How has the development of technology in Formula One improved driver safety and vehicle performance over time?

Shane Minihane

Final Year Project

BA Digital Humanities & Information Technology

Supervisor: Dr Sabin Tabirca

Digital Humanities

University College Cork

April 2025

Abstract

Formula One (F1) is widely considered as the pinnacle of innovation in motorsports, continuously pushing the boundaries of technology. Vehicle performance and driver safety are both important fields of study when it comes to Formula One. Technological advancements have allowed for the development of more advanced vehicles, aerodynamic and engine designs, and sophisticated safety features, all of which contribute to performance and protection of the cars and drivers in F1. This research project aims to explore how technological advancements have impacted both vehicle performance and driver safety over time in Formula One. This is achieved by designing and developing a digital artefact that includes interactive timelines showcasing the evolution of vehicle performance and driver safety in F1 over time.

Declaration

Declaration of Originality

In signing this declaration, you are conforming, in writing, that the submitted work is entirely your own original work, except where clearly attributed otherwise, and that it has not been submitted partly or wholly for any other educational award.

I hereby declare that:

- This is all my own work, unless clearly indicated otherwise, with full and proper accreditation;
- With respect to my own work: none of it has been submitted at any educational institution contributing in any way to an educational award;
- With respect to another's work: all text, diagrams, code, or ideas, whether verbatim, paraphrased or otherwise modified or adapted, have been duly attributed to the source in a scholarly manner, whether from books, papers, lecture notes or any other student's work, whether published or unpublished, electronically or in print.

Signed: Shane Minihane

Date: 16/04/2025

Acknowledgements

I would like to express my gratitude to my supervisor, Dr Sabin Tabirca, for his continuous support throughout this process. His guidance and encouragement have kept me focused on the end goal from the beginning of this journey.

Table of Contents

Table of Contents

Introduction

1.1 Challenge Overview

Formula 1 (F1) is widely regarded as the pinnacle of innovation in motorsports. Technology has played a pivotal role in shaping the sport today. Since F1's inception in 1950, technology has dramatically improved vehicle performance and driver safety over the decades. Advancements in engineering, science, materials, and data analytics have revolutionised vehicle performance in Formula 1, allowing cars to reach unprecedented speeds. Similarly, these technological innovations have also majorly improved driver safety, reducing the risk associated with high-speed collisions. Balancing the relentless pursuit of performance whilst prioritising driver safety presents a big challenge.

This project begins with a review of current literature on both vehicle performance and driver safety. Following this research, the findings will be applied to the design and development of a digital artefact that aims to explore the impact of technological evolution in Formula 1. This digital artefact will provide valuable insights to F1 enthusiasts, emphasising how technological advancements have shaped the sport since 1950.

1.2 Aims & Objectives

The goal of this project is to understand the impact of technology on vehicle performance and driver safety in F1 over time. This can be broken down into the following objectives:

This project will begin by researching current literature on vehicle performance and driver safety in Formula 1. This will be followed by pinpointing key technological innovations that have impacted the sport. Any gaps in literature regarding these areas will the be identified. This project will then examine how vehicle performance has been influenced by technological advancements. This project will also analyse how technological evolution has impacted driver safety. The projects focus will shift to designing and developing a website using WordPress to present the results from the research. The main objective of this website will be creating interactive timelines to visually represent the evolution of both vehicle performance and driver safety over time in F1. This project will then finish by highlight gaps in research and offer future insights regarding these fields.

1.3 Report Outline

This project will begin with a background review of the various tools and platforms being used for implementation of the digital artefact. This section will evaluate the capabilities of these tools and platforms and emphasise their strengths which will provide insight into their suitability for this project. Following this will be a comprehensive literature review on existing literature regarding vehicle performance and driver safety in Formula 1 and how technology has influenced them both.

In this literature review, a survey of existing knowledge will be conducted to cover what is known and unknown about these topics. The evolution of both vehicle performance and driver safety highlighting major innovations will be discussed in detail. The strengths and weaknesses of technological advancements will be evaluated in this literature review to see both sides of technology's impact on vehicle performance and driver safety in F1. A major part of this review is to identify gaps in current literature whilst discussing what this particular project will add to existing research. This review will conclude with a conclusion, highlighting key findings from the research and offering future insights.

Following this review will be an in-depth analysis of the problem that this project aims to solve. This section will be broken down into sub-problems for further analysis. The design of the digital artefact will be analysed following the analysis, discussing both the architecture and front and back-end development. The implementation of the digital artefact will then be examined in detail. Testing and evaluation of the digital artefact will follow this section, focusing on unit testing, performance, and usability. This project will then finish with a final conclusion outlining what has been achieved and highlighting plans for future work. The references will be clearly outlined at the bottom of this document.

