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# OPERATION RESEARCH IN TYRE MANAGEMENT AND STRATEGY BUILDING OF A FORMULA ONE CAR

**G Dinesh Reddy*1, Saksham Rastogi*2, Harshit Mahajan*3, Durvesh Chavan*4, Manit Gandhi*5, Clifton Fernandes*6**

*1,2,3,4,5,6Student, School Of Commerce, Narsee Monjee Institute Of Management Studies, Navi Mumbai, Maharashtra, India.

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## ABSTRACT

The following research paper is a thorough and thoughtful finding of the application of operations research in the tyre Management of a formula one car. It is an overview of how operations research is used in managing tyres and how Monte Carlo Simulation is used for race simulation. It discusses various factors that influence a tyre during free practice, qualifying and full race distance. The methodologies demonstrated in this report are crucial for a successful race weekend.

**Keywords:** Formula One, Tyre Management, Pirelli, Automobile, Race Simulation, Monte Carlo Simulation, Thermodynamics.

## I. INTRODUCTION

”Bono my tyres are gone, “ said, Sir Lewis Hamilton. The 7-time world champion, during the 2020 Silverstone Grand Prix in the UK. But still, he was able to win that race by a great margin. Fans and other teams were equally bamboozled, as we, the authors, of this report are while writing it. This is not the only instance where a driver pulled an immaculate stint, while everyone from the commentator to the fans and the team principals questioned the longevity of the tyre. In the history of Formula one, there were many bad strategy calls about tyres. Recently, Scuderia Ferrari has become infamous because of that. In 20the 21 Hungarian Grand Prix, the race start was chaotic and it was pouring rain. The session was red-flagged, meaning all the cars were to be aligned in the pit stop and wait for the debris of the cars to be cleared. Once the session was resumed, everybody exited the pit lane with wet or intermediate tyres on. As the formation lap was about to end the track was dry enough for slicks and the sun was shining like a hot summer day. At that exact moment, every driver except Lewis Hamilton pitted for slicks/dry tyres. And there goes an easy race win for the team, which was already feeling miserable because of the carnage at the race start. There are thousands of instances which suggest managing the tyres of a formula one car is a menace. Even a second slower pit stop for changing tyres can ruin your entire race or the championship. During the early days of formula one, there was multiple tyre supplier for the teams. Namely, Firestone, Continental, Goodyear and Dunlop. Until 1971, the tyres had threads in them. Similar to that of a road car. In the Spanish Grand Prix of 1971, Firestone introduced slick tyres to the teams(including Ferrari, Lotus, STP March Racing Team, etc). They had their first-hand experience only during the actual race on Sunday. As it was raining during the practice session on Saturday. Even though the teams wearing slicks did not provide phenomenal results, slicks were made the go-to tyres ever since. Where there is strategy, there is operation research. With the help of operations research, the entire process of managing tyres can become more predictable and reliable. After decades of race weekends and “tyre wars,” F1 chose Pirelli as its sole tyre supplier from the 2011 season onwards. Ever since, Pirelli has made their tyre compounds more sticky and durable, with revisions to their compounds almost every single year. Pirelli currently uses 5 dry weather tyre compounds (C1, C2, C3, C4 and C5) and 2 wet weather compounds (Intermediate and Wets). In the current race format, of the 5 tyre compounds. Pirelli gives the teams the 3 most suitable compounds for that particular race track and issues them in a total of 20 sets of tyres. 13 of them are for dry weather and 7 are for wet weather. The 13 sets of slicks/dry tyres are made up of softs, medium and hard (Showcased left to right respectively in Fig 1). And the remaining sets consist of intermediates and wets. For a race weekend, in total 1800 tyres are supplied to the teams. The tires are ecologically disposed of, which means that they are recycled, as part of Pirelli's green technology program for the benefit of the environment. After each Grand Prix, the tires are crushed to fit into fewer containers and sent to a cement factory near Didcot, Oxfordshire. Formula One has

