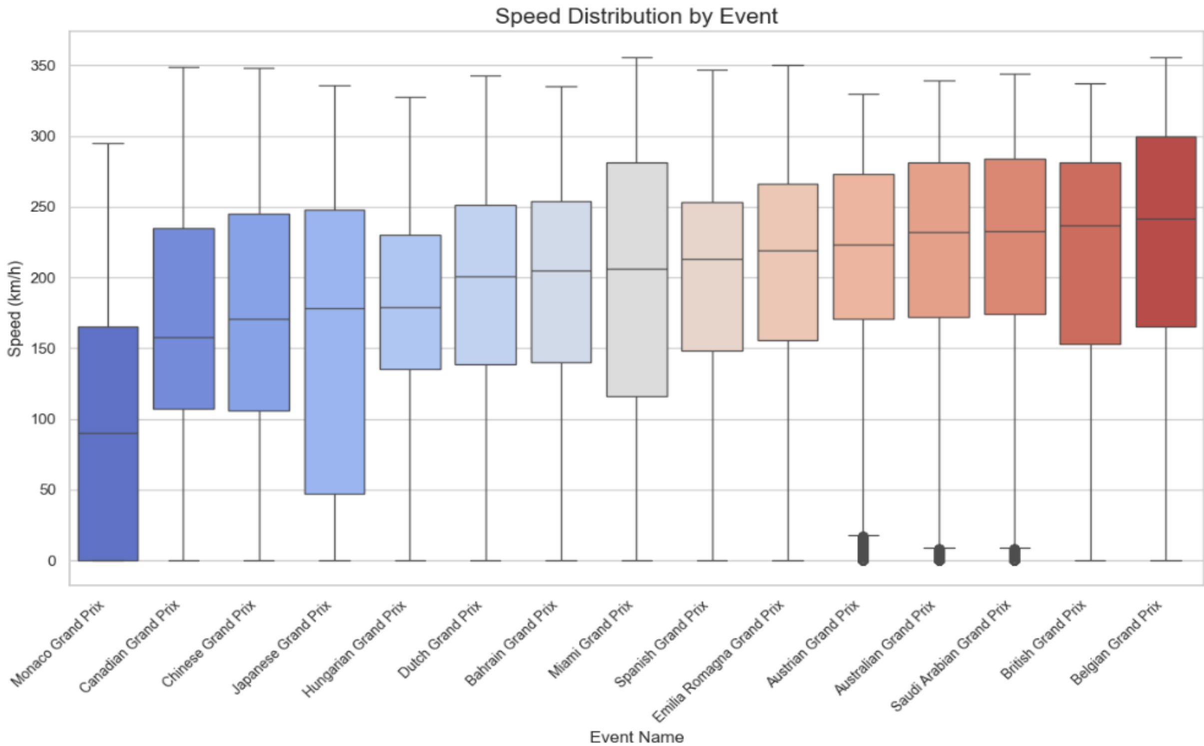
[1] The report will alternate between landscape and portrait orientations to enhance the readability of graphs and data, ensuring that all visualizations and detailed tables are presented in the most accessible format possible.

Quick Look at "car_data_2024"

The file named "car_data_2024" contains detailed telemetry data including key performance indicators such as speed, RPM, and DRS activation data from various races. Additionally, an engineered "acceleration" feature has been developed based on RPM and speed variations, allowing for the detection of potential anomalies during race events.

The telemetry data plays a crucial role in formulating race strategies and identifying opportunities to optimize vehicle performance as drivers navigate the track. Before each race, teams utilize this data extensively for testing and fine-tuning the vehicle setup to ensure peak performance on race day. The insights derived from this telemetry data not only inform immediate race decisions but also contribute to the ongoing development and preparation for future races. By analyzing this comprehensive dataset, teams can make informed adjustments to both equipment and strategy, ultimately enhancing their competitive edge throughout the season.

Figure 1. Speed Distribution by Event.



This figure illustrates the speed distribution across various events. The Monaco circuit stands out with an average speed significantly lower than any other track on the F1 calendar, typically ranging from 100-150 km/h, compared to the 200-250 km/h observed on other circuits.

While we conducted a thorough analysis of all tracks, this report focuses on the most notable examples in each section to maintain brevity and enhance readability. For further exploration of data processing and analysis steps, as well as additional graphs, tables, and plots, please refer to the files, data and code snippets provided in the footnote.[2]

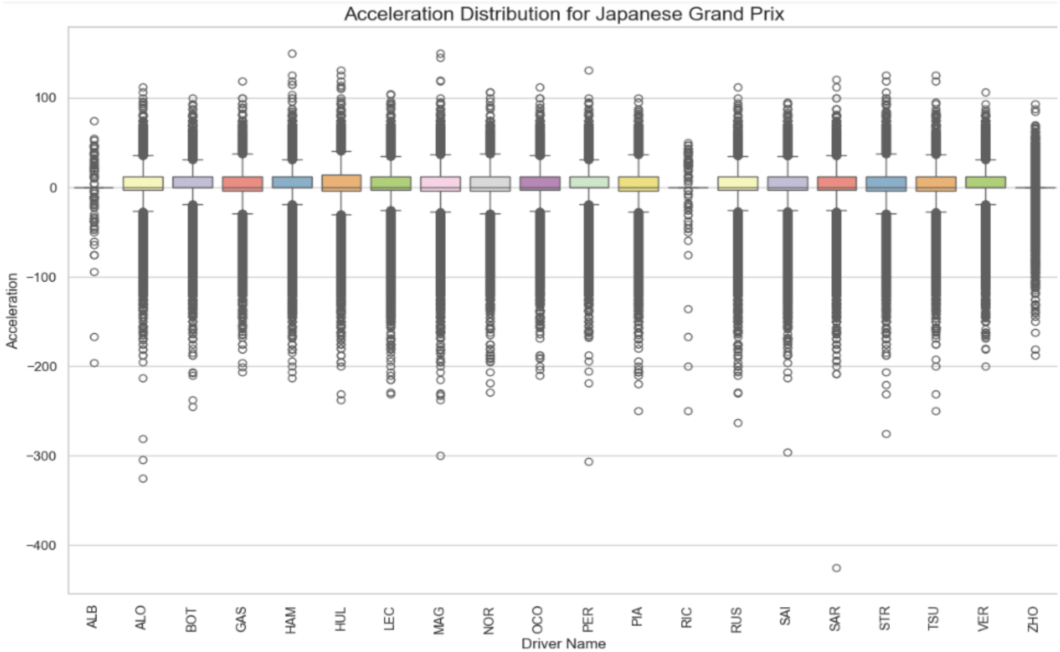
[2] https://github.com/yunusgumussoy/Formula-1-2024-Racing-Season-Strategy-Analysis

Figure 2. Speed Distribution for Monaco Grand Prix.

When ranking drivers by speed, we observed distinct differences in speed distribution among some drivers.

A notable example from the Monaco Grand Prix reveals that Esteban Ocon (OCO) from Alpine Renault, Sergio Perez (PER) from Red Bull Racing Honda RBPT, and both Kevin Magnussen (MAG) and Nico Hulkenberg (HUL) from Haas Ferrari were unable to complete their laps.

Figure 3. Acceleration Distribution for Japanese Grand Prix.



Another insightful example comes from our analysis of the engineered "Acceleration" feature. The figure highlights that Daniel Ricciardo (RIC) from RB Honda RBPT and Alexander Albon (ALB) from Williams Mercedes exhibit lower acceleration distributions compared to others. This anomaly aligns with the crash at the start of the Suzuka Japanese Grand Prix. Additionally, Zhou Guanyu (ZHO) from Kick Sauber Ferrari shows a distinct acceleration issue, correlating with the gearbox failure that led to his retirement from the race.

Quick Look at "circuit_2024"

Figure 4. Track Layout for Miami Grand Prix.

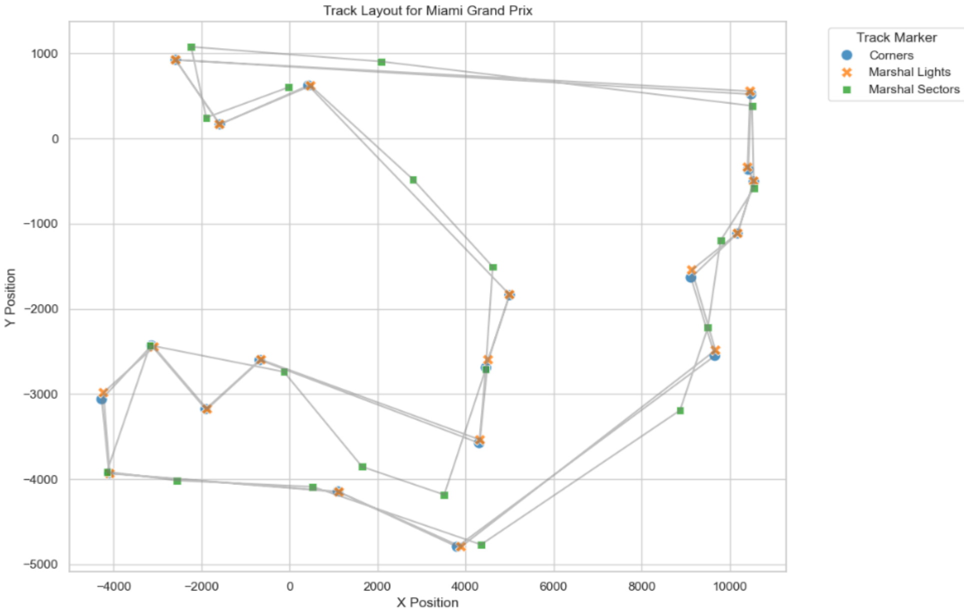
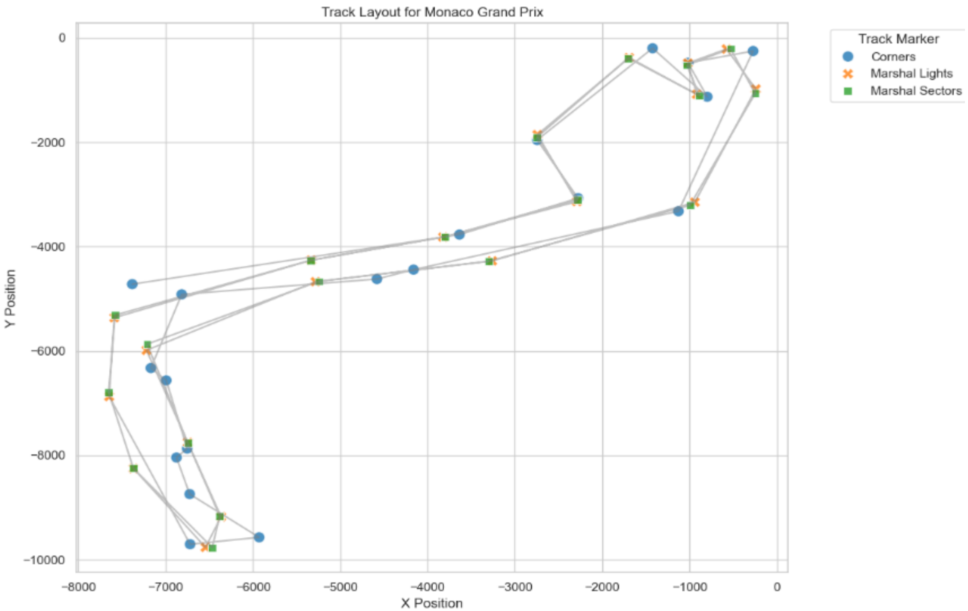


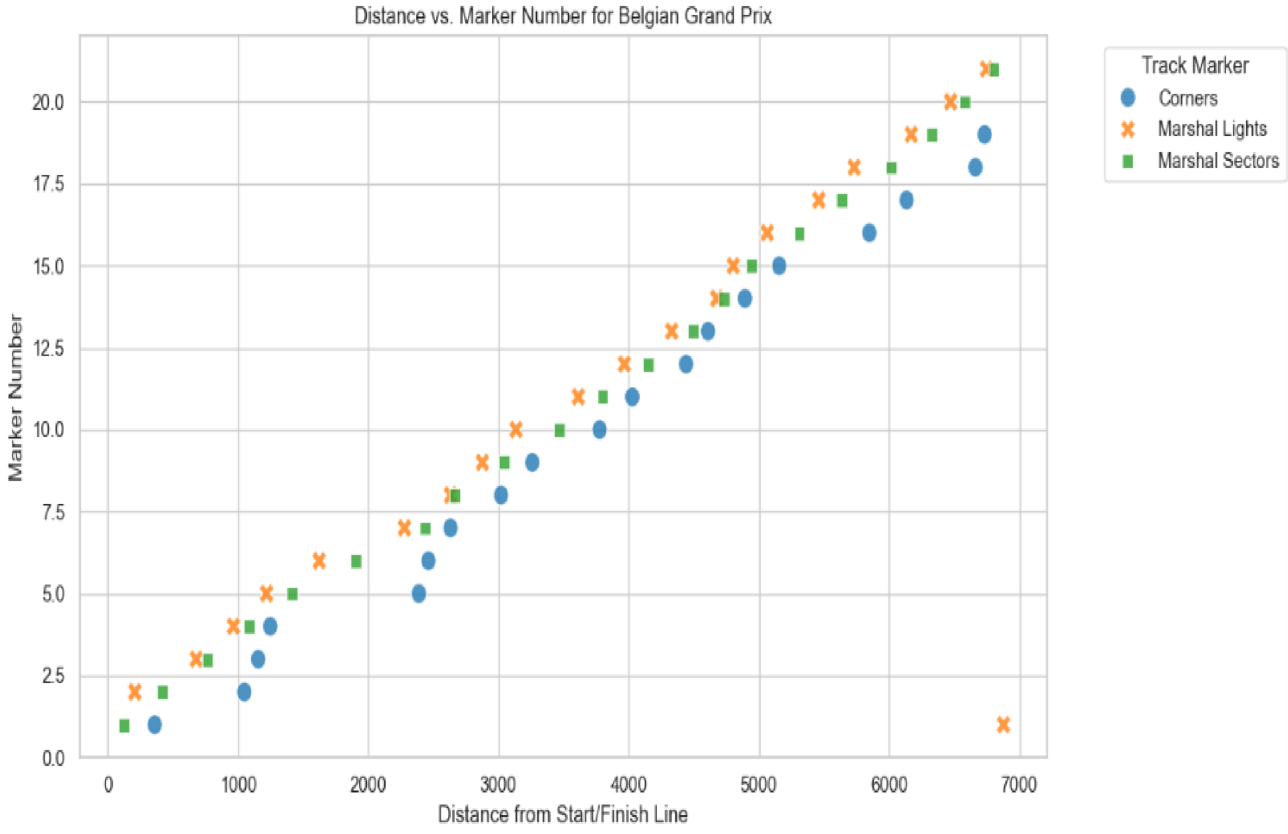
Figure 5. Track Layout for Monaco Grand Prix.



Circuit data is crucial for understanding the unique characteristics of each track, such as layout, overtaking zones, and corner profiles.

For instance, Figure 4 highlights the Miami circuit, where larger gaps between markers reflect the track's long straights, with fewer corners or notable features. In contrast, Figure 5 illustrates the Monaco circuit, where markers are densely packed, underscoring the track's tight turns and narrow streets, which demand precision and skill from the drivers.

Figure 6. Distance vs. Marker Number for Belgian Grand Prix.



We plotted distances between track markers to identify patterns, such as where markers (corners, straights, etc.) are densely clustered or how evenly spaced they are along the track. These plots provide insights into the layout complexity, revealing how different sections of the track vary in terms of marker spacing.

For example, Figure 6 illustrates the distances between markers at the Belgian Grand Prix (Spa-Francorchamps), one of the longest circuits in Formula 1 at approximately 7 kilometers. The plot for Spa shows markers spread over a larger distance compared to most tracks, highlighting its long straights and iconic sweeping corners like Eau Rouge.

Figure 7. Distance vs. Marker Number for Australian Grand Prix.

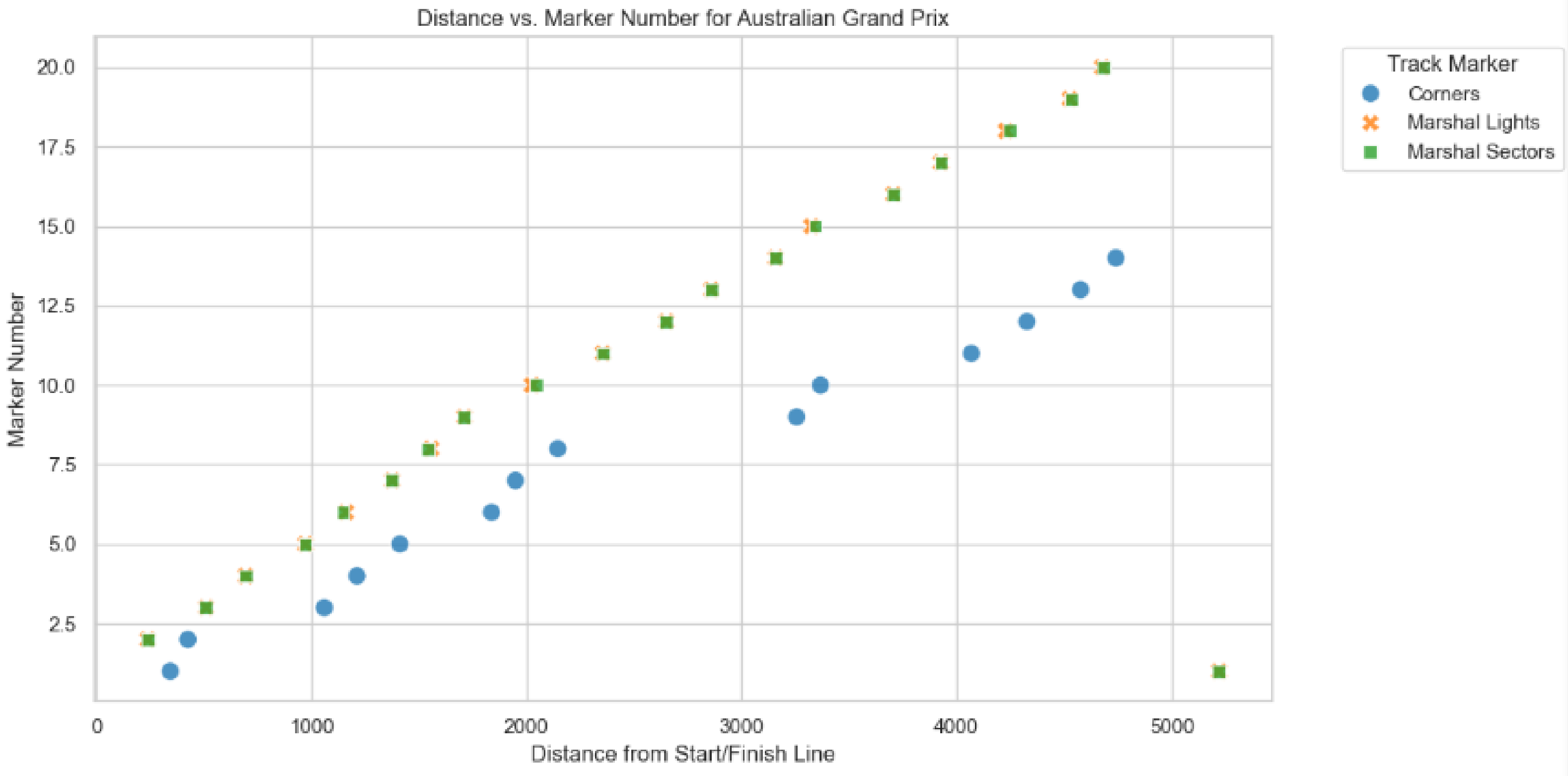


Figure 7 presents the Australian Grand Prix at Albert Park, a shorter circuit at around 5.3 kilometers. The plot reveals that some markers are close together while others are spaced farther apart, indicating that certain sections of the track are more complex—characterized by many corners in a short distance—while others are faster with fewer significant markers, such as long straights.

This pattern reflects Albert Park's nature as a street circuit, with frequent changes in direction and tighter turns. Clusters of markers over short distances suggest sections with several tight corners or technical parts of the track. For example, in circuits like the Belgian Grand Prix, markers are densely packed in specific areas due to the challenging tight turns. In contrast, at the Australian Grand Prix, sections where markers are spaced farther apart indicate straights, where there are fewer corners, allowing drivers to reach higher speeds.

Figure 8. Angle Distribution for Monaco Grand Prix.

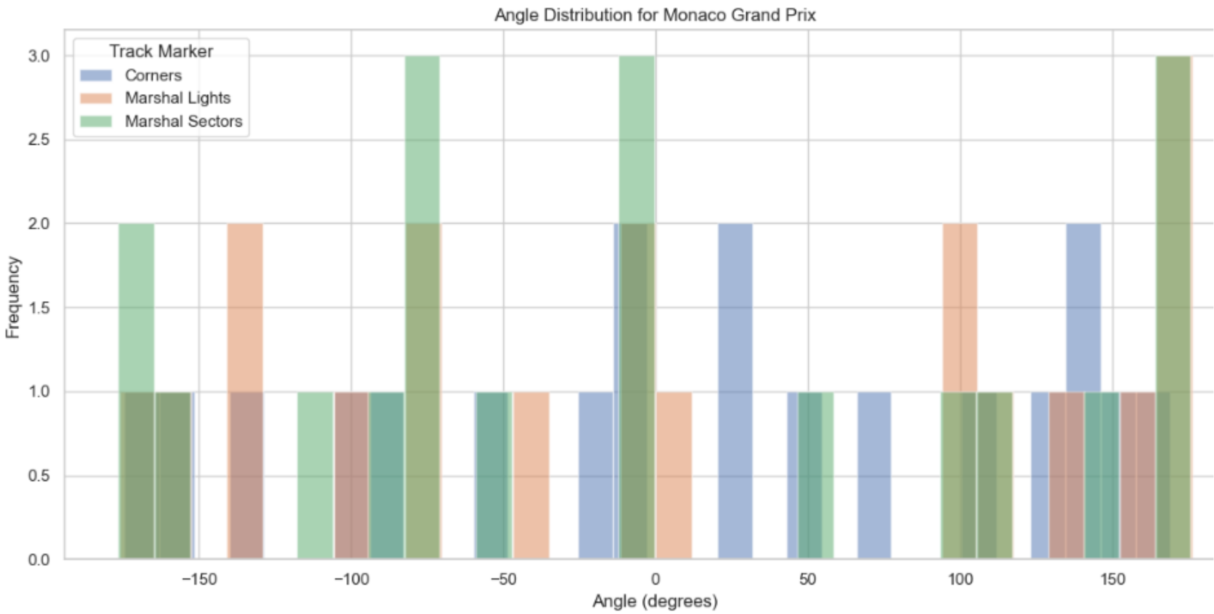
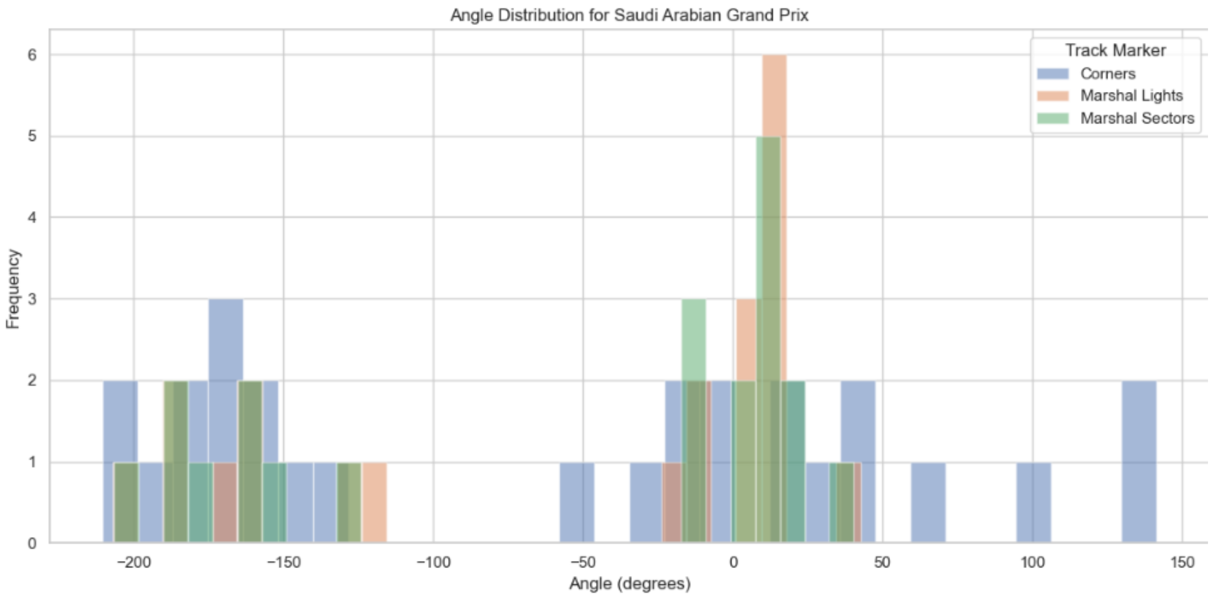


Figure 9. Angle Distribution for Saudi Arabian Grand Prix.



Finally, the "Angle" metric provides crucial insights for track geometry analysis, helping to characterize the layout of tight corners, sweeping turns, and straight sections. Figure 8 illustrates the histogram for the Monaco Grand Prix (Monte Carlo), which shows a notable frequency of extreme corner angles (close to 90 degrees or more) due to the circuit's tight and narrow design.

Monaco is renowned as the slowest and most technical circuit in Formula 1, featuring numerous tight corners and sharp hairpins, such as the Grand Hotel Hairpin. The histogram reveals a higher concentration of angles at the extreme end, indicating the sharp nature of these corners and underscoring the challenges drivers face on this iconic track.

In Figure 9, the histogram for the Saudi Arabian Grand Prix (Jeddah Street Circuit) displays a more evenly distributed range of angles, with significantly fewer extreme values. This reflects the flowing nature of the track, which features fast corners and a reduced number of tight, sharp turns compared to Monaco. The plot shows a greater concentration of bars at mid-range angles (approximately 45-70 degrees), highlighting the combination of medium-speed corners and high-speed kinks that characterize this modern street circuit. This balance contributes to a dynamic racing experience, allowing for higher average speeds throughout the event.

Quick Look at "control_message_2024"

Figure 10. Number of Messages by Event.

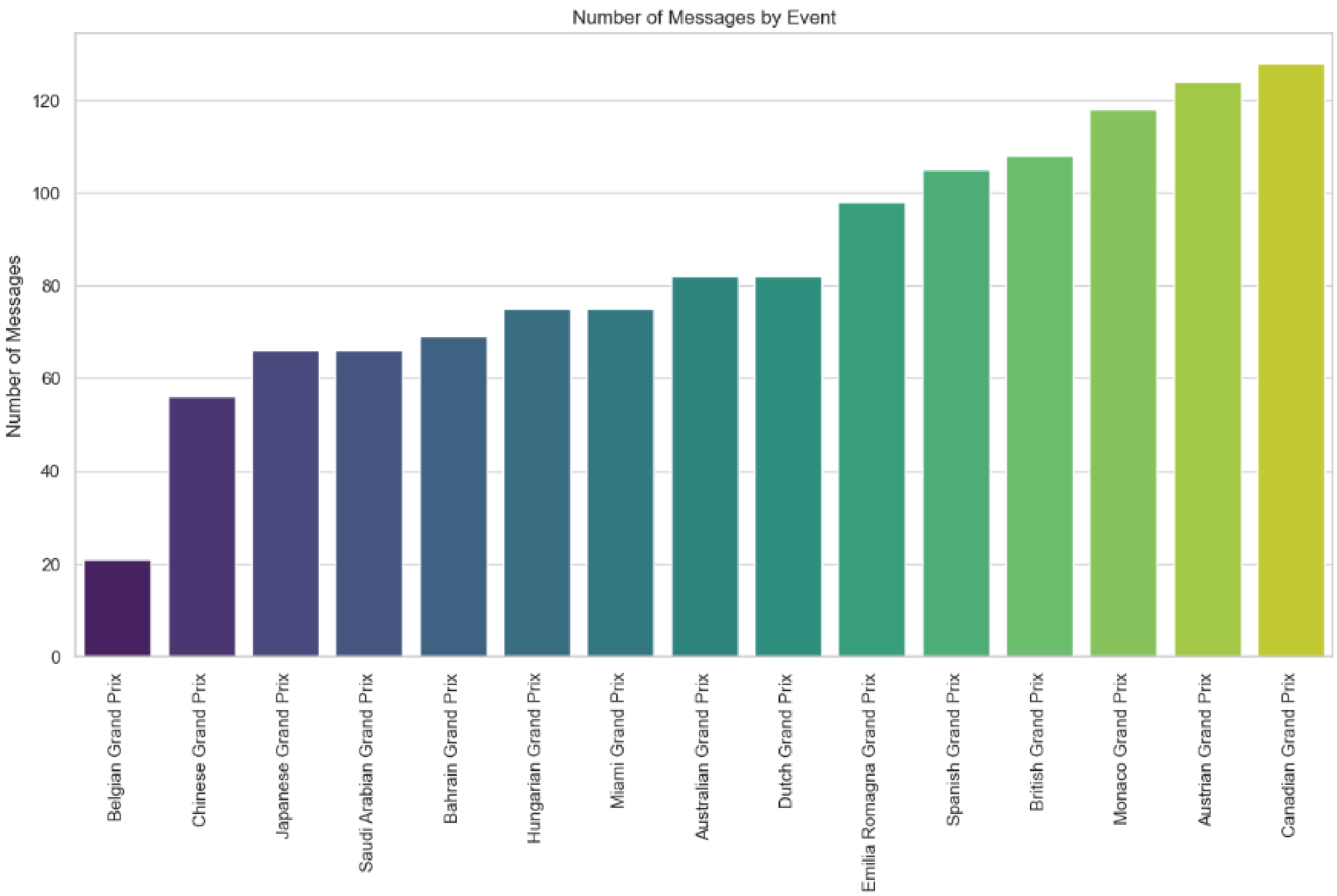


Figure 10 illustrates the total number of control messages—such as race control signals, flags, and DRS activations—issued during each Grand Prix. This data enables us to identify races characterized by a higher frequency of messages, which often indicates events with numerous safety car deployments, DRS activations, or caution flags.

By analyzing this information, we can gain insights into the overall intensity and complexity of each race, shedding light on how control measures impact race dynamics and driver strategies.

The Austrian Grand Prix, held at the Red Bull Ring, frequently experiences incidents due to its combination of tight corners and significant elevation changes. This challenging layout often results in more safety car deployments and a higher volume of flag-related messages, reflecting the track's tendency for incidents. Similarly, the Canadian Grand Prix at Circuit Gilles Villeneuve is infamous for its narrow confines and lack of run-off areas, which increases the likelihood of accidents. As a result, this circuit also sees a greater number of flags and safety car situations, underscoring the impact of track design on race safety and dynamics.

Figure 11. Message Categories by Event.

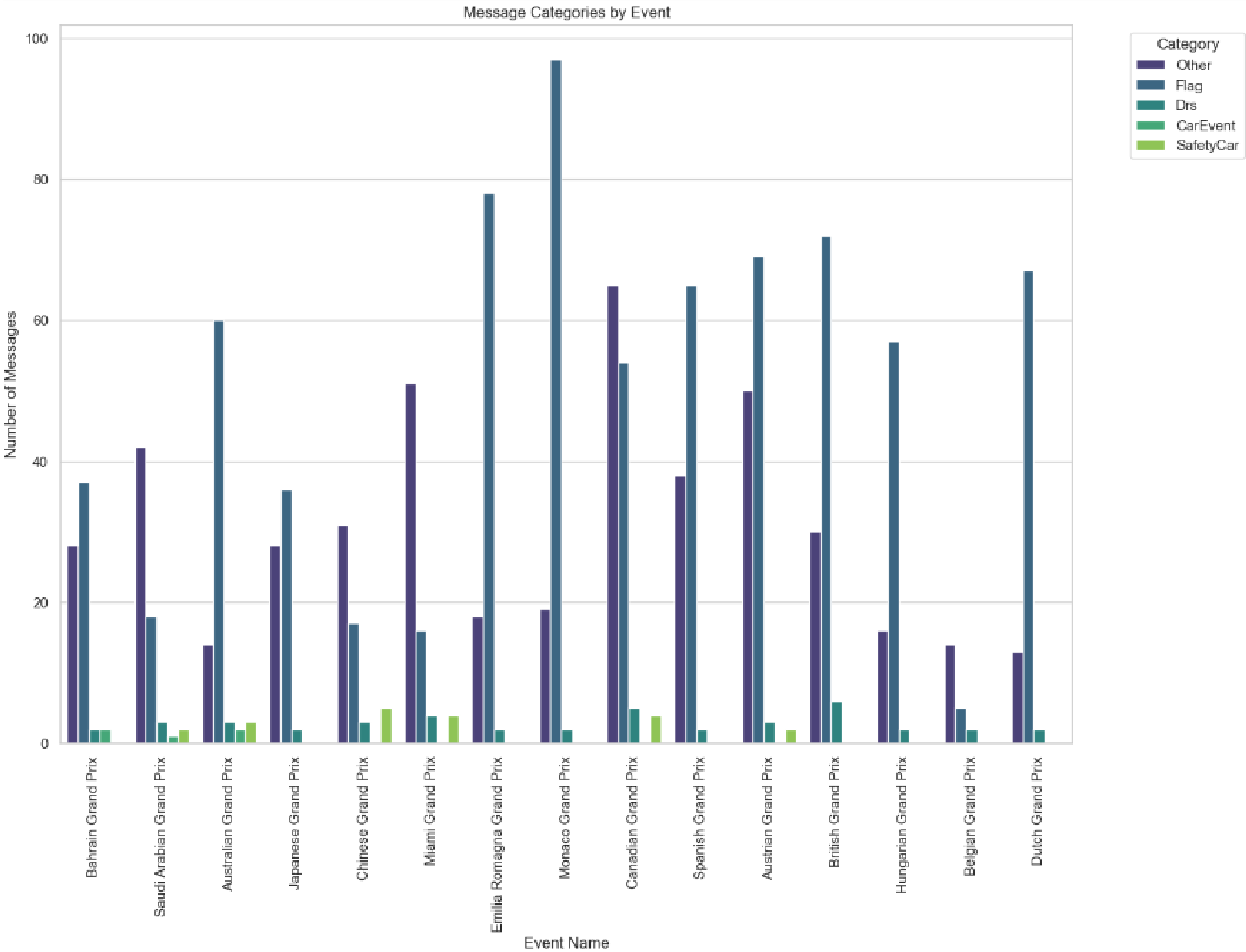


Figure 11 illustrates the distribution of message counts associated with each event, allowing us to discern patterns in the frequency and types of messages across different races.

For instance, tracks like Bahrain, Saudi Arabia, Japan, China, and Belgium exhibit low message volumes, suggesting that these races generally experienced fewer interruptions or incidents. This indicates relatively smooth racing conditions, with minimal accidents or track events requiring intervention.

In contrast, circuits such as Monaco, Emilia Romagna, Canada, and Austria demonstrate higher message volumes. These races are characterized by more complex racing conditions—whether due to challenging layouts, unpredictable weather, or technical difficulties—leading to increased instances of flags, safety cars, and other control messages. This trend highlights how the intricacies of a circuit can significantly impact race dynamics and necessitate greater race control measures.

Figure 12. Message Scope Distribution by Event.

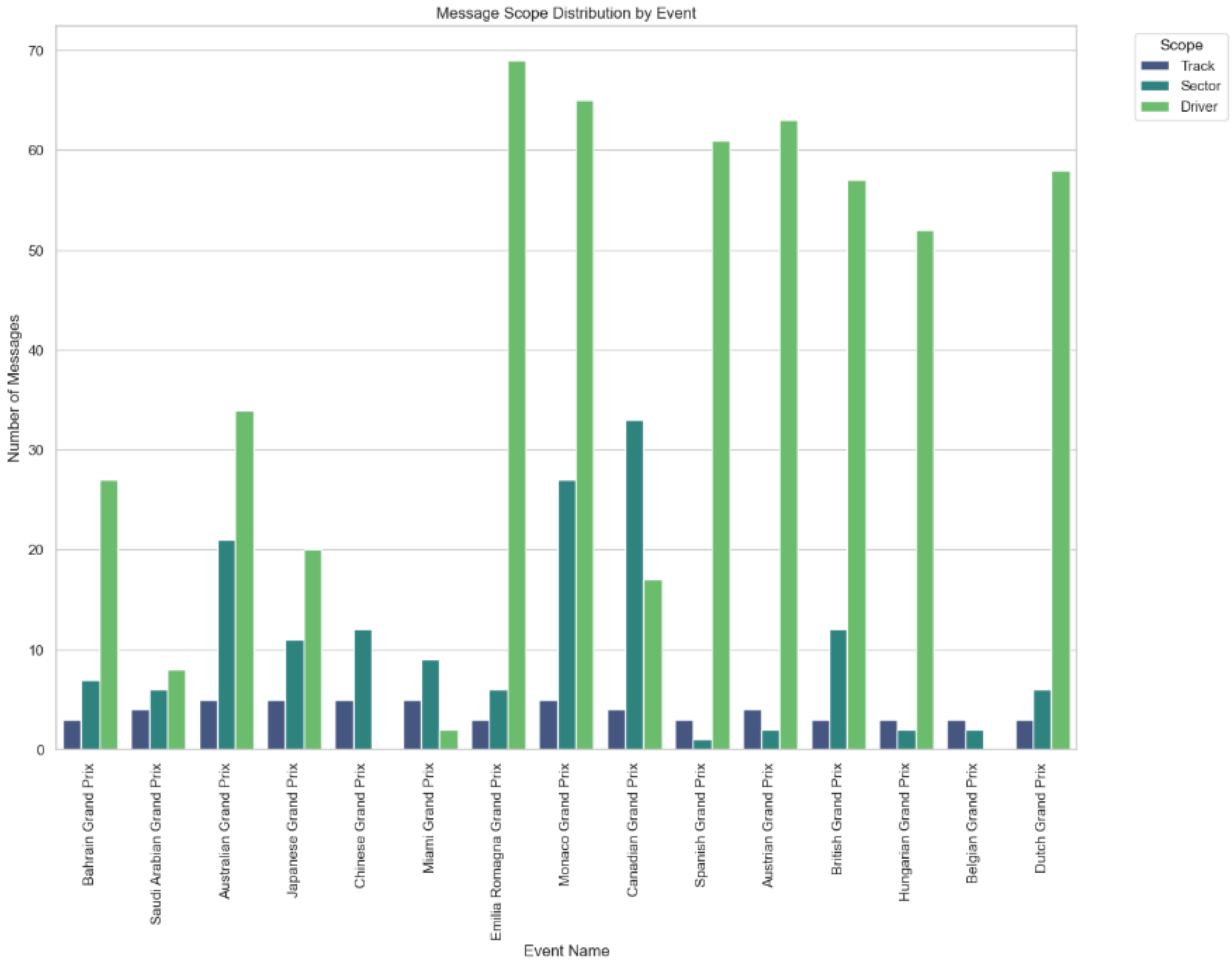


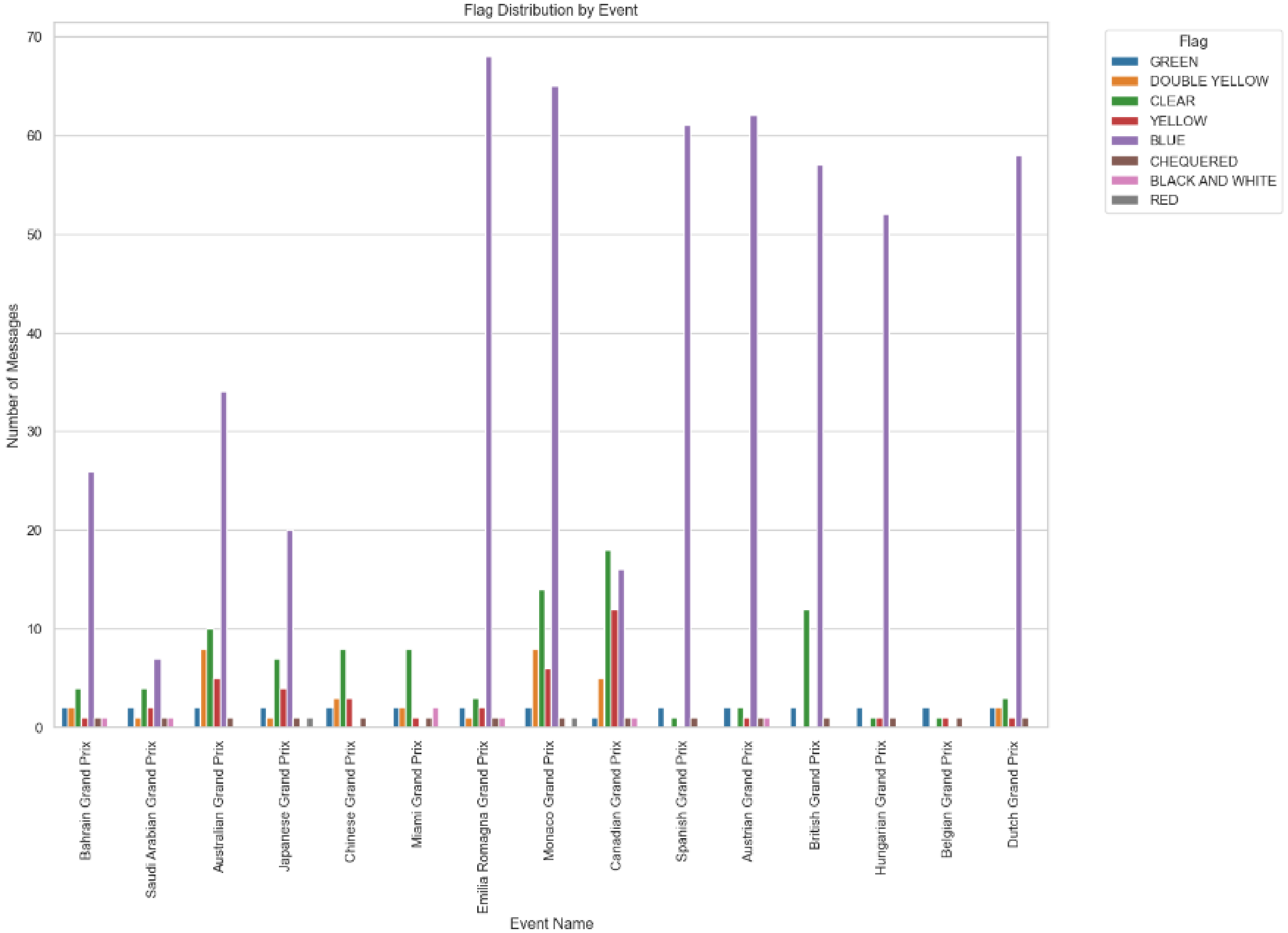
Figure 12 provides a breakdown of message counts by scope for each event, with each bar representing a race and colored segments indicating different message categories.

Races like Monaco, Emilia Romagna, and Canada show high message volumes in the "track" scope, indicating that these events experienced frequent interruptions affecting the entire circuit. This can be attributed to the challenging layouts of these tracks, which often lead to more incidents and require greater oversight from race control.

Conversely, events such as Bahrain, Saudi Arabia, and Japan have low track-scope message volumes, suggesting fewer full-circuit interruptions. This could be due to better visibility, more forgiving track layouts, or simply a lack of significant incidents during the race.

Overall, the patterns observed in the message volumes reveal that certain Grand Prix, particularly those with intricate designs, tend to generate more race control messages. In contrast, races characterized by smoother layouts, like the Belgian Grand Prix, Bahrain, Miami, and Saudi Arabia, typically involve fewer interruptions and less need for extensive race management.

Figure 13. Flag Distribution by Event.



Monaco experiences a high volume of yellow, double yellow, and safety car-related flags, primarily due to its narrow layout and frequent incidents. Similarly, the Emilia Romagna and Canadian GPs see numerous cautions, often influenced by weather conditions, resulting in elevated counts of yellow, double yellow, and red flags. The technical characteristics of these circuits also lead to more clear and green flags as incidents are managed. In contrast, the British and Dutch GPs are renowned for their unpredictable conditions and tight racing, resulting in frequent blue flags as drivers navigate the challenges of overtaking backmarkers.

Green Flags: Indicates that the track is clear, and normal racing conditions can resume after a caution period.

Double Yellow Flags: Warns of a hazard on the track, requiring drivers to slow down and be prepared to stop.

Clear (All Clear) Flags: Signals that any hazards or obstructions have been removed, allowing drivers to return to normal racing.

Yellow Flags: Alerts drivers to a hazard on the track, though the situation is not as serious as a double yellow.

Blue Flags: Informs a slower car that a faster car is approaching to lap them, indicating they should yield.

Chequered Flag: Signifies the conclusion of the race.

Black and White Flag: A warning for unsportsmanlike behavior or dangerous driving.

Red Flag: Indicates that the race is halted due to dangerous conditions, such as a severe crash, adverse weather, or track blockage.

Figure 14. Total Number of Pit Related Messages by Event.