Project Links:

Website Link: https://minihane3.wordpress.com/

GitHub Link: https://github.com/sm1123/Final-Year-Project

Google Colab Link:
https://colab.research.google.com/drive/1Gl0_BZrMVRdusDEmRUtQVQcriEfHV_S4?usp=sharing

Background

2.1 Tools & Platforms

In this section, various tools and platforms are considered for implementation of the digital artefact. The capabilities of these tools and platforms will be outlined below, providing insight into their suitability for this project.

2.1.1 WordPress

This project aims to create a digital artefact using WordPress to visually represent the key findings from the research. Having researched alternative tools and platforms, WordPress offered the best solution for this task. The main goal of this digital artefact is to create an engaging, user-friendly, and creative website that will effectively communicate the key findings from the research conducted. The biggest differentiator for using WordPress opposed to other platforms was its user-friendly interface. This allows for the design process of the digital artefact to be easier. Another factor that was considered was its customisability. Wordpress offers a wide variety of themes that offer flexibility when designing the website. The addition of interactive and other engaging elements will allow for a more dynamic and immersive user experience. This platform also offers easy media management, responsive design, and robust security features, ensuring the artefact is both secure and functional for users on any device.

2.1.2 GitHub & Google Colab

This project explores the impact of technology on vehicle performance and driver safety over time in Formula 1. Alongside using WordPress, other tools and platforms were considered to display data visualisations and graphs highlighting notable results from the research. These include GitHub and Google Colab. Focusing on GitHub first, this open-source tool is excellent for creating repositories and uploading and managing datasets, offering great collaboration features and version control. This is a diverse tool that acts as a central hub for datasets and can be easily connected to external tools such as Google Colab. GitHub allows users to seamlessly save and load Google Colab notebooks directly from GitHub repositories. Storing datasets in a GitHub repository is a terrific way to manage and share data, ensuring the datasets are well organised and easily accessible to external tools such as Google Colab. This seamless integration offers many benefits including data synchronisation, maintaining a history of changes (version control), and improves the overall efficiency of the research workflow.

As previously stated, GitHub offers version control through Git, allowing users to track and monitor any changes over time. Users are able to revert to older versions and offers seamless collaboration with others. Repositories can be created in GitHub which allow users to organise files including datasets, images and many more data types. GitHub is an effective tool for importing datasets and linking them to other tools such as Google Colab. This project aims to connect GitHub datasets which are stored in open-source repositories on GitHub, to Google Colab notebooks for data analysis and data visualisations. Public GitHub repositories and datasets within these repositories can be simply loaded into Google Colab notebooks, allowing users to easily access open-source datasets and code.

Google Colab is an excellent tool allowing users to leverage Python's extensive library collection to conduct data analysis within a collaborative environment. This tool allows users to write code and execute it directly in their browser. This makes the code easily accessible for all users. This project aims to execute Python code within a Google Colab notebook. Planning to conduct data analysis for this project, Google Colab supports seamless integration with many popular Python libraries such as Pandas and NumPy. This allows for easy data manipulation and data analysis. Visualisation libraries such as Matplotlib and Seaborn can also be imported into Google Colab notebooks to create engaging plots. These notebooks are easily accessible, shared and collaborated on, providing a suitable tool for this project.

Having analysed the capabilities of various tools and platforms, the most suitable options for the implementation of the digital artefact have been identified. Their strengths have been highlighted to show how they will contribute to achieving this project's goal.

Literature Review

3.1 Introduction to Literature Review

A thorough review of research projects, journal articles, and technical reports relating to vehicle performance and driver safety in Formula 1 was conducted. These projects, articles, and reports all contribute to shaping the current state of Formula 1, providing valuable insights, and informing decision-making processes in this research project.

3.2 Methodology

The literature review is produced using Google Scholar to find relevant and trustworthy sources. This includes journal articles, research projects, and technical reports. Keywords and particular search queries are used to ensure a wide range of results and perspectives are covered for this review. Recent publications are prioritised for this review to ensure the research is up to date. From this research, key themes, trends, and any gaps in existing literature are identified. This is done through critical analysis.

3.3 Overview and Research Focus

Formula One (F1) is widely considered as the pinnacle of all motorsports. It the highest tier of single-seater professional racing around the globe. Renowned for its fierce competition, innovative and groundbreaking technological breakthroughs, precision, and speed, Formula One consistently pushes the boundaries of what is possible in relation to both vehicle performance and driver safety. The sport licensed by the Fédération Internationale de l'Automobile (FIA) has undergone a huge transformation since its inception back in 1950 as it has "evolved into a highly competitive and technologically advanced sport, captivating audiences with its thrilling races and showcasing cutting-edge engineering" [6]. Technological evolution plays a vital role in F1 as it not only impacts the competitiveness of the sport but also the performance of the vehicles and safety of the drivers.

3.3.1 Technological Evolution in Formula 1

Technology in Formula One "has almost completed the transformation from the black art of the 1950's and 1960's to the science of the 2000's" [30].