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taken several green initiatives to achieve net carbon neutrality. Each tyre has a single lug nut to attach it to the car's axle. This is removed or attached via a wheel gun, which runs on compressed air and can spin at a speed of 10,000 rpm (Rotation per minute) and deliver up to 3000 NM of torque. During a tyre change during a race, there are more than 20 people involved in a pit stop. 3 people at each wheel. One tyre gunner, one tyre on and one tyre off. There are 2 crew members on each side who stabiles the car when it is up on the jacks. There are front, rear and side jacks. 2 people on each side to adjust the front wing angle. And 2 spare jacks on the front and rear, in case the original jack fails. There has been a recent addition of a crew member called the lollipop man. Whose job is to give a release signal when the new tyres are securely in place. This is to ensure that F1 pit stops don't get utterly fast and cause an accident, for which the lollipop man was introduced to add human reaction time on top of the normal pit stop time.

## II. METHODOLOGY

This white paper selects, analyzes, and synthesizes information from various research papers to provide insight into operations research and the application of operations research tools in Formula 1. We have read several research papers and numerous articles and watched multiple videos, organized the information, understood the papers, and then put them together to conclusions. During the work of this research paper, only secondary data were analyzed. Various simulation models were investigated and the behaviour of various simulation models used in different aspects of the sport was summarised. Models such as Monte Carlo simulations, tire models, fuel models, lap time models and pit stop models were considered.

**Difference between the tyres of a normal road car and that of a formula one car.**

A normal car has tyres that are suitable for all weather. Let the surface be as dry as a desert or as wet as an ocean. It is possible because of the groves and ridges a normal tyre has. They also usually last thousands of kilometres and don't need to be warmed to the optimum temperature for performing well. On the other hand formula, one tyres last anywhere between 30 to 120 kilometres. This is due to a trade-off between the performance and longevity of a tyre. Normal road tyres are meant to last longer and encounter a vast variety of terrain and weather, this is the reason why normal tyres are not able to deliver the same performance as any Pirelli F1 tyre.

**Reason for high degradation of a formula one tire**

Tyres of a formula one car degrade fast. This is due to the trade-off discussed in the earlier point. The trade-off suggests, greater performance can only be achieved when tyres can withstand more energy. By energy, we mean all the pressure a tyre absorbs under high-speed acceleration, high-speed corners, heavy breaking and the downforce created by the aerodynamic elements of the car. At high speeds, the downforce far exceeds the weight of the car. Which results in even higher tyre degradation. when the tire gets overheated, the rubber expands and starts opening. This is called blistering. It is visible with a high-speed camera and the teams are always surveillant of how the tyres look. Another visual artefact of tyre degradation is graining forming on top of the tyre surface. F1 tires also shred a lot of rubber during a race. The fallen rubber is called marbles and it is usually spotted on that part of the track that is not part of the ideal racing line. All circuits don't degrade the tyre in the same manner. Speaking of the 2022 calendar, Monaco is a low degradation circuit because of low-speed corners and low track ambient temperature. Whereas, tracks at Silverstone, Hungary, Imola, Monza (temple of speed) etc. Depending on levels of tyre degradation, Pirelli with Fédération Internationale de l'Automobile (FIA) selects 3 tyre compounds for any given race weekend, i.e. C1, C2, C3, C4 and C5. C1 is the softest and C5 is the hardest. Tire wear is not equal on all tyres. It depends on the type of track a race is being held. For example, circuits that have more right turns than left turns. The outside wheel (left side) will degrade less as compared to the inside wheel (right side). Driving style also plays a huge role in tyre degradation. If a driver does a lot of lifting and coast, it will reduce the wear significantly. Formula one legends like Sir Lewis Hamilton and Sergio Perez. Are masters at managing their tyres. They can make any set last longer and still deliver their absolute best. But also, a driver error comes at a huge cost. It is easy to form a flat spot by locking your tyres while going through a corner on an F1 car because of the absence of ABS. Tyres usually lock up when they are not at the optimum temperature or when a driver breaks too late into the corner. A flat spot leads to a significant drop in performance because the shape of the tyre becomes irregular.