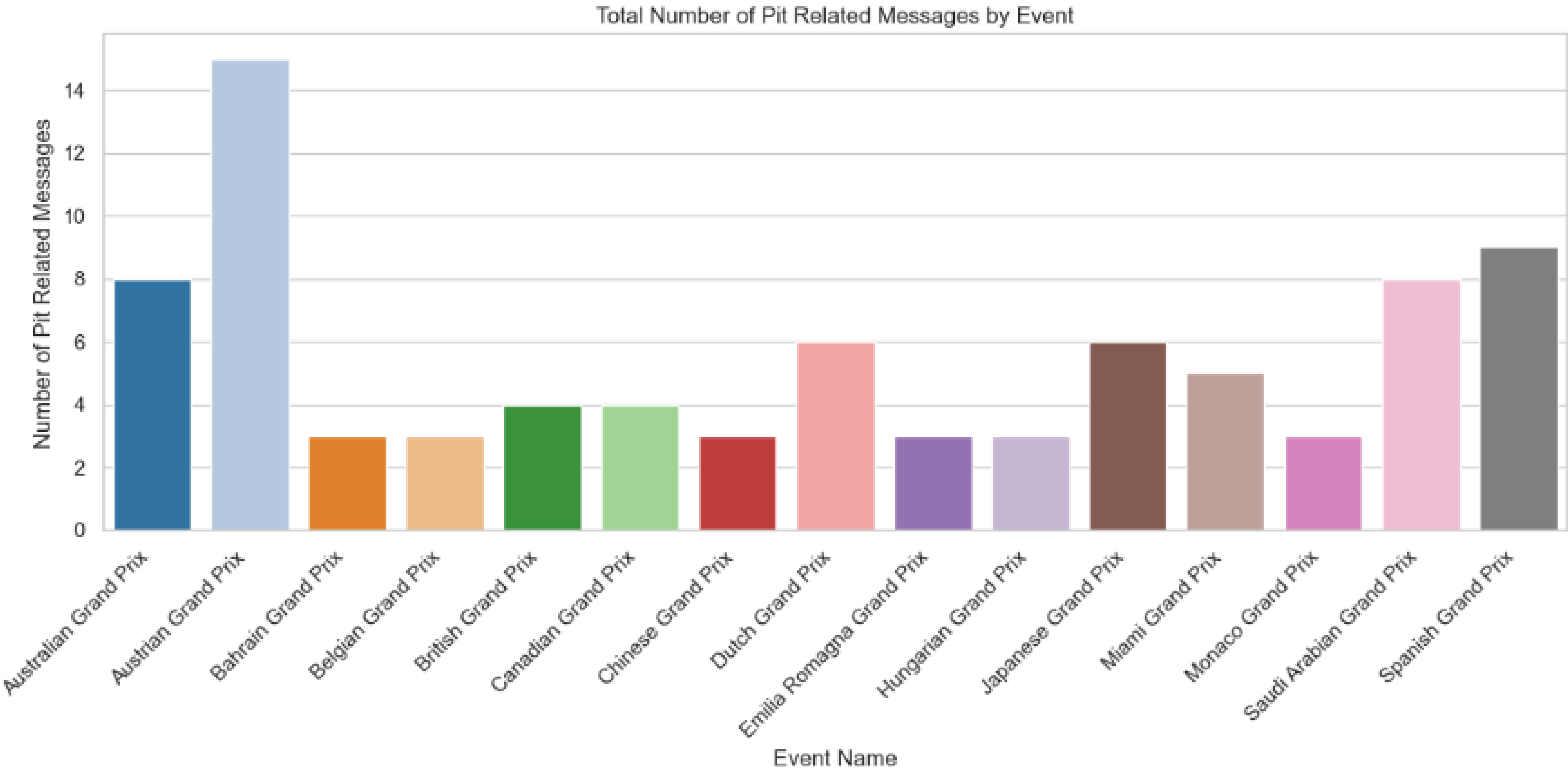
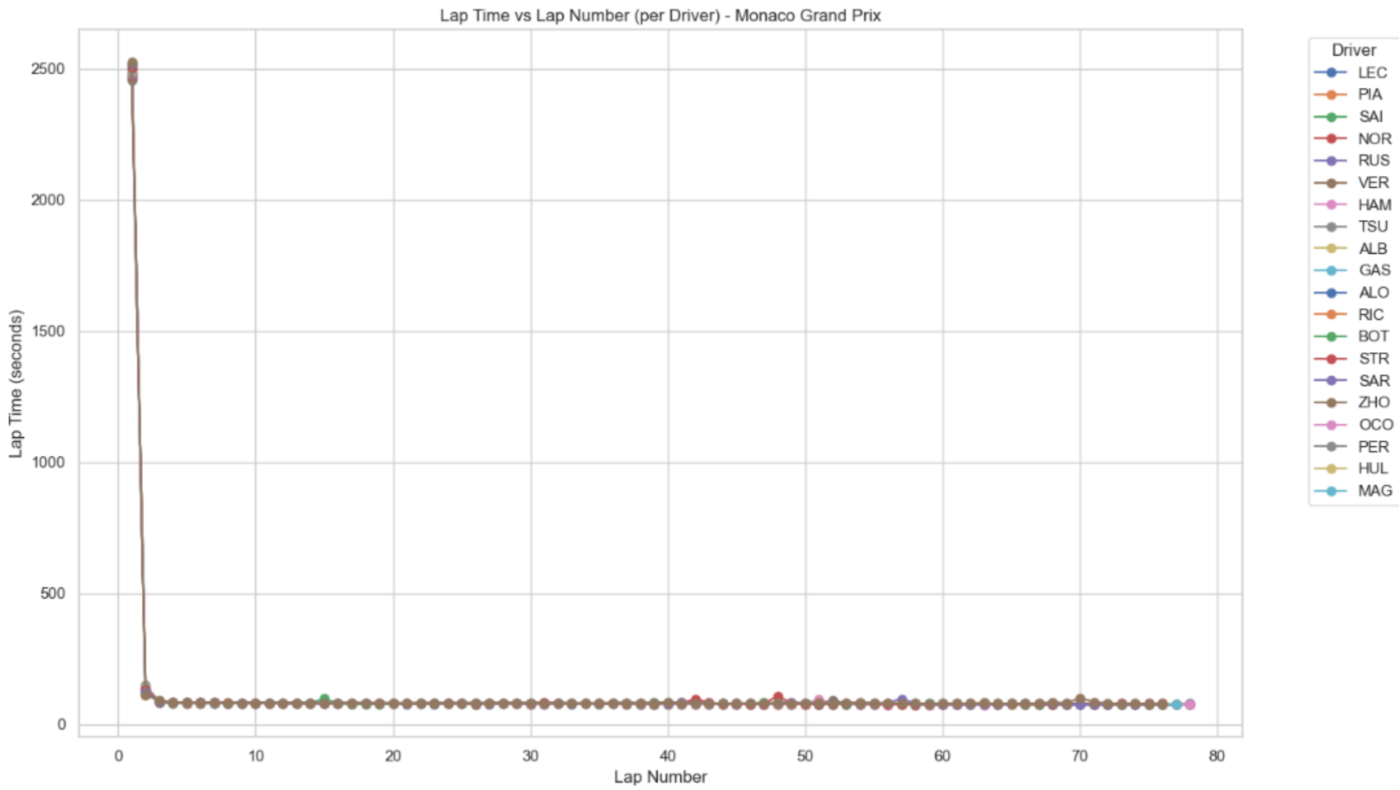


Figure 14 illustrates the total number of pit-related messages across various events. While this plot does not provide exact pit stop counts, it offers valuable insights into race dynamics, particularly concerning pit stop strategies, race conditions, and team tactics. For instance, the Spanish GP at Circuit de Barcelona-Catalunya is notorious for high tire wear, often resulting in multiple pit stops as teams adjust tire choices to maximize performance. Similarly, the Australian GP at Albert Park, a semi-permanent street circuit, tends to experience higher tire degradation, contributing to an increase in pit-related messages. In contrast, circuits with lower tire degradation, such as Monaco, typically generate fewer pit-related messages due to the reduced necessity for pit stops.

Quick Look at "lap_2024"

The "lap_data" file contains a wealth of race information, including lap times, tire choices, and driver performances. This dataset is essential for conducting a detailed analysis of driver strategies on a race-by-race basis, enabling insights into tire usage patterns and overall lap performance.

Figure 15. Lap Time vs Lap Number (per Driver) – Monaco Grand Prix.



We generated plots that visualize the evolution of lap times across different lap numbers for various drivers in each Formula 1 event. Each plot corresponds to a specific race, with separate lines representing individual drivers.

In Figure 15, focusing on the Monaco Grand Prix, we observe more consistent lap times due to the circuit's challenging layout, where overtaking is difficult and pit strategy becomes critical.

Notably, Red Bull's Sergio Perez (PER) and Haas drivers Kevin Magnussen (MAG) and Nico Hulkenberg (HUL) were involved in a significant crash on the opening lap, leading to a red flag that halted the race for nearly an hour, although the race timer continued to run. This incident impacted the overall race dynamics and strategies for the remaining drivers.

Figure 16. Lap Time vs Lap Number (per Driver) – Austrian Grand Prix.

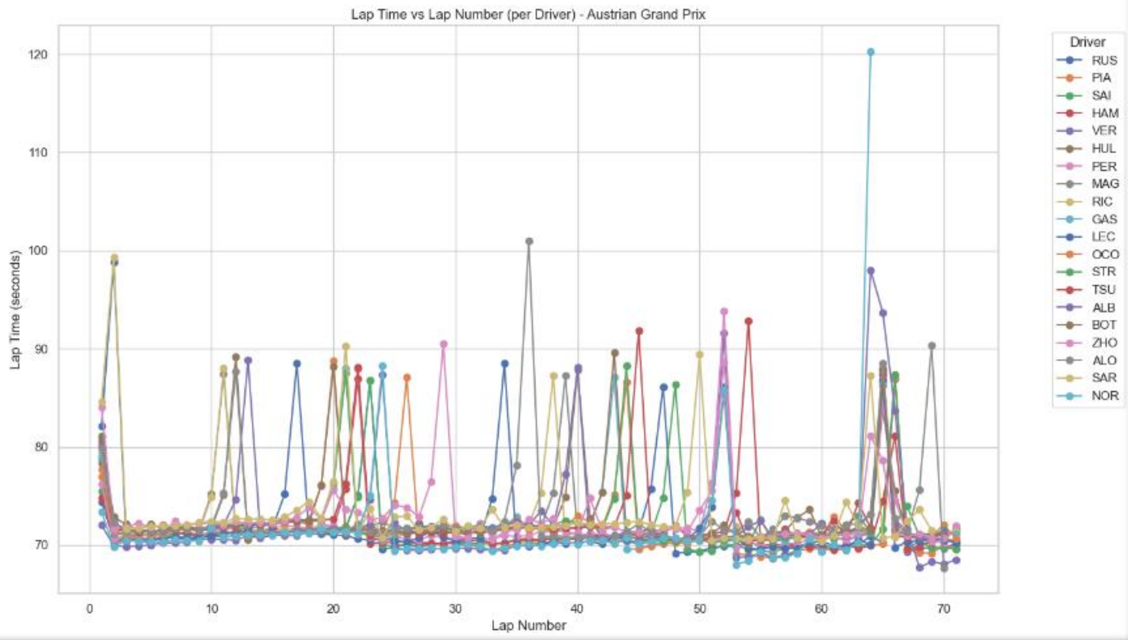


Figure 17. Lap Time vs Lap Number (per Driver) – Canadian Grand Prix.

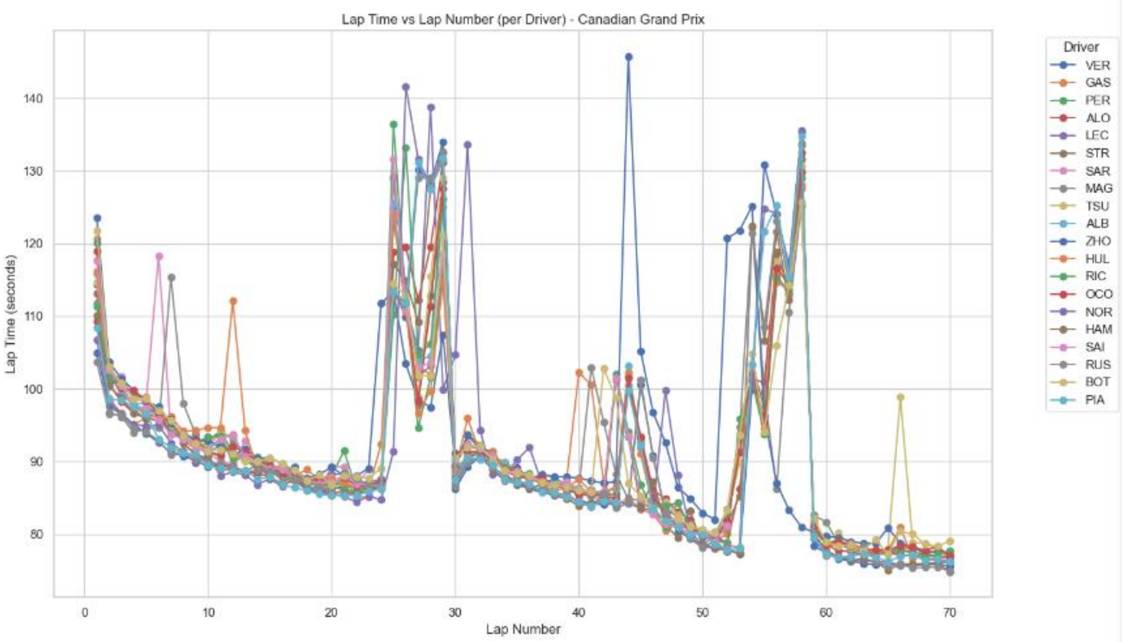


Figure 16 illustrates the lap time variations during the Austrian Grand Prix, highlighting sudden spikes and drops that correspond to fluctuating weather conditions and strategic tire choices. These fluctuations often reflect how teams adapt their strategies in response to changing track conditions, making pit stops or tire changes to optimize performance.

In Figure 17, we observe a general downward trend in lap times over the course of the race. This decline indicates that drivers are improving their lap times as the race progresses, typically due to reduced fuel loads as they consume fuel, resulting in lighter cars.

Sudden spikes in lap times, evident as abrupt jumps in the graph, often indicate pit stops. When a driver enters the pits, their lap time for that specific lap increases significantly due to the time taken for tire changes or any necessary adjustments to the car. This analysis highlights the intricate relationship between race dynamics, driver performance, and team strategies throughout the event.

Figure 18. Top 5 Drivers Position Throughout the Race: Monaco Grand Prix.

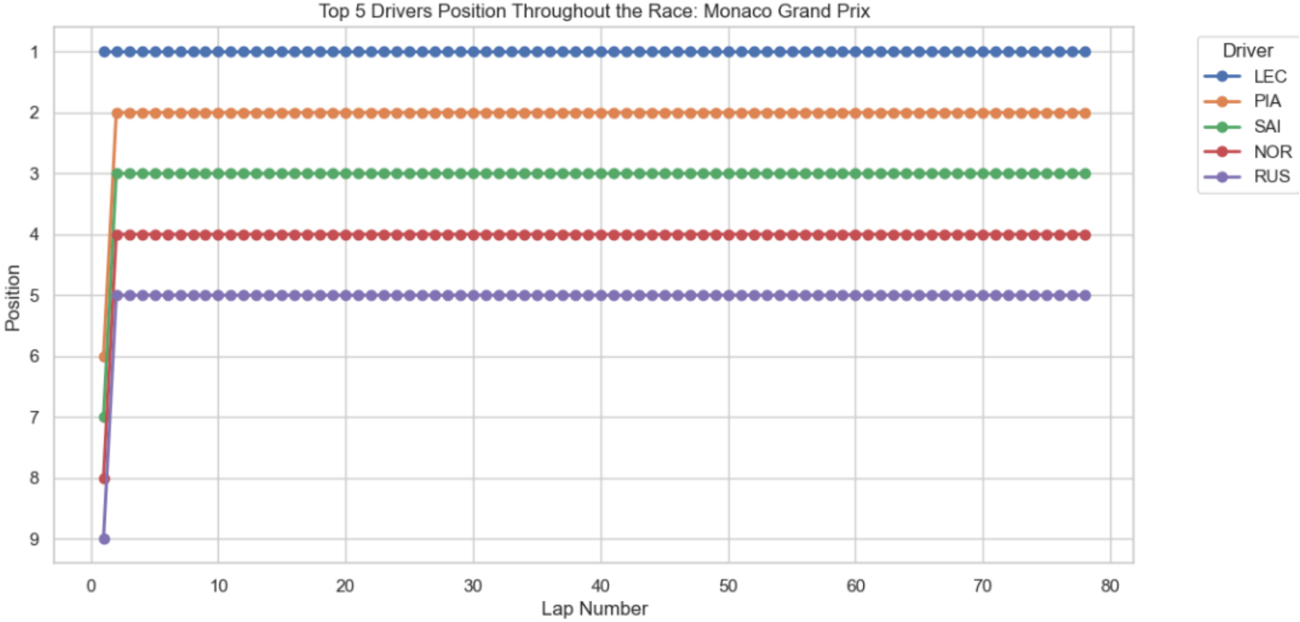
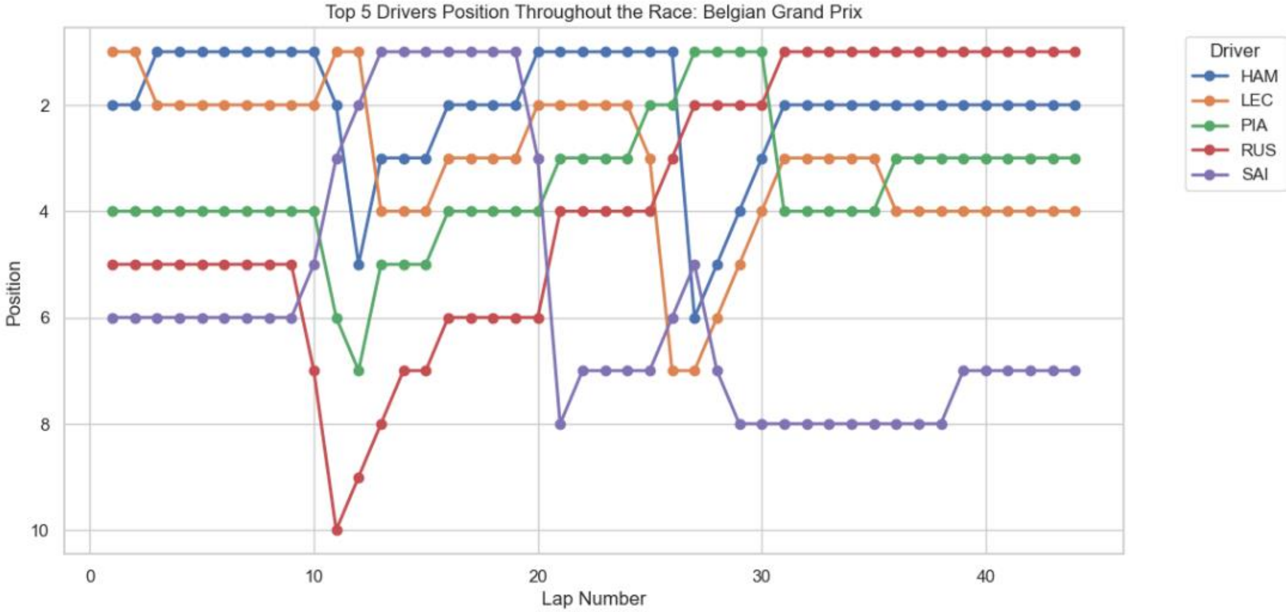


Figure 19. Top 5 Drivers Position Throughout the Race: Belgian Grand Prix.



We created plots to visualize the positional changes of the top five drivers (based on their final positions) throughout each race.

In Figure 18, which focuses on the Monaco Grand Prix, we observe minimal position changes among the drivers. This is largely due to the circuit's challenging layout, which makes overtaking extremely difficult. Most positional shifts are attributed to pit stops rather than on-track maneuvers, highlighting the strategic importance of pit strategy in this tightly confined environment.

Conversely, Figure 19 captures the Belgian Grand Prix, showcasing a more dynamic race. Here, we see frequent position changes among the drivers, driven by the track's layout, which offers more overtaking opportunities. Additionally, unpredictable weather conditions further contribute to the volatility in driver positions, emphasizing how external factors can influence race dynamics. This contrast illustrates the varying challenges and strategies that drivers must navigate across different circuits.

Figure 20. Tire Compound Performance: Lap Time Distribution by Tire Compound – Dutch Grand Prix.

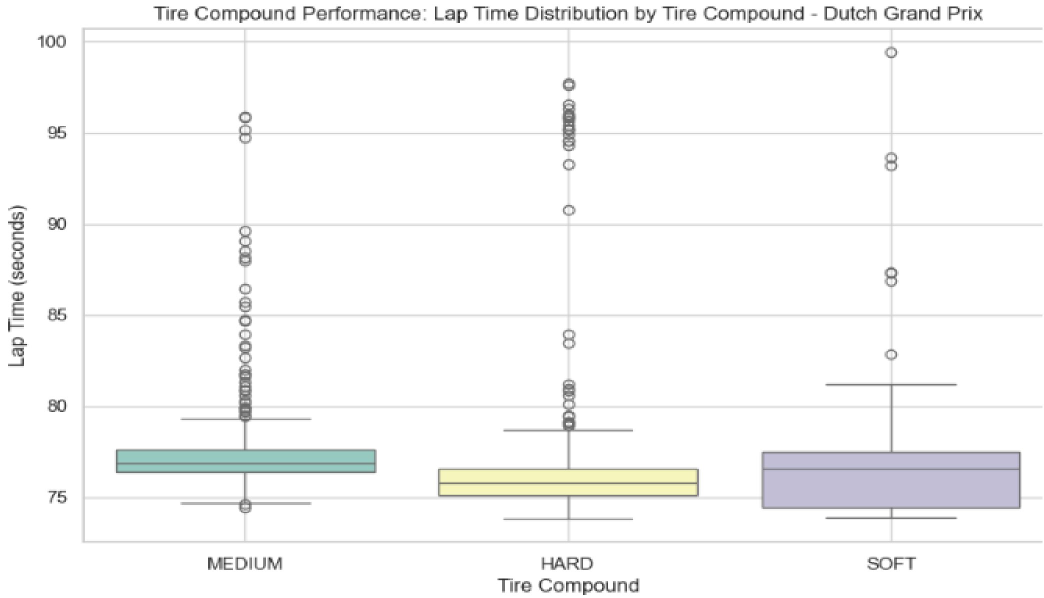
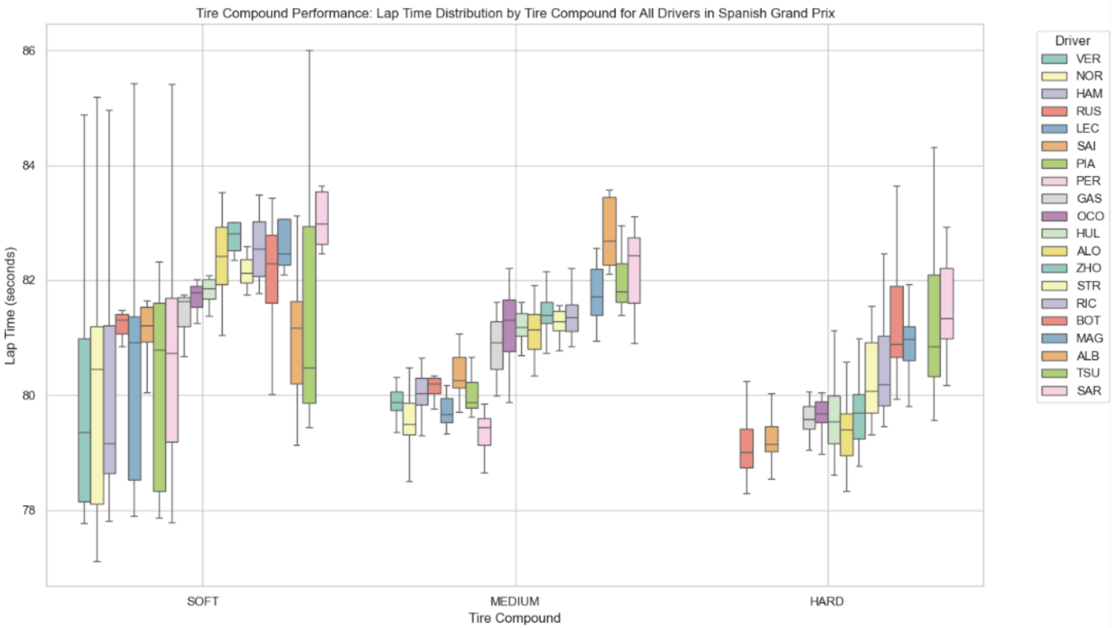


Figure 21. Tire Compound Performance: Lap Time Distribution by Tire Compound for All Drivers in Spanish Grand Prix.



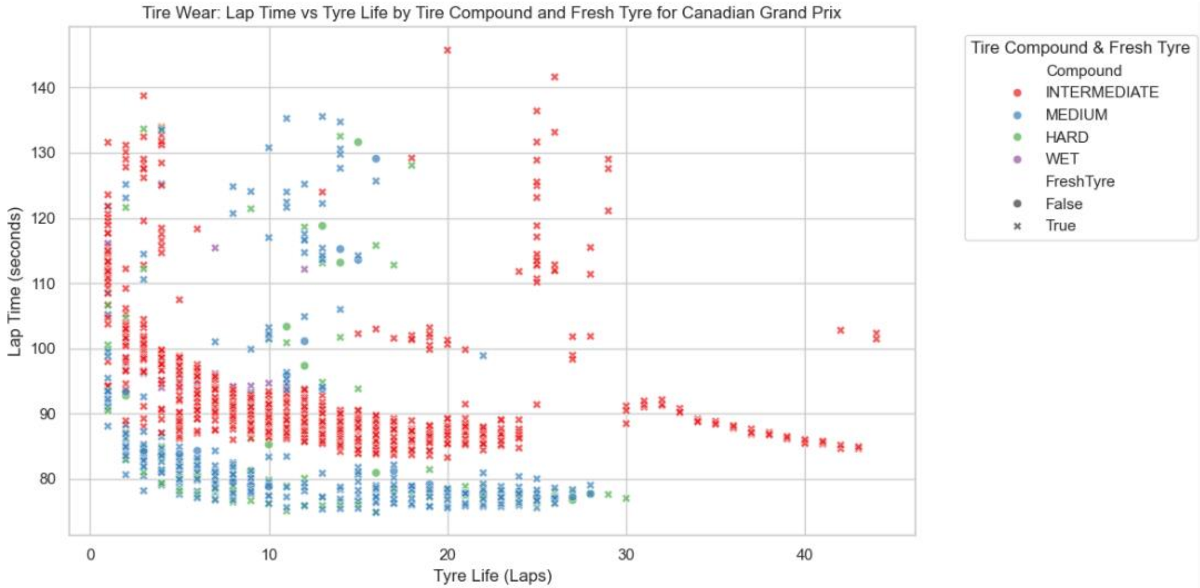
We created boxplots (Figure 20) to visualize the distribution of lap times associated with different tire compounds used during a Formula 1 event. Typically, soft tires deliver the fastest lap times due to their grip and performance but experience rapid degradation. As a result, the box for soft tires often exhibits a lower median, accompanied by a wider range and more outliers, reflecting the drop-off in performance as the tires wear.

In contrast, medium tires tend to offer a balance between speed and durability, resulting in more consistent lap times with fewer outliers. Their performance is steadier, making them a popular choice for drivers seeking reliability.

Hard tires, while slower overall, showcase greater consistency in lap times over the race duration. This reliability is beneficial for drivers looking to maximize their stints without the risk of significant performance drops. Overall, these boxplots illustrate the trade-offs involved in tire selection and their impact on lap performance throughout a race.

Figure 21 offers insights into the performance of various tire compounds utilized by all drivers during the Spanish Grand Prix. As observed in Figure 20, the soft tire compound displays a lower median lap time compared to the medium and hard tires, indicating that drivers could achieve faster and more consistent lap times while using the soft tires during this event. However, the wider spread of lap times for the soft tires highlights their quick degradation, which ultimately leads to a significant drop in performance as the race progresses. This analysis underscores the trade-offs drivers face when choosing tire compounds, balancing the need for speed against the challenges of maintaining tire performance over the course of the race.

Figure 22. Tire Wear: Lap Time vs. Tire Life by Tire Compound and Fresh Tire for Canadian Grand Prix.



Figures 22 and 23 facilitate an analysis of how tire wear—measured as tire life based on lap numbers—affects lap times, incorporating additional details on tire compounds and whether the tires are fresh or used.
As anticipated, the data reveals that lap times tend to increase as tires wear out, corresponding with higher lap numbers (tire life). This trend highlights the critical impact of tire degradation on performance; as the tires lose grip and effectiveness over the course of the race, drivers experience longer lap times. Additionally, the distinction between fresh and used tires emphasizes the importance of pit strategies in maintaining competitive performance, as teams must carefully manage tire life to optimize lap times throughout the race.

Figure 23. Tire Wear: Lap Time vs. Tire Life by Tire Compound and Fresh Tire for Dutch Grand Prix.

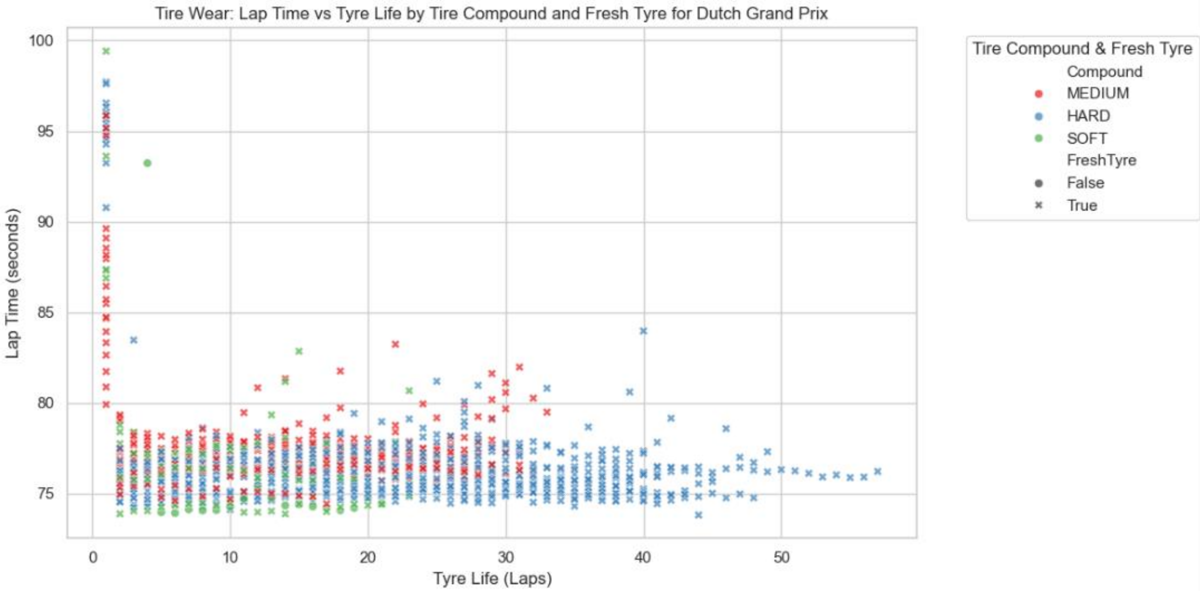


Figure 22 illustrates that during the Canadian Grand Prix, teams predominantly favored hard and medium tires, while Figure 23 highlights a preference for soft tires in the Dutch Grand Prix.
The data reveals that soft, intermediate, and medium tires exhibit a steeper increase in lap times compared to hard tires. This indicates that these compounds wear out more quickly, resulting in a more pronounced decline in performance over time. Teams must therefore carefully consider tire selection based on race strategy and track conditions, as the choice of tire can significantly impact overall race outcomes. The contrasting preferences between the two races underscore the varying demands of different circuits and the importance of adapting strategies accordingly.

Figure 24. Sector1 Performance: Time Distribution Across Events.

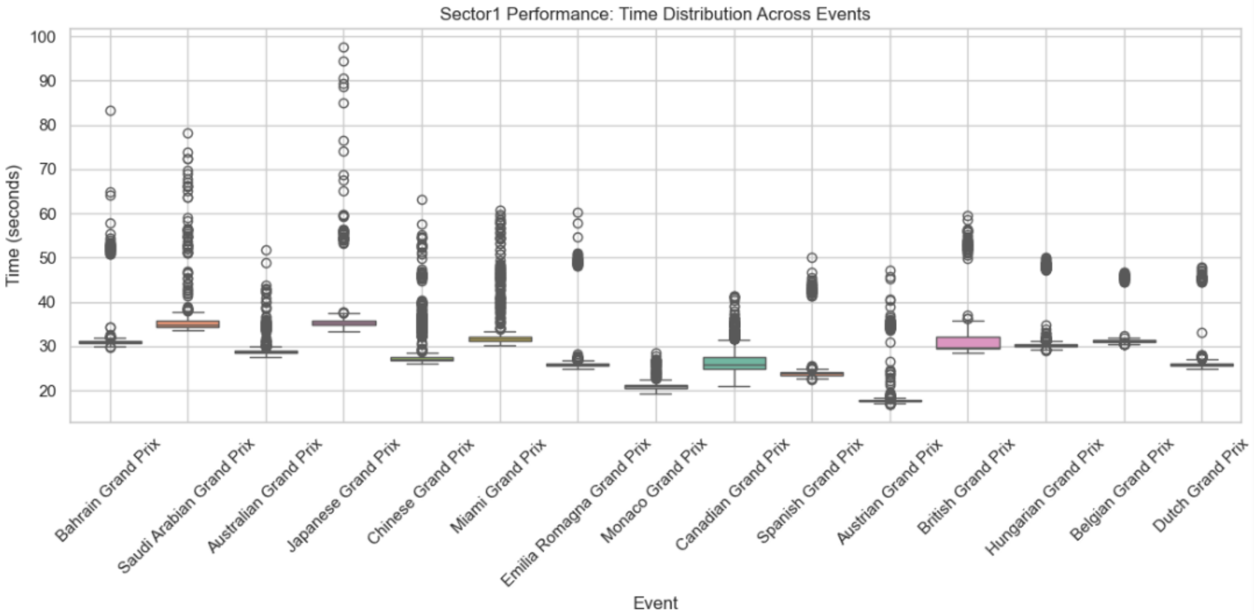
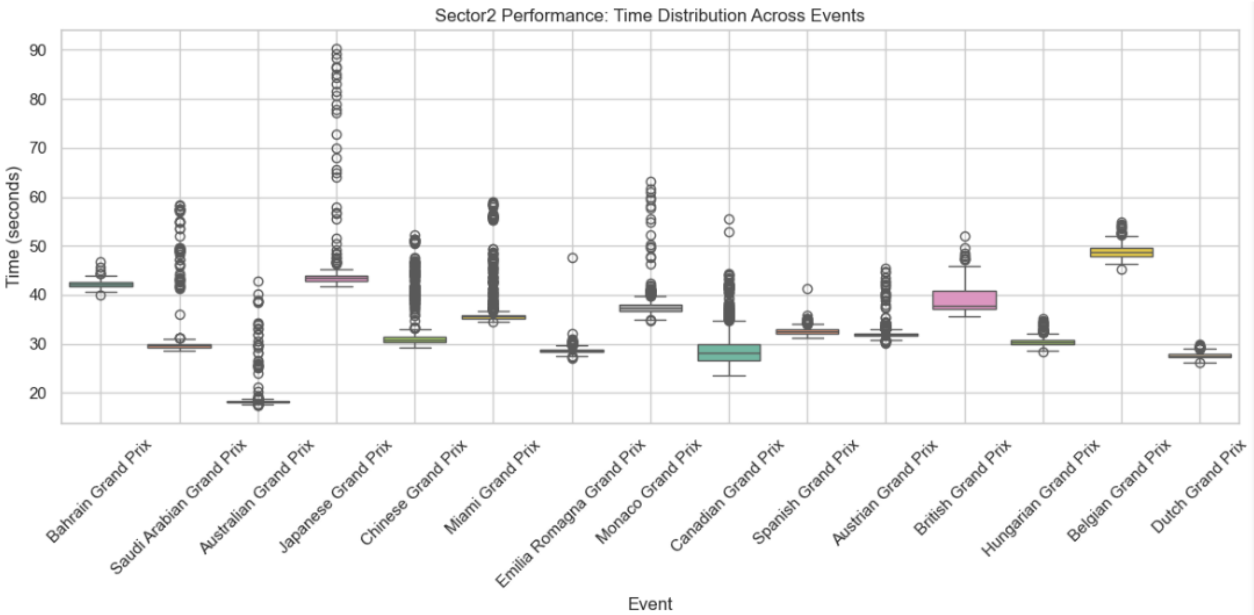


Figure 25. Sector2 Performance: Time Distribution Across Events.



In Figures 24, 25, and 26, we analyze sector performances across different tracks.

The Japanese and Canadian Grand Prix feature notable outliers, particularly in Sector 2 and Sector 3, likely attributable to challenging weather conditions or incidents during the race. These outliers underscore the unique difficulties presented by these circuits.

Conversely, the Austrian Grand Prix displays consistent lap times across all sectors, indicative of favorable track conditions and strong driver performance.

In the Bahrain Grand Prix, the lower median times in Sector 3 suggest a track design that favors quicker laps, allowing drivers to maintain competitive speeds.

Lastly, the Monaco Grand Prix exhibits a wider spread in Sector 3 times, reflecting the variability that arises from its tight corners and challenging track conditions. This variability emphasizes the complexity of racing in Monaco, where precision and adaptability are crucial.

Figure 26. Sector3 Performance: Time Distribution Across Events.

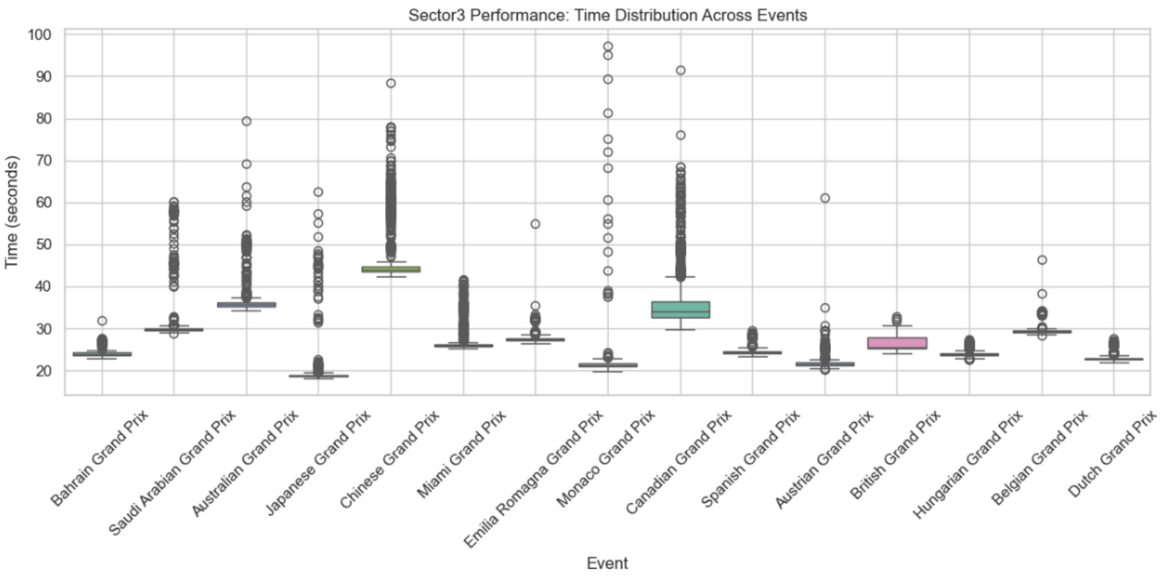
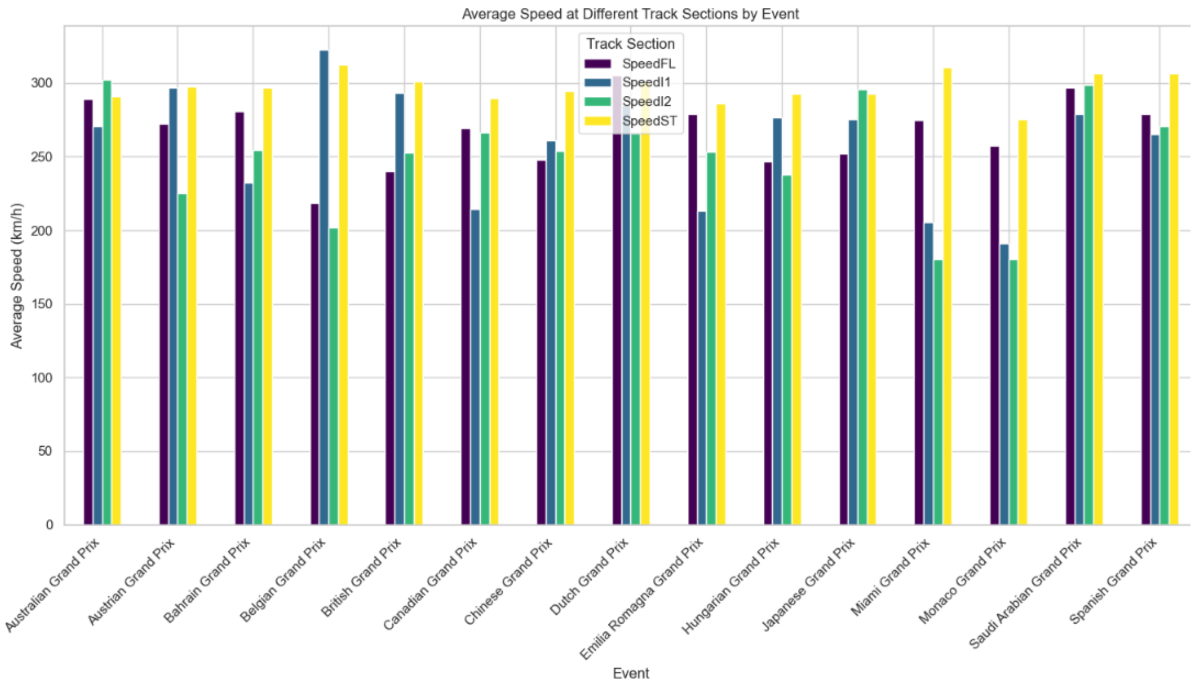


Figure 27. Average Speed at Different Track Sections by Event.



We generated plots (Figure 27) that visualize the speed distribution across different track sections, using a boxplot to compare speeds for various Formula 1 events.

The X-axis represents different track sections where speed is measured:

- SpeedI1: Speed in Sector 1
- SpeedI2: Speed in Sector 2
- SpeedFL: Speed at the Finish Line
- SpeedST: Speed on the Longest Straight

As anticipated, we observe higher speeds across all sections, particularly in SpeedST, on faster tracks like the Belgian, Bahrain, and Austrian Grand Prix. Notably, we also see elevated speeds in the Saudi Arabian and Spanish Grand Prix.

In contrast, more technical tracks like Monaco and Miami exhibit lower speeds, especially in the intermediate sections (SpeedI1, SpeedI2), where drivers must navigate tight turns and corners. However, Miami's long straight allows for higher speeds in SpeedST, showcasing how specific track features can significantly impact overall speed dynamics.

Figure 28. Speed Comparison at Different Track Sections – Bahrain Grand Prix.

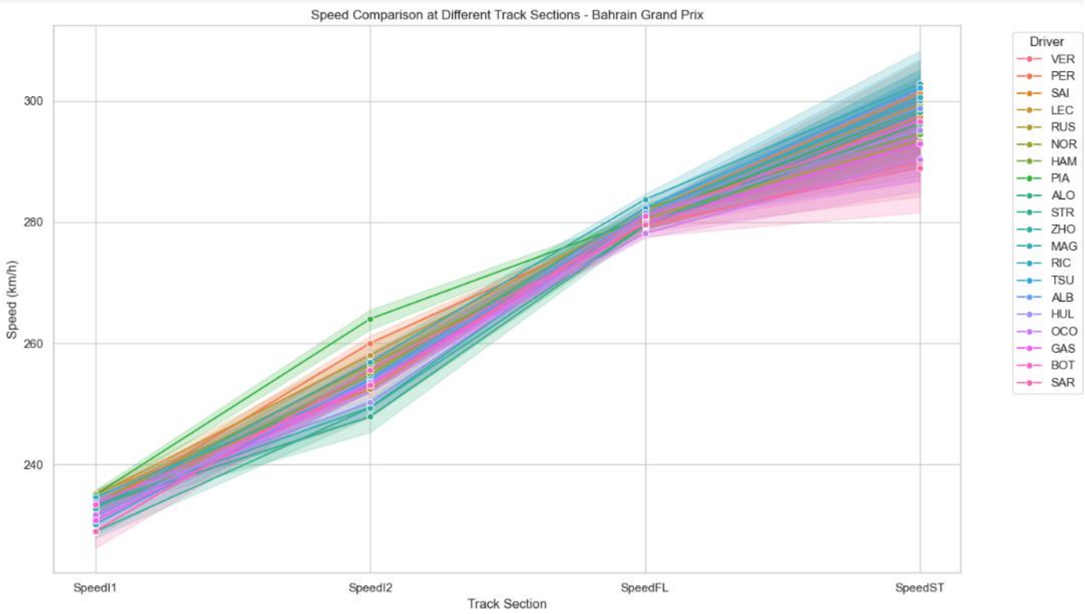
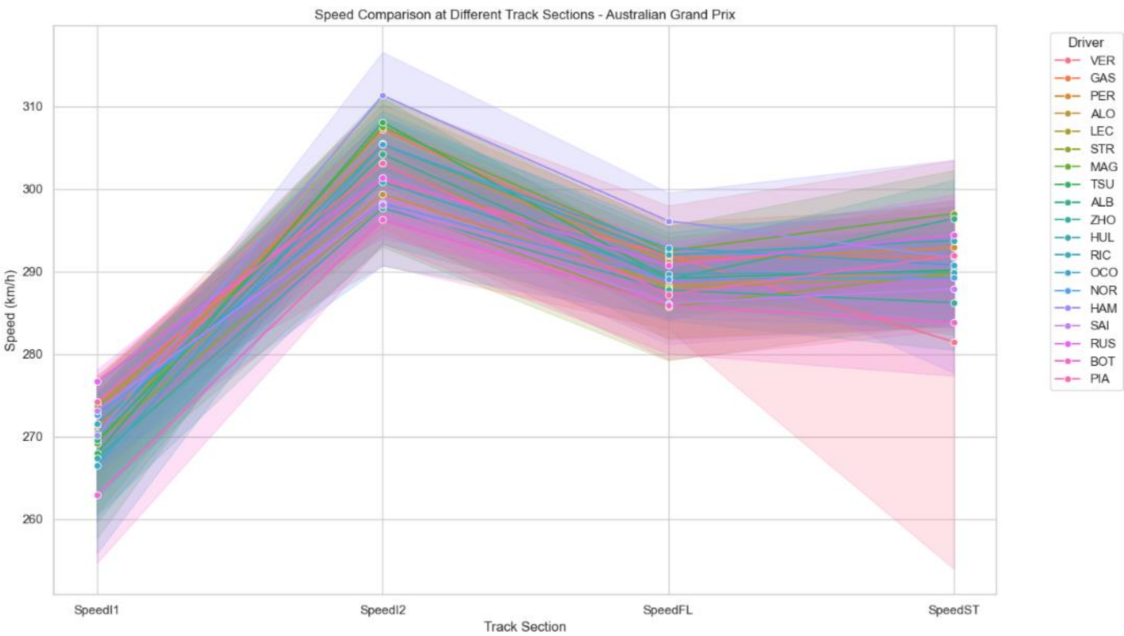


Figure 29. Speed Comparison at Different Track Sections – Australian Grand Prix.



