

MSc Motorsport Engineering

Research Proposal – Developing a MATLAB Tool for Race Strategy Predictive Analysis

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Abstract

This study focuses on the exploration of race strategy in motorsport engineering, where it serves as a link between technical vehicle performance and tactical decision-making during race events. The proposed research utilises MATLAB to develop a modular tool for race strategy optimisation, incorporating real-world data and probabilistic analysis to allow a race engineer to simulate a race and use this data to inform the selection of the optimal race strategy. Predictive strategy analysis is a cornerstone in top-flight circuit racing, used to set race strategies pre-race, react to changes during the race, and conduct retroactive assessments to aid future decision-making. The unique considerations for different motorsports are considered, such as tyre compound selection in Formula One and battery management in Formula E, and emphasis is placed on the need for rapid and accurate simulations due to the transient nature of races. The use of quadratic optimisation and Monte Carlo simulations are explored and analysed, and considerations are also made for complex nature of tyre behaviour given the number of variables involved in a grand prix.

1: Industrial Relevance

The study of race strategy is a critical element of motorsport engineering. Race strategy is a fundamental component of a race weekend, serving as a bridge between technical vehicle performance and tactical decision-making during the entire race event. This kind of predictive strategy analysis is present throughout top flight circuit racing. It is for a range of purposes, including setting a race strategy before a race, calculating optimal strategy based on reaction to changes within the race, and retroactive assessment of race strategy performance is also carried out using this method, which is used to improve strategy decision making for the future.

There is a great deal of individual considerations to be made for different motorsports as well. For example, in Formula One, predictive strategic analysis involves the selection of tyre compounds before a weekend, and in Formula E it concerns the management of battery energy and temperature. While it is important for these simulations to be accurate, it is equally imperative that these simulations can be generated quickly, given the highly transient nature of a race if a simulation takes more than even a few minutes to generate the input data may be wholly inaccurate, rendering the tool far less useful.

2: Literature Review

2.1: Quadratic Optimisation

One approach to pitstop analysis is that of a quadratic optimisation, which Heilheimer uses to simply model pitstop strategy in a clean air scenario (Heilheimer, Thomaser, Graf, & Betz, 2020). In this scenario, given an assumption that other competitors are disregarded and no probabilistic events occur, such as weather changes, safety cars, and so on, the question of race strategy can be solved simply. The overall race duration can be calculated for each pitstop eventuality, assuming the one-stop strategy is fastest. Therefore, the overall race time for each of these options can be graphed and a definitive best clean air strategy can be found (Heilheimer, Thomaser, Graf, & Betz, 2020).

This approach would be unsuitable for a full analysis given the number of disregarded variables, but may prove useful in an early stage as a framework from which to add considerations to the model before implementing a Monte Carlo simulation to fully simulate a race. Attempting to do this analytically would simply not be feasible, there are far too many variables and possibilities to compute entirely. Therefore, some probabilistic analysis is required to fully create a race simulation with any respectable degree of accuracy.

2.2: Probabilistic Analysis

2.2.1: Monte Carlo Simulation

Monte Carlo simulations have been used to carry out race simulations, modelling the probability of the uncontrollable factors within a race, such as safety cars, accidents, and variability in lap and pitstop times (Heilheimer, Graf, Betz, & Lienkamp, 2020).

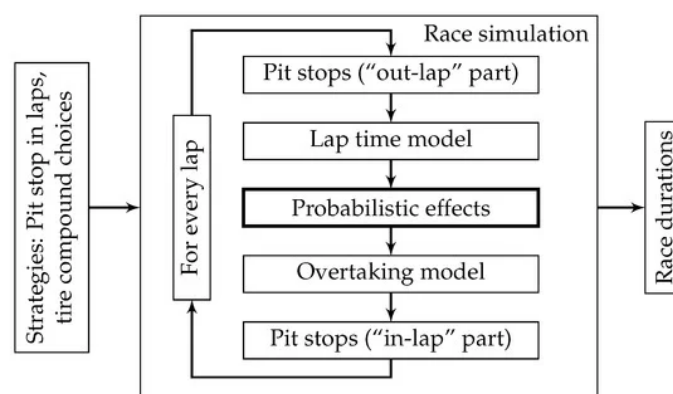


Figure 1 - An example of a Monte Carlo race strategy simulation (Heilheimer, Graf, Betz, & Lienkamp, 2020)

The simulation was set up to calculate overall race duration by inputting an array of strategies, and calculating lap by lap the lap pace, the likelihood of probabilistic events to occur, and thus the likelihood

to overtake, as well as taking into account the effect on normal lap time of taking a pitstop – the difference in pace between a normal racing lap and an in lap or out lap.