**Tyre management strategies**

Teams have a million options to play around with their tyres during a race. It depends on the type of circuit and the weather at that moment. Teams never pour concrete on their strategies decided before the race. They see how the race unveils and after taking consideration from both race engineers and the drivers, they execute a plan accordingly Two of the main strategies during the race are under-cut and over-cut. Under-cut is when a driver pits slightly earlier than their rival to get a huge lead ahead. An over-cut is when the driver tries to increase the longevity of the tyre and decides to stay out of the pit lane. Now, the teams have to decide during the race what strategy they will have to use. The tires are constantly monitored with various parameters. Such as tyre pressure and tyre temperature. Another such parameter is to look at the surface of the tyres with the help of high-speed cameras. This helps the teams to analyse tyres are degrading. Teams are also on the lookout for rival cars' tyres. To predict when they might pit and formulate their strategies.

**2022 FIA regulations. And how they impact the overall car.**

The 2022 season of formula one was gifted with a massive revamp to the car. These regulations were introduced and implemented to provide much closer racing, which meant reducing the dirty air an F1 car produces behind its back. Which resulted in removing a lot of aerodynamic elements from the car. Such as the barge- boards. The front wing was modified by way of simplification. The FIA regulation now clearly states, the front wing should be made up of a 4 element wing which is directly attached to the nose. And the end plate for the front wing should be made up of only one single piece. Rear-wing end plates were also banned. But since then, Aston Martin has come up with a creative solution to include an end plate in their rear wings during the 2022 Hungarian Grand Prix. To compensate for the downforce lost due to the removal of the various aerodynamic features, The ground effect was reintroduced to the sport. René Provost first introduced the so-called ground effect back in the 1920s and claimed to make cars even faster. By designing the underfloor of the car like an inverted aeroplane wing. Thinking that this design will create a negative lift and stick the car to the ground. Even though his model car wouldn't have been the one performing highly, his writings were put again to the test after almost 50 years by an engineer working at Lotus. Peter Wright applied Bernoulli's principle to the underfloor of Lotus 78. While he was designing the side- pods to fit the radiator, he accidentally re-discovered the ground effect during the testing. Once he understood how it works, he made sure to cover the side of the car with skirts to prevent any loss of air- pressure. However, the ground effect was banned in 1983 because the cars were touching ridiculous speeds and there was a high risk of a car flipping. Both problems could not be addressed due to that time's safety standards. Tires also changed significantly over the previous years. Now, the wheel size is 18 inches instead of 13 inches, resulting in a reduction of the tyre profile. This meant tires couldn't absorb undulations of the road surface as effectively as before. This nudged the teams to completely redesign their suspensions. The front suspension is of 2 types, namely, Push rod and pull rod. The push rod design means all the components of the front suspension are mounted high up in the nose and the suspension rod is pushed inside when it is compressed. Teams such as Scuderia Ferrari Mercedes-AMG, Alpine, Alfa Romeo, Haas, Scuderia Alphatauri, Aston Martin, and Williams use the push rod system. A pull rod system is where all the components of the suspension are mounted lower, and the suspension rod is pulled outside when it is compressed. The only teams that use the pull rod system are McLaren and Red Bull. The front suspension was completely re-tuned to compensate for the reduction in the size of the tyre profile. Drivers 'visibility is also hampered due to an increase in the size of the tyre. Making it harder to pick a proper racing line while taking a corner. However, they quickly adapted to this issue. With all these changes, the new cars were subject to porpoising. A phenomenon where cars bounce up and down at high frequency when going at high speed. This made the drivers very uncomfortable and some also reported body pains after a session. This issue was slowly ironed out as the cars were driven race weekend after race weekend. During the summer break, FIA issued regulatory changes, stating the frequency of the up and down oscillation should be at safe levels. FIA also reiterated that the plank present on the underfloor should of consistent thickness.