In this set of plots (Figure 28 and 29), we compare the speeds of Formula 1 drivers across different track sections during multiple Grand Prix events.

Max Verstappen (VER), Charles Leclerc (LEC), and Lando Norris (NOR) consistently achieve higher speeds in most sections, showcasing their skill and the performance capabilities of their cars. In contrast, drivers like Zhou Guanyu (ZHO) and Logan Sargeant (SAR) demonstrate lower speeds across the majority of track sections, which may reflect challenges in optimizing their performance or differences in their vehicles' setup. This comparison highlights the competitive landscape of Formula 1, where driver skill and car performance can significantly impact speed across various circuit layouts.

Figure 30. Lap Time Trends Across Stints – Dutch Grand Prix.

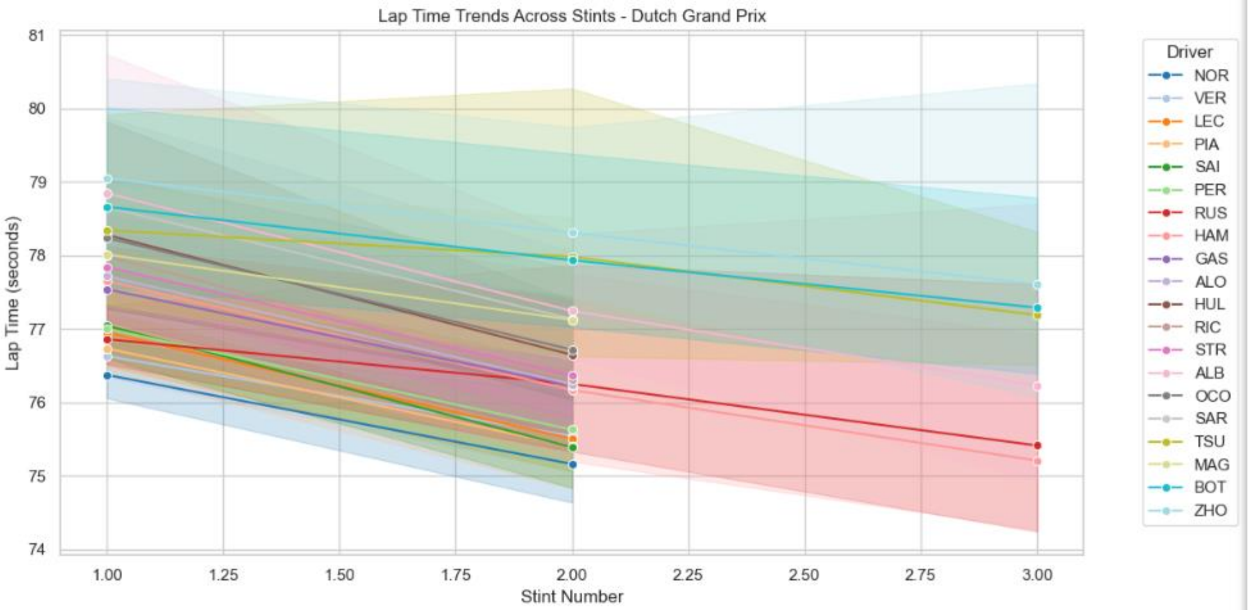
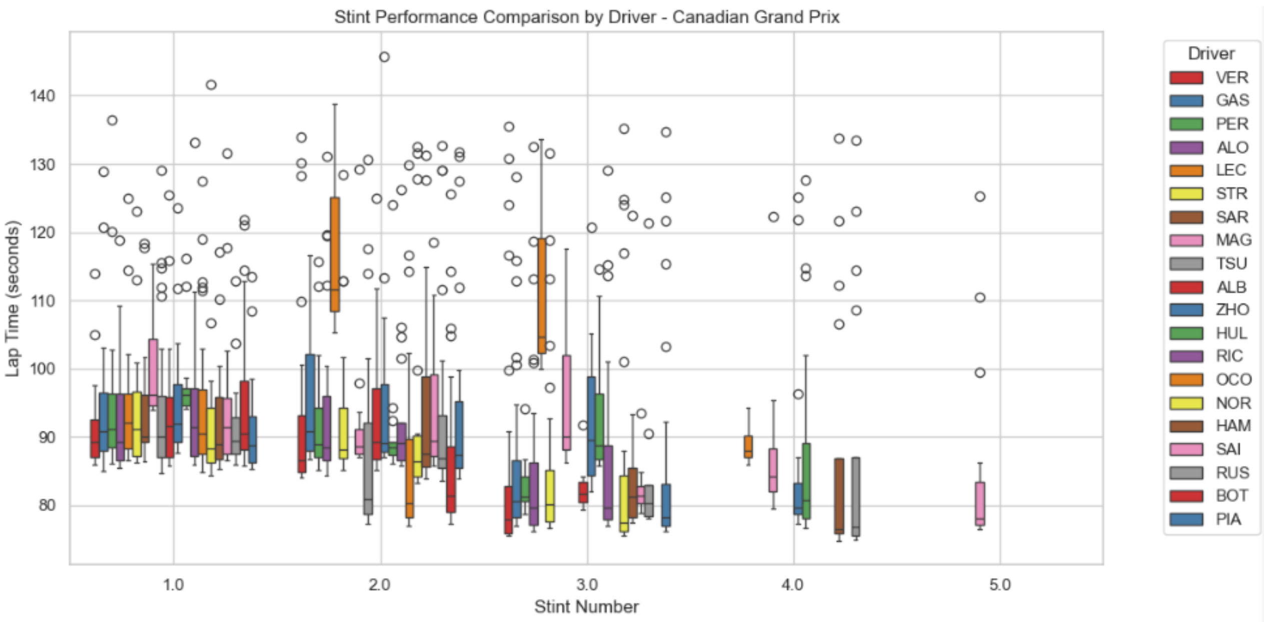


Figure 31. Stint Performance Comparison by Driver – Canadian Grand Prix.



We generated line and box plots of lap times across stints for different Formula 1 events.

As illustrated in Figures 30 and 31, the downward slope of most lines and boxes indicates that lap times generally improve over time. This trend can be attributed to several factors, including the reduction in car weight due to fuel consumption and the effectiveness of the drivers' and teams' strategies.

The decrease in lap times as stints progress can also be linked to tire warm-up and performance optimization. Initially, tires need a few laps to reach their optimal temperature and pressure range. During the early laps of a stint, when tires are still cold, grip is suboptimal, resulting in slower lap times. However, as the tires warm up and enter their performance window, grip improves, leading to faster lap times as the race unfolds. This dynamic showcases the importance of tire management and strategy in Formula 1 racing.

Quick Look at "position_2024"

Figure 32. Track Position for Drivers – Bahrain Grand Prix.

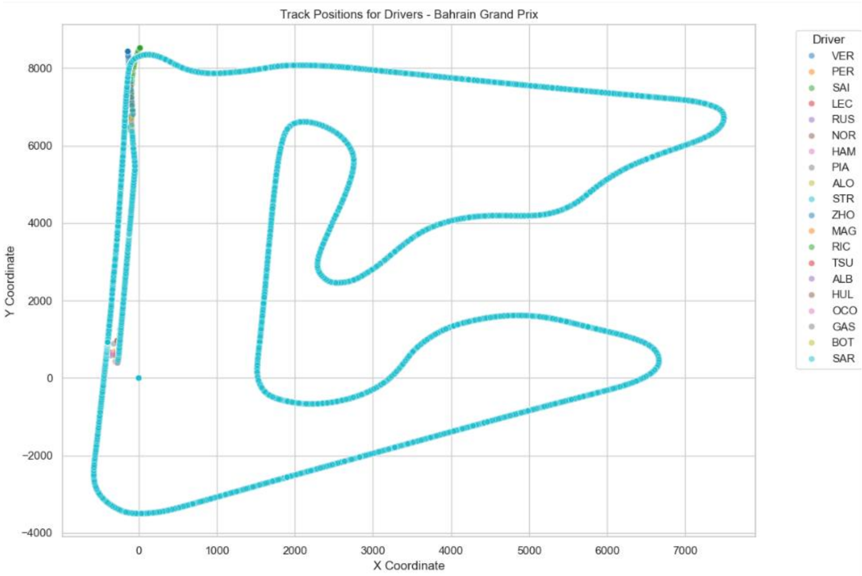
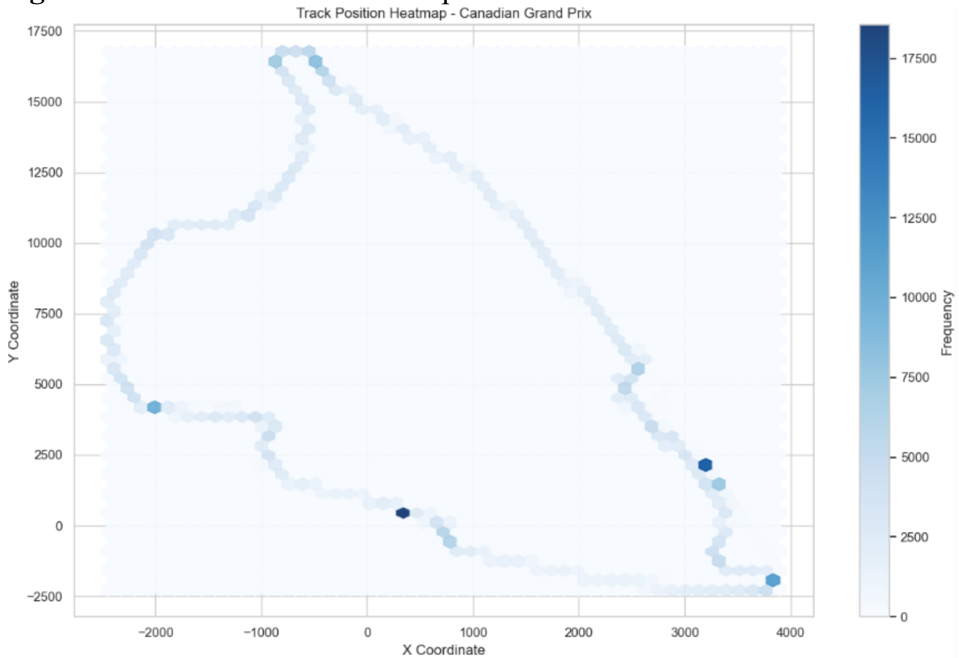


Figure 33. Track Position Heatmap – Canadian Grand Prix.



The "position_data" file captures the spatial information (X, Y, Z coordinates) of drivers during events, along with timestamps and driver statuses. This dataset is essential for analyzing driver movement and positioning throughout races, potentially providing insights into racing lines and overtaking maneuvers (see Figure 32).

We also generated heatmaps (Figure 33) to visualize where drivers spent the most time on the track. Areas represented by darker blue shades indicate higher concentrations of driver positions, suggesting that more drivers passed through or were located in those regions. The main racing line is often highlighted by these darker areas, indicating where drivers typically navigate during the event.

Additionally, regions with higher density suggest common overtaking spots, while unexpected clusters of high density may indicate potential bottlenecks, where drivers are likely to encounter traffic. This analysis of driver positioning can help teams refine their strategies and understand the dynamics of each race.

Quick Look at "result_2024"

The "result_data" file contains crucial information about race outcomes, including drivers' final positions, grid placements, and points, as well as additional metadata such as team and driver details. This dataset is invaluable for analyzing the performance of individual drivers and teams throughout the season. By examining this data, we can identify trends in race results, evaluate the consistency of driver performance, and assess the effectiveness of team strategies

Figure 34. Average Positions of Drivers Across Events.

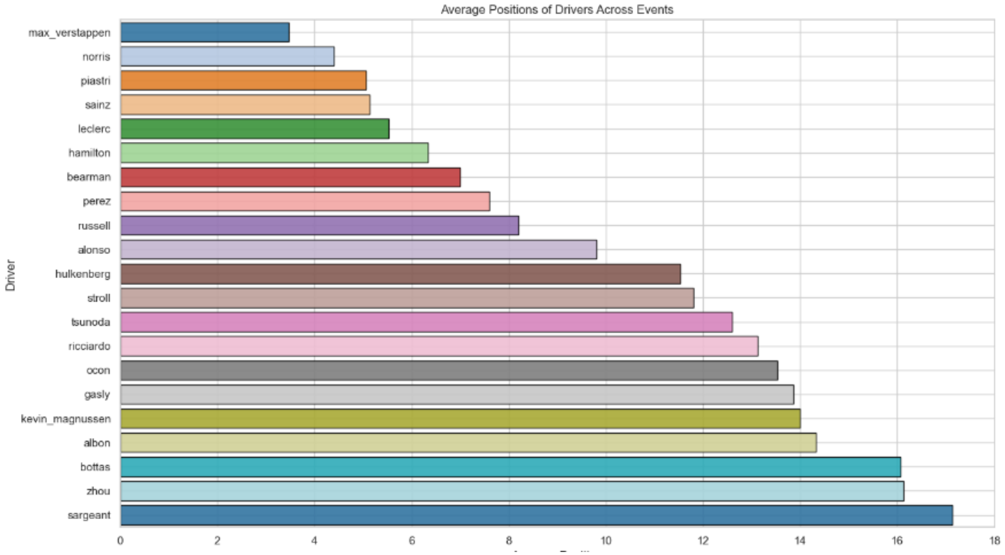
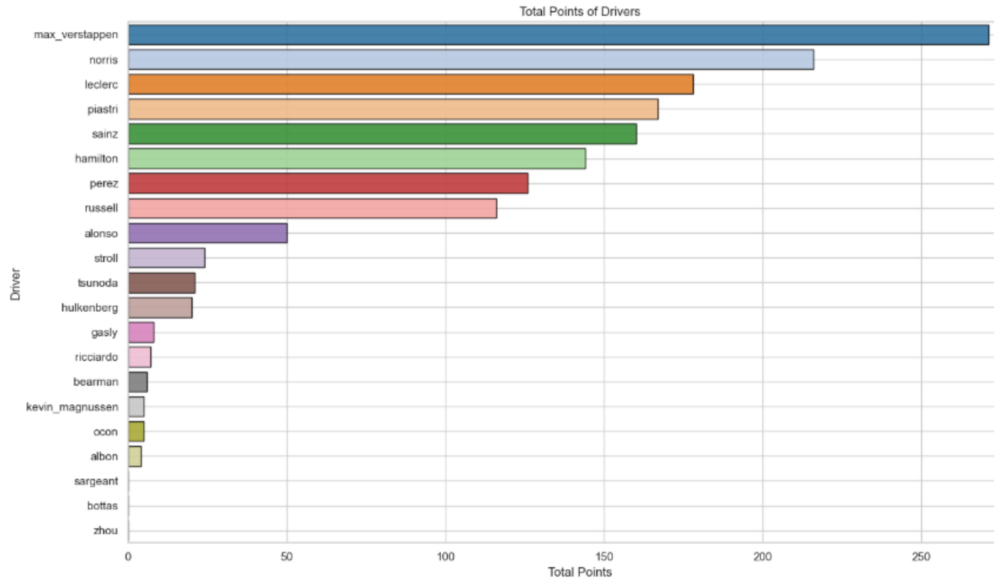


Figure 35. Total Points of Drivers.



Figures 34 and 35 illustrate the performance disparity among drivers throughout the season. Max Verstappen (VER) and Lando Norris (NOR) consistently achieve higher points and better final positions, showcasing their strong driving skills and effective team strategies. In contrast, Logan Sargeant (SAR), Valtteri Bottas (BOT), and Zhou Guanyu (ZHO) have lower points and less favorable positions, indicating challenges in their performance or team dynamics.

Figure 36. Grid Position vs. Final Position – Miami Grand Prix.

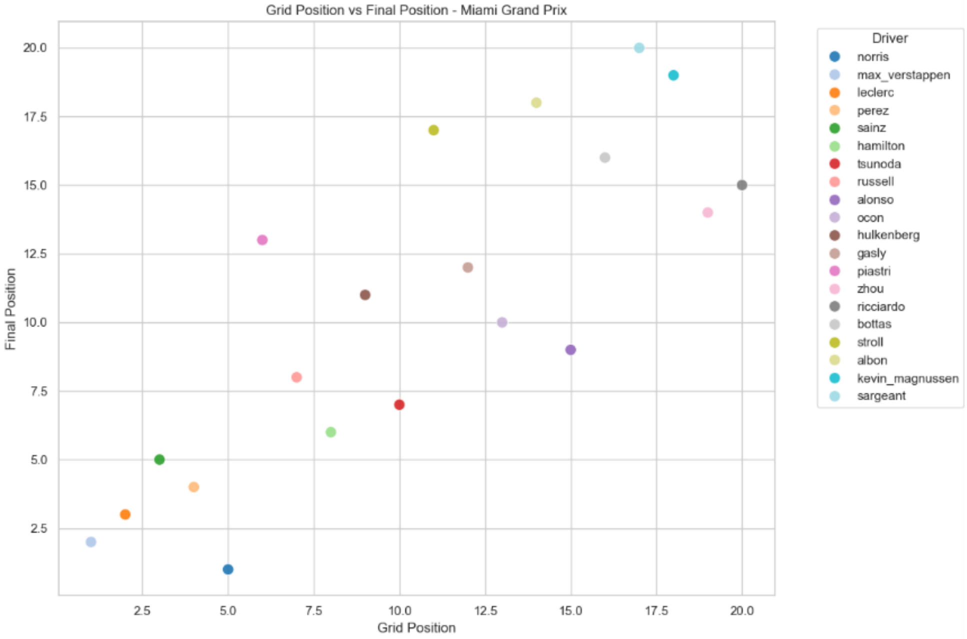
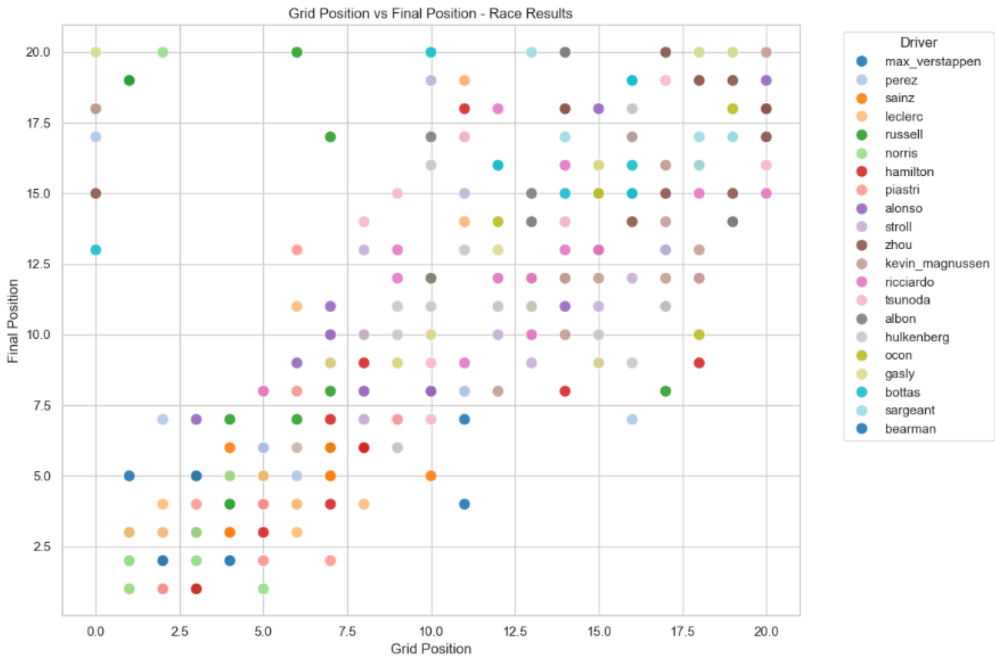


Figure 37. Grid Position vs. Final Position – Race Results.



Figures 36 and 37 highlight the performance dynamics of the top drivers, including Max Verstappen (VER), Lando Norris (NOR), Charles Leclerc (LEC), and Carlos Sainz (SAI), who maintain their advantageous grid positions and consistently finish in the top ranks. This demonstrates their ability to leverage their starting spots effectively and execute strong race strategies. In contrast, Logan Sargeant (SAR) and Zhou Guanyu (ZHO) struggle to improve from their less favorable grid positions, indicating challenges in their race execution or potential limitations in their cars' performance. This analysis underscores the competitive edge of leading drivers and the difficulties faced by those in lower-tier teams.

Figure 38. Driver Performance by Team.

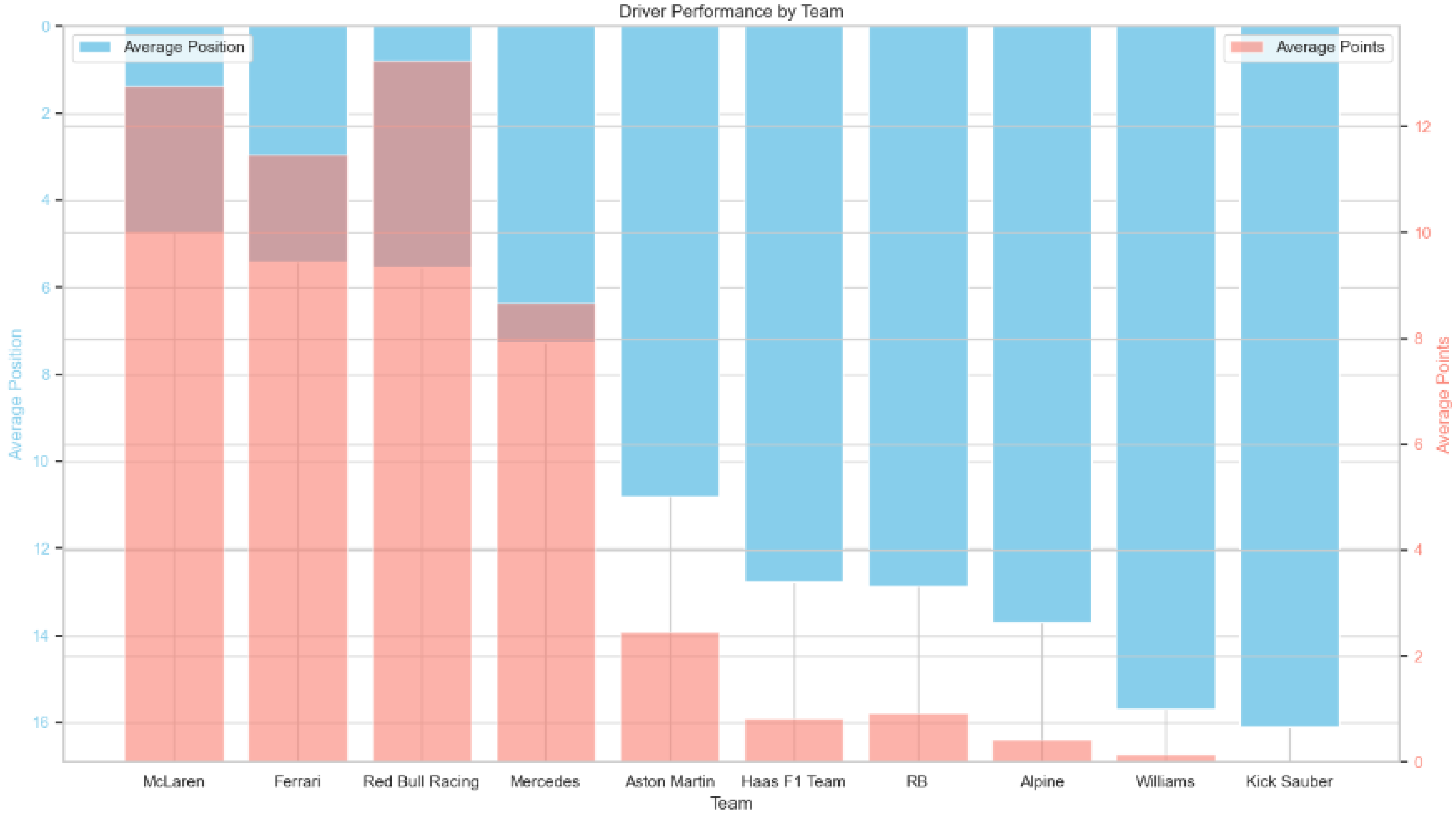
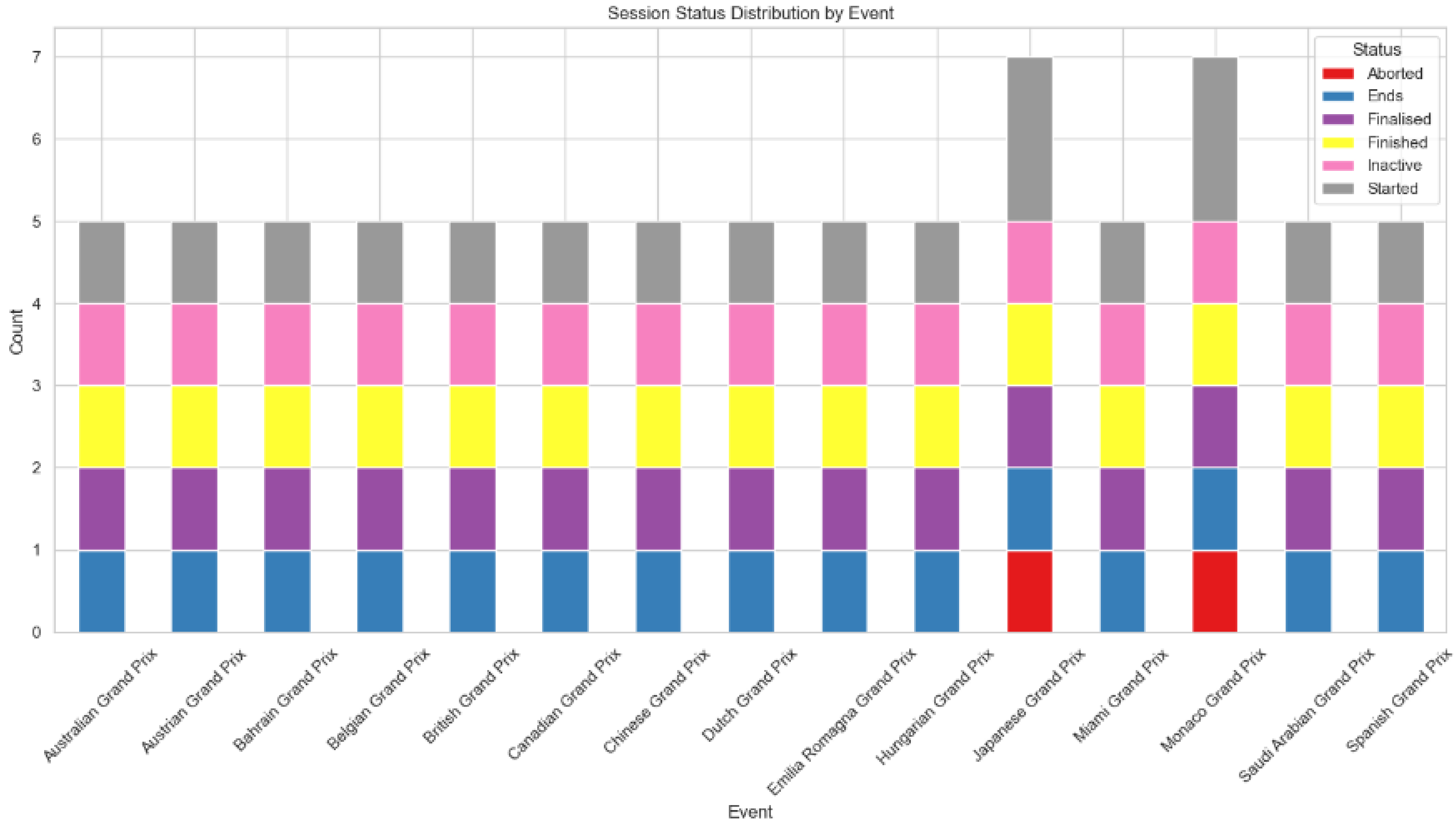


Figure 38 illustrates the competitive performance of teams in the 2024 season, with McLaren, Ferrari, and Red Bull achieving higher points and better positions than their competitors. Notably, McLaren leads the team standings, thanks to Lando Norris (NOR) securing 2nd place and Oscar Piastri (PIA) in 3rd. This highlights the effectiveness of McLaren's strategy and the strength of its driver lineup, allowing them to outperform other teams despite individual driver rankings. The data underscores the importance of teamwork and consistent performance in securing overall championship points.

Quick Look at "session_status_2024"

This data offers valuable insights into the progression of race events by capturing key status changes over time, such as when a session is 'Started,' 'Finished,' or 'Finalised.' These timestamps are crucial for analyzing the temporal flow of each event, providing context that complements other datasets related to car telemetry, track conditions, and race results. Figure 39 displays session status distribution by event.

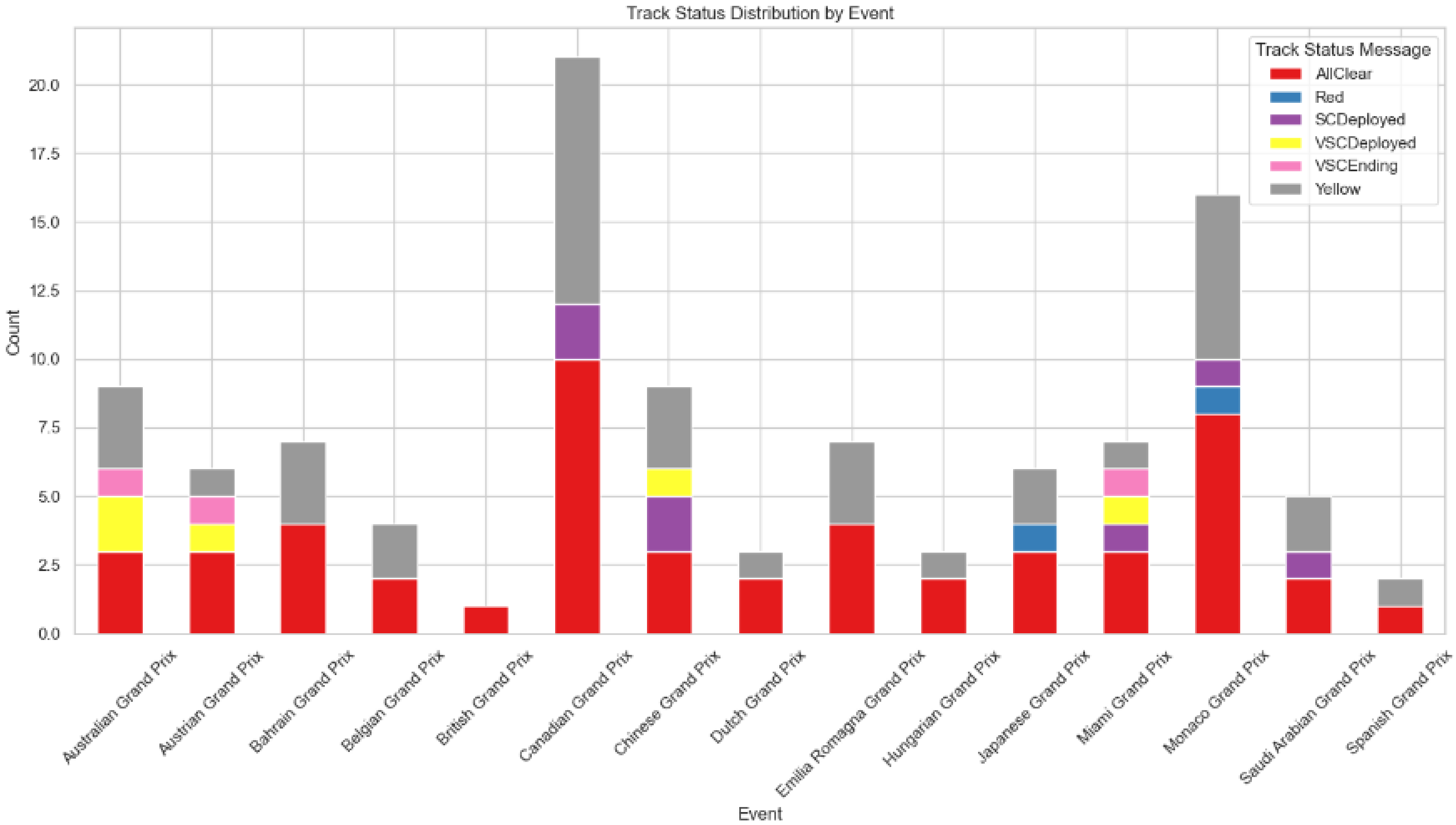
Figure 39. Session Status Distribution by Event.



Quick Look at "track_status_2024"

This file summarizes changes in track conditions during races, capturing critical moments such as yellow flags, all-clear signals, and other significant events. It serves as a vital component for analyzing how interruptions or incidents on the track affect overall race performance. By examining these changes, we can assess their influence on driver strategies, lap times, and race outcomes, providing deeper insights into the dynamics of each event and how teams adapt to varying conditions throughout the race. Figure 40 shows track status distribution by event.

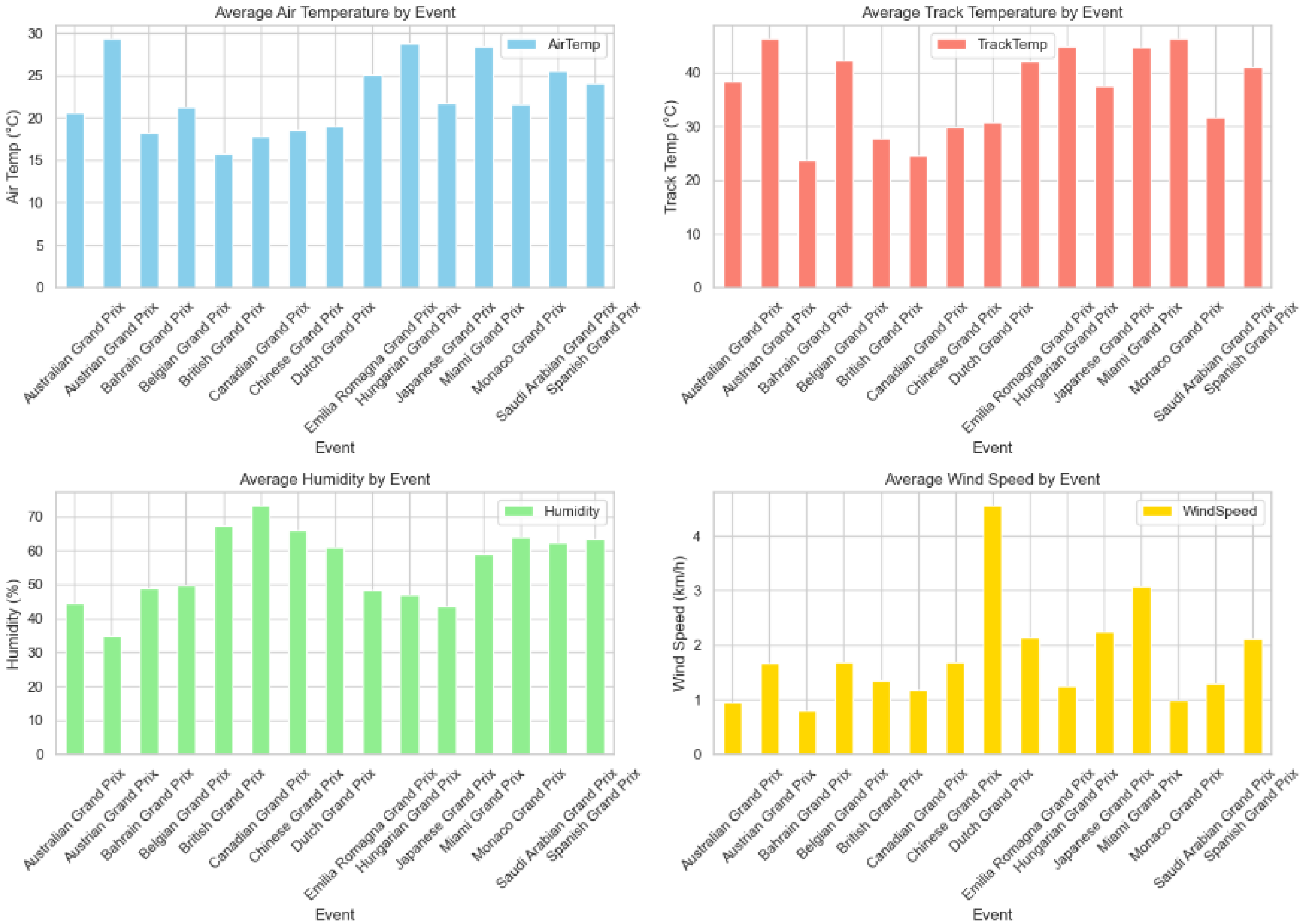
Figure 40. Track Status Distribution by Event.



Quick Look at "weather_2024"

This data covers weather conditions including air temperature, humidity, air pressure, rainfall, track temperature, wind direction and speed (Figure 41).

Figure 41. Weather Conditions by Event.



4. Data Visualizations
Exploratory Data Analysis (EDA)

Total Number of Pit Stops

Table 1. Total Number of Pit Stops by Driver.

	Driver	Driver Name	Total Pit Stops
20	ZHO	Zhou Guanyu	33
11	PER	Sergio Pérez	31
1	ALO	Fernando Alonso	30
17	STR	Lance Stroll	30
0	ALB	Alex Albon	29
3	BOT	Valtteri Bottas	29
5	HAM	Lewis Hamilton	28
6	HUL	Nico Hulkenberg	28
7	LEC	Charles Leclerc	28
8	MAG	Kevin Magnussen	28
16	SAR	Logan Sargeant	28
10	OCO	Esteban Ocon	28
12	PIA	Oscar Piastri	27
14	RUS	George Russell	27
4	GAS	Pierre Gasly	26
19	VER	Max Verstappen	26
9	NOR	Lando Norris	25
15	SAI	Carlos Sainz Jr.	25
18	TSU	Yuki Tsunoda	25
13	RIC	Daniel Ricciardo	22
2	BEA	Oliver Bearman	1

Table 2. Total Number of Pit Stops by Team.

	Team	Total Pit Stops
4	Kick Sauber	62
1	Aston Martin	60
8	Red Bull Racing	57
9	Williams	57
3	Haas F1 Team	56
6	Mercedes	55
0	Alpine	54
2	Ferrari	54
5	McLaren	52
7	RB	47

Table 1 and 2 present the total number of pit stops made by drivers and teams respectively during the season.

Zhou Guanyu (ZHO) leads with the highest number of pit stops at 33, followed closely by Sergio Pérez (PER) with 31. In contrast, Oliver Bearman (BEA) has made only 1 pit stop, reflecting his participation in fewer races.

Several drivers, including Lewis Hamilton (HAM), Nico Hulkenberg (HUL), Charles Leclerc (LEC), Kevin Magnussen (MAG), Logan Sargeant (SAR), and Esteban Ocon (OCO), have similar totals of 28 pit stops each, suggesting a comparable approach to race strategy. Meanwhile, Max Verstappen (VER) and Carlos Sainz Jr. (SAI) are further down the list with 25 pit stops each, indicating a more efficient pit strategy that allowed them to maintain competitive performance with fewer interruptions.

Figure 42. Total Number of Pit Stops by Driver – Australian Grand Prix.

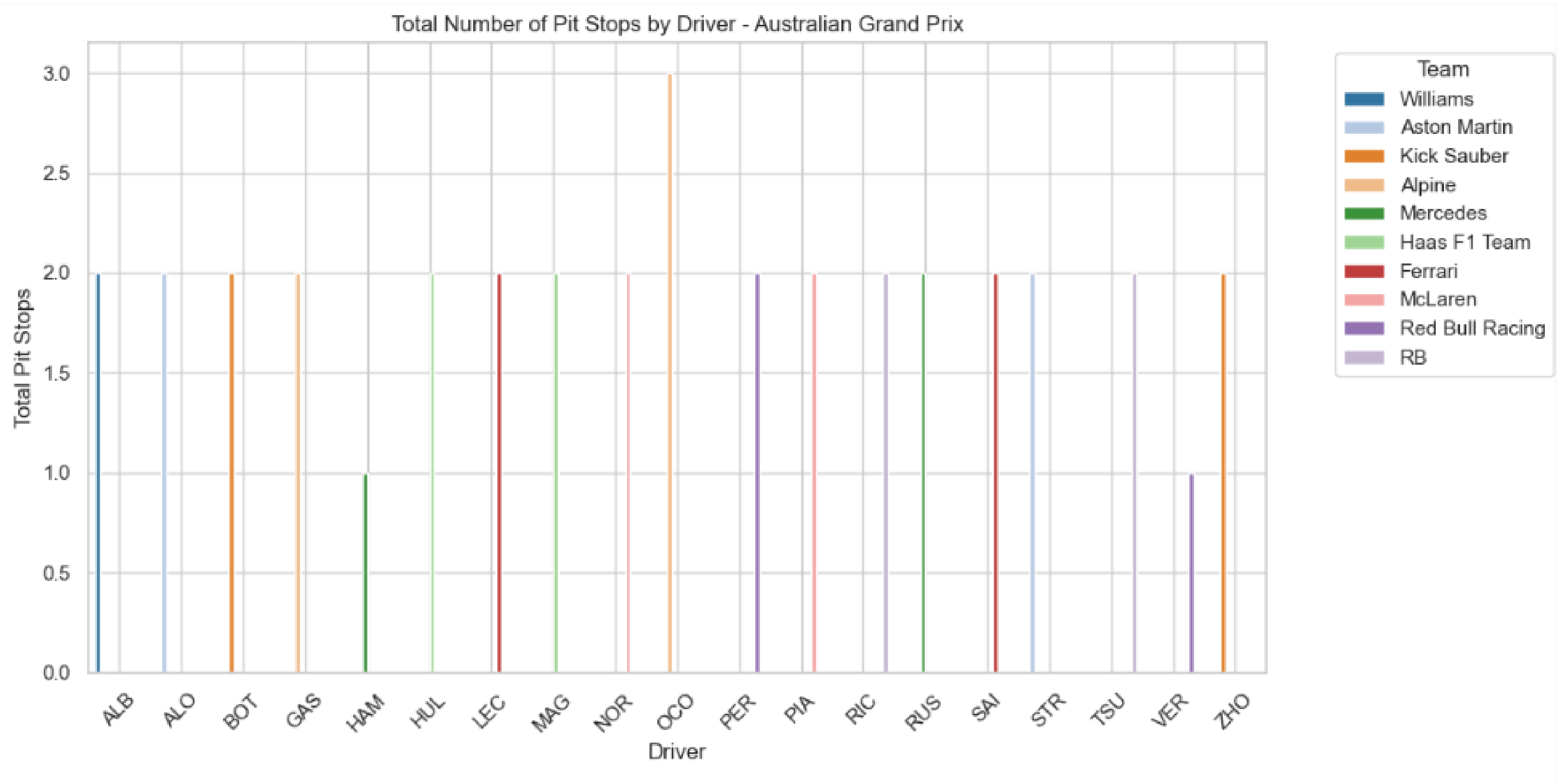


Figure 42 shows total number of pit stops by driver in Australian Grand Prix. The majority of drivers have 2 pit stop counts, which seems to be a typical count for most drivers during the season, suggesting fairly consistent strategies or pit stop needs. Estaban Ocon (OCO) leads with 3 pit stops, which may suggest his race strategy involved more tire changes or other adjustments, possibly due to race conditions or car issues.

Lewis Hamilton (HAM) and Max Verstappen (VER) only made 1 pit stop, which may indicate a unique race situation for keeping time advantage.

Figure 43. Total Number of Pit Stops by Driver Across Events.