2.2.2: Artificial Intelligence

More recent predictive race strategy models use emerging technology in artificial intelligence to create frameworks capable of simulating full races. This area of science is outside the scope of this project, but is important to consider in the wider academic landscape surrounding the subject. Artificial neural networks have been shown to be able to compute more complex systems than feasible in simple analytical models (Heilheimer, Thomaser, Graf, & Betz, 2020).

2.3: Tyre Modelling

A wide array of variables affect tyre behaviour and overall pace in a race. When creating a model with the goal of approximating this behaviour, certain factors are more critical in governing tyre performance than others. Foremost of these is temperatures, of both the track surface and the air. Higher temperatures generally cause an increased rate of tyre wear and make overheating the tyre easier, although will also allow the tyre to more easily get into and maintain a good operating temperature (Richardson, 2017). Track surface roughness also holds a significant positive correlation with tyre wear rate, as does the quantity of high speed corners in a circuit's layout (Szabo, 2025). Therefore, these factors will require accounting for when using real data to inform tyre behaviour.

2.3.1: Pacejka Models and Thermomechanical models

The Pacejka tyre model is an industry favourite for modelling tyre forces (Vogel, 2021), introduced by Hans Pacejka in 1987 (Pacejka, 2012). The model is used to model tyre forces across a wide range of applications, from video game vehicle multibody simulations and motorsport simulators (rFpro, 2009) to Pirelli F1 tyre design (Vogel, 2021). The model uses a set of coefficients to describe the force capacity of a tyre, however the input values lend the model more to multibody simulations, where access to camber angles, vertical load, and so on govern the force output of the tyre (Pacejka, 2012).

For the purposes of this simulation, a thermomechanical simulation may be easier to implement, where a grip correction factor can be applied to the tyre (Vogel, 2021), and therefore the lap time, as a function of tyre temperature (Michelin, 2001). Thus, the effects of track conditions and even the lap time effect of an out lap on colder tyres may be modelled using this system.

The validity and feasibility of implementing these models will be explored during further research and model development.

3: Proposed Methodology

3.1: Methodology

MATLAB will be used to carry out the proposed research. Initially, a simple analytical model will be created, capable of simulating simple tyre wear and pace on a set of fictional compounds and other basic variables like fuel burn. Beyond this, the model will be expanded further, with the capability of using real world data to extrapolate tyre wear and performance. These models will be focused on the optimisation of ideal pit strategy over a race distance, in a scenario without competitors, known as a clean air optimisation (Hatton, 2023). This could be carried out via a quadratic optimisation, a relatively simple method that will allow the foundational code functions to be streamlined.

Further development of the model will then include the addition of other cars, with considerations such as dirty air, the difficulty to overtake, tyre age, and many more. The tool will be created with a modular, well commented code structure, allowing for flexibility, scalability, and readability. This involves developing functions for each module, and will make the completion of the project. The tool will also be optimised for performance, focusing on improving the efficiency of the MATLAB code. To extend the tool, a Monte Carlo simulation could be run of the race scenario using the functions created previously, thus bringing the tool closer to the standard used in top-flight circuit motorsport. This

Further work could include preparing the tool for public release, which may comprise providing documentation, including code comments and function descriptions. This would facilitate greater ease of use and allow for easier further development by other researchers or strategists in motorsport.

3.2: Ethical Considerations

Given the nature of the research, there are little ethical concerns to be had. The project is entirely coding based and will be carried out without surveying others or gathering personal data. The full ethical considerations are made in the ethics form.