## III. MODELING AND ANALYSIS

**Monte Carlo Simulation**

A successful race in Formula one is executed with the help of numerous optimal strategies and decisive decisions taken during the race. This implies pitting the car at the perfect time and putting on the most optimal tire compound. Failure to which has been very well depicted in the above literature. The race engineers use simulation techniques to illustrate and understand the impact of various strategies which can be used during the qualifying session or actual race. But an average Formula one race weekend is full of random events. It includes a car crash which leads to a safety car or a virtual safety car or the weather outlook suddenly changing. These handfuls of situations have a huge implication on the race outcome and are external. Internal factors such as an unexpectedly slow pit stop, the mental and physical state of the drivers, the mechanical health of the car, set up of the car for any particular race weekend also affects the race outcome. These factors and many others should be taken into consideration when designing a simulation model. Race simulation is used for understanding the outcome of various race strategies. These simulation models are usually constructed to represent lap-wise data. Thus one of the major elements of the model is the expected lap time per lap. To estimate that, the simulation model adds up various time parts of a lap shown in the equation below.

**$T_{lap}$ (l) = tbase + ttire(atire , ctire) + tfuel(l) + tcar + tdriver+ tgrid(l, pg) + tpit,inlap/outlap (l) (Heilmeier, Graf, Betz, Linkamp, 2020.)**

Here the $t_{base}$ represents fastest car and driver combination that can be theoretically achieved during a race. With assumptions like the tires are fresh, fuel on board is bare minimum, resulting in a lighter weight of the car. $t_{tire}$ for the effect of tire degradation (dependent on tire age $a_{tire}$ and compound $c_{tire}$ ), $t_{fuel}$ for the time lost due to the fuel mass that is carried in the car, $t_{car}$ and $t_{driver}$ for the car and driver abilities, $t_{grid}$ for the time that is lost at the race start (dependent on grid position pg) and **tpit,in-lap/outlaw** for the time that is lost in pit stops. Consecutive lap times are summed up to obtain t race. Once race time is calculated, it is compared with that of other drivers on the grid to see whether an overtaking manoeuvre was Race simulations, specifically the modelling of probabilistic effects in this context, is the subject of little research. The Monte Carlo simulation (MCS) concept serves as the foundation for the published works on this subject.[3] Page 1 states that MCS "uses random sampling to study properties of systems with components that behave randomly. "The driver's final rank position is the result of interest for a strategy engineer. To estimate the estimated distribution of rank positions, MCS is applied by employing realistic models for the probabilistic effects and simulating a large number of races

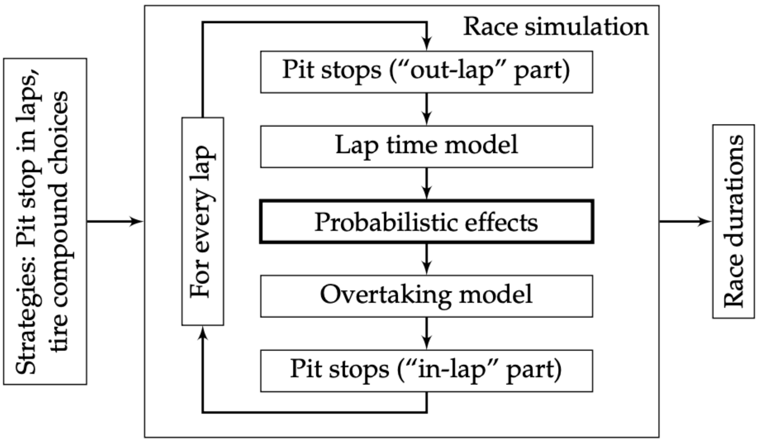


**Figure 1:** A flow chart based on race simulation.

### Tire degradation model

The optimum control problem includes tyre deterioration since it affects racing performance. There will be a consideration for both temperature and wear factors. the attribute of temperature-grip the tires' temperature-grip characteristic is the first mechanism that affects the car's performance. The temperature range where the greatest amount of grip is possible is shown by this curve, which is typical of a super-soft tyre. The tread-only model utilized by Tremlett and Limebeer (2016) is constrained because it overestimated the extent to which the tread can be cooled down after it has overheated. By raising the tread temperature to the optimal operating range, the optimal controller maximizes grip. Due to the relatively high thermal inertia of the carcass in comparison to that of the tread, lowering the temperature of an overheated tread necessitates lowering the temperature of the tyre carcass. As a result, it is critical to establish a temperature state for the carcass that