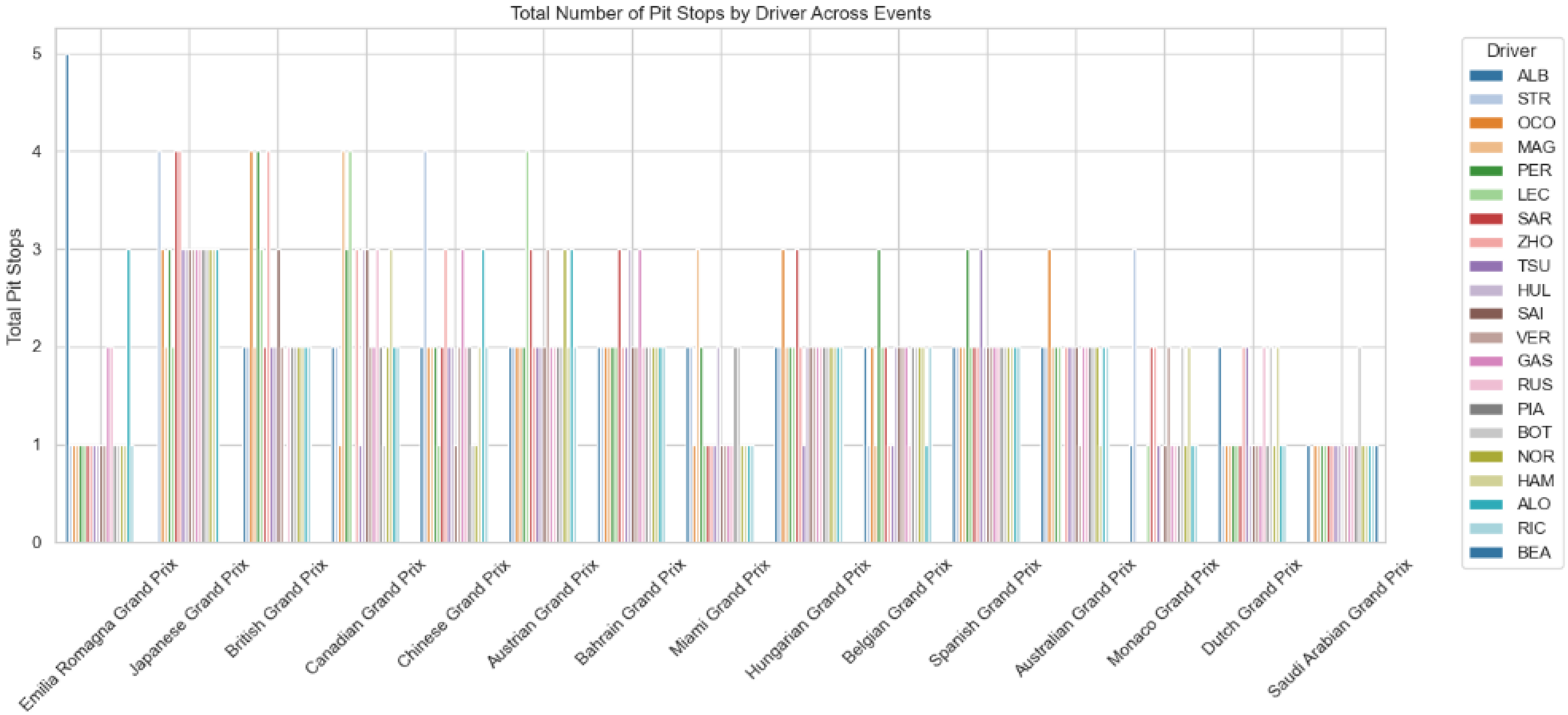


Figure 43 shows that Emilia Romagna, Japanese, British, and Canadian Grand Prix have higher pit stop counts compared to other races, and the Saudi Arabian, Dutch, and Monaco Grand Prix have lower pit stop counts. The higher pit stop counts in races like Emilia Romagna, Canada and Japan indicate more challenging race conditions, potentially due to tire wear, weather, and aggressive strategies.

On the other hand, lower pit stop counts in Saudi Arabia, the Netherlands, and Monaco suggest a focus on conserving track position, where teams managed with fewer stops, likely due to low tire degradation and strategic constraints like difficult overtaking.

Figure 44. Total Number of Pit Stops by Team Across Events.

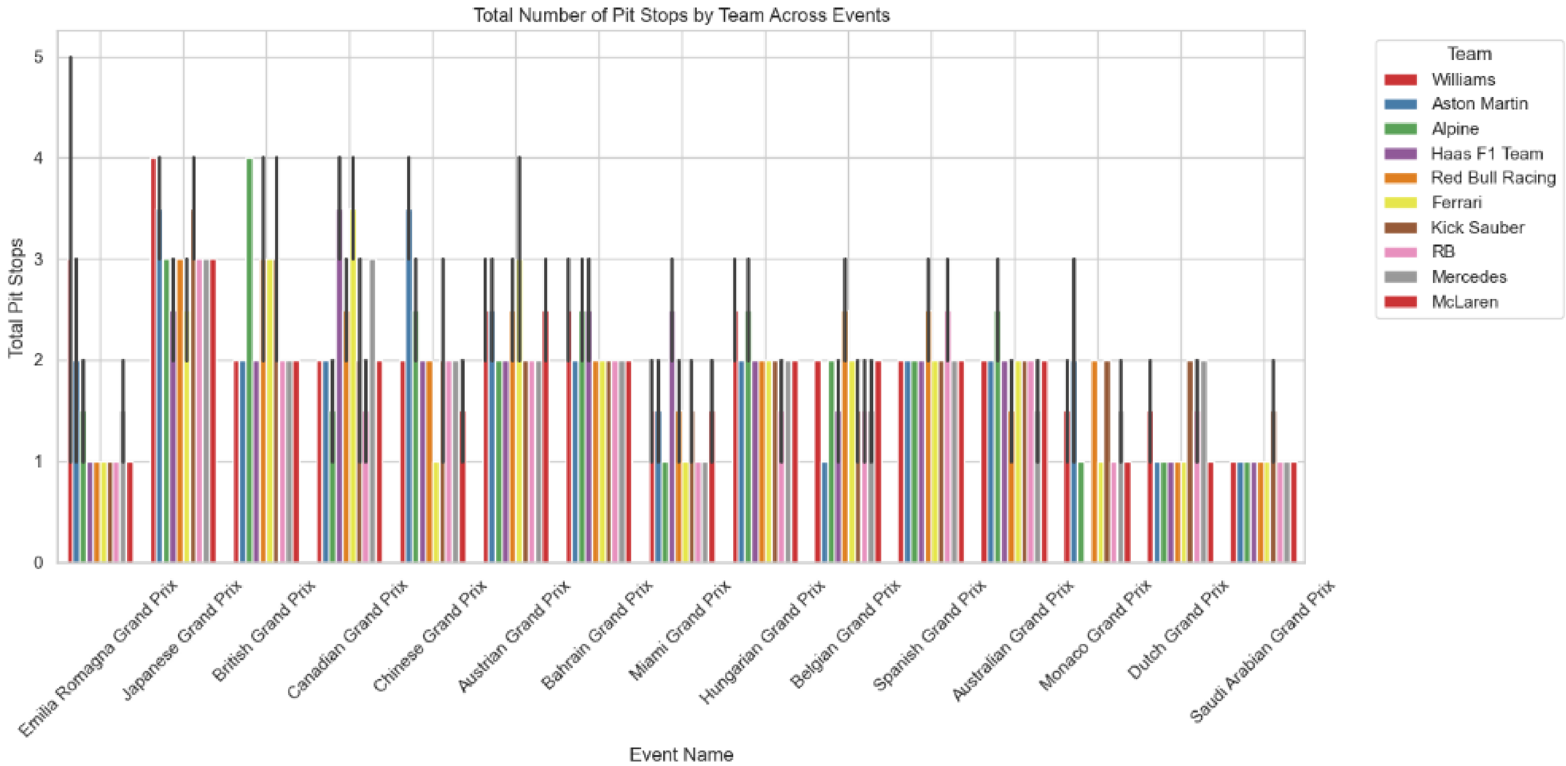


Table 2 and Figures 42 to 44 show the details about the total number of pit stops by teams and drivers.

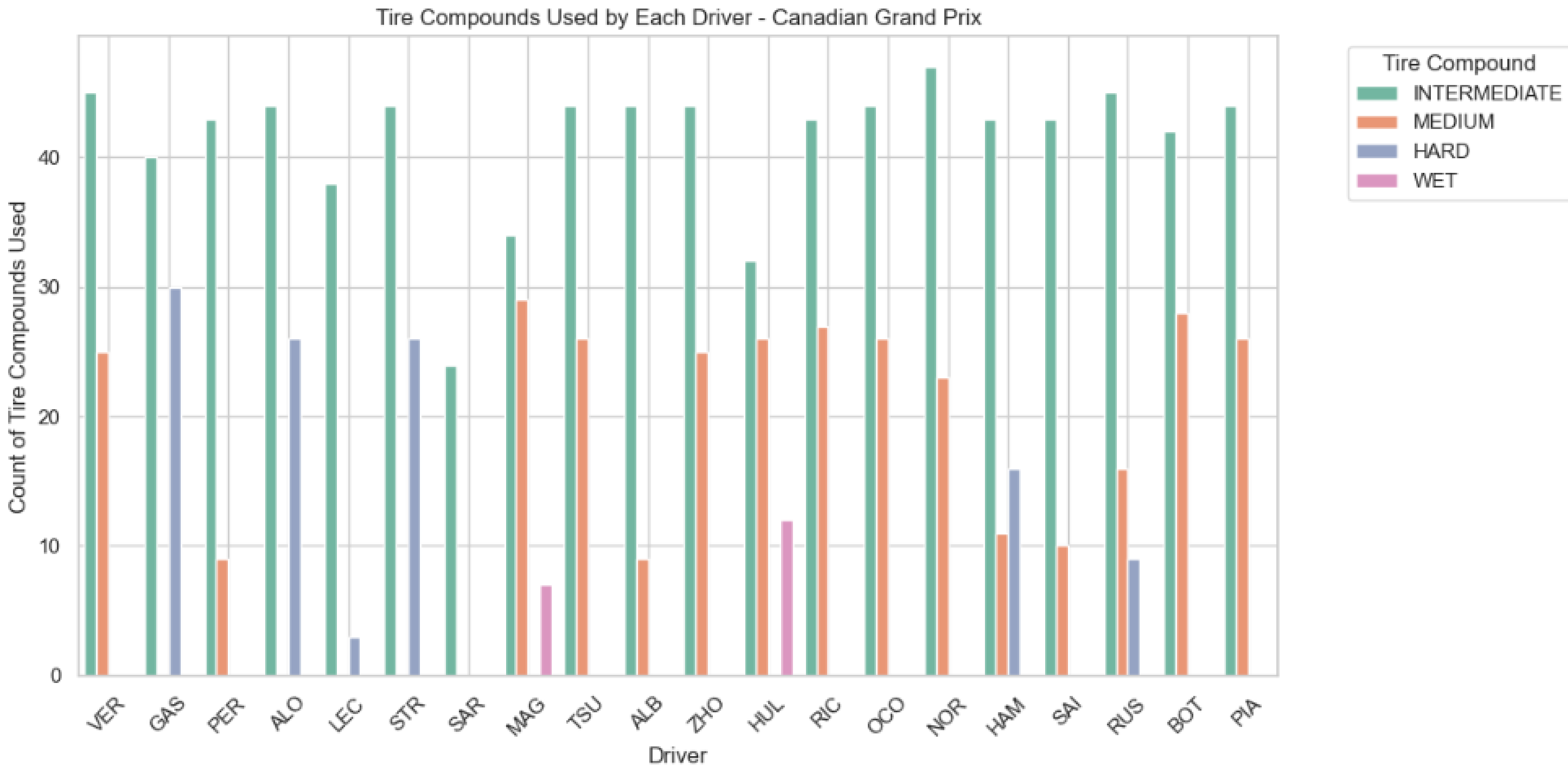
Kick Sauber leads the list with the highest number of pit stops at 62, suggesting that their race strategy or track conditions necessitated more frequent stops for both drivers. Aston Martin follows closely with 60 pit stops, indicating a similar approach or race circumstances.

Red Bull Racing and Williams are tied with 57 pit stops each, placing them in the middle of the pack. Haas F1 Team and Mercedes are also fairly close, with 56 and 55 pit stops, respectively.

On the other hand, teams like Ferrari, McLaren, and Alpine are lower on the list, with pit stop counts ranging from 52 to 54. This indicates fewer race interruptions, and a more streamlined pit stop strategy, allowing these teams to maintain better overall race efficiency.

Tire Compounds Used During the Race

Figure 45. Tire Compounds Used by Each Driver – Canadian Grand Prix.



Figures 45 and 46 reveal that only Kevin Magnussen (MAG) and Nico Hulkenberg (HUL) from the Haas Formula 1 team opted for the Wet Tire Compound during the Canadian Grand Prix. This choice highlights the challenging weather conditions during the race, which may have necessitated the use of wet tires to maintain grip and performance on the wet track.

Figure 46. Tire Compounds Used by Each Team – Canadian Grand Prix.

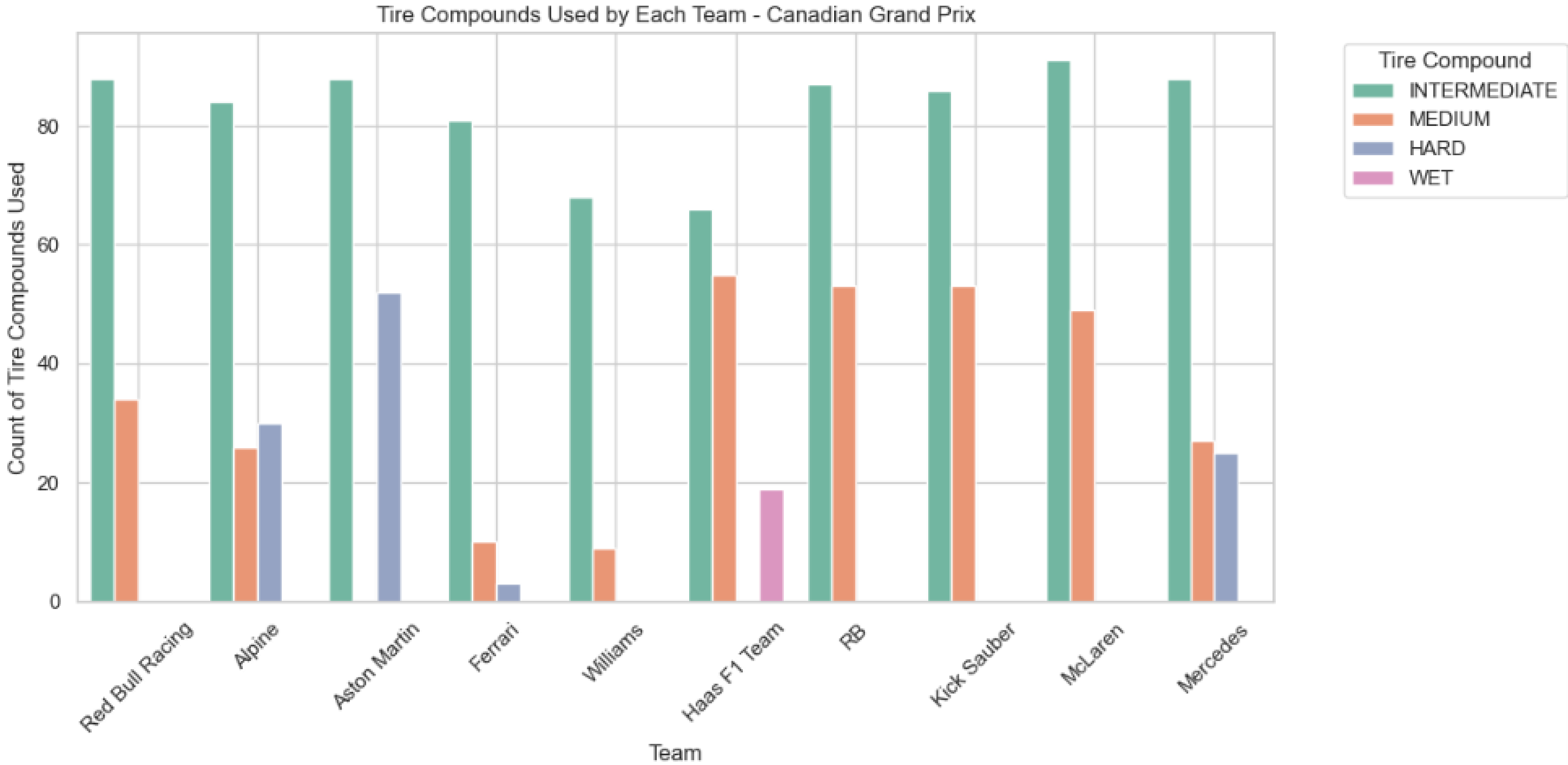


Figure 46 highlights that during the Canadian Grand Prix, the Haas Formula 1 team was the only one to strategically opt for the Wet Tire Compound.

Additionally, the Hard Tire Compound was exclusively chosen by the Alpine, Aston Martin, Ferrari, and Mercedes teams, while the remaining teams opted for either the Medium or Intermediate Tire Compounds.

Figure 47. Tire Compounds Used by Each Driver Across Events.

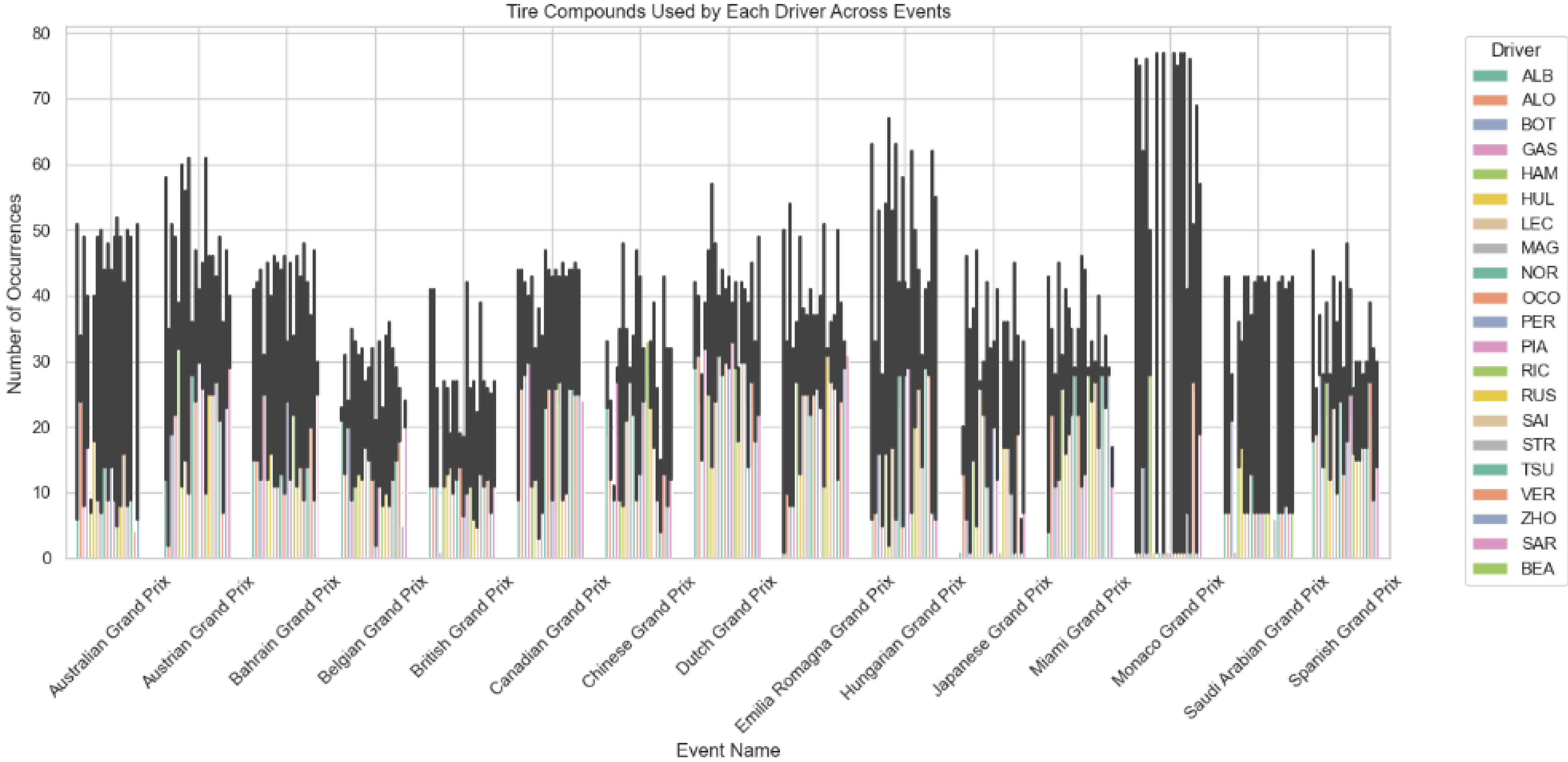
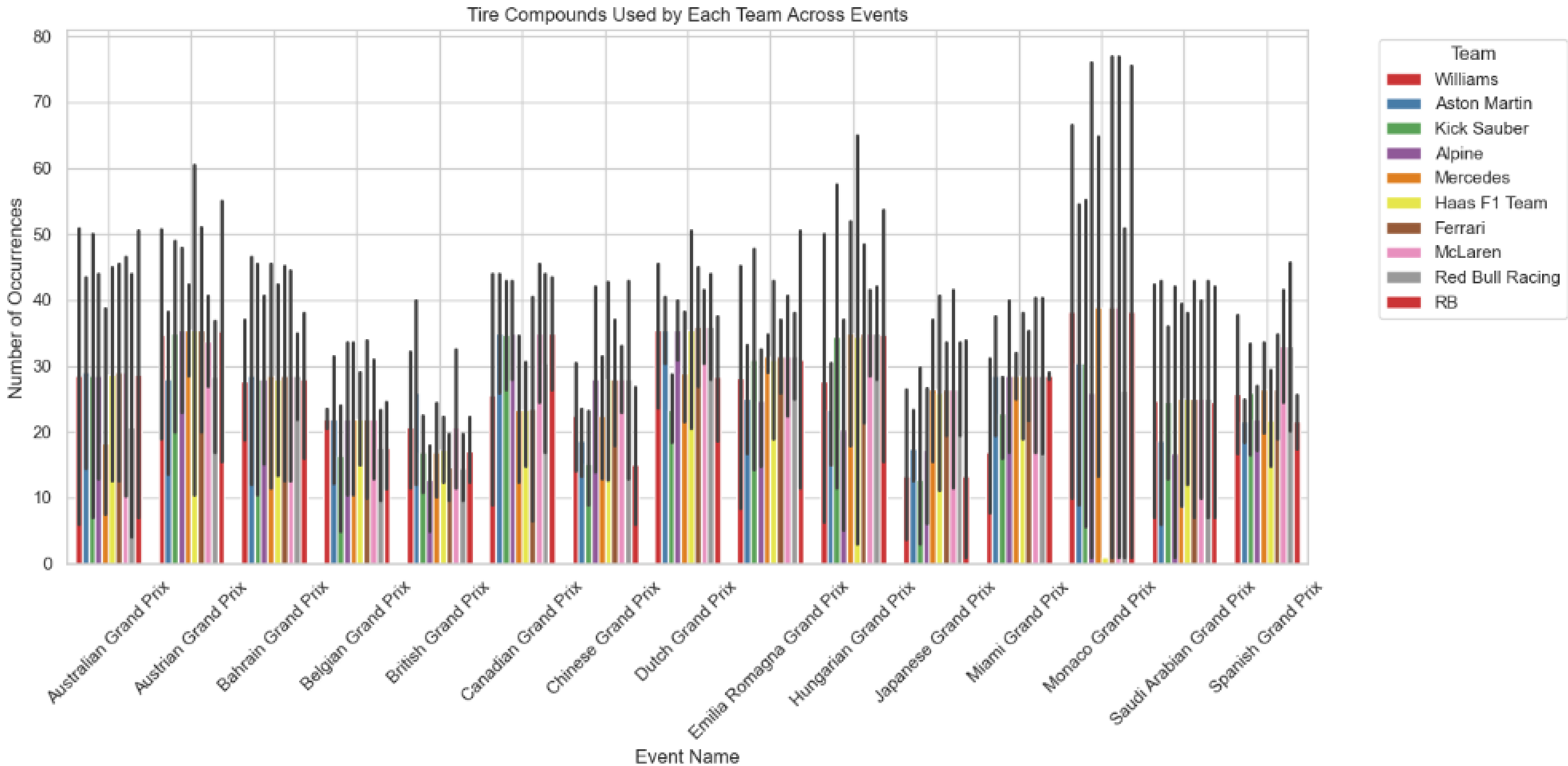


Figure 47 shows tire compounds used by each driver across various events, emphasizing that team-level tire strategies differ from race to race. Teams have adapted their strategies based on the unique conditions of each race. For instance, in Monaco, where maintaining track position is more crucial than tire performance, teams predominantly focused on one-stop strategies.

Figure 48. Tire Compounds Used by Each Team Across Events.



Similarly, Figure 48 presents the tire compounds used by each team across various events.

Lower numbers in races such as Saudi Arabia and Monaco suggest reduced tire wear, a strategic preference for fewer pit stops, and cleaner race conditions with fewer incidents.

These plots also reveal the flexibility of teams and drivers in their tire choices. Teams that employed diverse tire strategies likely adjusted based on race dynamics, while those with more uniform choices may have relied heavily on their core strategy.

Figure 49. Heatmap of Tire Compound Usage by Driver Across Events.

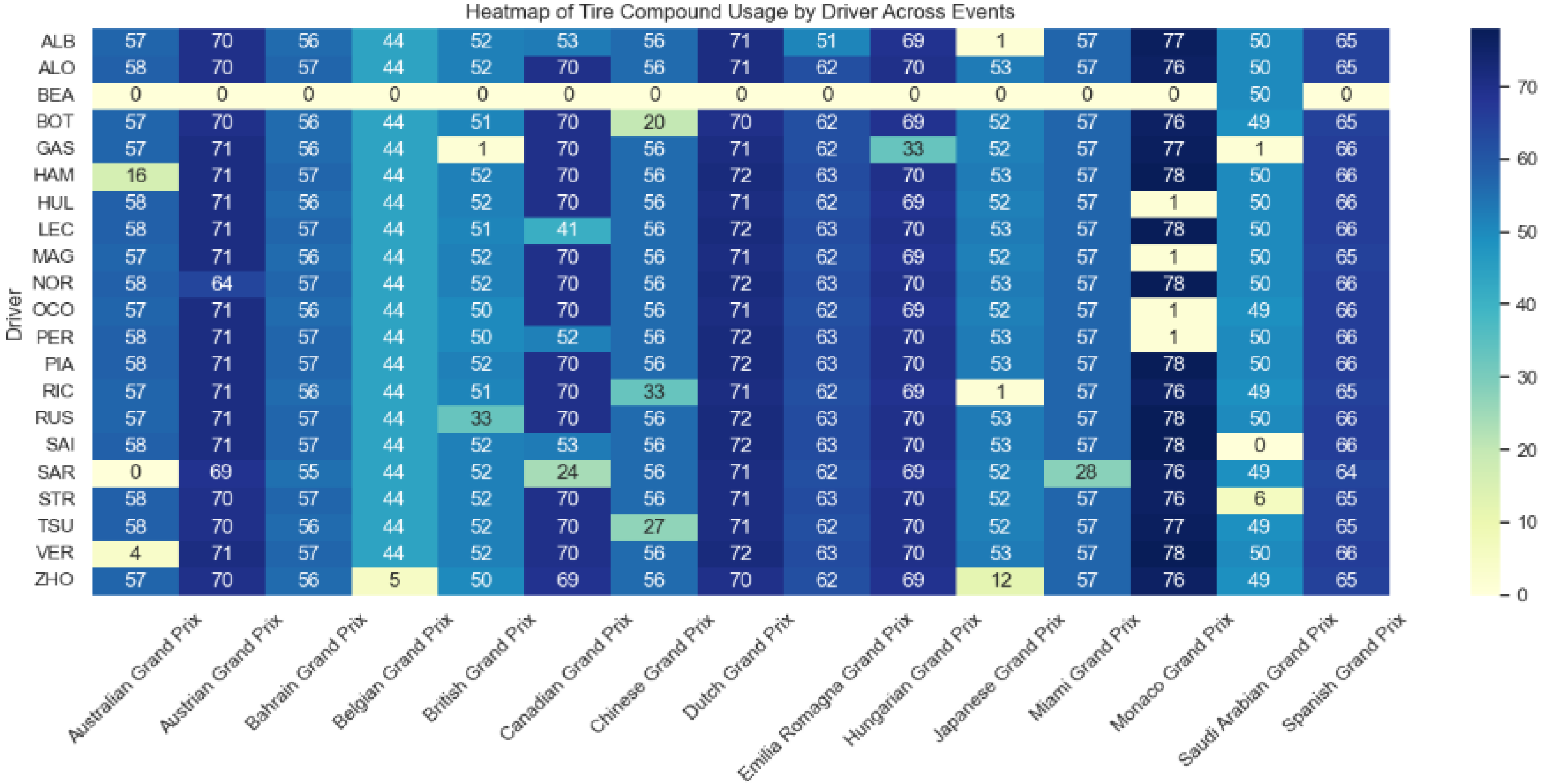
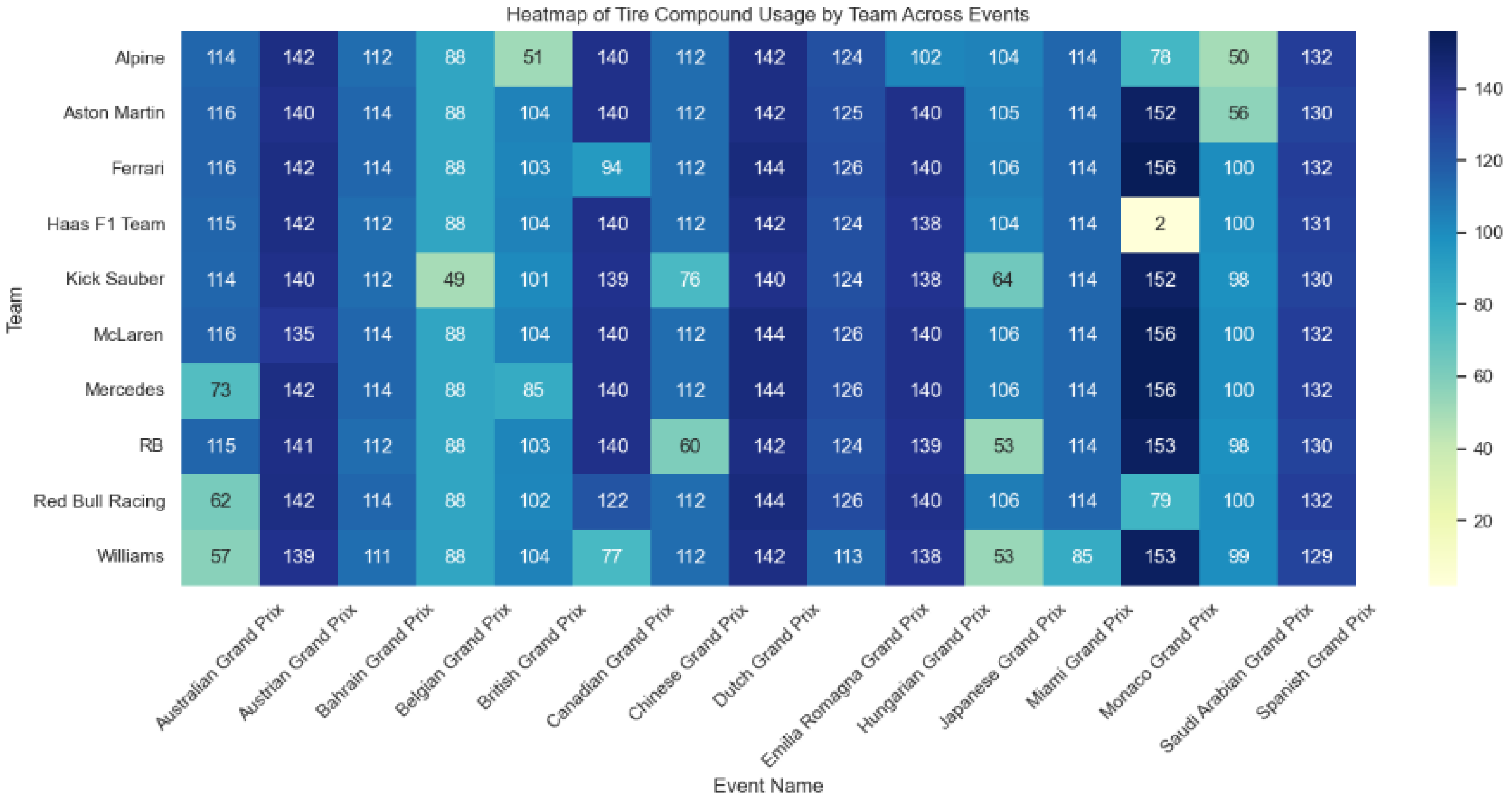


Figure 49 displays a heatmap of tire compound usage by drivers across various events. This heatmap is particularly valuable as it visually reveals patterns and strategies, showing how tire choices varied among drivers and teams based on race conditions and team strategies. The data indicates that most teams generally opted for similar tire compounds, with only a few exceptions observed across different events.

Figure 50. Heatmap of Tire Compound Usage by Team Across Events.



Similarly, Figure 50 presents a heatmap of tire compound usage by teams across different events. The heatmap reveals that during the Austrian, Bahrain, Dutch, and Spanish Grands Prix, most teams employed similar strategies for tire choices, with only a few exceptions.

Table 3. Distribution of Tire Compounds Used by Each Drivers Across Events.

	PE	AL	AL	BE	BO	GA	HA	HU	LE	MA	NO	OC	PI	RI	RU	SA	SA	ST	TS	VE	ZH
Australian	**58**	**57**	**58**		**57**	**57**	**16**	**58**	**58**	**57**	**58**	**57**	**58**	**57**	**57**	**58**		**58**	**58**	**4**	**57**
HARD	44	51	34		49	40	9	40	49	50	44	48	49	52	49	42		50	49		51
MEDIUM	14	6	24		8	17		18	9	7	14	9	9		8	16		8	9	4	
SOFT							7							5							6
Austrian Grand	**71**	**70**	**70**		**70**	**71**	**71**	**71**	**71**	**71**	**64**	**71**	**71**	**71**	**71**	**71**	**69**	**70**	**70**	**71**	**70**
HARD	30	58	33		51	22	32	60	15	61	28	24	26	61	25	25	29	27	49	28	47
MEDIUM	41	12	35		19	49	39	11	56	10	36	47	45	10	46	46	40	43	21	36	23
SOFT			2																	7	
Bahrain Grand	**57**	**56**	**57**		**56**	**56**	**57**	**56**	**57**	**56**	**57**	**56**	**57**	**56**	**57**	**57**	**55**	**57**	**56**	**57**	**56**
HARD	24	41	42		44	31	45	40	46	45	44	46	45	22	46	43	30	48	42	20	47
SOFT	33	15	15		12	25	12	16	11	11	13	10	12	34	11	14	25	9	14	37	9
Belgian Grand	**44**	**44**	**44**		**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**5**
HARD	21	21	31		24	35	33	13	32	27	29	32	33	23	34	36	20	32	29	18	5
MEDIUM	21	23	13		20	9	11	31	12	17	15	12	11	13	10	8	24	12	15	26	
SOFT	2													8							
British Grand	**50**	**52**	**52**		**51**	**1**	**52**	**52**	**51**	**52**	**52**	**50**	**52**	**51**	**33**	**52**	**52**	**52**	**52**	**52**	**50**
HARD	19															11				14	
INTERMEDIAT	18	11	11		11		11	13	18	10	12	14	10	11	6	13	11	13	11	12	18
MEDIUM	10	41	41		26	1	27	26	19	27	27	17	42	26	27	26	27	39	27	26	7
SOFT	3				14		14	13	14	15	13	19		14		2	14		14		25
Canadian	**52**	**53**	**70**		**70**	**70**	**70**	**70**	**41**	**70**	**70**	**70**	**70**	**70**	**70**	**53**	**24**	**70**	**70**	**70**	**69**
HARD			26			30	16		3						9			26			
INTERMEDIAT	43	44	44		42	40	43	32	38	34	47	44	44	43	45	43	24	44	44	45	44
MEDIUM	9	9			28		11	26		29	23	26	26	27	16	10			26	25	25
WET								12		7											
Chinese Grand	**56**	**56**	**56**		**20**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**56**	**33**	**56**	**56**	**56**	**56**	**27**	**56**	**56**
HARD	43	33	12		11	27	35	48	35	27	34	47	32		33	39	32	26	4	43	32
MEDIUM	13	23	24		9	29	12	8	21	29	22	9	24	33	23	17	12	21	15	13	8
SOFT			20				9										12	9	8		16
Dutch Grand	**72**	**71**	**71**		**70**	**71**	**72**	**71**	**72**	**71**	**72**	**71**	**72**	**71**	**72**	**72**	**71**	**71**	**71**	**72**	**70**
HARD	43	42	40		28	39	25	57	48	40	44	41	39	42	29	42	49	41	39	45	33
MEDIUM	29	29	31		27	32		14	24	31	28	30	33	29	25	30	22	30	18	27	18
SOFT					15		47								18				14		19
Emilia	**63**	**51**	**62**		**62**	**62**	**63**	**62**	**63**	**62**	**63**	**62**	**63**	**62**	**63**	**63**	**62**	**63**	**62**	**63**	**62**
HARD	37	1	33		54	22	36	49	38	25	41	37	40	51	31	36	31	26	50	39	33
MEDIUM	26	50	19		8	32	27	13	25	37	22	25	23	11	32	27	31	37	12	24	29
SOFT			10			8															
Hungarian	**70**	**69**	**70**		**69**	**33**	**70**	**69**	**70**	**69**	**70**	**69**	**70**	**69**	**70**	**70**	**69**	**70**	**70**	**70**	**69**
HARD	28	63	33		53	28	54	67	17	63	28	58	29	62	50	26	55	25	41	28	62
MEDIUM	42		30		16	5	16	2	53		42	6	41	7	20	44	8	31	29	42	7
SOFT		6	7							6		5					6	14			
Japanese Grand	**53**	**1**	**53**		**52**	**52**	**53**	**52**	**53**	**52**	**53**	**52**	**53**	**1**	**53**	**53**	**52**	**52**	**52**	**53**	**12**

HARD	20		20		46	35	38	47	27	30	42	32	41		36	17	33	12	45	19	5
MEDIUM	33		20			16	15		26	22	11	19	12	1	17	36	7	10	1	34	1
SOFT		1	13		6	1		5				1					12	30	6		6
Miami Grand	**57**	**57**	**57**		**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**28**	**57**	**57**	**57**	**57**
HARD	11	43	22		18	45	26	16	38	22	28	35	13	28	33	30	17	17	29	34	
MEDIUM	46	10	35		28	12	31	41	19	35	29	22	44	29	24	27	11	40	28	23	28
SOFT		4			11																29
Monaco Grand	**1**	**77**	**76**		**76**	**77**	**78**	**1**	**78**	**1**	**78**	**1**	**78**	**76**	**78**	**78**	**76**	**76**	**77**	**78**	**76**
HARD	1	76	1		62	1	28		77	1	77	1	77	75	1	77	57	7	76	27	69
MEDIUM		1	75		14	76	50	1	1		1		1	1	77	1	19	41	1	51	1
SOFT																		28			6
Saudi Arabian	**50**	**50**	**50**	**50**	**49**	**1**	**50**	**50**	**50**	**50**	**50**	**49**	**50**	**49**	**50**		**49**	**6**	**49**	**50**	**49**
HARD	43	43	43	43	28			17	43	43		42	43	42	43		42		42	43	
MEDIUM	7	7	7			1	36	33	7	7	37	7	7	7	7		7	6	7	7	41
SOFT				7	21		14				13										8
Spanish Grand	**66**	**65**	**65**		**65**	**66**	**66**	**66**	**66**	**65**	**66**	**66**	**66**	**65**	**66**	**66**	**64**	**65**	**65**	**66**	**65**
HARD			20		37	28		28		36		29		23	30	30	30	28	17		24
MEDIUM	18	18	26			24	27	26	23	19	24	24	25	26	21	21	20	20	18	27	32
SOFT	48	47	19		28	14	39	12	43	10	42	13	41	16	15	15	14	17	30	39	9
Grand Total	**820**	**829**	**911**	**50**	**868**	**774**	**875**	**835**	**887**	**833**	**910**	**831**	**917**	**832**	**897**	**850**	**771**	**867**	**880**	**863**	**823**

Table 3 detail how often each driver used specific tire compounds during each event. For instance, in the Australian Grand Prix, Driver Hamilton (HAM) used hard tires 16 times and soft tires 57 times. A higher frequency of softer compound usage generally points to a strategy centered around speed, while the use of harder compounds might suggest a focus on endurance.
Similarly, Verstappen (VER) extensively used the soft compound in events like the Bahrain Grand Prix, utilizing it 33 times, which indicates a strategy likely aimed at maximizing speed and achieving quicker lap times. Conversely, during the British Grand Prix, a significant number of intermediate tires were used, hinting at wet conditions that necessitated a more cautious approach.
The Monaco Grand Prix exhibited a different pattern, where many drivers opted for hard and medium tires over soft tires. This choice likely reflects the challenging nature of the Monaco circuit, where tire management is crucial. In the Spanish Grand Prix, both Norris (NOR) and Hamilton (HAM) displayed similar usage of the soft tire, suggesting they might have employed comparable strategies or faced similar race circumstances.
At the bottom of the table, the totals for each driver and tire type summarize overall tire usage across all events. For example, Hamilton (HAM) used a total of 875 tires, with a significant portion being softer compounds, indicating a potentially aggressive tire strategy heavily reliant on speed-oriented choices.

Number of Laps Completed on Each Tire Compound

Figure 51. Relationship Between Stint Length and Tire Compound Usage – Canadian Grand Prix.