Wright and Matthews state that technology in Formula One was relatively simplistic and rudimentary as there was a lesser scientific understanding of technology back in the mid 20th century. Fast forward to the 2000's, Wright and Matthews claim Formula One technology in the 2000's to be highly sophisticated and complex compared to previous decades. Formula One regulations are based "on the FIA International Sporting Code, which provides shared rules for all motorsports, and incorporate sporting and technical regulations unique to Formula One Championship" [26]. These regulations set the standard for teams within the sport so they can pursue their technical development to the very limits of the regulations.

The governing body of Formula One, the FIA "keeps regulations in step with technology evolution as technology enabled the cars to go faster" [19]. Papachristos declares technological evolution results in increased speed and better overall performance in Formula One. This aligns with Ugle, Kate, and Dolas's statement that "safety does not completely depend upon the driver, it also depends upon the technologies used in the cars" [29]. Technology plays a pivotal role in Formula One. This literature review aims to explore the evolution and development of technology in Formula One and its impact on both vehicle performance and driver safety. The research question that is guiding this review is: How has the development of technology in Formula One improved driver safety and vehicle performance over time? By analysing existing approaches and identifying their strengths and weaknesses, the goal of this literature review is to add to the understanding of technological impacts on Formula One and highlight key areas for future research.

3.4 Survey of Existing Knowledge: Driver Safety

In the early years of Formula One, safety was an afterthought and was not the primary concern. Formula One has always been associated with the risk of fatal injuries or death as the sports history is largely filled up with these accidents. The sport involves drivers travelling at tremendous speeds in open-cockpit and open-wheel racing vehicles in the same vicinity as nineteen other F1 drivers. This is a major risk to drivers as they deal with incredibly powerful forces on their bodies such as G-force. The danger involved in Formula One adds to the thrill of the sport to a certain point as Kempema argues, "measures must be taken to enhance driver safety, both preventively through track, car, and safety equipment, as well as improved medical interventions and care" [16]. These advancements are all possible due to the evolution of technology

3.4.1 History of Driver Safety

Before 1952, drivers wore minimal protection gear including their everyday clothing and cloth caps paired with goggles to protect their eyes from dirt. Then in 1952, cork helmets became mandatory to improve driver safety as they provided essential protection against head injuries during accidents. To provide an insight into how dangerous Formula One is; "from 1954 to 1994, 27 drivers died during racing, or in free practice or qualifying sessions" [17]. Lippi et al provide statistics showcasing how dangerous Formula One is as a sport. Throughout the years, driver safety has seen significant improvements. The introduction of mandatory seatbelts in 1972 marked a new era in F1 as they contribute to keeping drivers in their seats during collisions, reducing the chances of ejection and mimimising impacts on drivers. Fire resistant suits made from Nomex which were introduced in 1975, was able to withstand remarkably hot temperatures and provided extra time to drivers in case of a fire.

The survival cell in 1981 safety barriers and run-off areas in 1994, HANS device in 2003, Halo device in 2018 are some of the most renowned safety features in Formula One. These all add extra protection for the drivers, but the headgear is vitally important; "Head protection devices designed to decelerate the head in a controlled way so as to limit a sudden deceleration force on the brain during an accident are already available" [16]. Kempema states technology has allowed for improved head protection gear which has drastically reduced the risk of a driver getting injured during a collision. These are only some of the safety features added to Formula One to improve driver safety.

3.4.2 Driver Safety: Current Practices

"Over the past few decades, the races have seen a great improvement considering safety to to be the first priority. Advancement in science and technology has led to the decrease in deaths or critical injuries to the drivers during the racing" [29]. Ugle, Kate, and Dolas claim the evolution of technology and science are responsible for improved driver protection. This coincides with Young's research stating, "Formula One's relative freedom for technological development allows teams to develop even safer technology than the ones mandated, whether by design, or as a positive byproduct for a new technology or material used to improve performance" [31]. Young compares F1 to IndyCar which has had three fatal tragedies in recent years. Young compares this to Formula One where the last fatal accident was Ayrton Senna in 1994. She claims that Formula One drivers are better protected than their IRL and NASCAR counterparts as Formula One has the technological freedom to develop their own technology for safety. This adds to the notion that technological evolution in Formula One has enhanced driver safety.

3.5 Survey of Existing Knowledge: Vehicle Performance

Dating back to the inception of Formula One back in 1950 when the first World Championship took place, F1 racing vehicles were relatively basic in design and less capable of achieving optimal performance compared to modern day Formula One cars. In the 1950's, aerodynamics was largely an afterthought in F1. Drivers competed in front-engined cars with supercharged 1.5 litre or naturally aspirated 4.5 litre engines. These vehicle designs were simplistic in design with basic aerodynamic elements. Vehicle speeds reached up to 180mph in the late 1950's and 1960's. As technology developed "teams began to realize the importance of aerodynamics" [32]. Zhang argues that aerodynamic development has been key to shaping the performance of modern-day Formula One vehicles. Zhang refers to technological breakthroughs that improved aerodynamics on F1 cars which resulted in improved overall performance.