4: Results Collection and Analysis

In terms of results analysis, a variety of data output will be compared and analysed. Different iterations of the model will be compared, which will allow for the specific effect of changes to the model to be analysed. Adding or changing certain functions or variables are expected to make a varied difference on the generated outcomes, and so this comparison will inform the further development of the model. For example, an early version of the model may not account for the time it takes to get a new set of tyres up to their operating temperature, or may not account for the difference in time this takes depending on the softness of the tyre compound. Comparison of the model's strategy output before and after the addition of this consideration will affect the overall race time.

Real race timing data will also be analysed to understand what affects race time. To this end, a case study on a particular race may be employed to better understand these effects. An ideal race could be found to study tyre degradation, with a typical track temperature and surface quality, and without significant yellow flag running, safety car periods, or adverse weather. To further isolate variables, a race could be pulled from Formula 2, a spec series where the cars differ only by setup, but is still a circuit-based grand prix series.

Given that another key use of predictive strategic analysis is deciding whether to make a pitstop mid-race given an unexpected turn of events, this analysis can also be carried out, as is common in research in this area (Heilheimer, Graf, Betz, & Lienkamp, 2020). Here, real data can be used and a comparison can be taken from the outcome indicated by the model and the outcome that occurred in a real race, and analysis made of the reasons for any difference or similarity.

Conclusion

In conclusion, this research project explores the importance of race strategy in motorsport engineering, linking performance with tactical decision-making. The proposed research outlines an approach using MATLAB to develop a tool for race strategy optimization. By incorporating real-world data and probabilistic analysis, the research aims to add to the understanding of race simulations, ultimately contributing to the field of motorsport engineering.

Overall, this research will serve to contribute to the existing literature surrounding the use of analytical and probabilistic simulation of race strategy in motorsport. While this area has been explored in recent literature as shown above, this area of research is still somewhat emergent and certainly not a solved equation, given the difficulty of predicting and analysing an event with such variance as a grand prix. Therefore, additional research in this area will contribute to the collective thinking and may result in an advancement of this particular area of race strategy research.

References

- Hatton, G. (2023, September 1). *Mastering the Art of IndyCar Strategy*. Retrieved from Racecar Engineering: <https://www.racecar-engineering.com/articles/indycar-articles/mastering-the-art-of-indycar-strategy/>
- Heilheimer, A., Graf, M., Betz, J., & Lienkamp, M. (2020). Application of Monte Carlo Methods to Consider Probabilistic Effects in a Race Simulation for Circuit Motorsport. *Applied Sciences*, 10 (12).
- Heilheimer, A., Thomaser, A., Graf, M., & Betz, J. (2020). Virtual Strategy Engineer: Using Artificial Neural Networks for Making Race Strategy Decisions in Circuit Motorsport. *Applied Sciences*, 10 (21).
- Michelin. (2001). *The tyre - Grip*. Retrieved from Michelin: http://docenti.ing.unipi.it/guiggiani-m/Michelin_Tire_Grip.pdf
- Pacejka, H. (2012). Outlines of Three Advanced Dynamic Tire Models. In H. Pacejka, *Tire and Vehicle Dynamics (3rd Ed.)* (pp. 577-591). Delft.
- rFpro. (2009, February 28). *rFactor-Pro Overview*. Retrieved from Waybackmachine: <https://web.archive.org/web/20090223124337/http://rfactor-pro.com/LinkClick.aspx?fileticket=e3thdYQ%2FUBg%3D&tabid=55>
- Richardson, H. (2017). *Modelling the Evolution of Tyre Performance*. Gothenburg: Chalmers University of Technology.
- Szabo, B. (2025, January 6). *How do teams define race strategies?* Retrieved from F1Technical: <https://www.f1technical.net/news/25828#:~:text=In%20Formula%201%2C%20race%20strategy%20is%20a,tyre%20choices%2C%20pit%20stop%20and%20on%2Dtrack%20traffic.&text=%22Devising%20a%20strategy%20starts%20with%20what%20we,difficult%20to%20predict%20due%20to%20di>
- Vogel, J. (2021, September 27). *Tech Explained: Formula 1 Tyre Model Development*. Retrieved from Racecar Engineering: <https://www.racecar-engineering.com/articles/tech-explained-formula-1-tyre-model-development/>