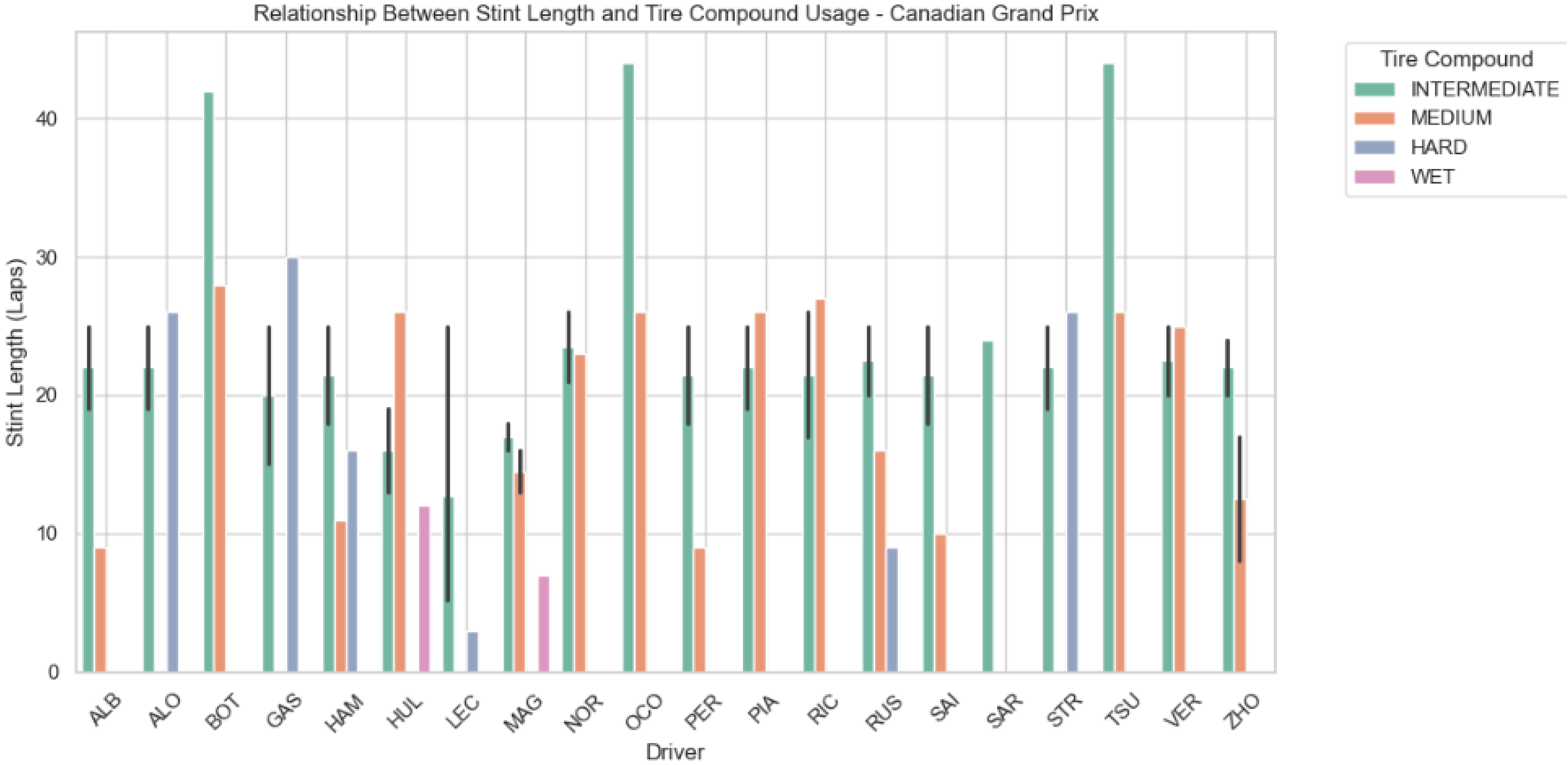
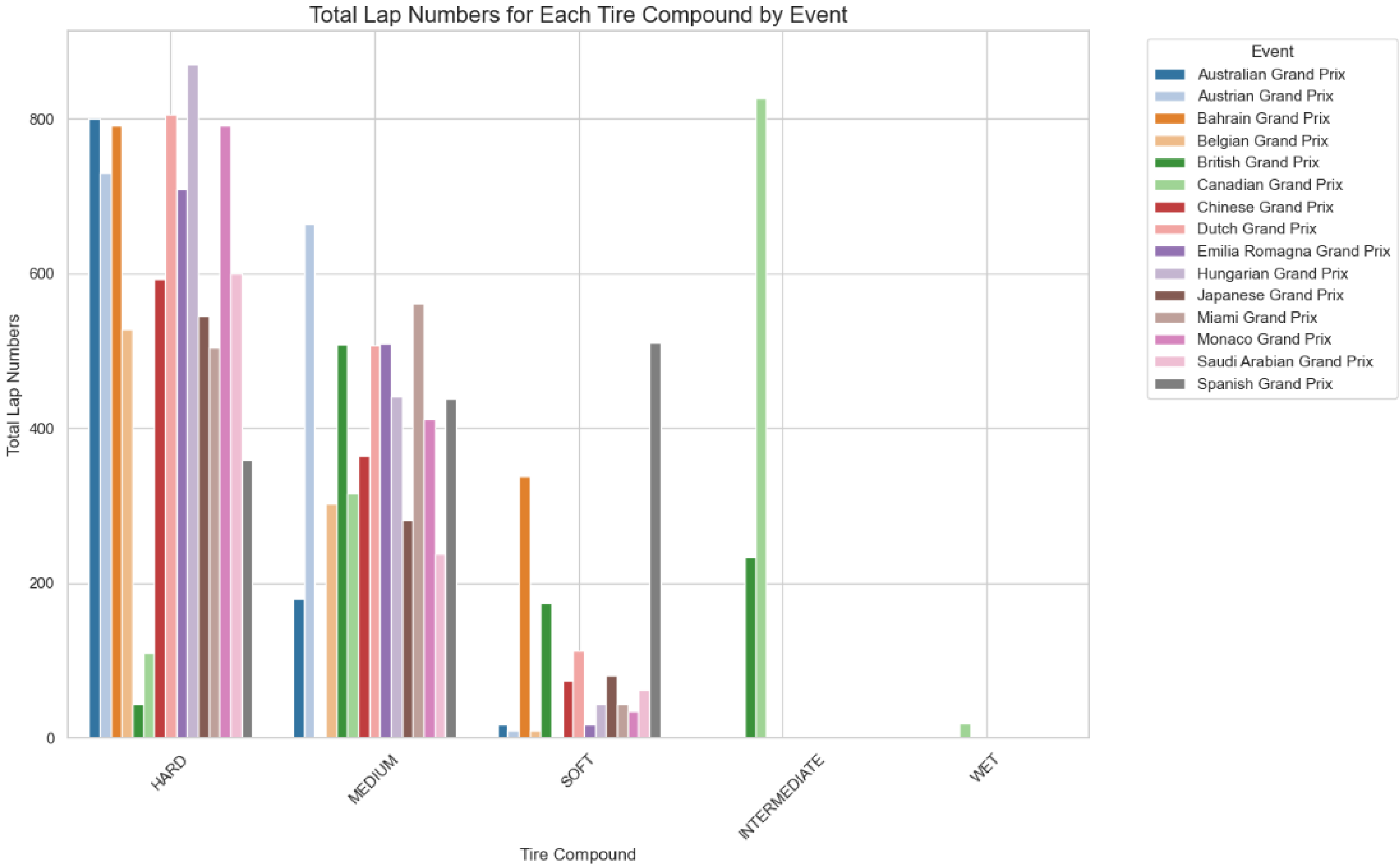


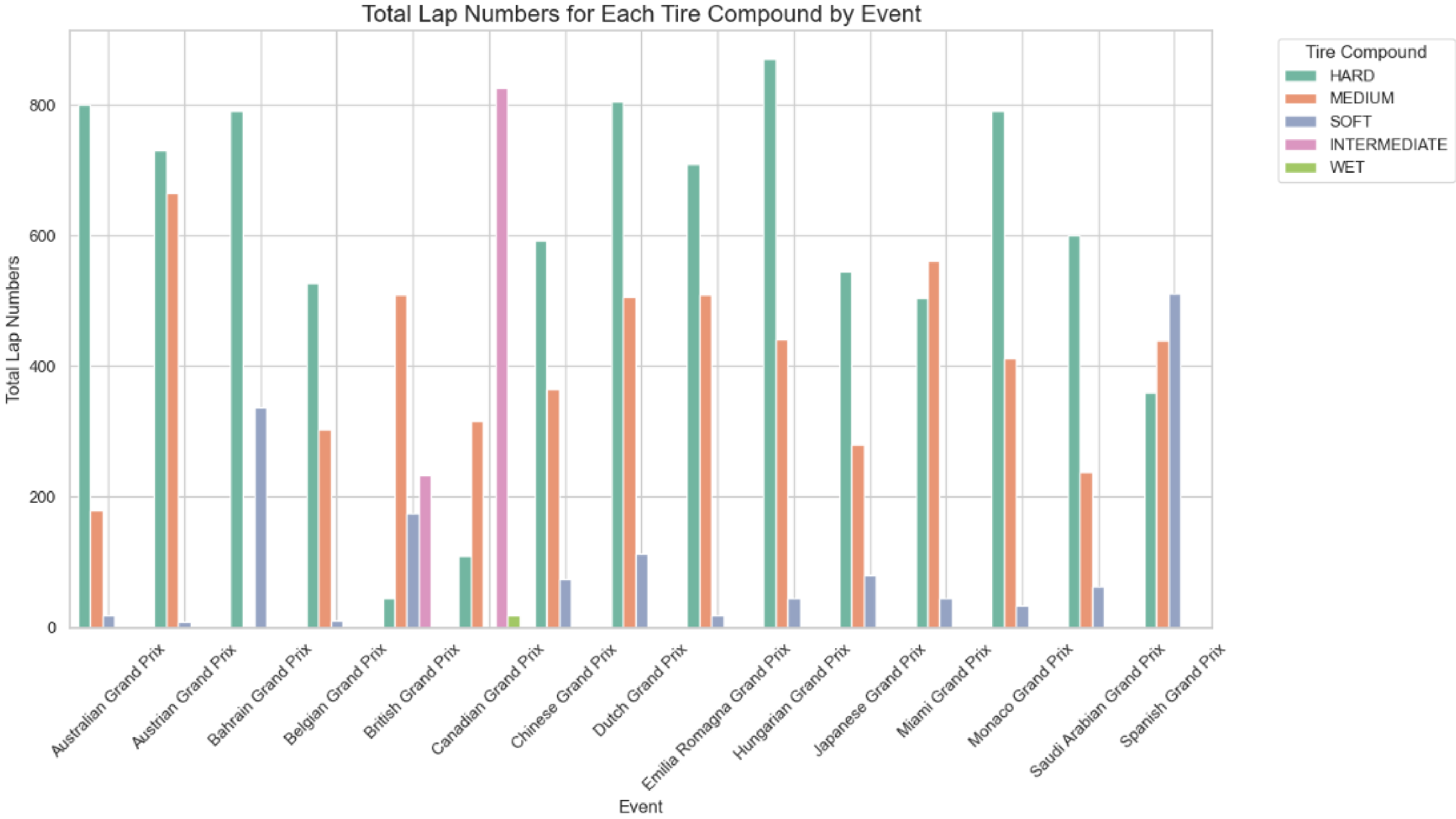
Figure 51 illustrates the relationship between stint length and tire compound usage in the Canadian Grand Prix. The data reveals that intermediate and medium tire compounds were used for the highest number of laps. Additionally, it shows that wet tires were exclusively used by drivers Hülkenberg and Magnussen.

Figure 52. Total Lap Numbers for Each Tire Compound by Event.



Figures 52 and 53 display the total lap numbers for each tire compound by event. The data indicates that hard and medium tire compounds were more commonly preferred compared to soft, intermediate, and wet tire compounds. Additionally, intermediate and wet tire compounds were predominantly used in the British and Canadian Grands Prix.

Figure 53. Total Lap Numbers for Each Tire Compound by Event.



In addition to Figure 52, Figure 53 reveals that the British and Belgian Grands Prix utilized hard tire compounds less frequently compared to other events. Furthermore, intermediate tire compounds were employed during both the British and Canadian Grands Prix, while wet tire compounds were used exclusively in the Canadian Grand Prix.

Figure 54. Total Laps in Compounds.

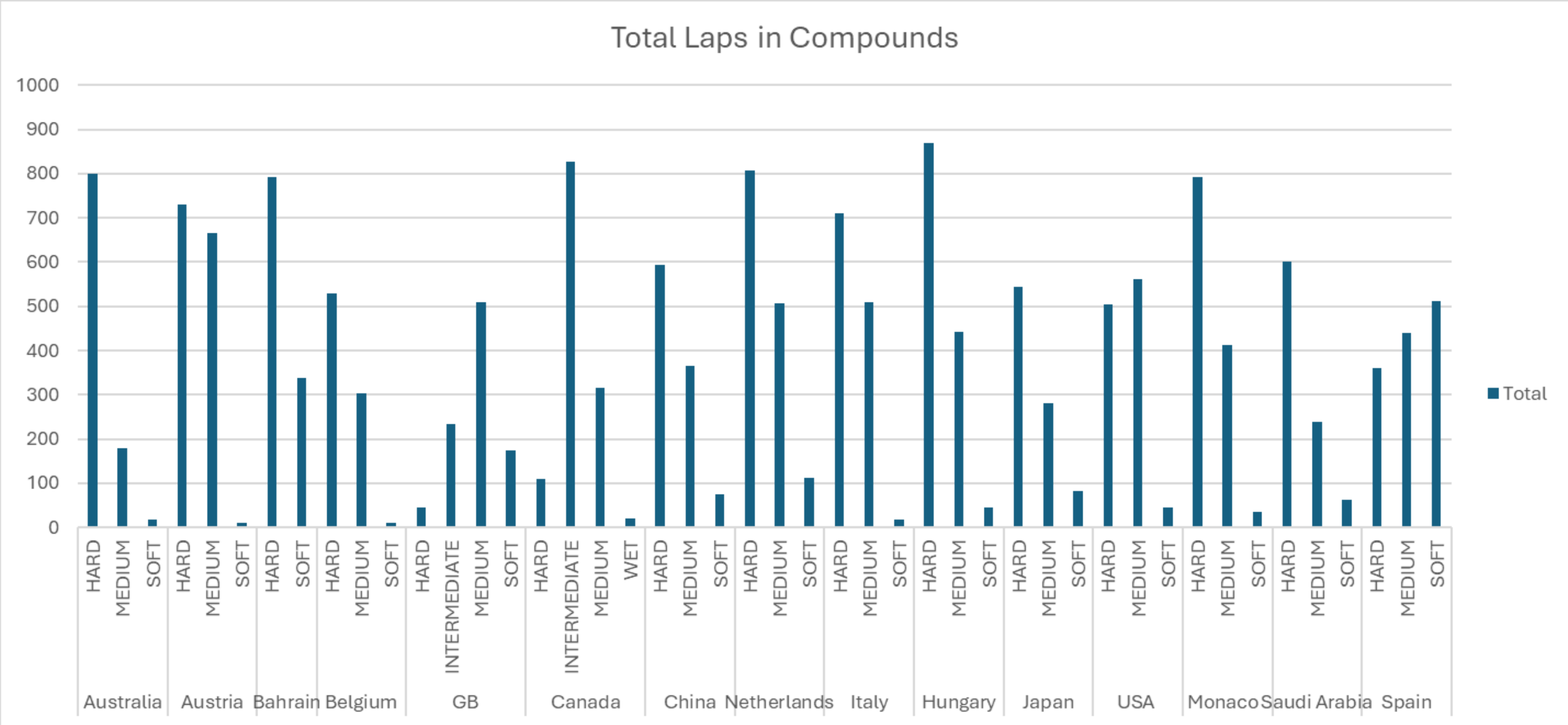


Figure 54 presents total laps for each tire compound in a distinct manner compared to Figures 52 and 53. This figure highlights that four different tire compounds were exclusively used in the British and Canadian Grands Prix: hard, intermediate, medium, and soft in the British Grand Prix, and hard, intermediate, medium, and wet in the Canadian Grand Prix. In contrast, all other Grands Prix featured mostly three tire compounds.

Average Lap Time per Stint and Delta Time per Tire Compound

Table 4. Average Lap Time per Stint for Drivers Across All Events.

Average Lap Time per Stint for Drivers Across All Events					
Driver / Stint	1.0	2.0	3.0	4.0	5.0
ALB	100.273780	94.289987	86.350159	90.5132	83.232522
ALO	106.027696	93.361091	95.840112	94.37186	-
BEA	102.011286	95.054405	-	-	-
BOT	699.747492	92.546891	89.447006	98.629233	-
GAS	110.442030	89.160686	87.908823	99.086813	-
HAM	112.943975	91.144166	84.337718	91.616768	-
HUL	91.960993	92.036172	94.288303	93.487831	-
LEC	95.347497	95.909718	89.706609	84.293	71.75625
MAG	93.152456	91.979590	95.340404	91.507077	85.013437
NOR	93.142682	90.116564	87.634878	96.707111	-
OCO	91.972347	95.251548	85.689499	93.836143	94.2755
PER	89.739828	88.953464	96.898366	91.129775	104.191333
PIA	93.071039	91.542744	87.849399	96.740238	-
RIC	99.093669	93.998652	89.099123	-	-
RUS	106.144132	90.158984	82.213011	91.863156	-
SAI	98.189754	91.675553	86.858358	98.170897	-
SAR	111.055279	94.606147	87.463733	87.775288	97.443727
STR	693.819217	93.604934	90.764791	96.044093	99.755333
TSU	97.164251	95.362369	89.028575	89.710893	-
VER	686.682651	89.284770	89.5643	85.176981	-
ZHO	96.792816	90.444539	92.842131	105.324072	94.395462

Table 4 displays the average lap times per stint for various drivers throughout the 2024 Formula 1 season, with data aggregated across all events. The average lap times are broken down by driver and stint (1, 2, 3, etc.), measured in seconds.

For example, Albon has an average lap time of 100.27 seconds during Stint 1, 94.29 seconds in Stint 2, and 86.35 seconds in Stint 3. This trend indicates that Albon's lap times tend to decrease as the race progresses, suggesting an improvement in performance after the first stint, potentially due to factors such as lower fuel loads or effective tire strategies.

Alonso has no recorded time for Stint 5, indicating that he did not complete a fifth stint in any race, possibly due to fewer pit stops or race retirements.

Notably, Verstappen and Stroll exhibit unusually high average lap times in Stint 1, at 686.68 seconds and 693.82 seconds, respectively. These high values may be attributed to anomalies such as pit stops during their first stint or interruptions in the race, like safety car deployments or mechanical issues.

Drivers with shorter stint times, such as Piastri and Russell, tend to show more consistent lap times, which may indicate smoother race execution or more effective strategies throughout the event.

Figure 55. Average Lap Time per Stint – Australian Grand Prix.

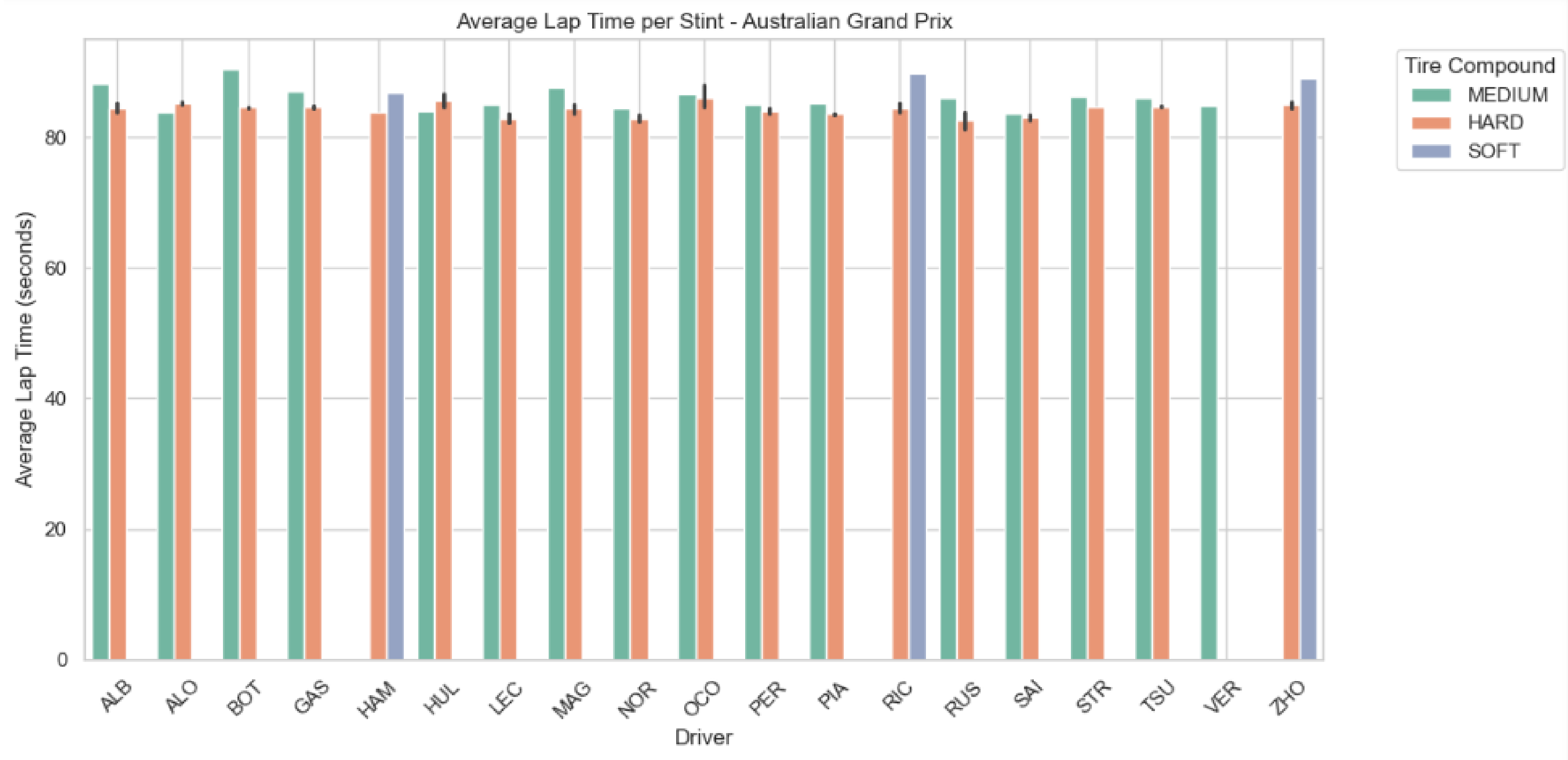


Figure 55 illustrates that in the Australian Grand Prix, average lap times per stint do not change significantly, except for those drivers who utilized the soft tire compound. This data highlights how tire strategy can impact lap times; a lower stint average may indicate that a driver was on fresh tires or that the team executed a more effective strategy, such as pitting at optimal times.

For instance, Pérez had a relatively consistent stint pattern but exhibited a longer lap time of 104.19 seconds in Stint 5, which may suggest tire degradation or other challenges late in the race. In contrast, Hamilton had an average lap time of 112.94 seconds in Stint 1, which dropped significantly to 91.14 seconds in Stint 2, indicating a notable improvement following his first pit stop. Meanwhile, Sainz displayed fairly consistent average lap times from Stints 1 to 4, suggesting steady performance throughout the race.

Table 5. Average Lap Time per Stint for Teams Across All Events.

Average Lap Time per Stint for Teams Across All Events					
Team / Stint	1.0	2.0	3.0	4.0	5.0
Alpine	102.526452	92.206117	86.799161	96.086430	94.2755
Aston Martin	399.923456	93.483012	93.809984	95.207977	99.755333
Ferrari	97.601599	93.972888	88.757192	89.844159	71.75625
Haas F1 Team	92.556724	92.011922	94.814354	92.992642	85.013437
Kick Sauber	398.270154	91.495715	91.387077	103.985104	94.395462
McLaren	93.106861	90.727784	87.742138	96.723675	-
Mercedes	109.544053	90.721945	83.275364	91.698897	-
RB	98.266776	94.777918	89.070904	89.710893	-
Red Bull Racing	388.211239	89.095452	93.755195	88.748657	104.191333
Williams	106.434637	94.425484	86.906946	88.687926	90.338125

Table 5 displays each team's average lap time for each stint. For example, Alpine has an average lap time of 102.53 seconds in Stint 1, 92.21 seconds in Stint 2, and 96.09 seconds in Stint 4. This trend indicates that Alpine's lap times improve after the first stint but slightly increase again by Stint 4, likely due to tire wear or race strategy.

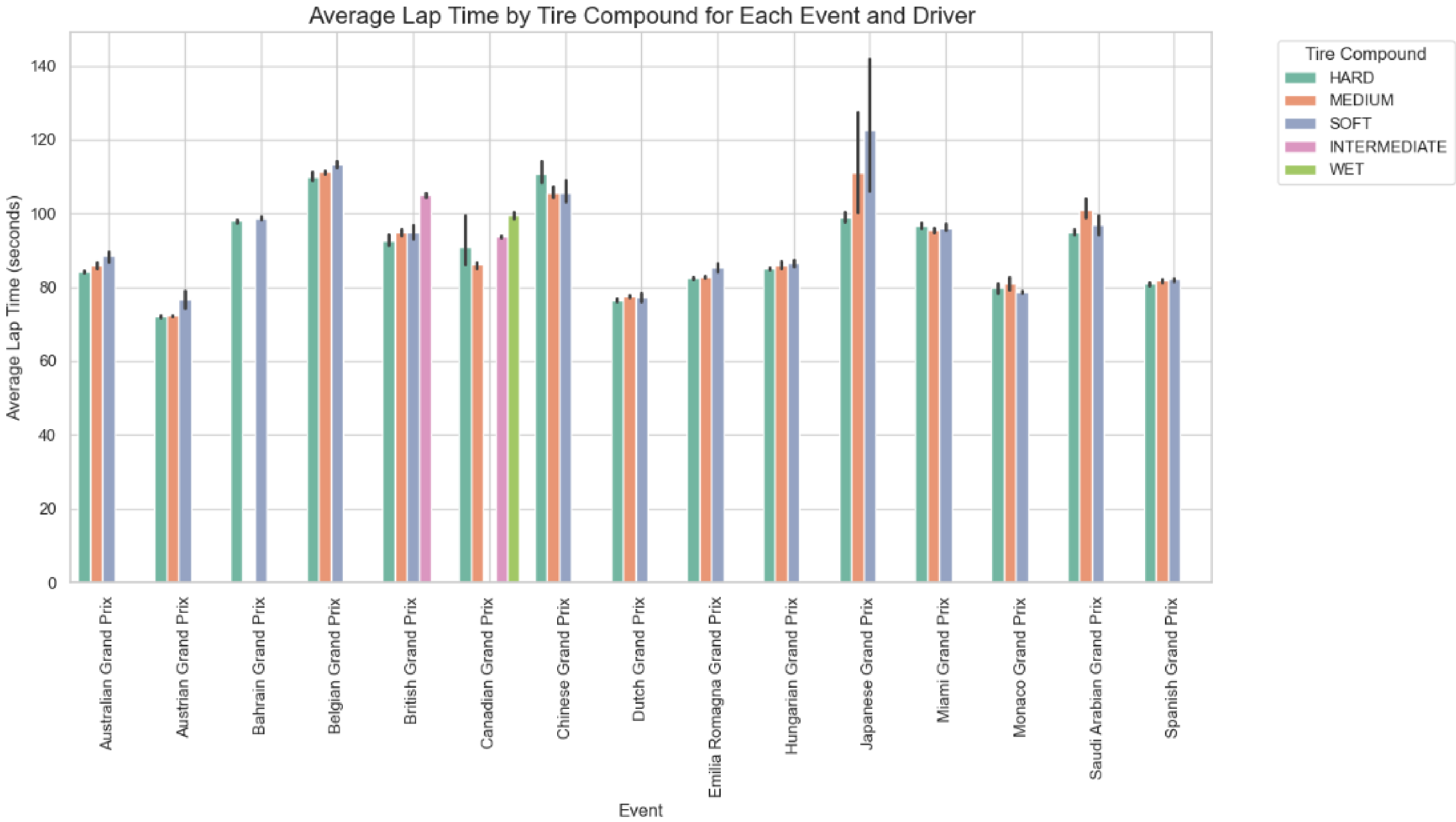
Some values in the table are anomalously high, such as Aston Martin in Stint 1 (399.92 seconds), Red Bull Racing in Stint 1 (388.21 seconds), and Alfa Romeo in Stint 1 (398.27 seconds). These inflated times likely reflect race incidents, such as a pit stop during the first stint, a crash, a safety car period, or other factors that disrupted normal lap times early in the race.

Teams with lower average lap times across most stints demonstrate more efficient race execution. For instance, McLaren shows fairly consistent average lap times across stints, with values such as 93.11 seconds in Stint 1, 90.73 seconds in Stint 2, and 96.72 seconds in Stint 4, indicating smooth performance throughout all stints. Ferrari also maintains relatively steady lap times, particularly in Stints 2 to 4, with consistent low times like 88.76 seconds in Stint 3, showcasing that their drivers sustained a competitive pace during different phases of the race.

Teams with higher lap times in later stints (e.g., Stint 5) may have struggled with tire degradation or suboptimal pit stop strategies. For instance, Aston Martin has an average lap time of 99.76 seconds in Stint 5, which is higher compared to earlier stints, potentially indicating that the team's tire management strategy in the later stages was less effective. Red Bull Racing also shows a significant increase in Stint 5, with an average lap time of 104.19 seconds, suggesting challenges with tire degradation or late-race incidents.

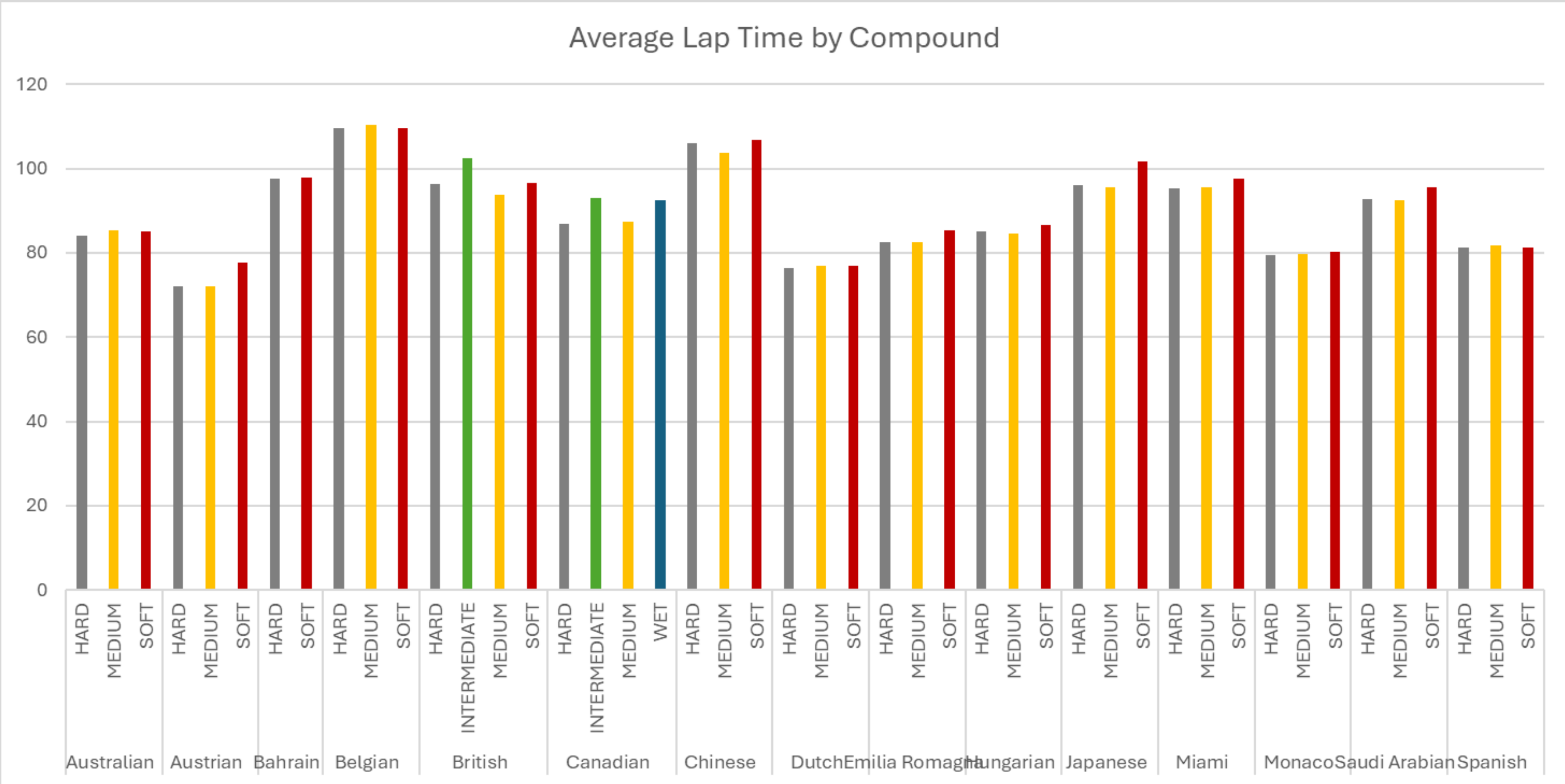
In contrast, Mercedes and McLaren demonstrate lower average lap times in their second and third stints, with times of 90.72 seconds and 83.28 seconds for Mercedes in Stints 2 and 3, respectively. This trend indicates that their performance improves after the initial phase of the race, likely due to effective tire and fuel strategies. Conversely, Williams exhibits consistently high lap times across all stints, such as 106.43 seconds in Stint 1, suggesting they may have faced challenges in maintaining competitive lap times, possibly due to car performance or strategic decisions.

Figure 56. Average Lap Time by Tire Compound for Each Event and Driver.



Figures 56 and 57 highlight how driver performance evolves throughout the race based on tire compounds across different events. These figures reflect the impact of tire strategy, pit stops, and race incidents on overall performance, illustrating how these factors can influence lap times and competitive positioning during the race.

Figure 57. Average Lap Time by Compound (Threshold for Lap Times).



While teams with consistently low stint times across all phases of the race, such as McLaren and Ferrari, tend to implement more efficient race strategies, there is a general similarity in average lap times for specific events.
Events with outliers and higher stint times, such as the Japanese Grand Prix, may have encountered race incidents or delays early on, which can significantly affect overall lap times and disrupt the flow of the race.

Table 6. Average Delta Time per Tire Compound for Drivers Across All Events.

Driver / Compound	Hard	Intermediate	Medium	Soft	Wet
ALB	-0.477543	-42.227509	10.466493	-0.957729	-
ALO	6.172417	-42.769727	-0.245229	-0.937795	-
BEA	-1.339780	-	-	4.757833	-
BOT	4.588215	-45.176038	-0.366537	-0.194567	-
GAS	6.225336	-58.5545	-0.479083	-0.573848	-
HAM	6.151846	-43.309741	0.335578	-1.222142	-
HUL	-0.290207	1.647489	-0.432683	0.573512	-0.362909
LEC	-0.145157	-41.204889	7.754648	-1.084358	-
MAG	-0.549769	1.74375	0.141283	-0.860024	0.598667
NOR	-0.059463	-38.673051	7.354286	-1.132700	-
OCO	-0.338366	0.180579	-0.524496	1.318170	-
PER	-0.189662	1.5683	-0.342513	-1.502711	-
PIA	-0.195765	-42.58063	6.919974	-0.483692	-
RIC	-0.201441	-43.085963	10.970208	-0.675533	-
RUS	5.174501	-45.20702	-0.223874	-0.831977	-
SAI	-0.201745	-40.798161	7.525908	-1.800667	-
SAR	5.327620	-70.750324	-0.096416	-0.659423	-
STR	6.422382	-41.259842	-0.301598	-1.171767	-
TSU	-0.338228	-42.957164	10.997075	-1.315268	-
VER	6.467701	-40.986632	-0.088969	-0.870000	-
ZHO	-0.104180	-37.278968	10.733339	-1.470791	-

Table 6 provides insights into the tire performance of each driver across all events, revealing patterns in their speed and tire strategy.

For instance, Albon has a delta time of -0.48 seconds on hard tires, indicating that he was slightly faster on these compounds compared to his previous laps. Alonso shows a delta of -42.77 seconds on intermediate tires, suggesting a significant improvement in lap time, which points to very effective tire performance under those conditions. Hamilton, with a delta of -1.22 seconds on soft tires, demonstrates strong performance, indicating effective tire management during his stint.

Figure 58. Delta Lap Time per Tire Compound – Australian Grand Prix.

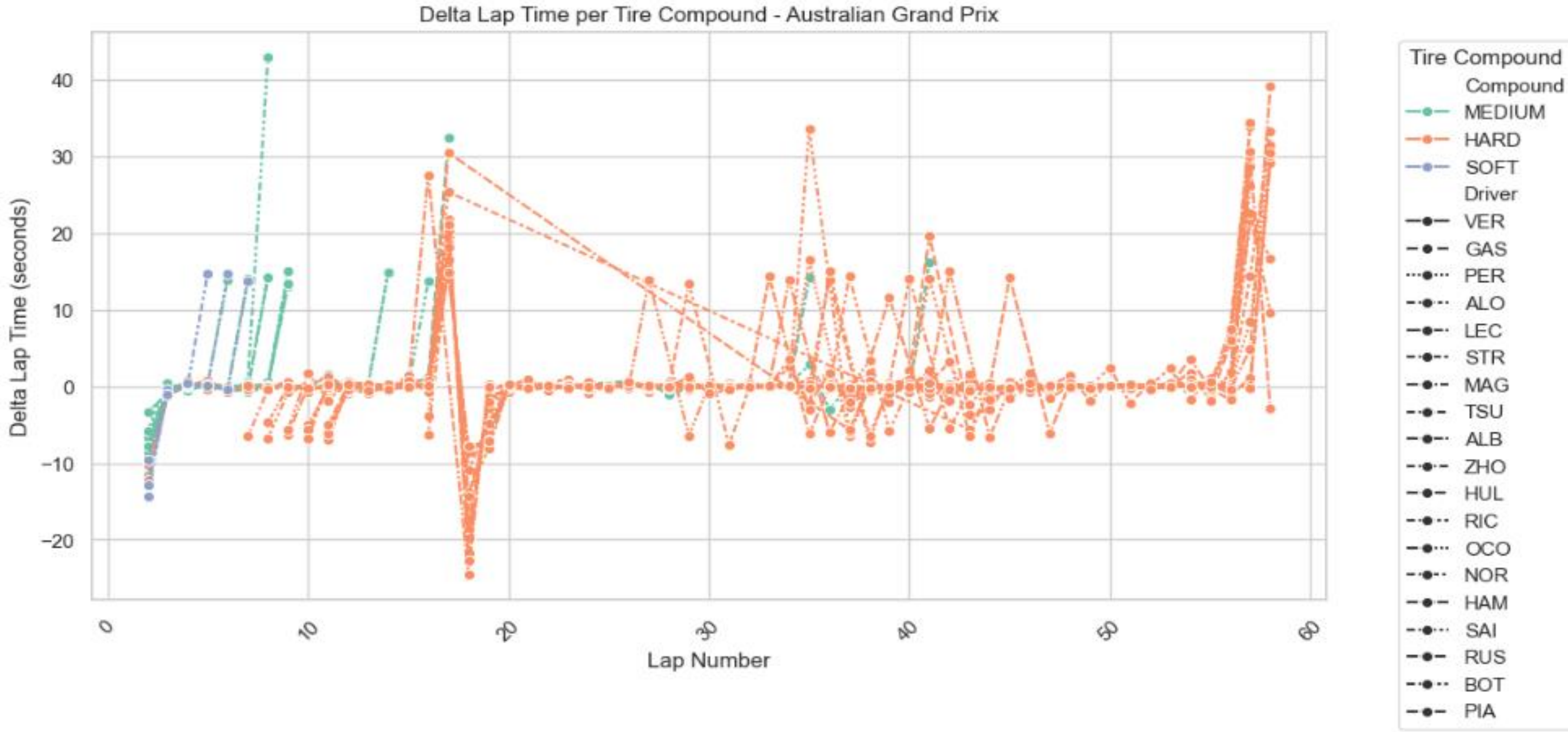


Figure 58 illustrates the delta lap time per tire compound for the Australian Grand Prix. We observe that hard tires exhibit both very negative and positive values, while soft and medium tires have more moderate delta values. These variations primarily reflect drivers' performance. For instance, drivers like Gasly and Bottas have very negative values on intermediate tires, indicating they excelled with that compound. Gasly's delta of -58.55 seconds suggests a notably strong performance, likely due to track conditions that favored the intermediate tires. Conversely, drivers showing positive delta times across various compounds may be struggling with those tires. For example, Pérez demonstrates a positive delta of 1.50 seconds on soft tires, suggesting less effective performance with that compound.

Table 7. Average Delta Time per Tire Compound for Teams Across All Events.

Team / Compound	Hard	Intermediate	Medium	Soft	Wet
Alpine	2.943485	-29.186961	-0.501789	0.372161	-
Aston Martin	6.297399	-42.014785	-0.273413	-1.054781	-
Ferrari	-0.562228	-41.001525	7.640278	0.624269	-
Haas F1 Team	-0.419988	1.695619	-0.145700	-0.143256	0.117879
Kick Sauber	2.242018	-41.227503	5.183401	-0.832679	-
McLaren	-0.127614	-40.626840	7.137130	-0.808196	-
Mercedes	5.663174	-44.258380	0.055852	-1.027059	-
RB	-0.269835	-43.021563	10.983642	-0.995401	-
Red Bull Racing	3.139020	-19.709166	-0.215741	-1.186355	-
Williams	2.425038	-56.488916	5.185039	-0.808576	-

Table 7 presents the average delta time per tire compound for teams across all events. A team with consistently negative delta times for a particular tire compound is likely skilled at managing those tires effectively, while teams with positive delta values may need to reassess their tire strategies or management techniques.

For example, Alpine demonstrates a strong performance on intermediate tires with a delta of -29.19 seconds, indicating effective tire management under those conditions. Ferrari, on the other hand, shows a delta of 7.64 seconds on medium tires, suggesting that these compounds may not have been optimal for them in the analyzed events. Williams stands out with a significant delta of -56.49 seconds on intermediate tires, reflecting exceptional performance likely influenced by specific conditions favoring that tire type.

Additionally, teams like Aston Martin and Mercedes report significant negative delta values on intermediate tires (-42.01 and -44.26 seconds, respectively), indicating they excelled with that compound.

Conversely, teams with positive delta times across various compounds might be struggling to find effective tire strategies. For instance, Haas F1 Team shows mixed results, with a positive delta on hard tires and a negative delta on intermediate tires, indicating variability in performance depending on the tire choice.

Figure 59. Average Lap Times per Stint.

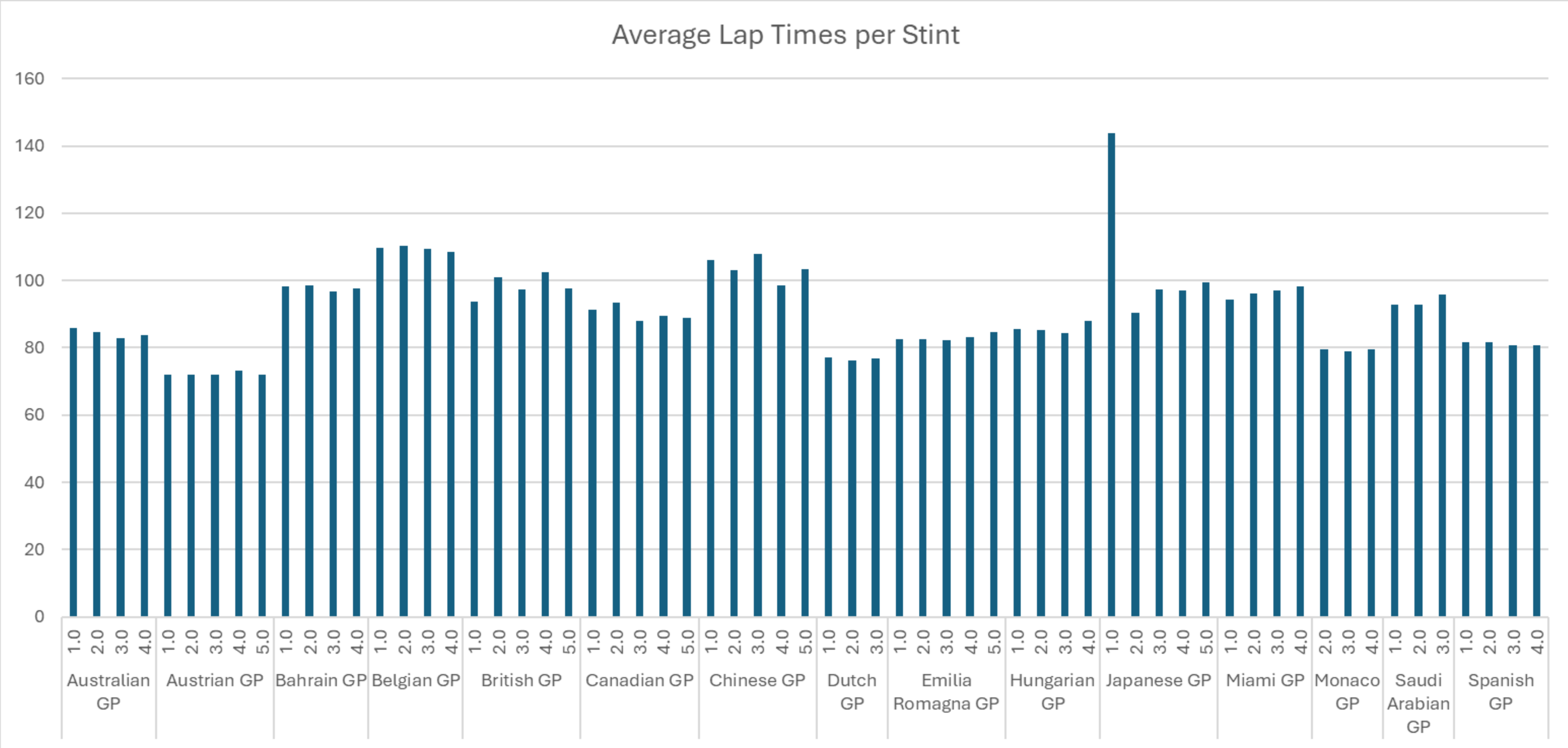
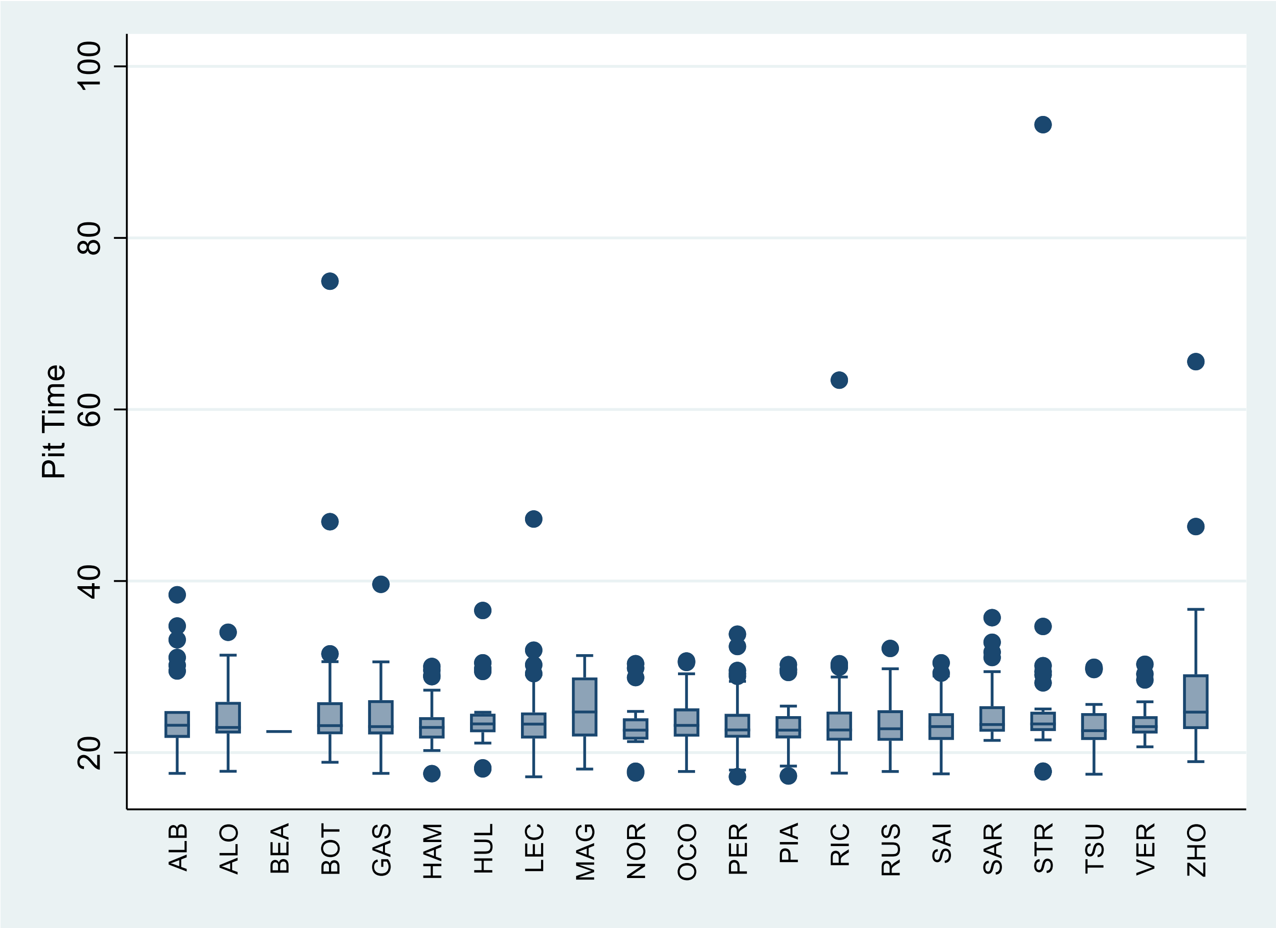


Figure 59 illustrates average lap times per stint across events, revealing general similarities in average lap times for certain races. Events with unusually high stint times, such as the Japanese Grand Prix, likely experienced incidents or delays early in the race, which adversely affected overall lap times. In contrast, the Australian Grand Prix, Austrian Grand Prix, Dutch Grand Prix, Monaco Grand Prix, and Spanish Grand Prix exhibit shorter bars, indicating significantly faster average lap times (with possibly shorter laps) during those events.