3.5.1 History of Vehicle Performance

Vehicle performance during the early years of F1 was characterised by pure engine power. This changed over time as regulations changed. In 1955, disc brakes replaced drum brakes which provided more efficient and consistent braking performance. The 1960's marked a pivotal era in relation to vehicle performance in Formula One as the monocoque chassis was introduced in 1962, reducing car weight, and improving rigidity which resulted in better overall performance. One of the most revolutionary innovations was the introduction of front and rear wings in the 1960's; "The introduction of wings, diffusers, and other aerodynamic components has significantly improved the downforce and stability of F1 cars, allowing them to achieve higher speeds and better cornering capabilities" [6]. Ekanem et al underscores the importance of technological evolution in shaping aerodynamics in Formula One. Ekanem not only mentions technology's impact on vehicle performance in Formula One but also the automotive industry as a whole. This aligns with Zhang's argument for technology playing a vital role in improving vehicle performance as Zhang states "the introduction of wings and spoilers to gain downforce improved the grip and cornering speed" [32]. He emphasises these technological innovations have dramatically improved overall performance of F1 cars.

Aerodynamics became more prevalent in the 1970's and this decade also saw the introduction of turbocharged engines. The late 1960's and 1970's marked the beginning of the aerodynamics era in F1. Aerodynamics is a major part in extracting the optimal vehicle performance in Formula One. It allows for "literally tons of downforce to be created and so this has been the key performance differentiator in recent years" [28]. Toet mentions that F1 is governed by strict regulations that limit the impact of technology and aerodynamics. Toet argues that few people understood aerodynamics during this period; "in those days very few F1 people understood just how much load could be generated and how that would change the structure of a race car" [28].

3.5.2 Vehicle Performance: Modern Approaches

The introduction of lightweight materials in F1 has significantly enhanced vehicle performance in the sport; "technological advances gained from these advanced materials have produced cars that are lighter, faster and safer than ever before" [20]. Savage makes the case that modern F1 cars would not be where they are today without the evolution of technology. Savage claims "composites materials science and engineering has had a significant, often pivotal, role in the development of Formula 1" [20]. Savage states the key to success in F1 is to find the optimal solution of combining "pilot, engine, tyres, performance, technical innovation and reliability" [20].

Modern Formula One cars are so advanced, they stand out from everything else, "on one hand, technological developments mean that highly advanced cars can really stand out" [3]. Bell et al state Formula One driver performance "comes down to the ability to overtake one's rivals, aided in recent years by Kinetic Energy Recovery Systems and Drag Reduction Systems" [3]. Due to technological innovation, they claim vehicle performance has significantly improved due to new innovations such as the KERS and DRS systems.

3.6 Evaluating Technological Advancements in Formula 1

The evolution of technology in the world of Formula One has brought about significant strengths and weaknesses that have contributed to shaping the sport over time. On one hand, technological advancements have led to improved safety measures, boosted vehicle performance, and better fuel efficiency in Formula One. On the other hand, these innovations come along with weaknesses including inflated cost of technology, increased complexity of systems and technology, and the need for never ending technological innovation in the sport to stay competitive with rival teams.

3.6.1 Strengths of Technological Advancements: Driver Safety

The introduction of safety features such as the monocoque chassis in the 1980's, Head and Neck Support (HANS) device in 2003, the Halo device in 2018, and many more features have dramatically improved driver safety within the sport. In the 1960's "the rate of fatal and serious injury within Formula 1 was one in every eight crashes" [21]. Driver safety was not the primary concern in Formula One in the early years of the sport. The monocoque chassis also known as the survival cell significantly reduced the risk of major injury and fatalities in Formula One over the years. It is "designed to dissipate energy irreversibly during the impact, thereby reducing the forces to the survival cell and hence the driver. designed to dissipate energy irreversibly during the impact, thereby reducing the forces to the survival cell and hence the driver" [21]. Savage states between 1980-1992, a 6-fold decline in fatalities occurred due to innovations such as the survival cell.

The HANS device made mandatory in F1 in 2003 is another technological innovation that rapidly improved driver safety in F1, "up to 2019, 126 deaths have occurred as a consequence of crashes and it has been estimated that of these 126 deaths, 27 % circa could have been prevented by using a HANS device" [9]. Gazaneo emphasises the importance of this device as it is now mandatory across most racing competitions around the globe. The device "minimizes the relative movement of the head and neck keeping them restricted from snapping forward and keeping them aligned with the torso in such a way vertebrae are not overloaded" [9], therefore reducing the risk of major injury to Formula One drivers.

One of the most influential technological innovations is the Halo device. This device "protects the driver against significant risks of injuries due to vehicle-to-vehicle contact, vehicle-to-environment contact, and external object hit" [4]. Demirel et al state F1 vehicles did not include a canopy around the cockpit, protecting drivers from incoming objects. They argue that some drivers find this device to be intrusive, but it makes up for itself with drastic improvements in relation to driver safety in F1. Technological development has drastically improved driver safety in Formula One over time as Savage claims; "advances in technology and stringent safety rules have combined to significantly reduce the risk of death and injury resulting from crashes in Formula 1 races and tests" [21]. Savage argues that driver safety would be much more of a concern had technology not improved it in recent decades.