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accurately reflects this thermal inertia-related lag. The track goes through quick temperature changes all through a lap, while the cadaver temperature differs even more leisurely. Re-cooling the carcass after it has heated up, possibly to an excessive temperature, takes time as well. Tire wear The temperature change in tire tread performance is a fully reversible effect in isolation (as it is depicted here). The tyre's reversibility is not a tyre-wear property; once it is worn out, it remains. Therefore, a mechanism that prevents the optimal controller from regaining maximum grip after tire degradation has occurred must be incorporated into the model. Farroni et al. provide examples of how various types of tires lose performance as the tyre degrades (2017). Racing tires are designed to provide enhanced grip for a shorter period, whereas passenger tires are typically designed for longevity. The figure depicts the wear curve of a compound for super-soft tires. Because racing tires are subjected to a curing process and are not fully vulcanized during the manufacturing process (Haney, 2003), the grip initially increases before beginning to degrade.

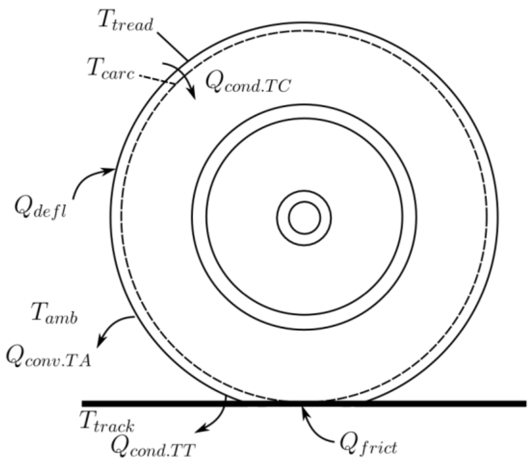


**Figure 2:** Thermodynamic model with dominant heat flows

## IV. RESULTS AND DISCUSSION

**Lap time and pit duration**

Since no driver can perfectly repeat a lap, real lap times can be observed to be scattered around a mean value when analyzing them. The effects of tire degradation and burned fuel mass, for example, must be eliminated as much as possible from the analysis of this effect on lap times. Therefore, the actual lap times $t_{lap}$ for each stint are fitted by quadratic polynomials of the form $t_{lap, ply}(l) = k_2 l^2 + k_1 l + k_0$. Figure 3's upper portion illustrates this. The first two laps, which are heavily influenced by the start of the race, and all laps that are impacted by pit stops or full course yellow (FCY) phases must be removed from the process because we only want to include "clean" laps. Race control uses FCY phases to slow down when there is danger on the racetrack.