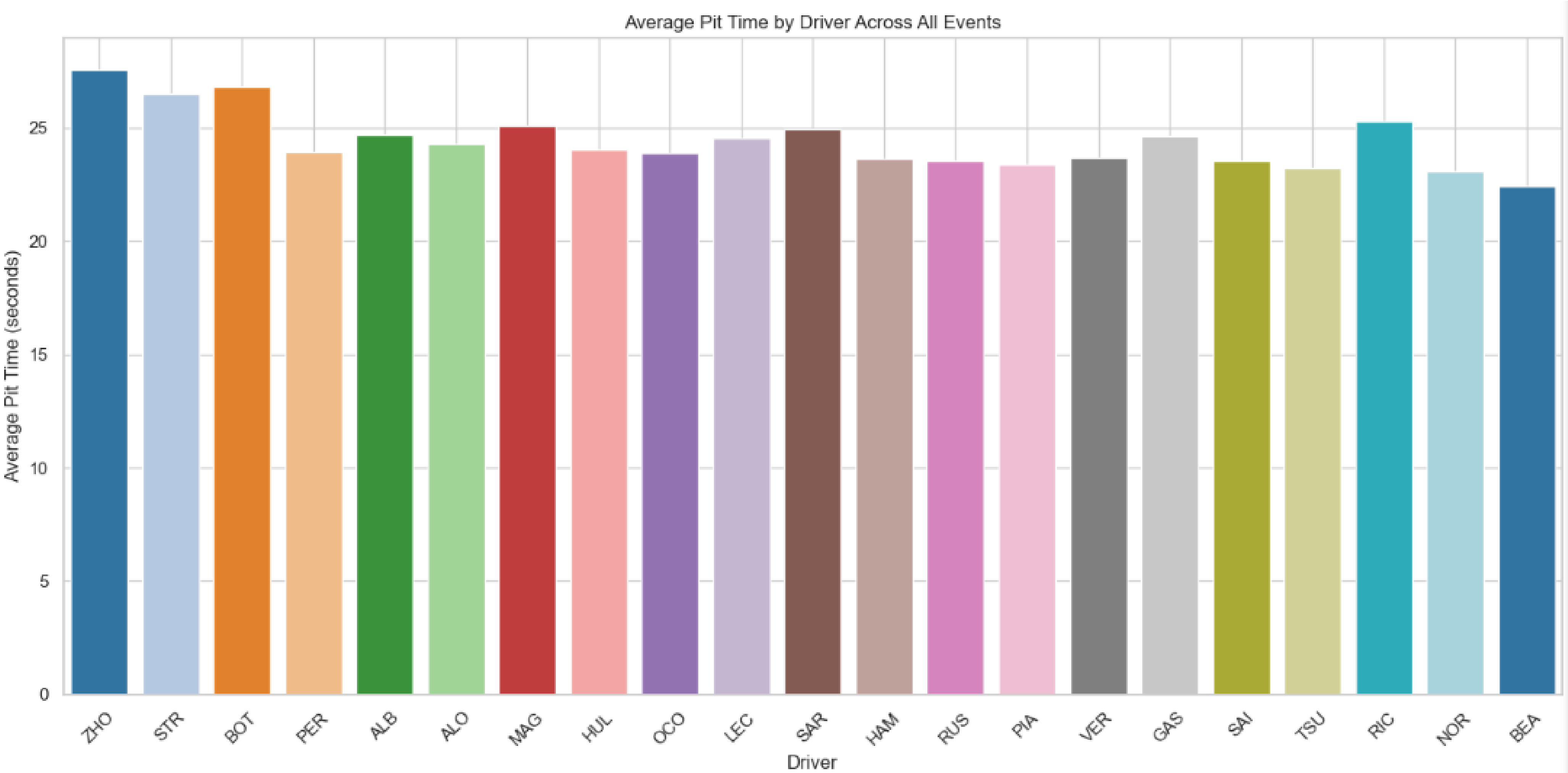
Time Spent in Pits

Figure 60. Average Time Spent in Pits by Drivers.



Figures 60 and 61 display the average pit stop times (in seconds) for various drivers throughout the Formula 1 season. These figures provide insight into how efficiently each driver and their team executed pit stops, which can significantly influence overall race performance. Analyzing these times helps identify patterns in pit stop strategy and highlights drivers who consistently achieve quick pit stops, contributing to their competitive edge during races.

Figure 61. Average Pit Time by Drivers Across all Events.



While Beauchamp and Norris exhibit some of the shortest average pit stop times, indicating very efficient pit stops and benefiting from effective teamwork and strategies, which positively contribute to their race performance, drivers like Zhou, Stroll, Bottas, and Ricciardo have some of the highest average pit times. This suggests that they may face inefficiencies or challenges during their pit stops compared to their peers, potentially impacting their overall race outcomes. It must be noted that Beauchamp only pitted once in this season.

Table 8. Driver and Average Pit Times.

Driver	Average Pit Time (seconds)
ALB	24.71
ALO	24.27
BEA	22.45
BOT	26.79
GAS	24.62
HAM	23.61
HUL	24.02
LEC	24.52
MAG	25.08
NOR	23.06
OCO	23.89
PER	23.93
PIA	23.37
RIC	25.31
RUS	23.55
SAI	23.54
SAR	24.95
STR	26.52
TSU	23.25
VER	23.68
ZHU	27.57

Table 8 lists the average pit stop times for various drivers. Beauclerc recorded the fastest average pit stop at 22.45 seconds; however, this figure is based on a single instance. Consequently, the next fastest average pit time belongs to Norris, who achieved an average of 23.06 seconds. In contrast, Zhou experienced the longest average pit time at 27.57 seconds, highlighting potential areas for improvement in the team's pit strategy. Overall, the average pit times across all drivers reflect a competitive field, with most drivers averaging around the mid-20 seconds mark.

Figure 62. Total Pit Time by Drivers Across all Events.

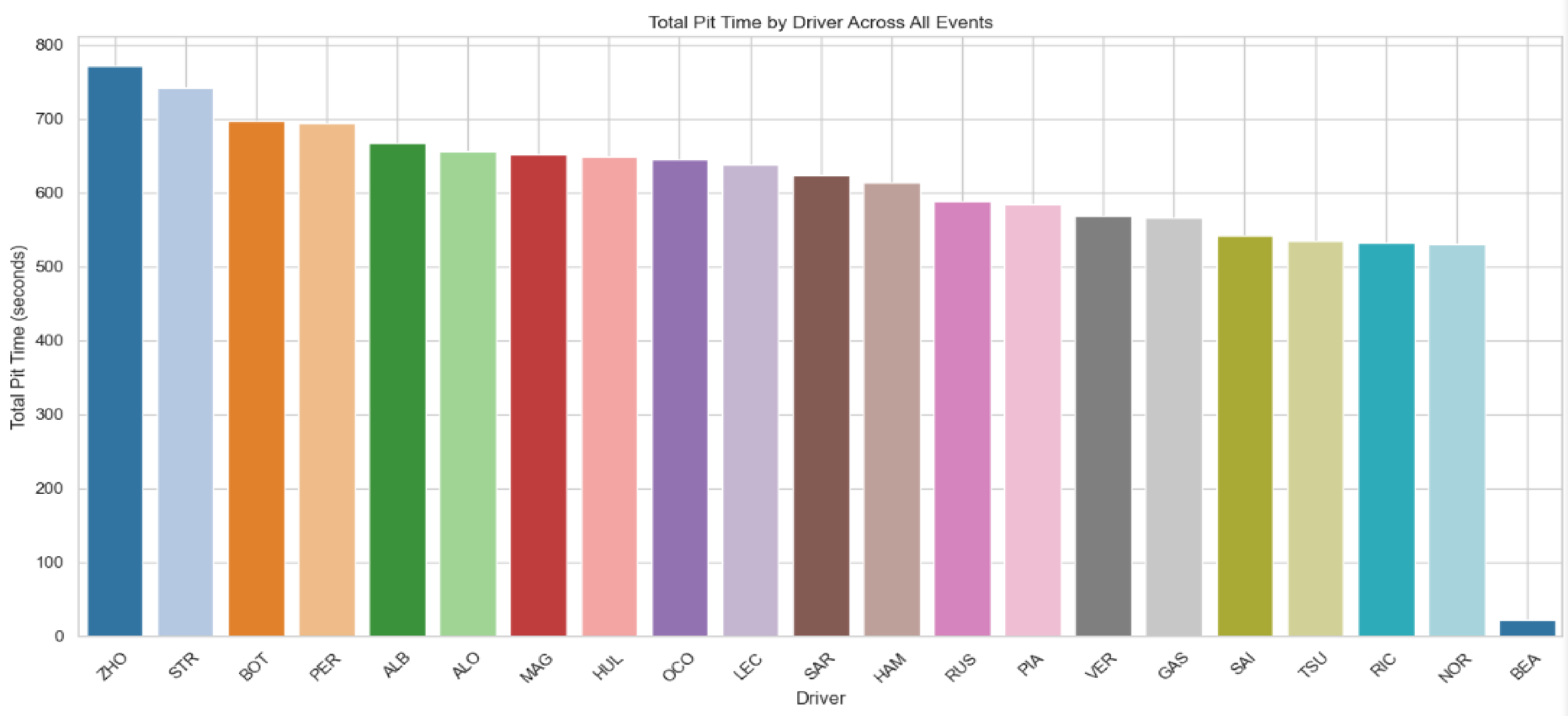
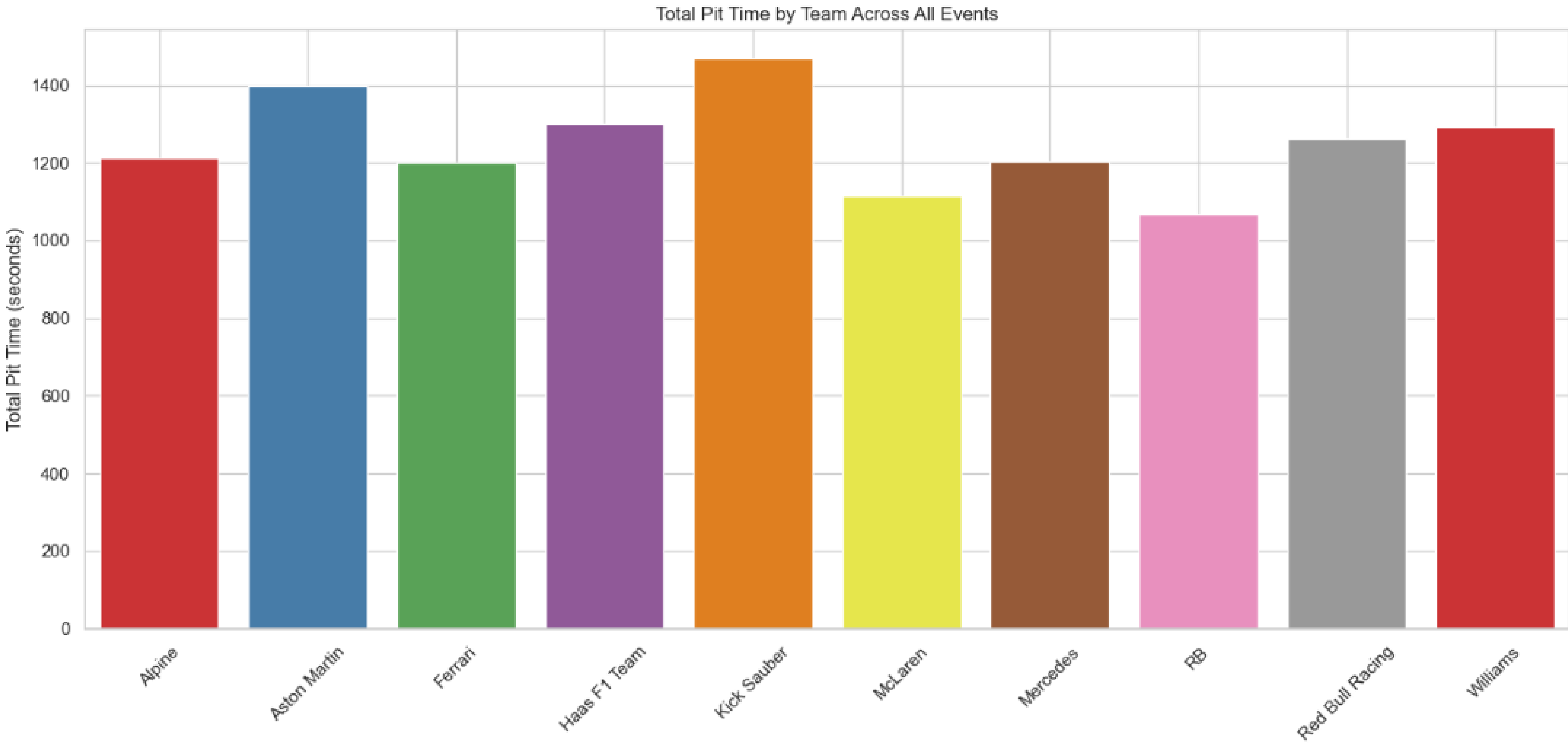


Figure 62 illustrates the total pit stop times (in seconds) for various drivers across events during the Formula 1 season. Beauclerc has the shortest total pit stop time, which reflects a single pit stop throughout the season. Norris consistently records shorter pit stops, indicating efficient pit strategies. Conversely, drivers like Ricciardo, Norris, and Tsunoda seem to benefit from effective teamwork and strategies, positively impacting their race performance through potentially fewer and shorter pit stops. In contrast, Zhou, Bottas, and Stroll have some of the highest total pit times, suggesting potential inefficiencies during their pit stops compared to their competitors.

Figure 63. Total Pit Time by Teams Across all Events.



Figures 63 and 64 display the total and average pit times by team across all events. Teams with lower total and average pit times, such as McLaren, Mercedes, and Red Bull Racing, likely demonstrate more effective pit strategies and practices. This efficiency can significantly enhance their overall race performance, allowing drivers to minimize time lost during pit stops and maintain competitive positions on the track.

Figure 64. Average Pit Time by Teams Across all Events.

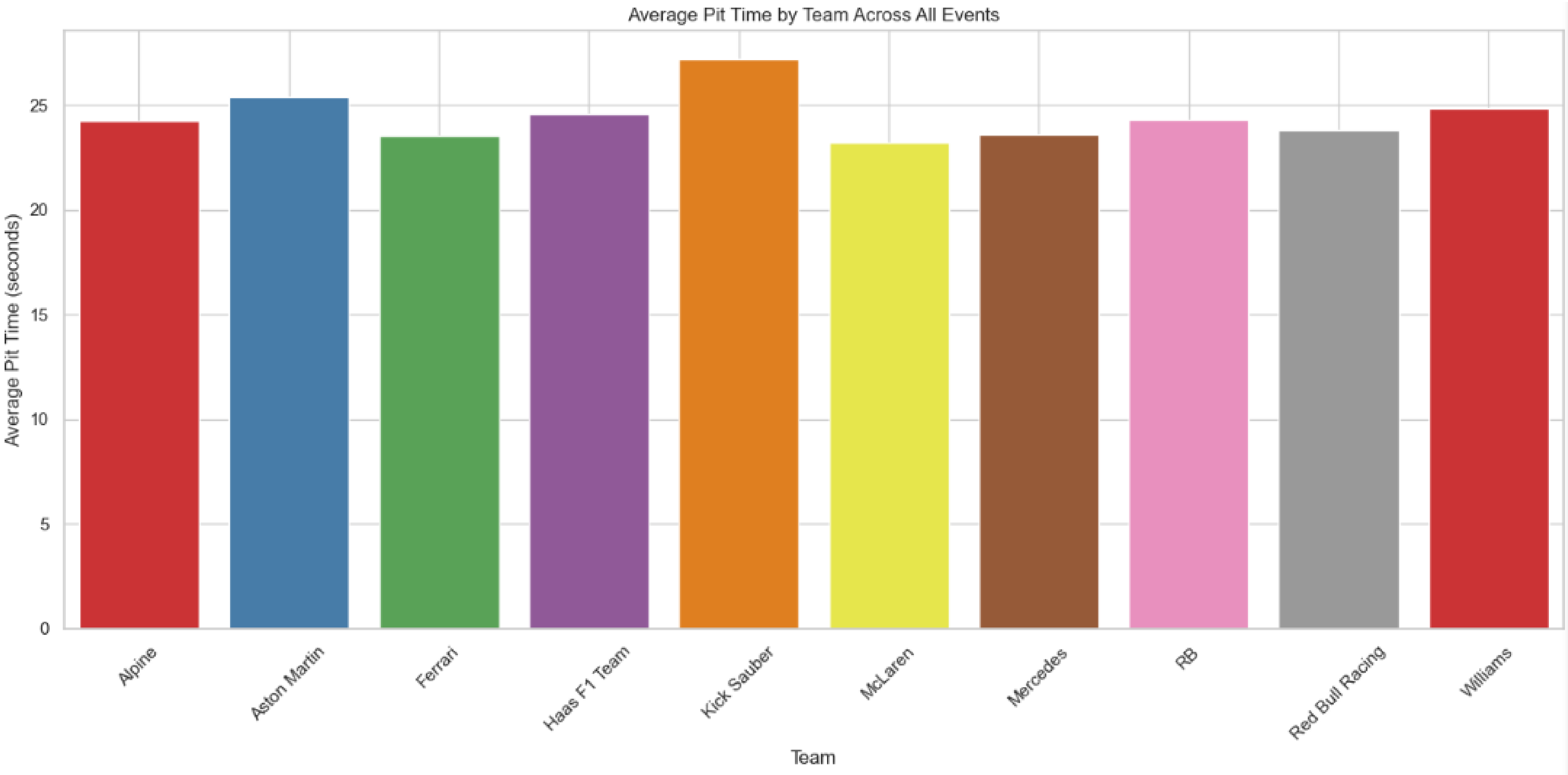


Table 9. Average Pit Time for Each Team.

Team	**Average Pit Time (seconds)**
Alpine	24.23
Aston Martin	25.42
Ferrari	24.03
Haas F1 Team	24.54
Kick Sauber	27.19
McLaren	23.22
Mercedes	23.58
RB	24.23
Red Bull Racing	23.82
Williams	24.83

As shown in Table 9, McLaren has the shortest average pit time at 23.22 seconds, indicating a higher level of efficiency during their pit stops.
Kick Sauber has the highest average pit time at 27.19 seconds, suggesting potential inefficiencies or challenges during their pit stops compared to other teams.
Most teams have average pit times within a close range of around 24 to 25 seconds, indicating that while some differences exist, overall pit stop efficiency is relatively consistent across the field.

Figure 65. Time Spent in Pits by Teams.

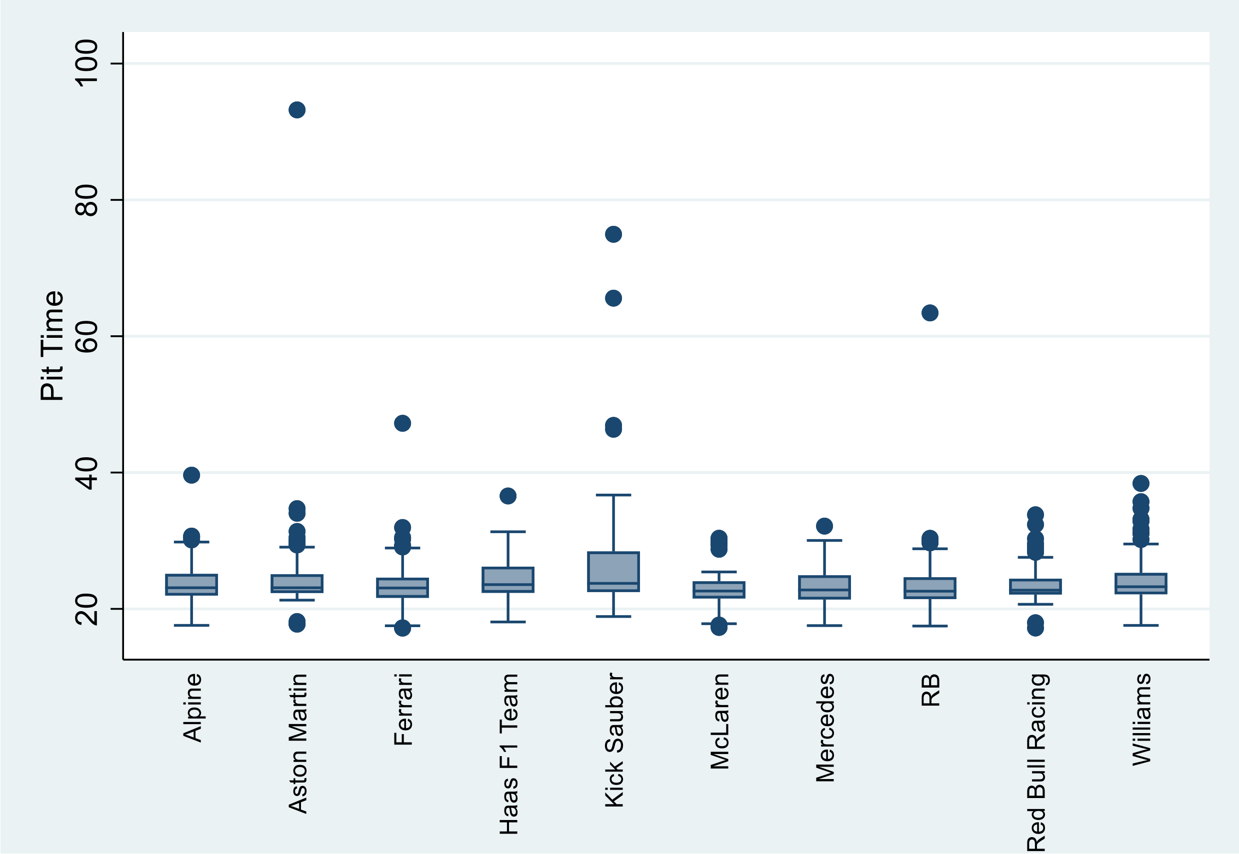


Figure 65 illustrates the time spent in the pits by each team, revealing that Kick Sauber has the highest overall pit time. This extended duration in the pits may indicate challenges or inefficiencies in their pit strategies compared to other teams, potentially impacting their overall race performance.

Figure 66. Time Spent in Pits by Events.

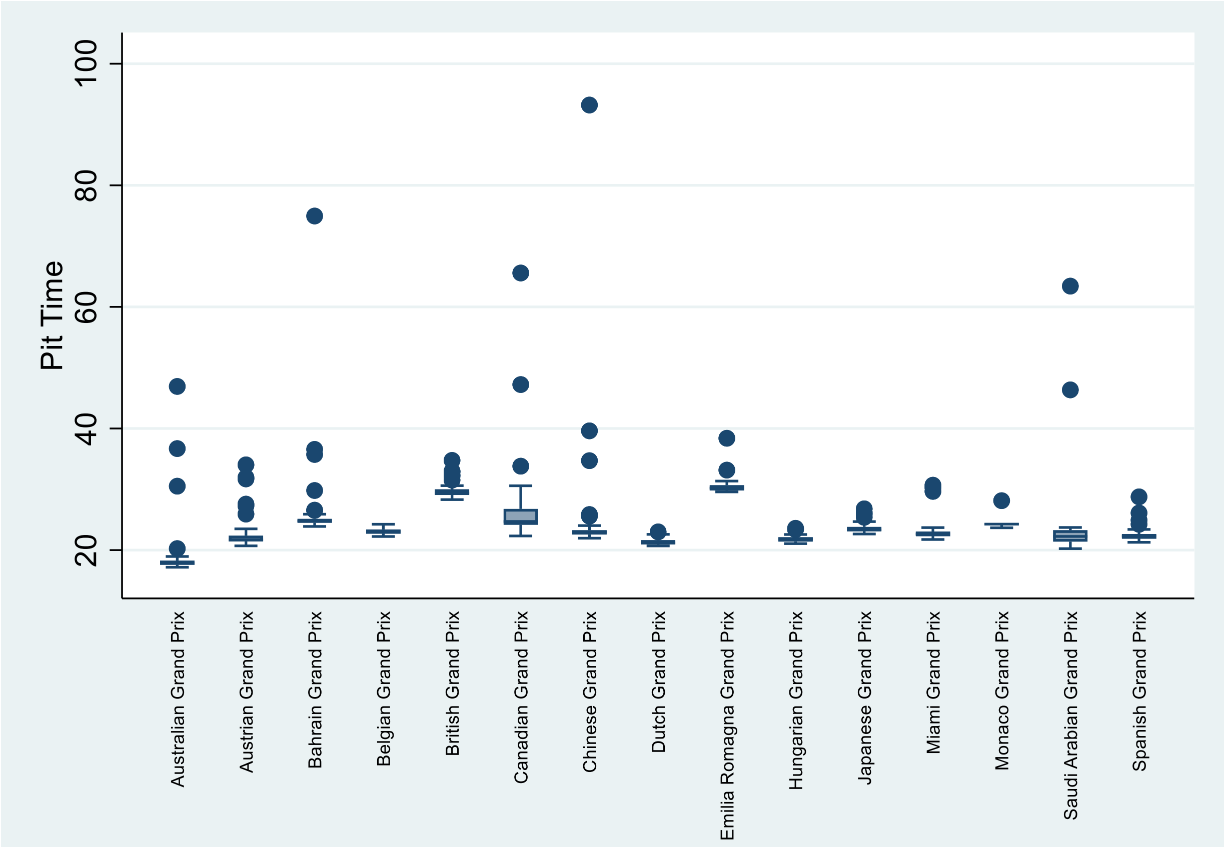


Figure 66 displays the average time spent in the pits across various events. Notably, the Bahrain, Canadian, and Saudi Arabian Grands Prix recorded significantly high pit times, which may suggest potential inefficiencies or challenges faced by teams during these races. Such prolonged pit durations could have affected their overall race strategies and outcomes.

5. In-Depth Analysis

Relationship 1: Tire Compound Choice vs Lap Time

We employed correlation and regression analyses for lap times, tire compounds, race phases and stints.

Table 10. Lap Time, Compound, Race Phase and Stint Correlation.

	Lap Time	Compound	Race Phase	Stint
Lap Time	1.0000			
Compound	0.0653	1.0000		
Race Phase	-0.2662	0.0643	1.0000	
Stint	-0.2963	0.2651	0.2035	1.0000

Soft Compound: Significantly reduces lap times across all models. It shows a consistent negative effect, indicating faster lap times when using the soft compound.

Medium Compound: Also reduces lap times, but the reduction is slightly less than that of the soft compound.

Hard Compound: Reduces lap times, though the effect is weaker compared to the soft and medium compounds, especially in later models.

Intermediate Compound: This compound increases lap times, meaning it is slower compared to dry compounds (Soft, Medium, Hard). This is likely because Intermediate tires are typically used in wet or mixed conditions, which are inherently slower.

Wet Compound: Similarly, this compound significantly increases lap times, the most among all compounds, as Wet tires are used in heavy rain, which slows down cars.

Race Phase and Lap Times: The variable "Race Phase" consistently shows a significant negative effect on lap times, indicating that as the race progresses, lap times generally get faster. This could be due to lighter fuel loads, optimization of race pace strategy, tire wear, and rubber out of the tire sticking on to the racing line that increase grasp.

Stint and Lap Times: "Stint" also shows a significant negative effect, suggesting that as drivers go deeper into a stint (i.e., more laps on the same tires), lap times slightly decrease. This might be counterintuitive but could be explained by drivers adapting to tire degradation or track evolution over time.

Comparison Across Models: The effects of tire compounds are consistent across different models, though the magnitude changes slightly when controlling for race phase and stint. In models where race phase and stint are controlled (Models 2 and 3), the coefficients for the compounds decrease slightly, indicating that some of the effect of compounds on lap times is mediated by these factors.

Conclusions

- **Soft and Medium compounds** are generally faster, with the Soft compound being the quickest across all models.
- **Hard compounds** are slower than Soft and Medium but still faster than Intermediate and Wet compounds.
- **Race phase** and **stint** significantly impact lap times, with lap times generally decreasing (getting faster) as the race progresses and as drivers go deeper into a stint.

Table 11. Regression Analysis of Lap Time and Soft, Medium and Hard Compounds.

	(1)	(2)	(3)
Soft Compound	-6.085***	-4.640***	-6.418***
	(-13.45)	(-10.34)	(-14.85)
Medium Compound	-8.181***	-7.126***	-6.567***
	(-21.85)	(-19.18)	(-18.36)
Hard Compound	-7.492***	-5.052***	-2.519***
	(-20.76)	(-13.76)	(-7.01)
Race Phase		-6.308***	-5.340***
		(-35.61)	(-30.66)
Stint			-0.254***
			(-46.60)
Constant	96.24***	108.4***	112.1***
	(289.37)	(230.71)	(240.21)
N	16982	16982	16982

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12. Regression Analysis of Lap Time and Intermediate and Wet Compounds.

	(1)	(2)	(3)
Intermediate Compound	7.547***	5.822***	4.763***
	(21.43)	(16.40)	(13.85)
Wet Compound	10.75***	6.871***	3.699*
	(6.14)	(3.83)	(2.09)
Race Phase		-6.012***	-4.889***
		(-34.57)	(-28.36)
Stint			-0.213***
			(-42.43)
Constant	88.63***	102.0***	105.6***
	(864.05)	(239.73)	(242.57)
N	16982	16982	16982

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 67. Stint and Lap Time for Different Compounds.

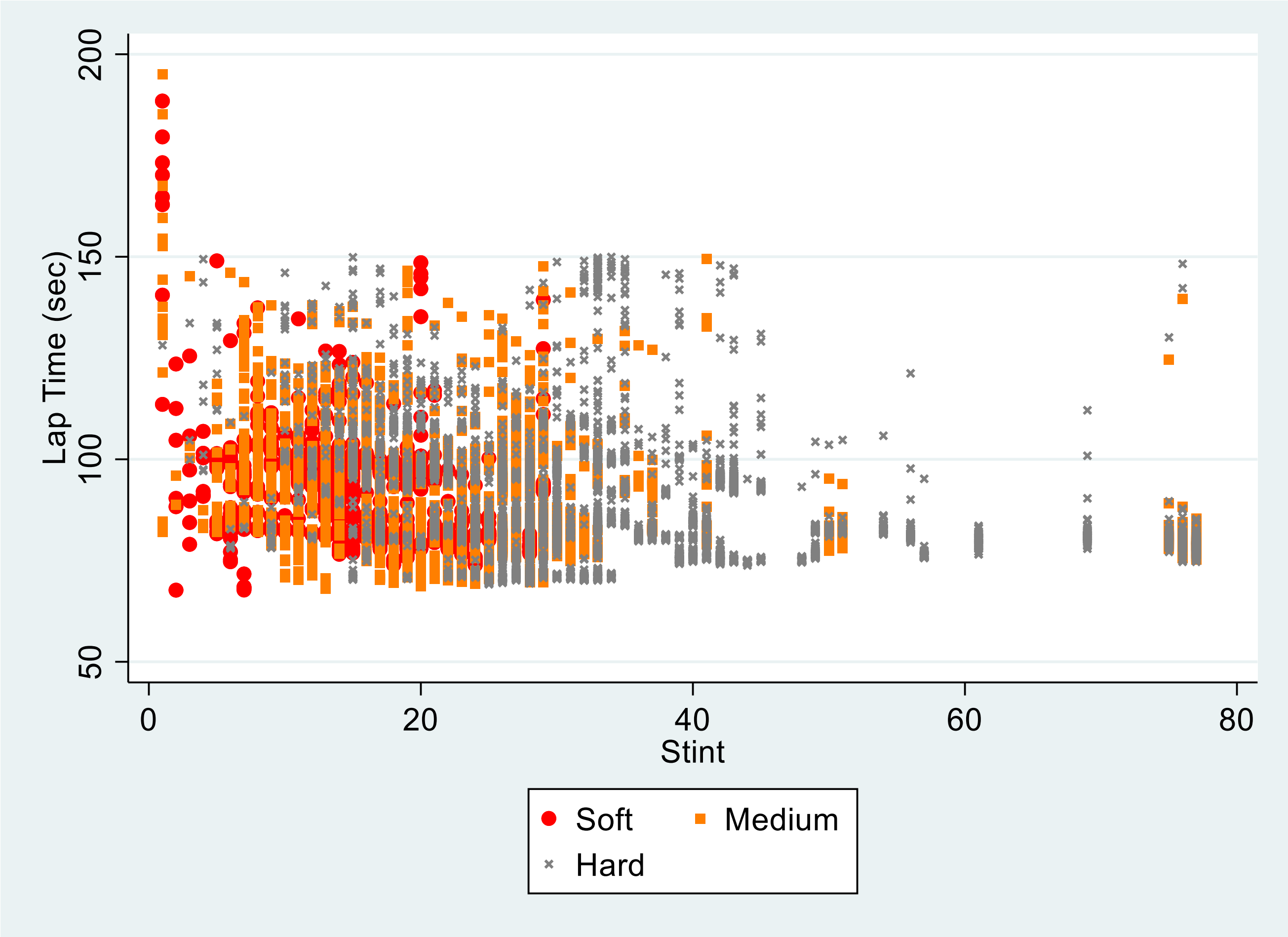
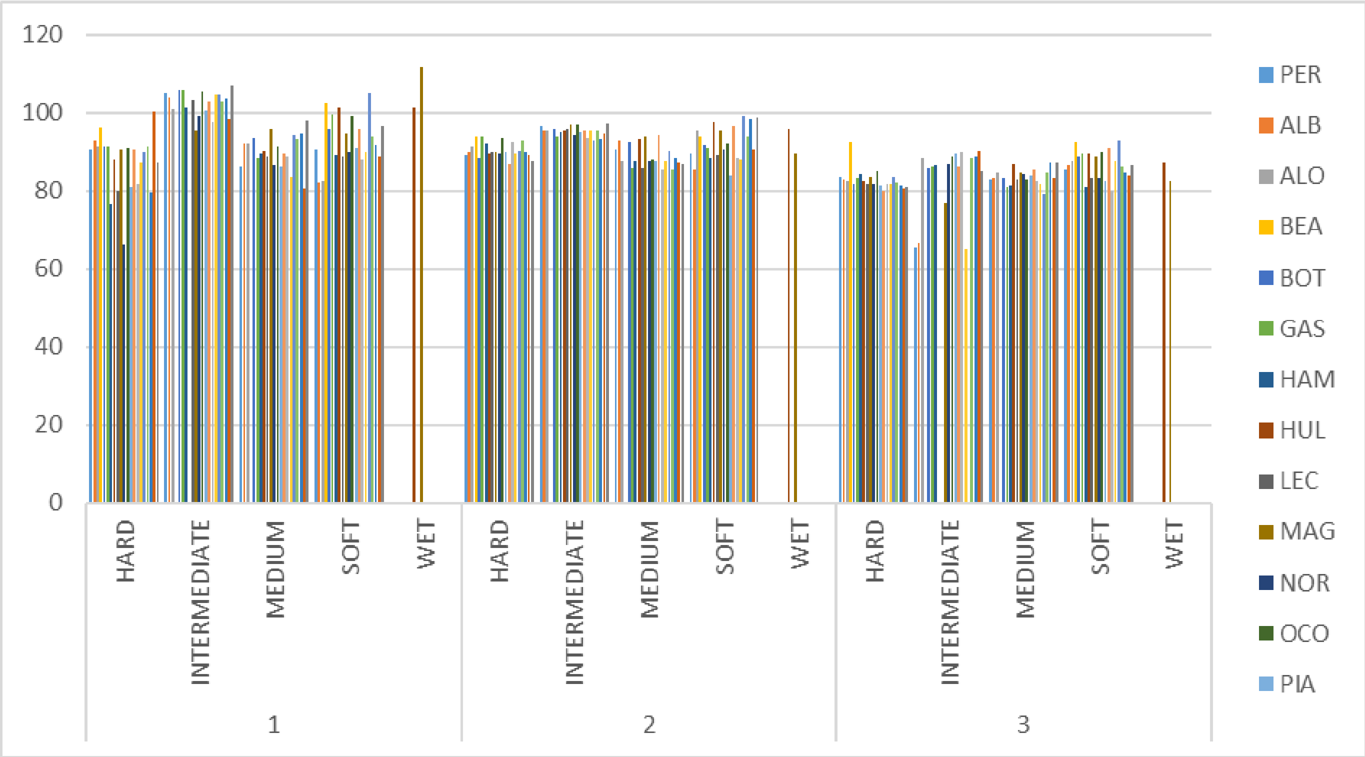


Figure 67 supports our statistical findings. We can see the negative effect of Stint over time, suggesting that as drivers go deeper into a stint (i.e., more laps on the same tires), lap times slightly decrease. Across all compounds, we can see a somewhat U curve where the lap time starts slow, gets quicker in time, and then slows as the stint usage increases. In addition, lap times give a similar result across all compounds for stint.

This analysis suggests that tire selection, combined with race strategy (considering race phase and stint), plays a crucial role in optimizing lap times during a Grand Prix.

Figure 68. Lap Time Averages Divided to Driver, Compounds and Race Phases.



In Figure 68, we see that lap time averages in general decline throughout the race and be the fastest at the end of the race.

Figure 69. Race Phases and Compounds.

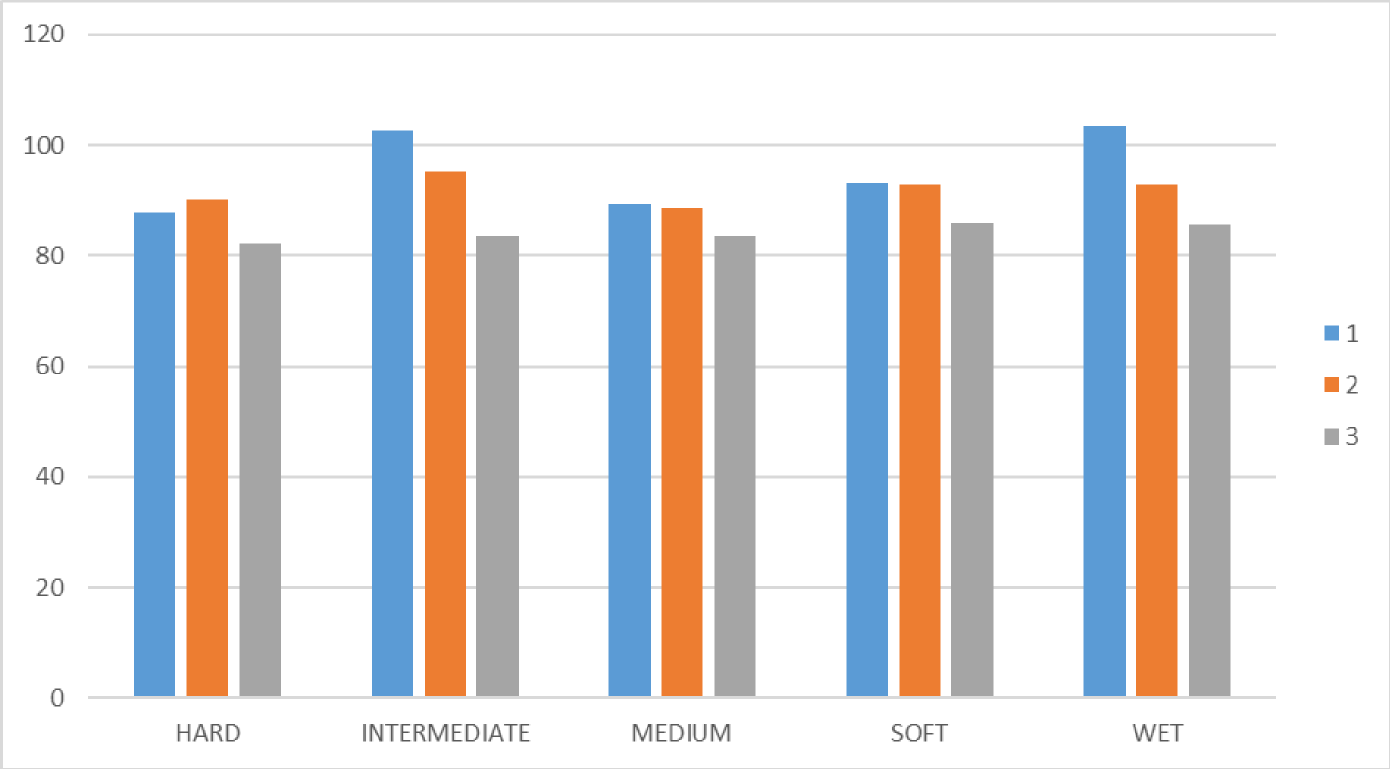


Figure 69 displays that no matter the compound, lap time averages get faster over the course of the race, with the end of the race (Race Phase 3) being the fastest. While this is the case, soft compound tires almost give similar lap time averages for the beginning and middle race phases. Also, hard compound tires get a bit slower during the middle phase of the race.

Figure 70. Lap Time vs Tire Compound.

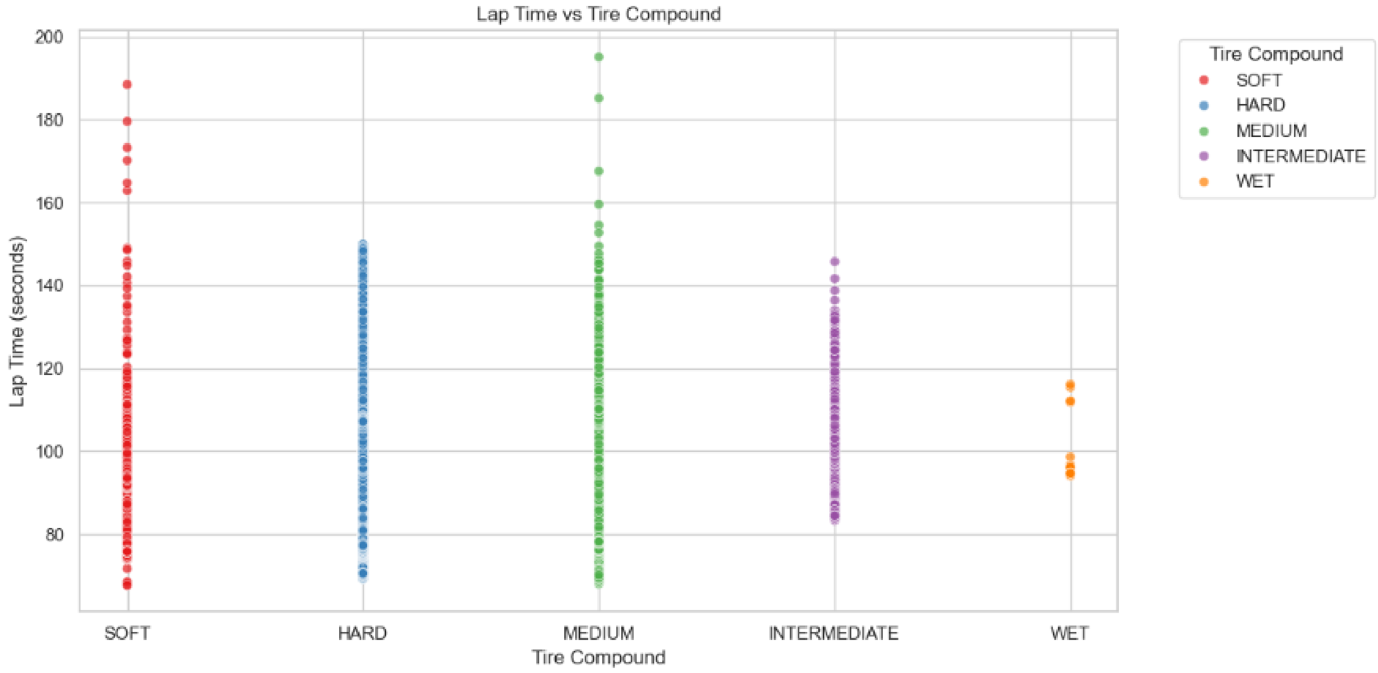


Figure 70 illustrates the relationship between lap times and tire compounds, highlighting how lap times vary with different tire types. Overall, we observe that soft, hard, and medium tire compounds generally yield faster lap times compared to intermediate and wet compounds.