3.6.2 Strengths of Technological Advancements: Vehicle Performance

Improvements in Formula One vehicle performance can be seen through technological innovations such as the introduction front and rear wings during the aerodynamics era, hybrid power engines, the drag reduction system (DRS), and many more innovations have contributed to improving vehicle performance in the sport over time. The beginning of the aerodynamics era in Formula One was marked by the introduction of front and rear wings. These wings greatly improve downforce, stability, and airflow management around the car. Due to "continuous advancement of racing technology and the constant adjustment of rules, the front wing design has gradually become more complex and optimized" [12]. Hou outlines the importance of front wings in generating considerably more downforce on F1 cars, resulting in massive improvements in overall vehicle performance. Hou highlights how generating more downforce improves vehicle performance, "higher downforce enhances the vehicle's maneuverability, making it easier for drivers to control and improve its braking performance" [12]. This results in faster lap times, providing a competitive edge over competitors if the wings are designed right which optimises aerodynamic efficiency. Hou states that technology has been a key factor in shaping this area, "with the continued application of new materials, technologies and regulations, front wing will become more lightweight, efficient, and intelligent. This will enable Formula One cars to achieve greater breakthroughs in performance and bring more exciting races to the audience" [12].

In 2014, Formula One changed engine configurations from 2.4 litre V8 engines to 1.6 litre V6 engines. These hybrid power units combine a highly efficient internal combustion engine with energy recovery systems such as the KERS and HERS systems. The combination of these systems provides "increased power output but also improved fuel efficiency, making F1 cars more sustainable" [6]. Ekanem et al emphasise how these engines have been a product of technological evolution, and they revolutionised the sport in terms of vehicle performance and efficiency. Being introduced in 2014, they immediately improved fuel efficiency and performance as "thermal efficiency of combustion engines grew from approx. 35–37% in 2014 to approx. 45–47% in 2015 and 51% in 2016" [23], and "maximum power output of the power units grew from approx. 750 KM (552 kW) in 2014 to approx. 950 KM (699 kW) in 2015" [23]. STĘPIEŃ claims the durability of engines has also improved along with efficiency and performance. The performance grew each year during this period according to STĘPIEŃ which adds to the idea that technology positively impacts vehicle performance.

3.6.3 Technological Advancements: Key Weaknesses

The weaknesses of technological advancements in Formula One as stated previously include inflated cost of technology, increased complexity of systems and technology, and the need for continuous technological innovation in the sport to stay competitive with rival teams. Despite technological innovation majorly boosting vehicle performance throughout time, it is also true that the downsides are impactful.

A study was conducted to identify if F1 teams' budgets and performances were interconnected. This study concluded that "budgets and performances are interconnected in F1. However, additional parameters are incorporated when it comes to the total output of an F1 team" [14]. Their findings state there are three top teams including Ferrari, Mercedes, and Red Bull in these categories. They outline that Formula One is a “motorsport that relies on past development and experience. Evidently, the top teams will still have an advantage in the early years of the budget cap enforcement due to past R&D, knowledge, and experience” [14]. Technology cost is lesser, and experience is greater for the top teams in Formula One which they claim provides an unfair advantage.

Another study finds that due to technology evolving, it has reduced the competitive balance within the sport. This study claims the “kinetic energy recovery system (KERS) and the drag reduction systems (DRS) have provided further issues relating to the use of technology in the sport” [22]. They argue that regulation changes provide better competition in F1. Due to technological evolution, technology within the sport has become increasingly complex therefore becoming an obstacle for teams to overcome. Schneider and Rocha outline the sport’s competitiveness has reduced as technology has evolved so dramatically, “as recent years have proved, the expected competitive balance has not returned to F1, demonstrating the complexity of the issues associated with tire use in F1 and the importance of understanding its impact on the sport” [22]. Their research concludes that technological advancement has negatively impacted fan engagement with the sport as it has increased complexity for teams.

The continuous need for technological innovation in Formula One is exhausting for F1 teams. Suarez claims Formula One to be a “dynamic environment with frequent technical, organizational and regulation changes of varying magnitude that constitute a unique case of capability development and erosion, industrial and technological evolution” [25]. Suarez argues that competitive advantage in the sport depends on exploitation and exploration of technology and regulations combined. Suarez highlights the importance of technology in shaping the sport seen today but makes the case that it has negatively impacted the competitiveness of the sport as there is a constant hunt for perfection. Whilst technological innovation has greatly benefited Formula One, they also present many obstacles that have been outlined in this literature review. These weaknesses present obstacles to the ten teams within the sport, and they must continue to learn how to navigate around these obstacles to remain or be successful in Formula One

3.7 Gaps in Existing Literature

Formula One is a relentless cycle of innovation and change, where technological evolution has majorly influenced both vehicle performance and driver safety over time. Despite the extensive research and development in the sport, there remains gaps in literature where our understanding is limited. Identifying these gaps in literature in Formula One is vital as it emphasises the limitations of past and current research whilst also highlighting the need for further research. This section of the literature review aims to highlight these gaps in literature, providing a pathway for future research. The goal is to further my understanding of the dynamic relationship between technology, vehicle performance, and driver safety in the world of Formula One.