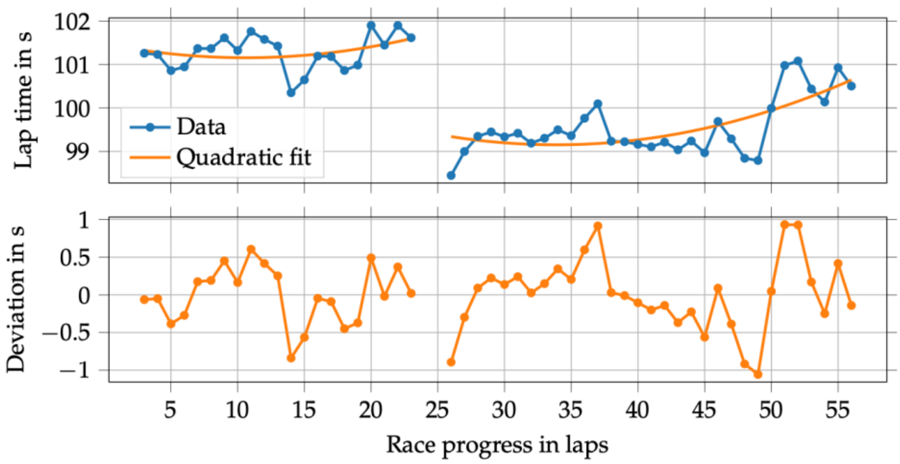


**Figure 3:** Hamilton's variation in lap times.

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The significance of the modifications to the model that were made by Tremlett and Limebeer (2016) is shown through two simulations. First, a multi-lap simulation of the proposed tire thermodynamic model's impact on a multi-lap optimal control problem was conducted without tire wear. After that, we look into how wear affects the best control solution. Tyre wear influences are now introduced as the general-purpose optimal control problem. The wear rate model was "tweaked" so that a tyre is completely worn out in a single lap to emphasize the impact of tire wear. The figure depicts the velocity profiles for various wear scenarios. The fastest lap is unavoidably due to the base case's lack of wear. There are only slight deviations from the base case when the wear rates are set to their nominal values. Given that racing tires are made to last for multiple laps, this is to be expected. The maximum speed of the vehicle increases until the peak of the wear curve depicted in Fig.4 is completed.

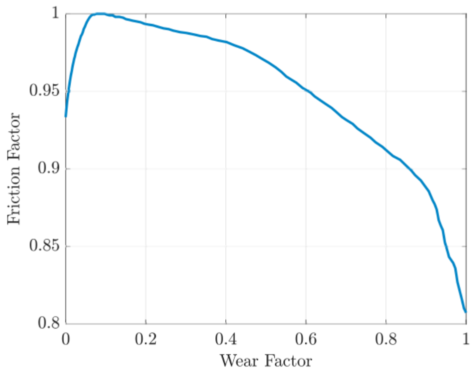


**Figure 4:** Tyre wear of a super-soft compound.

The vehicle speed is decreased as the nominal wear rate is increased to prevent the tires from being completely worn out before the lap is over. To make it easier to perform multiple laps, the tyre wear model has been returned to its nominal values. The consequences of a multi-lap recreation are displayed. For the tires to quickly reach the top of the friction factor curve, they are initially intentionally worn and heated. The grip improves over the first two laps as the tread temperatures reach the ideal range and the tires wear down. The second lap is the fastest. The lap times increase roughly at the same rate between laps three and eight. Over this tyre usage range, there has been a roughly constant decline in the characteristic friction factor that has led to this. Tire wear has a greater impact on performance after lap eight, and lap times begin to decline more quickly. The changes in the friction factor curve's slope can be blamed for this. It also becomes harder to keep the tread within the optimal temperature range when the tires become increasingly worn out. As the race progresses, it is evident that there are increasing deviations from the optimal temperature operating window for the treads. The lap time T does not slow down as the tires wear down; rather, it continues to rise at a faster rate. This demonstrates for the first time the irreversible nature of tire wear. At some point, the car's performance deteriorates to the point where it is no longer competitive, necessitating a tire change.

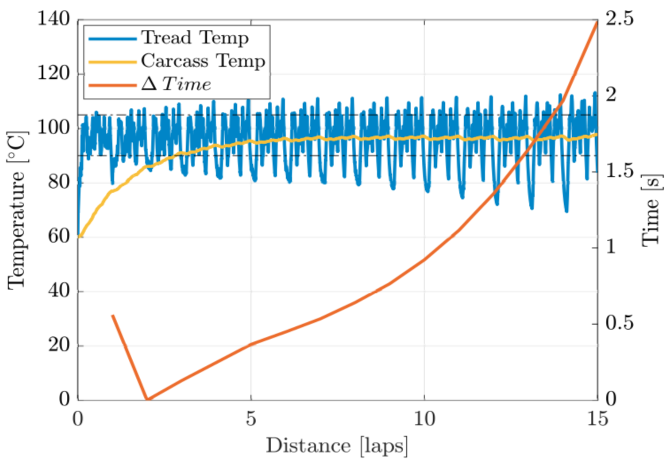


**Figure 5:** Tyre wears with temperature simulation.

## V. CONCLUSION

Operation research is not only used for managerial activities, instead but it can also be applied to a wide variety of problems we face in the real world. Here we tried to apply it in the world of motorsport, in particular Formula One. Models like Monte Carlo simulation and thermodynamics have been used to illustrate the impact of various elements on tires and the overall car. Formula One teams are constantly developing models to get the most out of the race weekend and things that are learned here can be applied to road cars for increasing their efficiency.

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