However, when examining the data closely, some points significantly above the general trend can be identified as outliers. These outliers indicate that, under certain conditions, intermediate and wet tire compounds can achieve faster lap times than the others.

To enhance clarity, a threshold of 200 seconds was applied to filter out extreme values, allowing the plot to focus on more relevant lap times. Consequently, any laps exceeding this duration were excluded from the analysis, which may limit the visibility of potential anomalies related to tire performance under challenging race conditions.

Figure 71. Average Lap Time by Tire Compound.

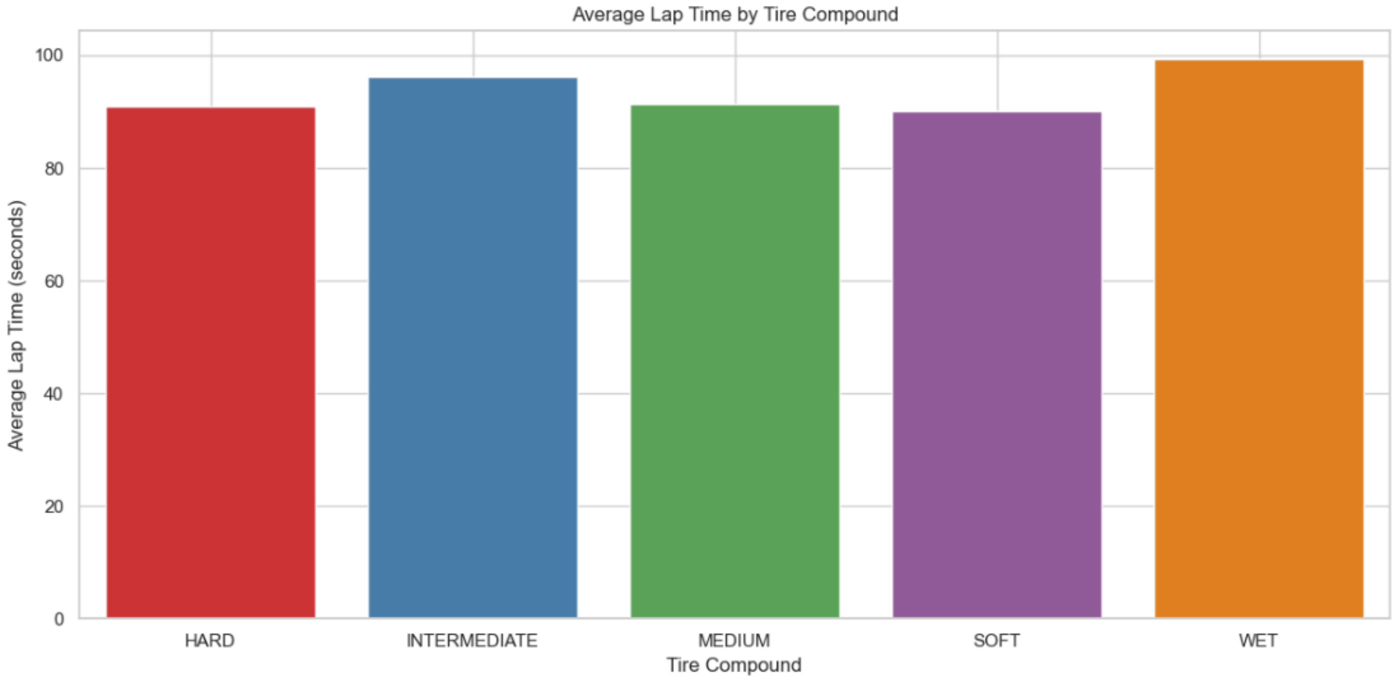


Figure 71 presents the average lap times by tire compounds, revealing significant insights into their performance characteristics. The soft compound consistently exhibits lower average lap times, indicating its superior performance on the track. In contrast, the hard compound also shows relatively low average lap times, suggesting its suitability for the prevailing track conditions.

Conversely, the wet and intermediate compounds display higher average lap times, which is primarily attributed to challenging weather conditions. These results underscore the impact of tire choice on race performance, highlighting the advantages of softer compounds in terms of speed and efficiency while acknowledging the limitations faced in adverse conditions with wet and intermediate tires.

Figure 72. Tire Compound vs Lap Time – Canadian Grand Prix.

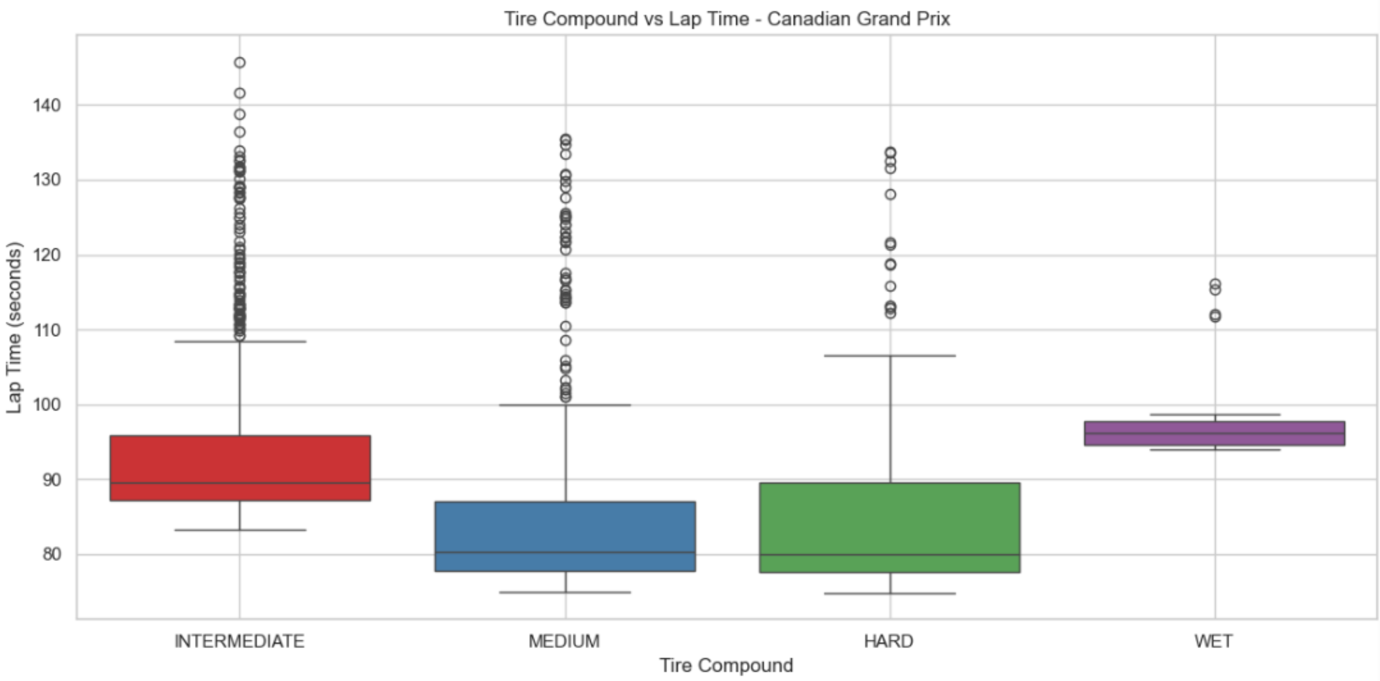


Figure 72 illustrates the lap times from the Canadian Grand Prix categorized by tire compounds, providing valuable insights into their performance. The position of the median line within each box indicates that the medium and hard tire compounds achieved the fastest median lap times during the race.

Additionally, the length of each box reflects the variability in lap times for each tire compound. Shorter boxes indicate greater consistency in lap times, suggesting that the wet tire compound demonstrated more reliable performance compared to the other compounds. This analysis highlights the importance of both speed and consistency in tire strategy during the Canadian Grand Prix, with medium and hard tires excelling in speed and wet tires showcasing stability.

Figure 73. Lap Time by Tire Compound for Each Driver.

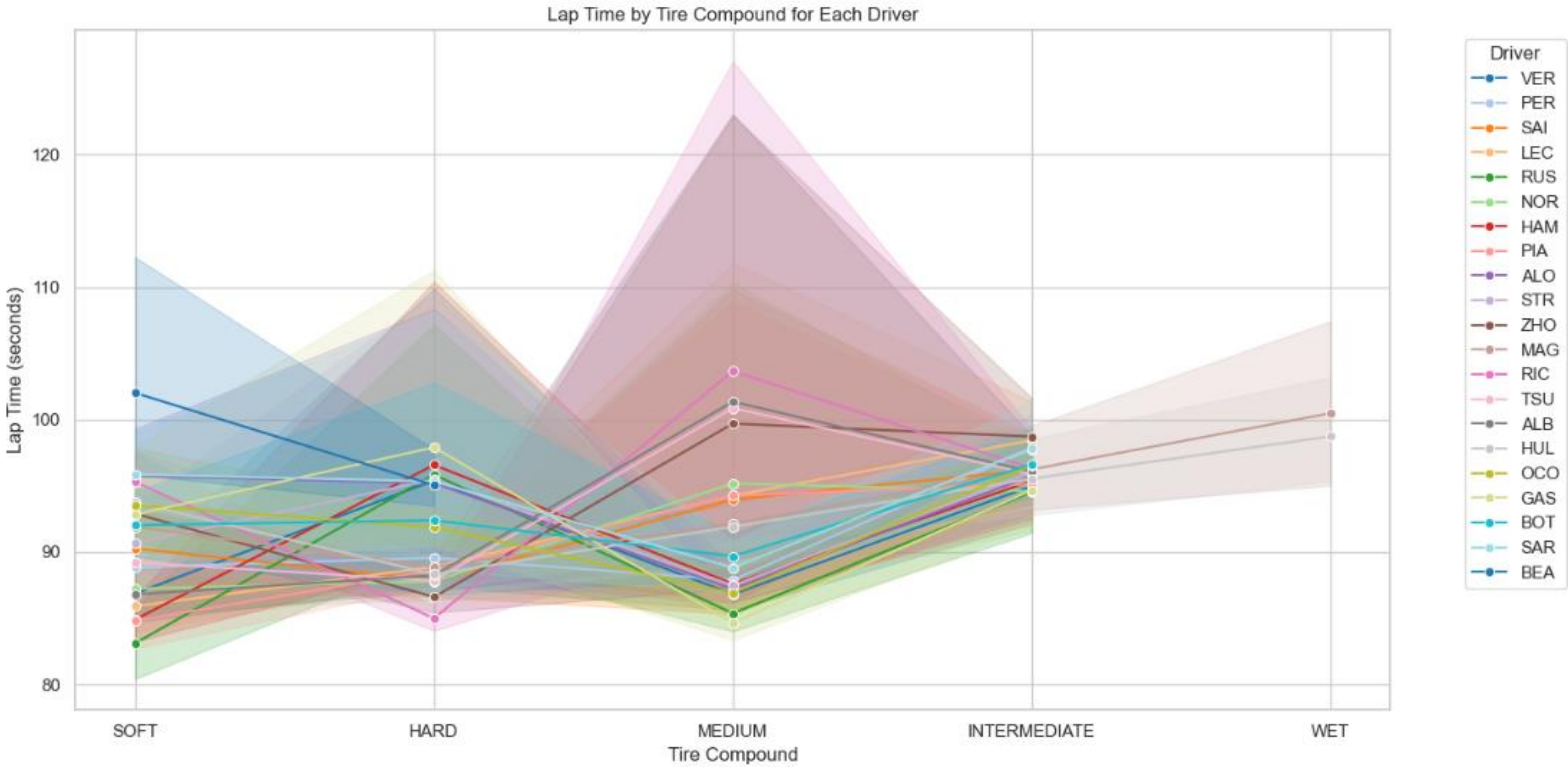


Figure 73 presents lap times categorized by tire compound for each driver, revealing important insights into their performance. A few drivers consistently show lower lap times on the soft, hard, and medium tire compounds, indicating their proficiency with these tires.

The spread of the lines within each tire compound category highlights variability in performance. Notably, the medium tire compound exhibits the widest spread, suggesting greater fluctuations in lap times among drivers when using this compound. In contrast, the shaded areas around the lines indicate the range or distribution of times for each driver, reflecting their consistency or variability. Here, the wet tire compound shows a degree of consistency across drivers, while the medium tire compound is marked by variability, emphasizing the challenges and performance differences that arise from tire choice during the races.

Figure 74. Lap Time by Tire Compound for Each Event.

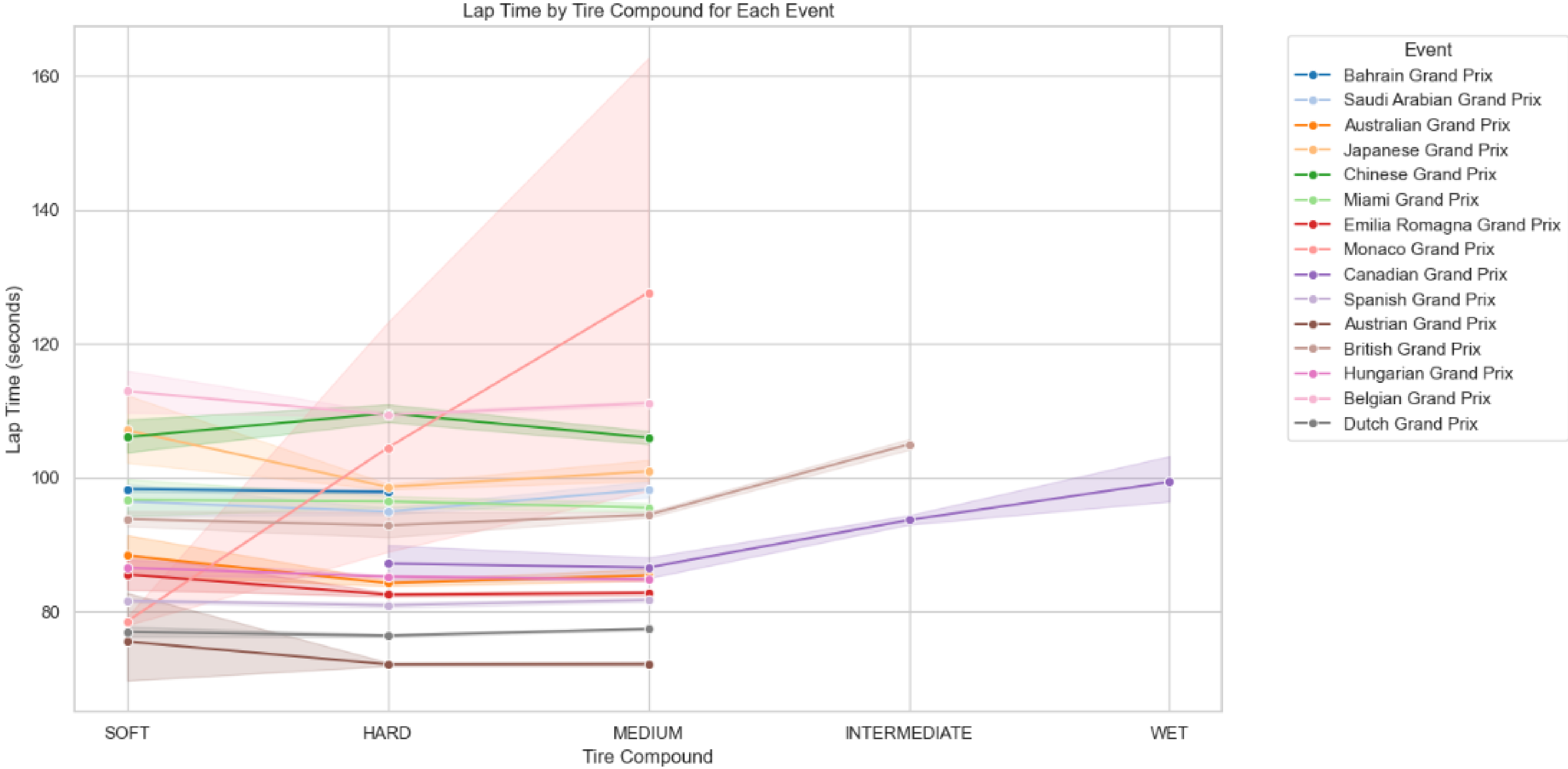


Figure 74 illustrates lap times categorized by tire compound for each event, revealing trends in performance across the season. Most events display consistent lines along the y-axis for soft, hard, and medium tire compounds, suggesting faster or more steady lap times with these tires.

In contrast, the lines representing intermediate and wet tire compounds are positioned higher on the y-axis, indicating slower lap times overall. This trend suggests that drivers generally experience greater difficulty achieving competitive lap times with these compounds, likely due to less optimal conditions or the inherent characteristics of the tires in varying weather scenarios.

Relationship 2: Starting Tire Type vs Final Classification

Correlation between Position and Starting Compound: The correlation between starting compound and final position is slightly negative (-0.0985), suggesting a very weak inverse relationship. This implies that starting with a particular compound has a minimal impact on final race position on average.

Table 13. Finish Position and Starting Compound Correlation.

	Finish Position	Starting Compound
Finish Position	1.0000	
Starting Compound	-0.0985	1.0000

Regression Analysis:

- **Starting on Soft Tires**: Drivers who started on Soft tires tended to finish slightly worse, on average, than those who started on other tires. However, this difference isn't statistically significant, meaning we can't confidently say that starting on Soft tires negatively affects the final position.
- **Starting on Medium Tires**: There was no significant impact on final position for drivers starting on Medium tires. This suggests that starting on Medium tires neither helped nor hurt drivers in a meaningful way.
- **Starting on Hard Tires**: Similar to Soft tires, starting on Hard tires showed a slight tendency for worse finishing positions, but again, the difference isn't significant. This means that starting on Hard tires doesn't seem to strongly influence where a driver finishes.
- **Starting on Intermediate or Wet Tires**: These tires are used in wet or mixed conditions. The analysis compared other tires against these as the baseline, and no significant advantages or disadvantages were found for starting on Intermediate or Wet tires.

Table 14. Regression Analysis of Starting Compound and Finish Position.

	(1)
Soft – Starting Compound	2.381
	(1.70)
Medium – Starting Compound	-0.692
	(-0.53)
Hard – Starting Compound	2.385
	(1.55)
Constant	9.500***
	(7.67)
N	283

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Conclusions:

- **Minimal Impact**: The choice of starting tire compound (whether Soft, Medium, Hard, or wet-weather tires) doesn't appear to have a significant effect on where a driver finishes in the race. This suggests that other factors, like race strategy, driver skill, and car performance, are likely much more important in determining the final outcome.
- **Strategy Over Tires**: While tire choice is certainly important for managing a race, these findings suggest that starting on a particular tire compound alone isn't a game-changer. It's the broader race strategy and execution that play a bigger role in a driver's success.

In Table 15, most of the drivers tend to start with medium compound tires. Overall, almost 65% of starting compound tires include medium compound, with 25% Soft, and almost 10% Hard compound.

Table 15. Starting Compounds of Drivers (Canada excluded because of wet start).

Starting Compounds	**Soft**	**Medium**	**Hard**	**Total**
PER	2	8	3	13
ALB	3	10		13
ALO	5	6	3	14
BEA	1			1
BOT	6	7	1	14
GAS	4	6	2	12
HAM	5	7	2	14
HUL	3	9	1	13
LEC	2	12		14
MAG	3	7	3	13
NOR	2	12		14
OCO	4	9		13
PIA	2	12		14
RIC	4	8	1	13
RUS	2	10	2	14
SAI	2	10	1	13
SAR	4	7	2	13
STR	5	8	1	14
TSU	4	10		14
VER	2	11	1	14
ZHO	4	7	3	14
Grand Total	**69**	**176**	**26**	**271**

Figure 75. Starting Tire Type vs Final Classification.

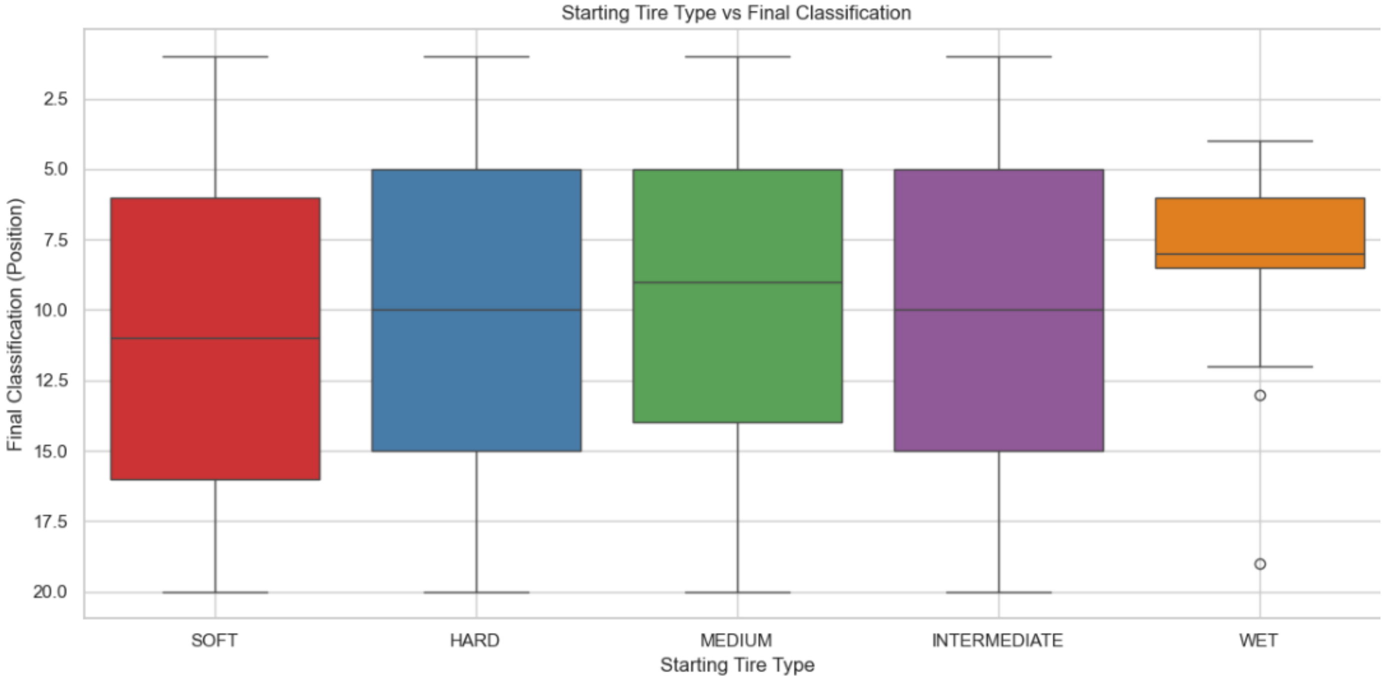


Figure 75 compares the final classification positions achieved by drivers using different tire compounds: soft, hard, medium, intermediate, and wet. The data reveals that the wet tire compound often leads to better final positions, although this outcome is contingent on specific race conditions, such as rain or wet track surfaces.

Following the wet tires, the medium tire compound also shows relatively strong performance, securing better final positions than the soft tires. In contrast, both the hard and intermediate tire compounds yield better final standings compared to the soft compound. Notably, the wet tire compound demonstrates the most consistent performance across events, suggesting its reliability in suitable conditions, while other compounds exhibit more variability in final results.

Figure 76. Starting Tire Type vs Final Classification – Spanish Grand Prix.

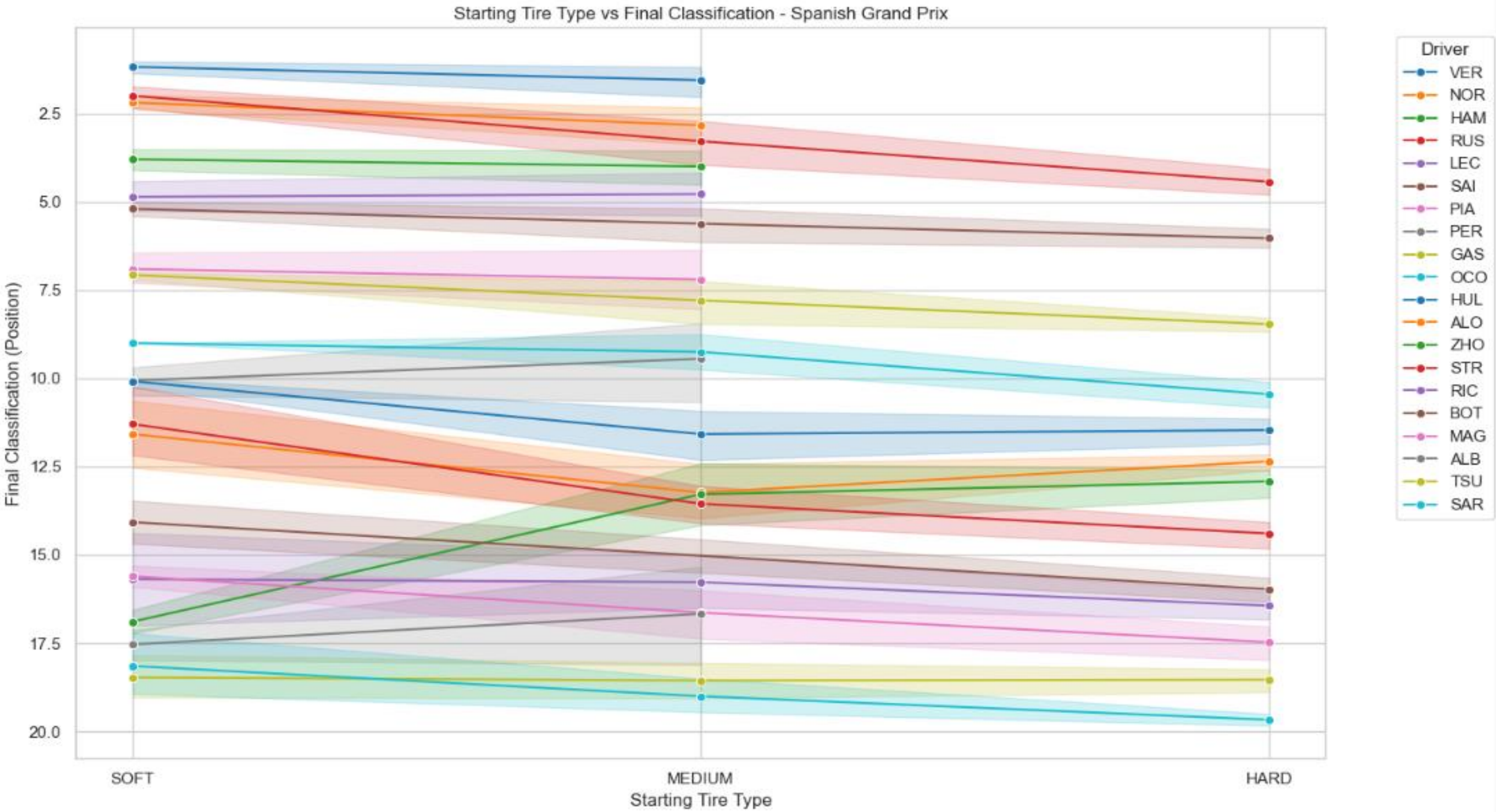


Figure 76 illustrates the impact of different starting tire types on the final race positions of drivers in the Spanish Grand Prix. The data indicates that many drivers who started on soft tires ended the race in higher positions, closer to 1, suggesting that starting with soft tires provided a competitive advantage. Conversely, drivers who began the race on medium and hard tires tended to finish in lower positions, further from 1, indicating that these tire choices may have been disadvantageous in this event. This trend highlights the importance of tire strategy at the start of the race and its potential influence on overall performance.

Figure 77. Starting Tire Type vs Final Classification – HAM.

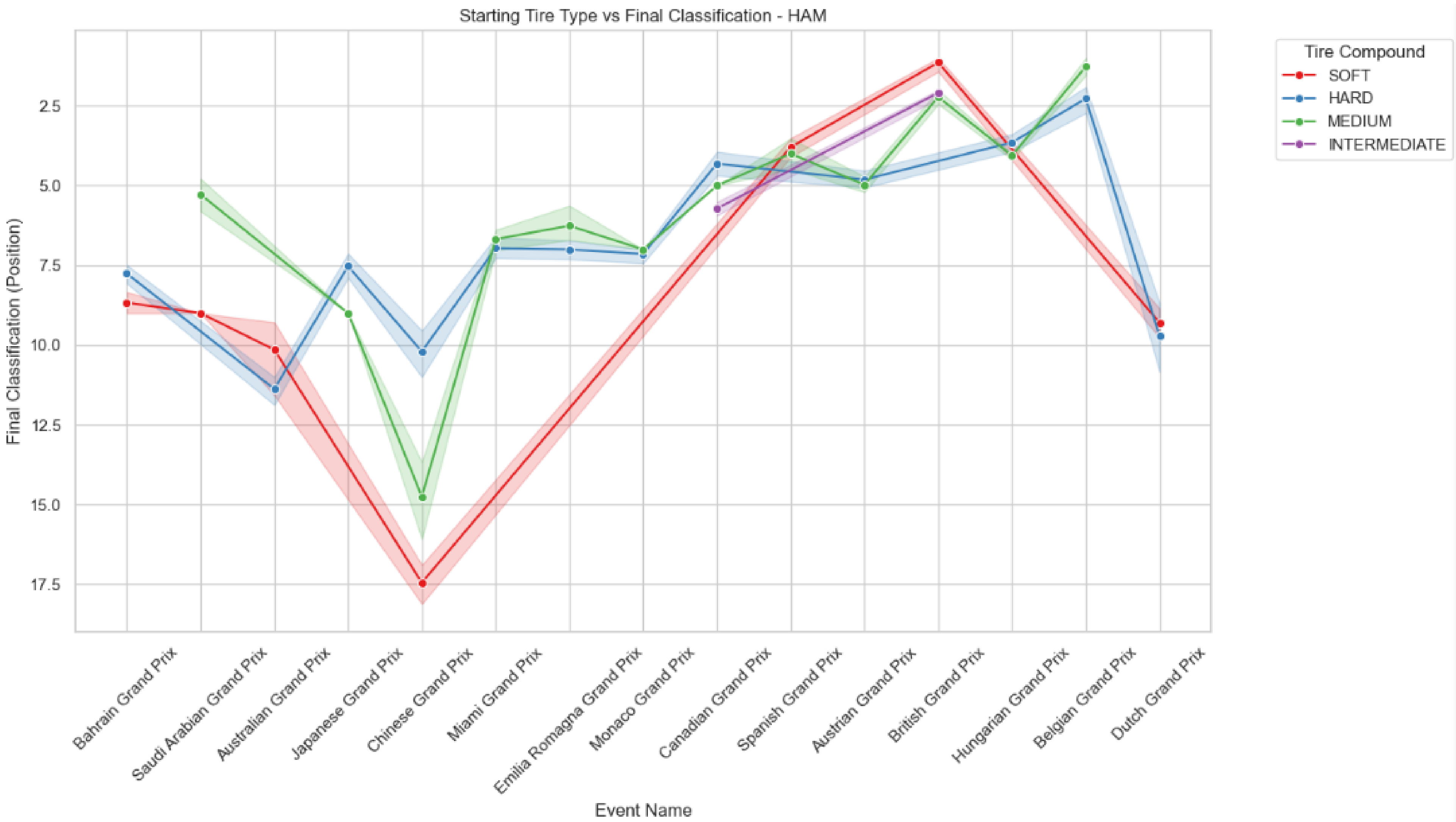


Figure 77 illustrates the final classification positions of Hamilton with different tire compounds (hard, soft, medium, intermediate) across various events. The data indicates that the soft tire compound was disadvantageous for Hamilton in the Chinese Grand Prix, leading to a lower final position. In contrast, the soft tire proved advantageous for him in the British Grand Prix, contributing to a higher classification. This analysis highlights the varying effectiveness of tire compounds depending on the specific race conditions and tracks.

Relationship 3: Number of Laps on a Compound vs Delta Time

Small Positive Correlation: There is a slight, positive relationship between the number of laps driven on a tire and the change in lap time. This means that, generally, as a driver stays on the same set of tires for more laps, their lap times tend to get slightly slower.

Table 16. Delta Time and Tire Life Correlation.

	Delta Time	Tire Life
Delta Time	1.0000	
Tire Life	0.0781	1.0000

Impact of Tire Wear on Lap Times:

The regression analysis shows that as the tires wear down (with more laps), lap times increase slightly. The regression result confirms that for each additional lap on a tire, the lap time gets a bit slower. Although the effect is small, it is statistically significant, meaning it's a consistent pattern across the data.

Specifically, the coefficient for "Tire Life" (0.0429) indicates that for every lap a tire is used, the lap time increases by about 0.04 seconds. While this might seem minor, it can add up over the course of a race.

Starting Point:

The constant term (-0.808) suggests that, on average, lap times might initially decrease slightly (by about 0.8 seconds) at the beginning of a stint, possibly due to the car getting lighter as fuel is burned off. However, as tire wear becomes more pronounced, lap times begin to slow down.

Conclusions:

- **Tires Wear Out Gradually**: As drivers continue to use the same set of tires over multiple laps, their lap times get gradually slower. This slowing down isn't huge, but it is consistent. Tire wear leads to reduced grip, which makes the car slower.
- **Strategic Implications**: Teams and drivers need to balance tire life with performance. Knowing that lap times will slowly get worse as tires wear out helps teams decide when to pit for fresh tires. Timing the pit stops correctly can make a big difference in maintaining competitive lap times.

Table 17. Regression Analysis of Delta Time and Tire Life.

	(1)
Tire Life	0.0429^{***}
	(10.52)
Constant	-0.808^{***}
	(-7.88)
N	16612

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 78. Delta Time and Tire Life.

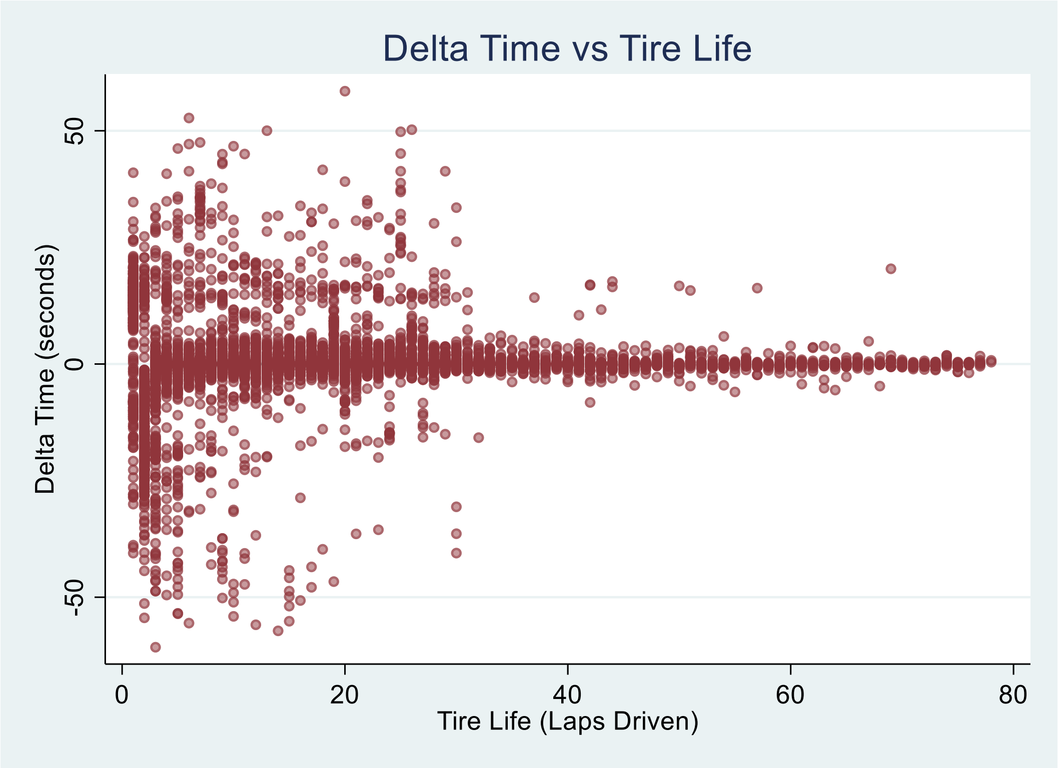


Figure 78 shows that tire wear is a slow and steady process that gradually increases lap times. While the effect might seem small on a lap-by-lap basis, it can significantly impact overall race performance, making tire management and pit stop strategy crucial for success.

Figure 79. Relationship Between Number of Laps and Delta Time by Tire Compound.

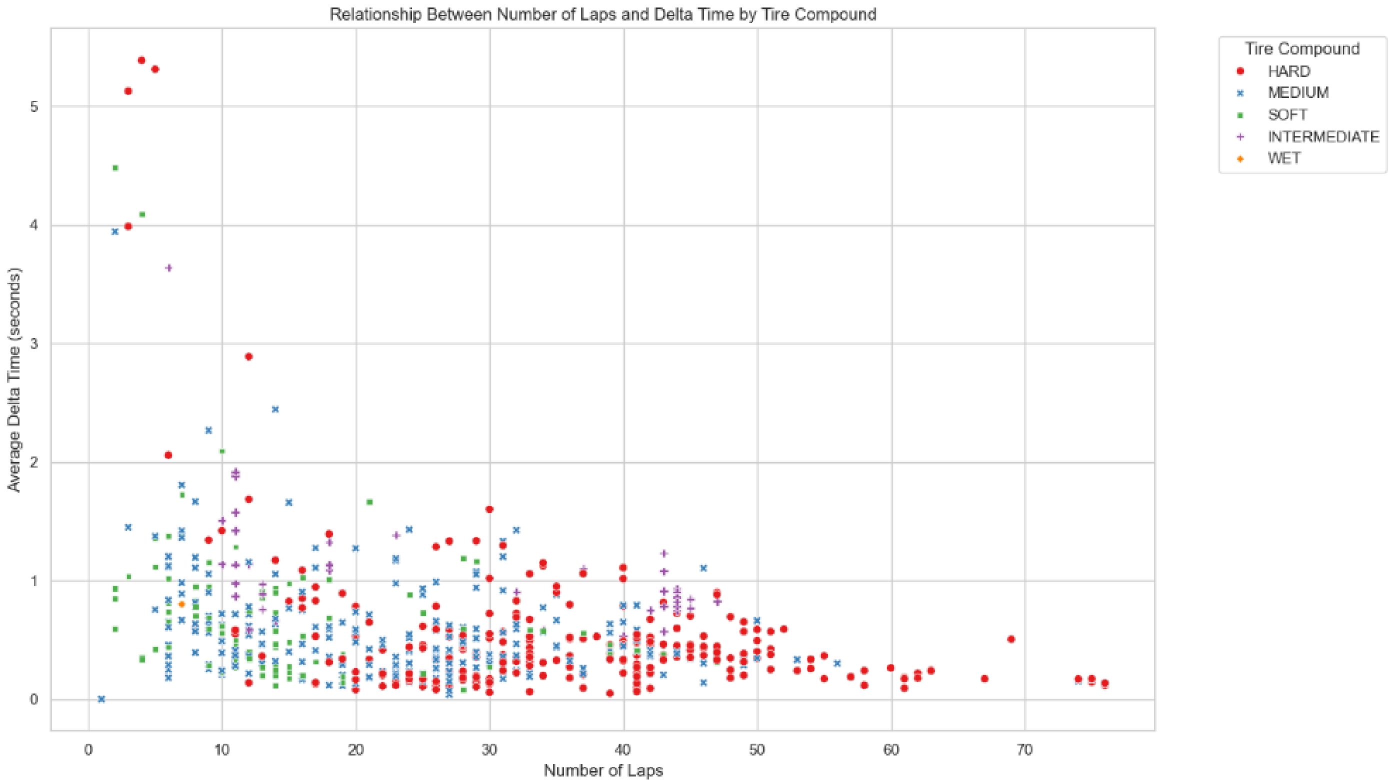


Figure 79 illustrates the performance of different tire compounds over an increasing number of laps. The average delta time generally decreases with more laps, suggesting that tire performance improves over time as drivers adjust to conditions. However, the soft tire (represented by green dots) shows a rapid increase in delta time as the number of laps increases, indicating that soft tires experience quicker degradation and wear out faster compared to other compounds.

Figure 80. Number of laps vs average delta time – Bahrain Grand Prix.

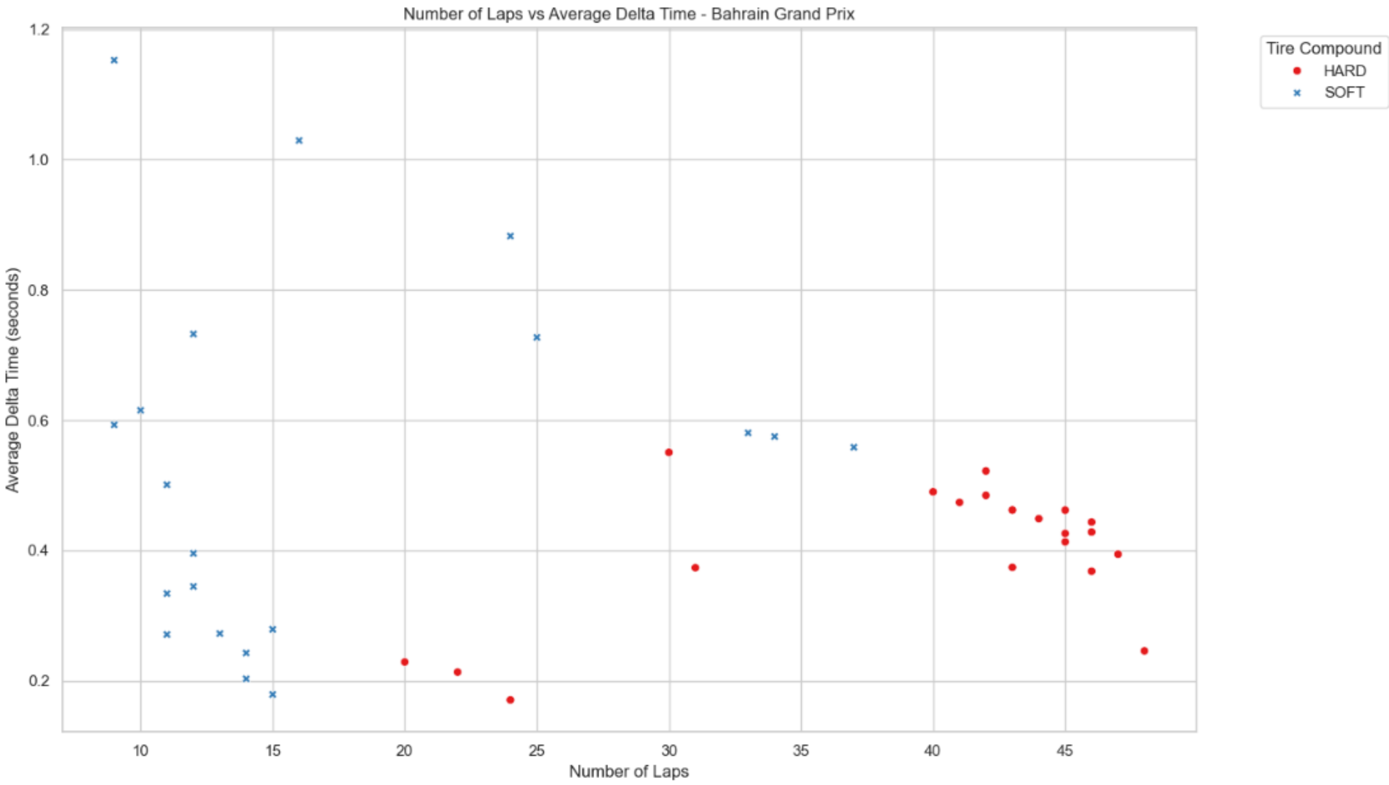


Figure 80 depicts the relationship between average delta time and the number of laps for different tire compounds in the Bahrain Grand Prix. The data shows that the average delta time for both soft and hard tire compounds increases as the number of laps increases, indicating that the performance of both tires degrades over time. Additionally, the red dots representing soft tires exhibit higher delta times at greater lap counts compared to hard compounds, suggesting that soft tires experience faster degradation and loss of performance.

Figure 81. The Average Delta Time Per Tire Compound by Team Across All Events.