3.7.1 Impact of Regulation Changes on Vehicle Performance

Papachristos argues that the governing body of F1, the FIA, adapts regulations to technological developments, "The regulatory body of F1 Federation Internationale de l'Automobile (FIA) keeps regulations in step with technology evolution as technology enabled the cars to go faster" [19]. Papachristos states the development of technology in the 1990's reached such an elevated level that it altered the competitiveness in the sport dramatically. This study analyses regulation changes from 1990-2013, to provide an insight about the 2014 regulation changes. Another study conducted by Erruas et al claims "regulations from 2017 showed notable compromises, the newer regulations have significantly improved these compromises" [7]. Erruas et al focused on the aerodynamic justification from the 2022 regulations. Comparing these regulations to the 2017 changes, Erruas et al concluded that aerodynamic performance did improve from 2017 to 2022. This study only focuses on aerodynamics and no other aspect of vehicle development in relation to regulation changes. A clear gap in literature can be identified here.

As previously stated, regulation changes are kept in line with technological advancements by the FIA. These recent studies briefly discuss regulations from 1990-2013 and 2017-2022, respectively. This research does not factor in every aspect of technological development in Formula One. Papachristos does not detail how regulation changes impact vehicle performance but Erruas et al does but only regarding aerodynamics. Though aerodynamics is a major player in Formula One, it does not not represent all aspects of technological development. Further study needs to be conducted on current regulation changes from 2022 to the present to understand the impact of these regulation changes not only in terms of aerodynamics but every aspect of technological development.

3.7.2 Impact of Artificial Intelligence and Machine Learning on Vehicle Performance

The recent rise of artificial intelligence and machine learning has changed the landscape of technology forever. Hardik Inani et al state "by employing artificial intelligence (AI) and machine learning (ML) to create predictive models, teams can drastically improve their cars' racing efficacy" [10]. They mention how artificial intelligence (AI) and machine learning (ML) could influence the sport in the future but do not provide current research on this. With AI and ML being introduced on a global scale only recently, it is evident that there would not be comprehensive research on this area. They emphasise that “forefront technologies like AI and ML are set to redefine vehicular dynamics” [10]. Their research is predicatet on future projection and not facts. AI and ML are widely used in Formula One today. There is a clear gap in knowledge in this field of technology in F1. In regard to vehicle performance, further research on the technological impact of regulation changes and AI and ML could enhance our understanding of vehicle performance in the modern age.

3.7.3 Impact of Artificial Intelligence and Machine Learning on Driver Safety

Having looked at AI and ML’s impact on vehicle performance, this section focuses on the impact it has had on driver safety in Formula One. A study completed by Sturm states “with a greater emphasis on driver safety, the encroachment of technologies mitigates against potential fatalities while literally taking elements of bravado and risk-taking out of the driver’s control” [24]. As a relatively recent study, Sturm briefly mentions how technology has impacted driver safety. Sturm refers to AI as a “futuristic motorsport innovation” [24], adding to the notion that it is the future of driver safety. Despite this brief mention, Sturm’s study does not detail the current impact AI has on F1. This aligns with my previous take that there is little to no research analysing the impact of AI and ML in this case on driver safety. Further studies need to be conducted about the current use of AI and ML with driver safety.

3.7.4 Crash Testing

Turning the focus to crash testing in F1, there is a lack of research regarding this area in the sport. Crash testing in Formula One plays a significant role in relation to driver safety. Crash testing simulates real crash scenarios to understand the impact on the car and the driver. Research completed by Heimbs et al applies “FE code LS-DYNA for the crushing simulation of an F1 racing car front impact structure in a frontal crash against a rigid wall” [11]. Their research analyses crash testing scenarios for F1 cars and drivers to understand the loads and impacts on them. This method they propose is separate from crash testing as they attempt to find a replacement, but their analysis concludes that it cannot replace crash testing. They only propose one method which lacks depth in knowledge about finding alternatives to crash testing.

Another study completed by Arya et al analyses two methods for “simulating crash events and evaluating the crashworthiness of a tyre barrier system” [1]. They outline their findings are “crucial for assessing the effectiveness of safety barriers” [1], which is pivotal for understanding the impact of technology on driver safet in Formula One. Their research uses two crash scenarios, and they emphasise “there is an opportunity for further refinement” [1]. By researching various other methods and further research, they underscore this could improve the effectiveness of safety analysis. This clearly demonstrates there is a gap in literature in this area. Further studies focusing on these areas of safety in Formula One could significantly enhance our understanding of the technological impact on driver safety.

3.8 Project Contribution

The goal of this research project is to contribute to existing research about vehicle performance and driver safety in Formula One and also to highlight areas for further study. This research project focuses on technology's impact on both vehicle performance and driver safety from the beginning of F1 dating back to 1950, to the present time. Having previously analysed existing research about these topics, there are clear gaps in literature as already mentioned. Having thoroughly researched these fields; a conclusion can be made that there is a lack of research that is comprehensive and research that focuses on large periods of time. This research project aims to contribute comprehensive research and analysis that focuses on the entire lifespan of F1, providing in depth detail about technology's impact on vehicle peformance and driver safety.

As Young states, "technology has always been a central feature in Formula One" [31]. She makes the case for technology possibly replacing drivers in Formula One but argues that technology is central to the sport, and it should not be abolished. She claims, "both the DRS system and the adjustable rear wing are examples of appropriate technology regulation" [31]. Young makes the case that technology has advanced so much that it needs to be properly regulated, but when it is, innovations like the drag reduction system and adjustable rear wings add to vehicle performance.

Another study aims to highlight the impact of technology being able to predict accidents before a race occurs as they "attempt to make the sport safer by predicting in advance the possibility of accidents in an upcoming race" [5]. Dhanvanth et al use datasets from 1950-2020 but do not outline what datasets are used, leaving the study's findings to be questioned. They conclude that the model has an accuracy of 64.7% in predicting outcomes but cannot predict unforeseen circumstances. Completed studies such as this leaves questions for the reader as they do not clearly state what datasets are used and what factors are being considered for their data model to try to improve driver safety.

3.8.1 Project Insight

The contribution of this research project aims to clarify technology's impact on driver safety and vehicle performance. As outlined previously in this literature review, much of the research focuses on noticeably short periods of time and only factors in some insignificant things. This project aims to shed a light on these gaps in literature by providing an analysis on technological evolution throughout time in Formula One and not smaller periods of time.

The introduction of advanced AI and ML in F1 combined with advanced data analytics poses an interesting duo when it comes to performance and safety in the sport. It is currently used to optimise car performance and for testing safety features being added to the sport. As technology continues to develop, it will provide unimaginable improvements in performance and safety in the sport. This research project analyses safety and vehicle innovations added to the sport over time such as the HANS & Halo device for safety and DRS and aerodynamics for performance. This project aims to highlight how technology has improved these areas.

3.9 Literature Review: Conclusion

In conclusion, this literature review focuses on technology's profound impact on vehicle performance and driver safety in Formula One over time. Advancements in driver safety such as the survival cell (or monocoque chassi), Halo & HANS devices and developments in performance such as aerodynamics, lightweight materials, hybrid power engines, and DRS have continuously pushed the boundaries of technology and have greatly improved vehicle performance and driver safety in F1.

By addressing what is already known about vehicle performance and driver safety, analysing the strengths and weaknesses of technological advancements in both areas, and by identifying gaps in existing literature, this research project offers new insights into how technological developments have shaped the sport we see today, offering a deeper understanding of their dual impact on driver safety and vehicle performance. The gaps that remain in existing literature include the role of artificial intelligence and machine learning on performance and safety in the sport.

3.9.1 Future Research Insights

AI can analyse vast amounts of data from sensors and other technologies on Formula One cars, possibly being able to predict potential accidents and to alert drivers in real-time. Analysing things like tire condition and performance, engine performance, and environmental conditions could lead to fewer accidents in Formula One, further enhancing driver safety. On the other hand, AI is currently used in Formula One to optimise race strategies for teams, but it is unclear how much of a role it plays in choosing the right strategy. AI could transform vehicle performance by optimising pit stop strategies, tire performance and management, fuel management, engine performance, and many more factors. Artificial intelligence algorithms could use live data during races to optimise vehicle performance depending on weather conditions, offering new insights to F1 teams. With generative AI emerging as a new field in the world of Formula One, it could potentially revolutionise driver safety and vehicle peformance in the sport. Integrating AI and ML into

Formula One ensures the sport continues to push the boundaries of innovation and that it maintains its current position as the pinnacle of all motorsports.

Analysis

This chapter of the project plans to decompose the general problem into clear requirements. This involves identifying functional and non-functional requirements.

4.1 Home Page

All kinds of users will visit this website with different objectives in mind. Passionate F1 enthusiasts will appreciate the detailed interactive timelines alongside the in-depth analysis of technological advancements over time in the sport. On the other hand, casual fans may navigate to the latest news updates in Formula 1 and engage with a variety of interactive elements on this website that makes learning about F1 that more enjoyable through engagement. The home page serves as the central hub of the website, providing an engaging overview of the project's objectives to visitors and offering easy navigation to other sections of the site. The home page should address the following:

Functional Requirements:

The home page should provide a brief overview of the project and its goal to visitors. Users should be provided with easy navigation around the site to ensure quick access to all the features and content available to them. Website visitors should be allowed to search for specific aspects of the webpage to find information more efficiently. Visitors should be able to easily browse the website through links between pages. Finally, users should be able to subscribe to the website for further information on this first page of the website.