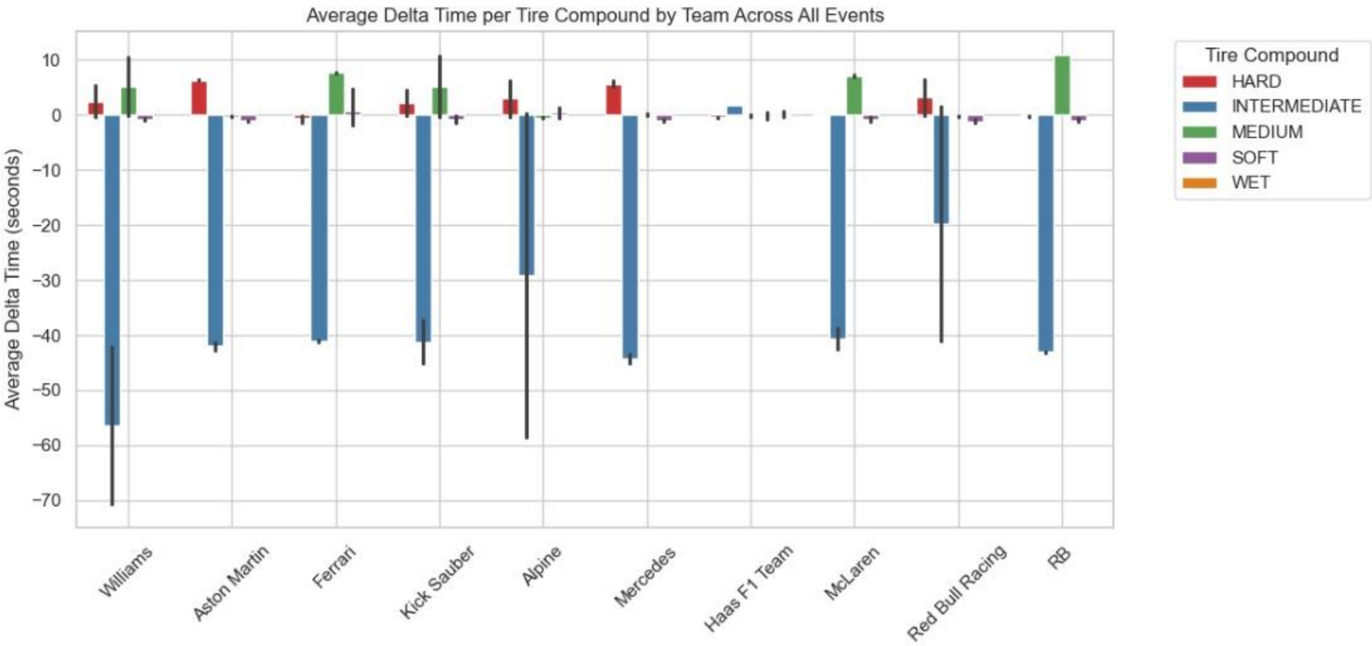


Figure 81 illustrates the average delta time per tire compound by team across all events. The analysis reveals that the intermediate tire compound produces the most significant negative delta time, indicating a notable reduction in lap times and effective performance under suitable conditions. The soft tire compound also shows a reduction in lap times, albeit to a lesser extent compared to the intermediate. Conversely, both hard and medium tire compounds generally lead to increased lap times, suggesting less optimal performance in comparison.

The wet tire compound's impact is limited since it was only utilized during the Canadian Grand Prix, while the intermediate was used in both the British and Canadian Grands Prix. To focus on more commonly used tire compounds, the visualization was subsequently repeated after excluding the intermediate and wet compounds, allowing for a clearer comparison of performance among the remaining tire types.

Figure 82. The Average Delta Time Per Tire Compound by Team Across All Events (Intermediate and Wet Tire Compound Excluded).

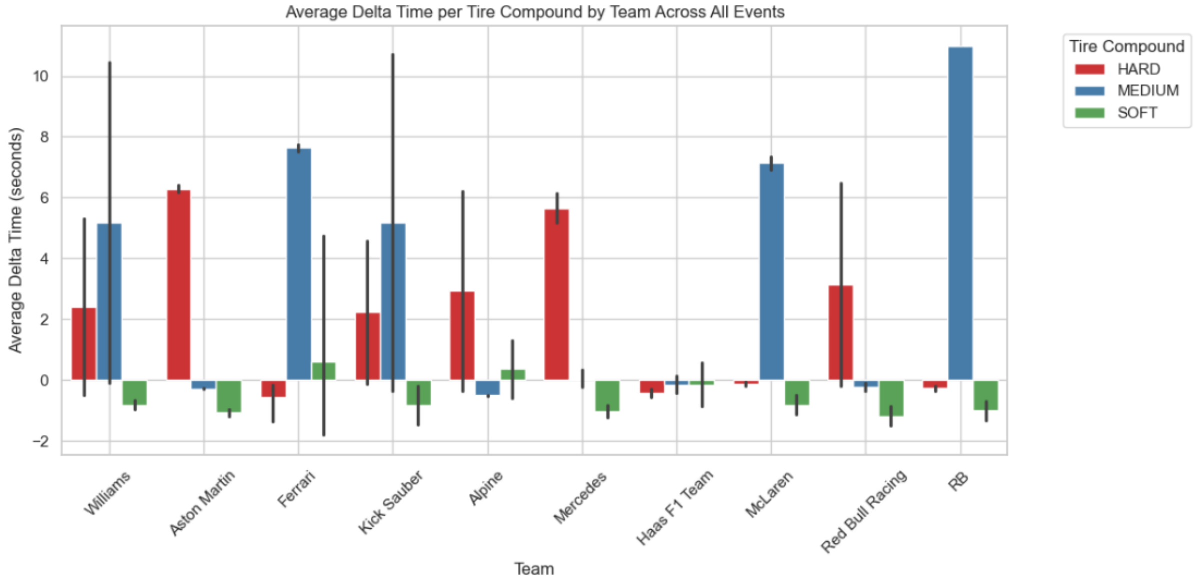


Figure 82 shows the average delta time per dry tire compound, excluding the intermediate and wet compounds, by team across all events. In this case, the green bars (representing the soft tire) display the largest negative delta, indicating that the soft tire compound is generally faster than the hard and medium compounds for most teams.

Relationship 4: Number of Stops vs Final Position

The correlation between the number of pit stops and the final race position is slightly positive (0.0838). This suggests that as the number of pit stops increases, there is a slight tendency for drivers to finish in a worse position. However, this correlation is weak, meaning the relationship is not very strong.

Table 18. Finish Position and Total Pit Correlation.

	Finish Position	Total Pit
Finish Position	1.0000	
Total Pit	0.0838	1.0000

Impact of Number of Pit Stops on Final Position:

The regression coefficient for Total Pit is 0.581. This means that for each additional pit stop, a driver's final position could worsen by about 0.6 places on average. However, the effect is not statistically significant, which means that while there is a general trend, it is not strong enough to draw firm conclusions.

Conclusions:

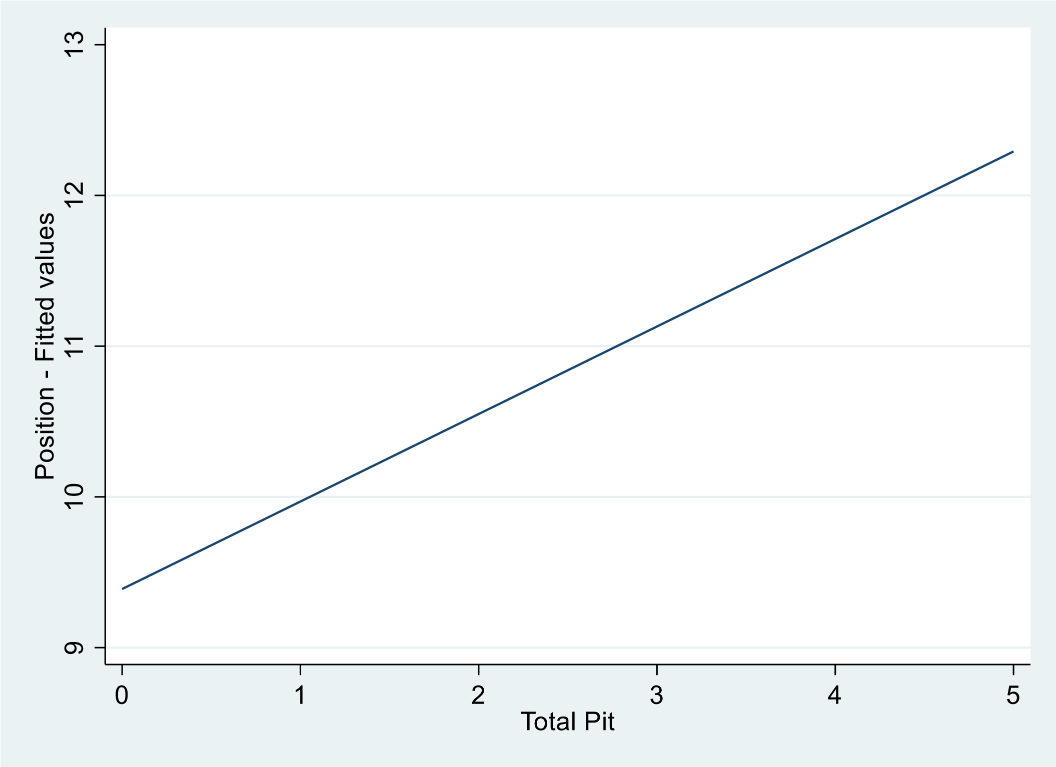
- **More Pit Stops, Slightly Worse Results**: The analysis suggests that making more pit stops during a race is generally associated with slightly worse finishing positions. However, this effect is not very strong, indicating that while pit stops do have some impact, they are not the sole determinant of race outcomes.
- **Strategic Balance**: This weak relationship highlights the importance of pit stop strategy. While fewer pit stops might help save time and improve final positions, it is also essential to consider other factors like tire wear, fuel management, and track conditions. The best strategy often balances the number of stops with maintaining optimal performance on the track.

Table 19. Regression Analysis of Position and Total Pit Count.

	(1)
Total Pit	0.581
	(1.30)
Constant	9.389^{***}
	(10.10)
N	299

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 83. Fitted Prediction Values of Total Pit and Finish Position



The fitted prediction values of Total Pit and Finish Position in Figure 83 shows a positive slope, meaning the more pit stops a driver makes, the higher (worse) their final position tends to be. This visually supports the weak positive correlation found in the data. While making more pit stops can slightly hurt a driver's final position, this effect is not overwhelmingly strong.

Relationship 5: Race Length vs Strategy

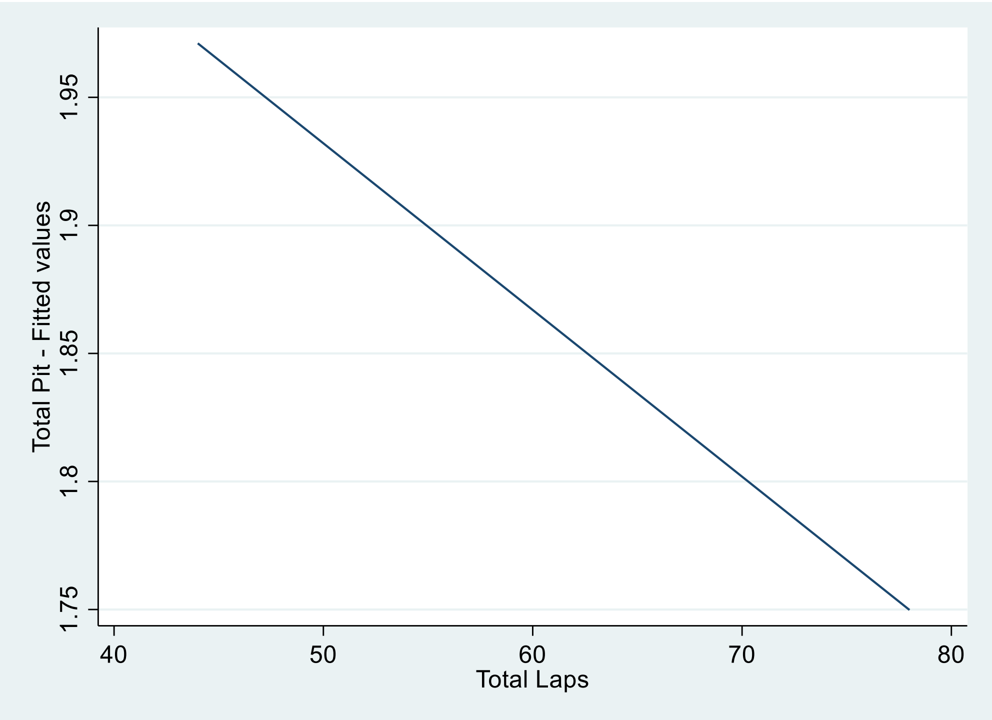
The correlation between the total number of laps in a race and the number of pit stops is slightly negative (-0.0737). This suggests that, on average, longer races are associated with fewer pit stops, but the relationship is very weak.

Table 20. Total Pit and Total Laps Correlation.

	Total Pit	Total Laps
Total Pit	1.0000	
Total Laps	-0.0737	1.0000

The regression analysis and Figure 84 confirms this weak relationship. The coefficient for Total Laps is -0.0065, meaning that for every additional lap in the race, the number of pit stops decreases by a very small amount. This finding is also supported in the predicted fitted values of total pit and total laps in Figure 84. However, this effect is not statistically significant, indicating that race length does not strongly predict the number of pit stops.

Figure 84. Predicted Fitted Values of Total Pit and Total Laps.



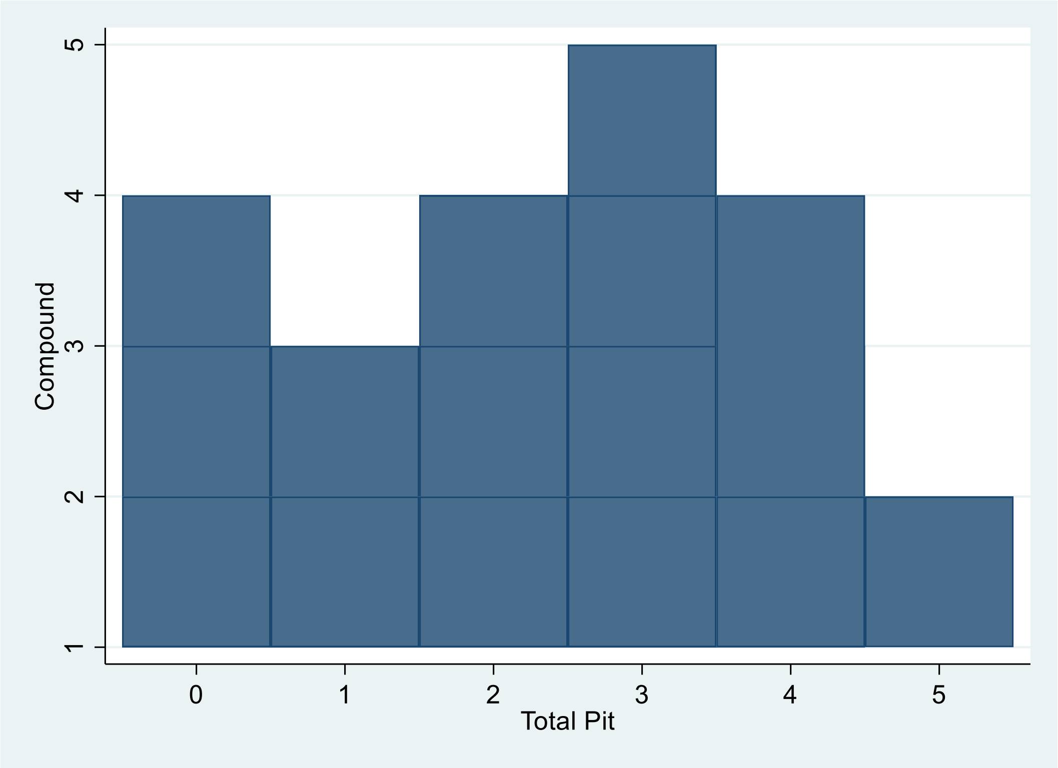
The correlation between race length and the choice of tire compound is virtually zero (0.0037). This means that the total number of laps in a race has almost no effect on the type of tires chosen by teams.

Table 21. Compound and Total Laps Correlation.

	Total Pit	Total Laps
Total Pit	1.0000	
Total Laps	0.0037	1.0000

In Figure 85, where tire compound goes from Soft to Wet, we see that in the case of weather change and with rain, more pit stops are expected.

Figure 85. Box Plot of Compound and Total Pit.



The ordered logistic regression (Model 2) and Figure 85 further confirm this. The coefficient for Total Laps is -0.0012, indicating a negligible and statistically insignificant relationship between race length and tire choice. The choice of tire compound does not seem to depend on the length of the race.

Table 22. Regression and Order Logistic Regression Analyses of Total Pit and Compound with Total Laps.

	(1) Total Pit	(2) Compound
Total Laps	-0.00651 (-1.24)	-0.00122 (-0.11)
Constant	2.257*** (6.92)	
Total Laps Cut 1		-2.385*** (-3.42)
Cut 2		0.0126 (0.02)
Cut 3		2.459*** (3.60)
Cut 4		5.623*** (4.91)
N	299	299

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The weak and statistically insignificant relationships suggest that race length does not play a major role in determining either the number of pit stops or the tire compounds used.

Table 23. Total Pit Stops and Mean Lap Times.

Total Pit Stops	Mean Lap Time
0	80.31317
1	88.21473
2	89.08455
3	92.8238
4	95.67761
5	84.49362
Total Average	**89.11492**

The summary of average lap times based on the number of pit stops reveals several insights.

1. **Performance Trends**: As the number of pit stops increases, the average lap time also tends to increase. Drivers with no pit stops have the fastest average lap time at approximately 80.31 seconds, while those with four pit stops have the slowest average lap time at about 95.68 seconds. This trend suggests that frequent pit stops may negatively impact overall race performance.
2. **Optimal Strategy**: The data highlights the potential importance of a balanced pit stop strategy. While a single pit stop results in a relatively low average lap time (88.21 seconds), two stops lead to a slight increase (89.08 seconds). It may indicate that drivers are finding an optimal point with one pit stop to maintain competitiveness without compromising their lap times significantly.
3. **Variability in Performance**: The average lap time for drivers with three and five pit stops (92.82 and 84.49 seconds, respectively) indicates variability, suggesting that external factors (like tire wear, traffic, or strategy decisions) could be influencing performance in these cases.

Conclusions:

- **Race Length's Limited Role**: The total number of laps in a race does not significantly influence how many times a driver will pit or which tires they will use. This suggests that teams consider many other factors when making these decisions, and race length alone is not a strong determinant.
- **Strategy Over Simplicity**: The findings indicate that pit stop strategies and tire choices are complex and tailored to specific circumstances rather than being straightforward responses to how long a race is.

While one might expect longer races to lead to more pit stops or specific tire choices, the data shows that race length does not have a significant impact on these strategic decisions.

Bonus: Monaco Grand Prix

Significance of the Monaco Grand Prix

The Monaco Grand Prix is one of the most prestigious and challenging races in Formula 1, known for its narrow streets, tight corners, and lack of overtaking opportunities. These characteristics make strategy, particularly tire choice, pit stops, and starting position, crucial to achieving a good result. Given Monaco's unique attributes, these factors often play a more significant role here than in other races.

In this analysis, the first lap was excluded due to a significant crash in the 2024 Monaco Grand Prix, which led to a red flag stopping the race for nearly an hour, although the race timer continued. This incident could have skewed the data, making it unrepresentative of normal race conditions.

Selected Attributes and Their Relationships

1. **Tire Compound Choice vs Final Classification:**

Monaco is a low-degradation track due to its relatively short, low-speed layout. However, given the difficulty of overtaking, tire strategy becomes crucial, particularly the choice of starting tire and pit stop timing. Teams may opt for softer compounds to maximize grip and lap times, but the durability of the tires also becomes a concern. A critical decision for teams is whether to start on Soft, Medium, or Hard compounds, as track position is key.

Monaco may see most drivers start on Soft tires, given the importance of grip off the line and through tight corners. Drivers who manage to make the Soft compound last longer without a pit stop may gain an advantage in track position.

The correlation between starting tire compound and final position (0.3539) suggests a moderate relationship. The regression analysis and Figure 86 shows that starting on a harder compound is associated with a worse finishing position (coefficient = 3.261, significant at $p < 0.001$).

Table 24. Starting Compound and Finish Position Correlation.

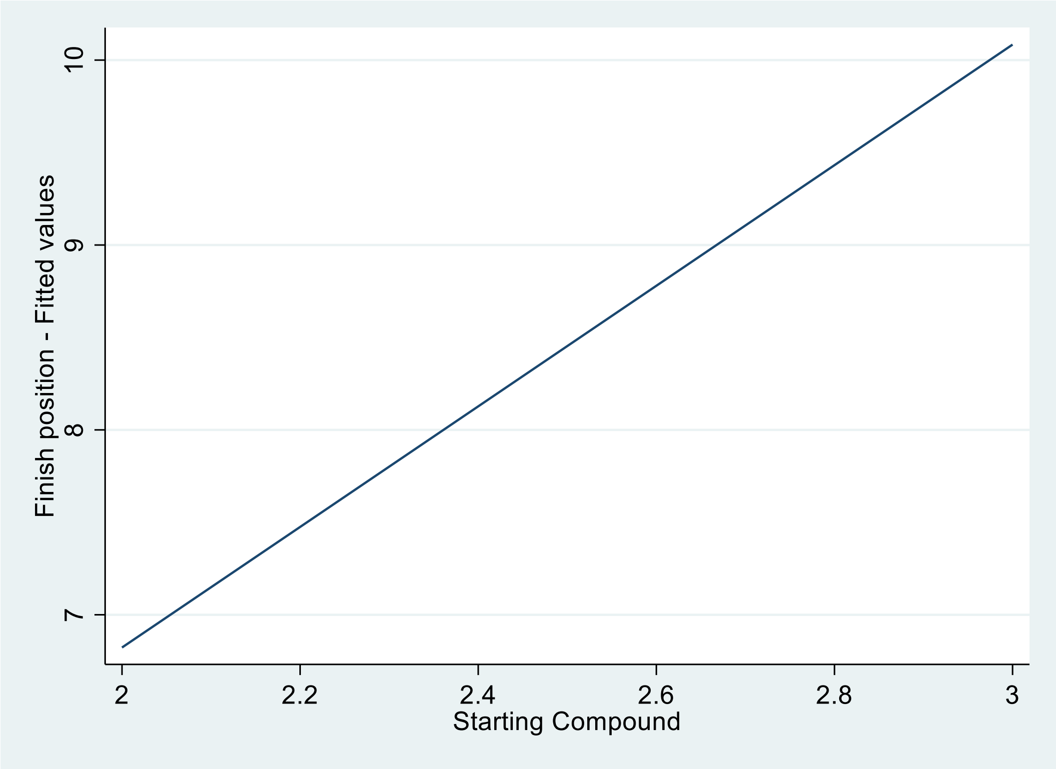
	Starting Compound	Finish Position
Starting Compound	1.0000	
Finish Position	0.3539	1.0000

Table 25. Regression Analysis of Starting Compound and Finish Position.

	(1) Finish Position
Starting Compound	3.261^{***}
	(13.28)
Constant	0.302
	(0.46)
N	1233

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 86. Predicted Fitted Values of Starting Compound and Finish Position.



Below is a more detailed interpretation of the lap time data for different tire compounds when using fresh tires during the 2024 Monaco Grand Prix.

Soft Compound

- Average Lap Time: 78.56 seconds
- Standard Deviation: 1.89 seconds
- Laps Analyzed: 34 laps
- Range: 74.72 to 85.30 seconds

The Soft Compound tires are associated with the fastest average lap times and the least variability. With a narrow range of lap times and a low standard deviation, this compound shows consistent performance. This consistency suggests that drivers on fresh Soft tires were able to maintain high speed with minimal degradation, making it an ideal choice for short stints where maximum grip is crucial.

Medium Compound

- Average Lap Time: 129.91 seconds
- Standard Deviation: 343.60 seconds
- Laps Analyzed: 290 laps
- Range: 75.23 to 2526.25 seconds

The Medium Compound displays a significantly higher average lap time and an extremely wide range of times, with a very high standard deviation. This suggests that while Medium tires can perform well under normal conditions, the large variability indicates that some laps were likely affected by external factors such as safety cars, traffic, or possibly even damage to the car. The high maximum lap time also hints at potential incidents on the track where cars may have been significantly slowed down or stopped temporarily.

Hard Compound

- Average Lap Time: 119.90 seconds

- Standard Deviation: 308.73 seconds
- Laps Analyzed: 302 laps
- Range: 74.73 to 2521.75 seconds

The Hard Compound shows a slightly better average lap time than the Medium Compound, but it still has a substantial standard deviation and a wide range of times. Like the Medium Compound, the high variability indicates that while the Hard tires may offer durability, their performance can be unpredictable under different race conditions. The high upper range suggests that some laps were likely affected by external disruptions or extensive tire wear.

The data reveals that fresh Soft Compound tires provide the most reliable and fastest lap times, making them a preferred choice for aggressive strategies where immediate speed is critical. The Medium and Hard compounds, while potentially more durable, show much greater variability in lap times. This could be due to their use in longer stints where tires undergo more wear, or it could reflect interruptions like safety cars, pit stops, or race incidents.

The significant variation in lap times for Medium and Hard compounds indicates that race strategies involving these tires must account for the potential impact of external factors more carefully. Teams might opt for these compounds when aiming for longer stints, but they need to be prepared for the higher risk of variable performance.

To compare it, here is a comparison of lap times for different tire compounds when using used tires during the 2024 Monaco Grand Prix:

Soft Compound

- Observations: 0 laps.
- Analysis: There are no recorded lap times for the Soft Compound when the tires were used, indicating that teams may have opted not to run this compound in worn condition. This absence could suggest a strategic choice to avoid the performance drop associated with older Soft tires, which may struggle significantly on the challenging Monaco circuit.

Medium Compound

- Average Lap Time: 122.11 seconds
- Standard Deviation: 308.81 seconds
- Laps Analyzed: 118 laps
- Range: 77.94 to 2468.04 seconds

The Medium Compound shows an average lap time of 122.11 seconds, with a very high standard deviation. This indicates considerable variability in lap times, likely due to factors such as tire degradation, driver performance inconsistencies, and possible race incidents. The wide range (from 77.94 to an extremely high 2468.04 seconds) suggests that while some laps were relatively quick, others were heavily impacted by external disruptions, such as crashes or mechanical issues.

Hard Compound

- Average Lap Time: 94.82 seconds
- Standard Deviation: 190.97 seconds
- Laps Analyzed: 482 laps
- Range: 74.17 to 2513.18 seconds

The Hard Compound has a significantly faster average lap time of 94.82 seconds compared to the Medium Compound. The lower average lap time, combined with a smaller standard deviation, indicates that the Hard tires were generally more consistent in their performance when worn. This could reflect their durability and ability to maintain competitive lap times even after multiple laps. However, the high maximum lap time also points to potential disruptions affecting some laps.

Performance on Used Tires: The lack of data for the Soft Compound suggests teams likely reserved it for short stints when fresh to maximize grip and performance, rather than risking poor performance on worn tires. Conversely, both the Medium and Hard compounds were utilized, with the Hard Compound outperforming the Medium in terms of average lap time and consistency.

Variability: The significant standard deviation in both used tire compounds suggests that while the Hard Compound provided more reliable performance, the Medium Compound's wide variability could have been influenced by external race factors, possibly making it less reliable in a critical race like Monaco.

Strategy Implications: The analysis indicates that teams may favor the Hard Compound for longer stints or conditions where tire wear is a concern, given its better average performance under used conditions. The Medium Compound, while useful, appears to carry more risk in terms of performance consistency.

Monaco's narrow and twisty circuit favors softer tires for better grip and agility, making tire choice critical. Starting on softer compounds could provide a performance edge, but harder compounds may be used by teams aiming to avoid early pit stops, impacting their final classification negatively.

In the context of the Monaco Grand Prix, where tire strategy is vital due to the circuit's unique characteristics, the data underscores the importance of choosing the right tire compound and the timing of pit stops. The absence of Soft Compound usage on worn tires reinforces the need for teams to maximize their performance through strategic tire management, especially on a challenging track where maintaining position is crucial.

2. **Number of Pit Stops vs Finishing Position:**

Pit stop timing can make or break a race at Monaco, especially with limited chances for overtaking. A well-timed undercut or overcut can help gain track position, but teams also need to minimize the number of pit stops due to the difficulty of recovering lost positions. Analyzing the total number of pit stops and pit stop timing will reveal which strategies were effective in keeping track position or gaining advantages.

Since overtaking is tough at Monaco, expect fewer pit stops for drivers, especially those leading the race. A one-stop strategy will likely be the most common and successful.

A strong positive correlation (0.5670) between the number of pit stops and finishing position indicates that more pit stops generally result in a worse finishing position. The regression analysis supports this, with each additional pit stop increasing the finishing position by 4.3 places (significant at $p < 0.001$). It is evident in Figure 87 that making more pit stops leads to lower finish positions.

Table 26. Total Pit and Finish Position Correlation.

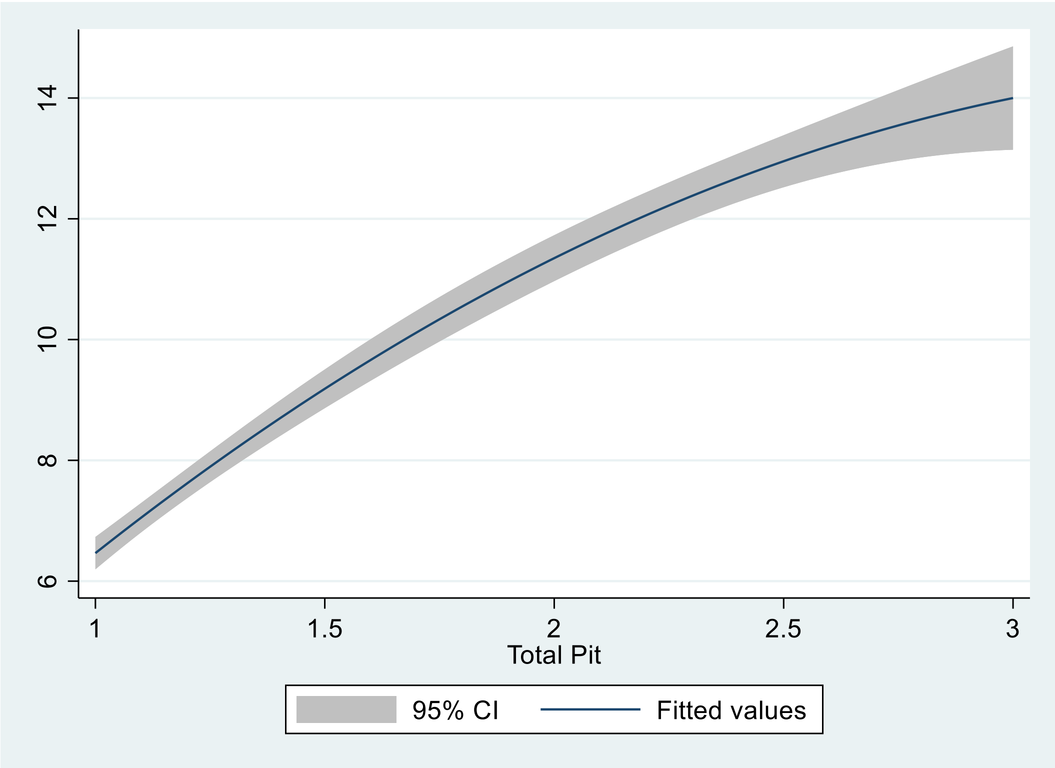
	Total Pit	Total Laps
Total Pit	1.0000	
Total Laps	0.5670	1.0000

Table 27. Regression Analysis of Total Pit and Finish Position.

	(1) Finish Position
Total Pit	4.300***
	(0.14)
Constant	2.279***
	(0.24)
N	1217

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 87. Predicted Fitted Values of Total Pit and Finish Position.



In Monaco, where track position is paramount due to limited overtaking opportunities, making fewer pit stops is often critical to success. Each pit stop can drop a driver several positions, especially on a track where recovering lost ground is difficult.

3. **Average Lap Time vs Tire Compound:**

Due to Monaco's unforgiving layout, driver consistency plays a major role. Mistakes in cornering, managing tires, or braking can have a major impact. By examining drivers' lap times and lap time deltas, we can assess who manages the narrow, twisty circuit best over long stints.

Consistent drivers who avoid mistakes through Monaco's narrow streets will perform better over longer stints. We would normally expect lower lap time deltas for top drivers like Verstappen or Leclerc, with tire degradation playing a lesser role compared to track management.

Table 28. Lap Time and Compound Correlation.

	Lap Time	Compound
Lap Time	1.0000	
Compound	-0. 0340	1.0000

Table 29. Regression Analysis of Lap Time and Compound.

	(1) Lap Time
Compound	-0.325
	(-1.26)
Constant	80.86***
	(116.69)
N	1210

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The correlation between lap time and tire compound is weak (-0.0340), and the regression analysis indicates that tire compound has a negligible and statistically insignificant effect on lap time (coefficient = -0.325). The Figure 88 also shows a weak relationship between lap time and tire compound in Monaco.

Figure 88. Predicted Fitted Values of Lap Time and Compound.

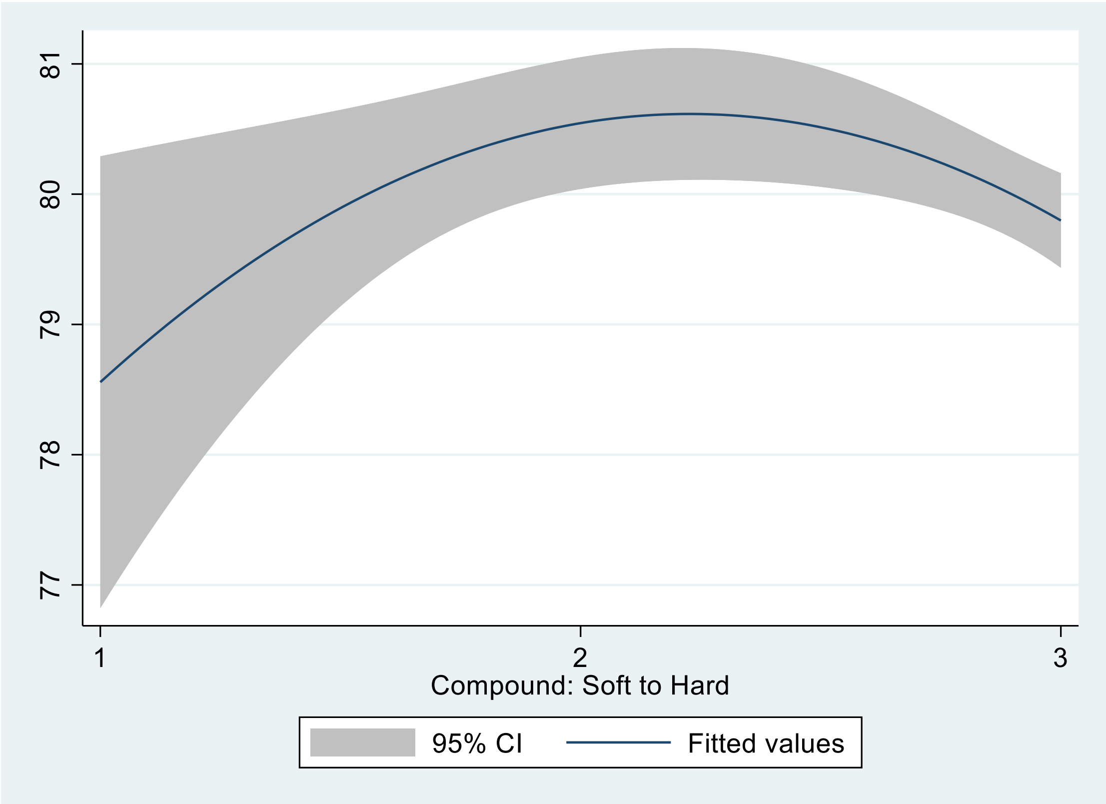
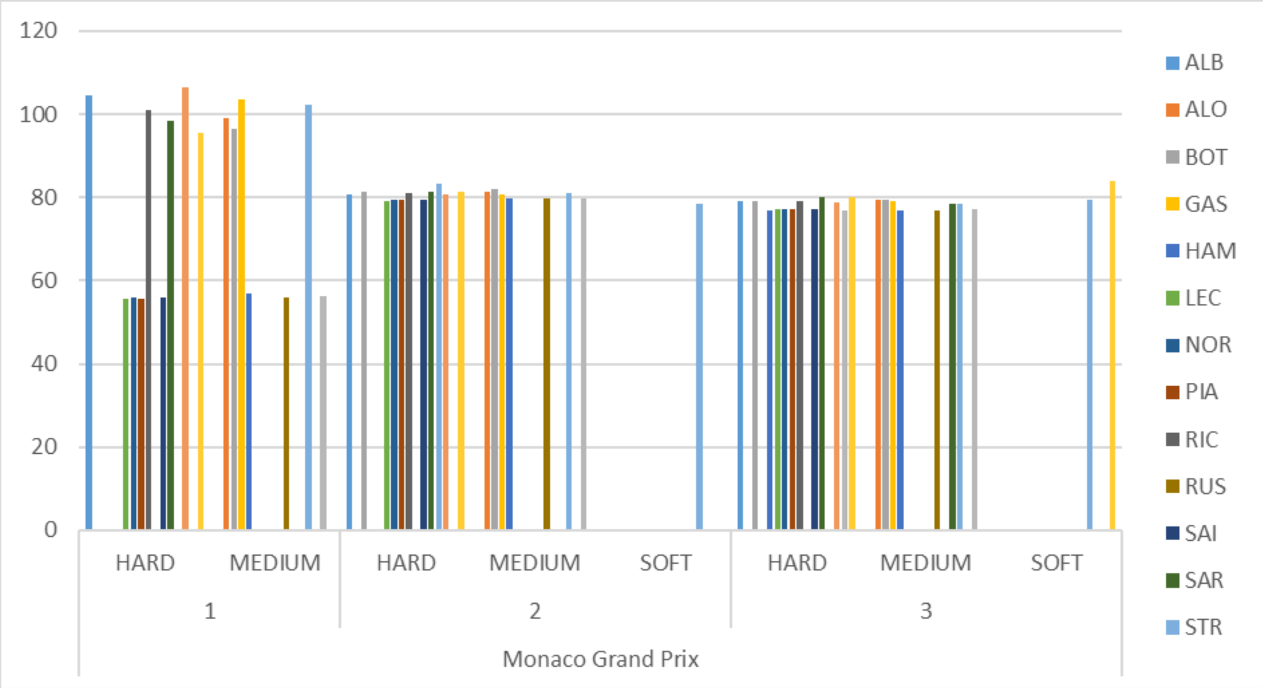


Figure 89. Compound Choices by Race Phases.



As shown in Figure 89, in the beginning phase of Monaco Grand Prix, none of the drivers opt soft compound. Most of the drivers decided to go with hard and medium compounds throughout the race.

4. Starting Position vs Final Position:

Given the difficulty of overtaking, qualifying position at Monaco has a significant impact on race outcomes. Starting near the front can be key to winning the race, with very few opportunities for those starting further back to make their way through the field.

The relationship between starting position and final classification will be tight, with top finishers likely starting in the top 5. Track position matters more than tire choice in some cases.

A very strong correlation (0.9734) between grid position and final position indicates that starting near the front is crucial to finishing well. The regression analysis and Figure 90 confirms this, with starting position almost perfectly predicting finishing position (coefficient = 0.947, significant at $p < 0.001$).

Table 30. Grid Position and Finish Position Correlation.

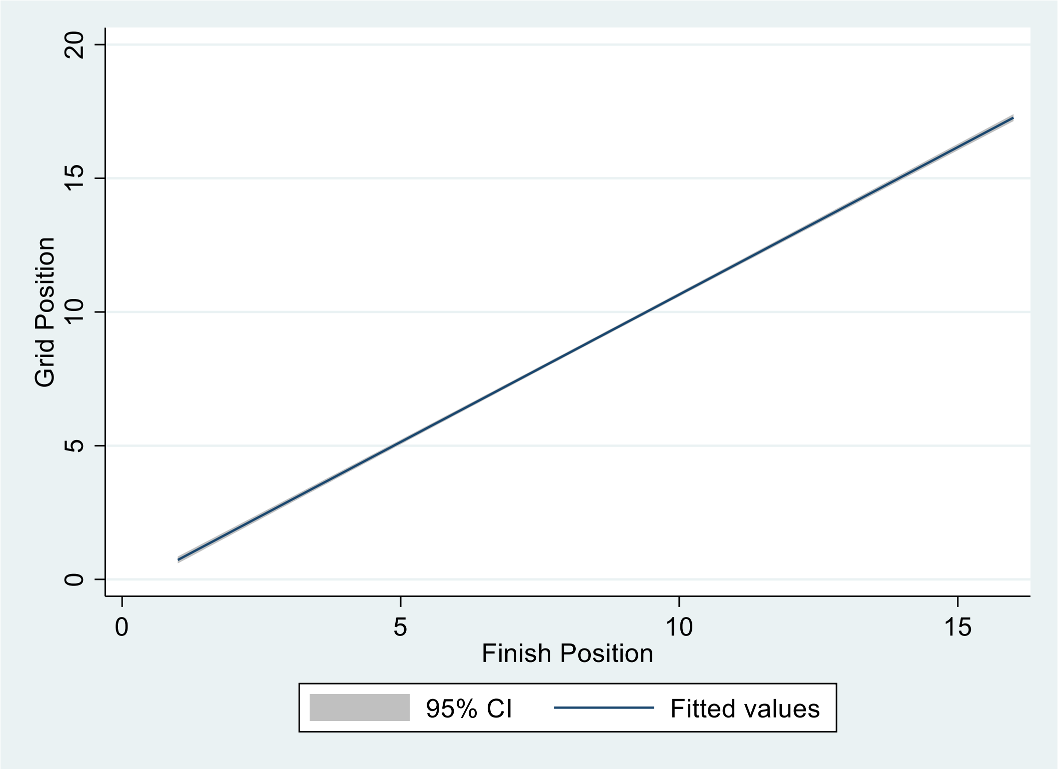
	Grid Position	Finish Position
Grid Position	1.0000	
Finish Position	0.9734	1.0000

Table 31. Regression Analysis of Grid Position and Finish Position.

	(1) Position
Grid Position	0.947^{***}
	(18.22)
Constant	0.553
	(1.35)
N	20

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 90. Predicted Fitted Values of Grid Position and Finish Position.



The predicted fitted values of grid and finish positions in Figure 90 displays that, due to Monaco's limited overtaking opportunities, drivers who qualify well are more likely to finish in a strong position. This makes qualifying performance one of the most critical aspects of the race.

Conclusion:

The analysis of the Monaco Grand Prix reveals the importance of several strategic elements:

- **Starting Position**: This is the most critical factor, given the track's limited overtaking opportunities. Qualifying well almost guarantees a strong finish.
- **Pit Stop Strategy**: Minimizing pit stops is crucial, as each stop can severely affect race outcomes due to the difficulty of regaining lost positions.
- **Tire Compound Choice**: While not as decisive in determining lap times, tire choice significantly influences the overall race strategy, particularly when considering pit stops and race phases.

These insights reinforce the idea that success at Monaco requires careful planning, with a focus on maintaining track position and minimizing disruptions like pit stops.

6. Conclusion

Through this comprehensive analysis, we gained valuable insights into the strategies employed by teams and drivers during the 2024 Formula 1 season. By systematically breaking down the data into visualizations and tables, we were able to clearly observe how different strategies were utilized across various races, revealing patterns that significantly influenced race outcomes.

This analysis not only enhances our understanding of F1 race strategy but also demonstrates the powerful role of data science in informing decision-making within high-pressure sports environments. The findings underscore the importance of strategic tire choices, pit stop timing, and qualifying performance, highlighting how these elements intertwine to shape race results.

The insights gained here could inform future strategies in Formula 1, contributing to the ongoing evolution of the sport. As teams continue to adapt to changing regulations and competitive landscapes, leveraging data-driven analysis will be essential for maintaining an edge. By integrating these findings into their strategic planning, teams can enhance their performance and navigate the complexities of each race more effectively.

The analysis of the 2024 Formula 1 season reveals critical insights into race strategies, emphasizing the intricate relationships between tire choices, pit stop decisions, and overall race performance. Key findings illustrate that:

1. **Tire Strategy:** The choice of tire compounds significantly influences lap times and race outcomes. Soft tires generally offer the best performance, while hard compounds tend to lag behind, particularly towards the end of a stint. Teams must remain adaptable to track conditions to optimize tire usage.
2. **Pit Stops:** A well-timed pit strategy is crucial for achieving favorable race results. Teams that minimize pit stops while effectively managing tire wear tend to secure higher finishing positions. This is particularly relevant in races like Monaco, where overtaking is limited and track position is paramount.
3. **Race Phase Dynamics:** As races progress, lap times tend to improve due to factors like reduced fuel loads and driver acclimatization. Understanding these dynamics can help teams strategize their approach to stints and pit stops more effectively.
4. **Starting Position:** A strong correlation exists between starting grid position and final race outcomes, underscoring the importance of qualifying performance. Teams should prioritize qualifying strategies to enhance their chances of success.

To capitalize on these findings, teams should consider several recommendations. First, optimizing tire strategy by analyzing historical data will help refine tire choices based on track conditions and race phases, ensuring that the best compounds are leveraged for optimal performance. Additionally, enhancing pit stop efficiency through investments in technology and training can minimize time lost during stops, directly impacting race positions. Given the strong link between starting position and finishing results, focusing on qualifying with rigorous strategies and practice sessions is crucial for securing better grid placements. Finally, teams should closely monitor weather conditions and adapt their strategies accordingly to gain a competitive edge, particularly in races prone to variable weather. By integrating these recommendations into their strategic planning, teams can enhance their performance and navigate the complexities of each race more effectively.

Future analyses should incorporate real-time telemetry data and explore advanced predictive modeling techniques to further understand the impacts of race strategy elements. Additionally, conducting comparative studies across different seasons could reveal evolving trends and help teams adjust their approaches to remain competitive.

Overall, this report delivers critical insights that illuminate the intricate world of Formula 1 racing, offering teams, analysts, and enthusiasts a roadmap to navigate the complexities of strategy and performance. As the sport continues to evolve with new technologies and regulations, the findings here serve as a powerful reminder of the importance of data-driven decision-making. By harnessing these insights, stakeholders can better anticipate challenges, refine their strategies, and ultimately enhance the excitement and competitiveness of each race. In the fast-paced realm of Formula 1, knowledge is not just power—it is the key to victory.