Non-Functional Requirements:

Webpage visitors should be met with a welcoming, professional, and easy-to-use interface upon entering the webpage. Content on the home page should be automatically displayed and organised in a clear manner. Users should be allowed to scroll up and down the page easily without interruption.

4.2 Events Page

Users are not always interested in the same things. Both passionate and casual visitors should be able to engage with and understand all aspects of the website. Therefore, the website provides key information to all visitors, ensuring both newcomers and devoted fans of F1 can easily understand and engage with all content. All upcoming events should be clearly displayed to the user. The requirements are outlined below:

Functional Requirements:

Content regarding upcoming events in Formula 1 in 2025 should automatically be displayed to users upon entering the page. Content should provide key information about the events including dates, location, and name of the event. Additional information should be provided to users about each event through the use of links to other webpages. Users should be provided with a search bar to search for information more efficiently. The link to this page should be functioning correctly and should directly take users to this page.

Non-Functional Requirements:

The events page should be loaded quickly and efficiently. Content should be structured in a clear manner, organised in a chronological fashion by date. Users should be able to easily scroll through the page, with content displaying correctly to ensure a smooth browsing experience.

4.3 About Page

Users visit websites with varying levels of interest and knowledge about certain things. All types of users should be able to engage with and understand the diverse content provided. Therefore, about pages should contain generic information that is easily understood by all. It should clearly outline the background of the website and what its intentions are. Users should be able to navigate the page as outlined below:

Functional Requirements:

Visitors should be provided with a brief introduction of the project and its creator. Content on this page should offer key information about the current state of Formula 1 for those users who may not know about it and should be presented clearly. Users should be able to engage with an interactive map including all Grand Prix locations around the globe to learn more about the sport.

Non-Functional Requirements:

The page should be presented in a visually appealing and professional manner, aligning with the theme of the site. Users should be able to effortlessly scroll around the page and engage with a functioning interactive world map. Content should be neatly organised and structured in an engaging fashion.

4.4 Vehicle Performance Interactive Timeline

Interactive timelines should allow the user to interact and engage with the content provided in the timeline, enhancing the user experience. The content should be interactive by scrolling through the timeline and giving priority to the user to click on various engaging elements. There are several requirements for this:

Functional Requirements:

Content should be easily understood by all web visitors. Multimedia content should automatically be displayed and be interactive for users to engage with. Users should be able to interact with polls provided before and after the interactive timeline and should be able to submit answers and see results. Users should be able to easily find and access a GitHub repository which is connected to a Google Colab notebook containing findings after conducting data analysis. Visitors should be able to easily navigate to more in-depth timelines from each timeline block, providing additional information about significant milestones in F1.

Non-Functional Requirements:

Visitors should be able to browse through the interactive timeline and engage with all aspects of the page. Content in the timeline should be neatly organised, and interactive elements should be clearly highlighted. Links to other pages along with external links to a GitHub repository should be functioning correctly. Timeline blocks should be alternating sides and should vary in colour for an aesthetic look.

4.5 Driver Safety Interactive Timeline

To make timelines more engaging for the user, interactivity is added to enhance the user learning and experience. Users should be able to engage with various elements and move at their own pace. The requirements for this are as follows:

Functional Requirements:

Users should be able to interact with various buttons linking to an interactive timeline using an external tool, TimelineJS. Upon clicking the link to the timeline, users should be presented with an engaging and fun interactive timeline providing data on driver safety over time in Formula 1 with various interactive elements allowing for a better user experience.

Visitors should be able to interact with surveys on the page, quizzing them about their knowledge of driver safety in Formula 1. Timeline content should be presented in a structured manner whilst ensuring navigation is at the user's discretion, allowing them to move at their own pace. Users should easily be able to navigate throughout the page and timeline.

Non-Functional Requirements:

Links to TimelineJS and the GitHub repository should be functioning correctly. Timeline content should be visually appealing and entirely interactive.

4.6 GitHub & Google Colab Findings

Users should be provided with comprehensive insights alongside what they see on the website to back the findings up. Data analysis offers graphs, visualisations, and conclusions for users to draw on which improves users understanding of the project's scope and results. Users should be allowed to freely explore these findings, to gain a better understanding of the data. The requirements for this are as follows:

Functional Requirements:

Visitors should be able to access the GitHub repository and Google Colab notebook through the use of functional links. Users should be able to explore and interact with the GitHub repository and Google Colab notebook easily. Users should be presented with clear documentation explaining the findings and drawing conclusions to further improve their understanding. Users should be able to search for datasets and easily browse through them within the GitHub repository.

Non-Functional Requirements:

Links to the GitHub repository and Google Colab notebook should be working correctly. GitHub repository and Google Colab notebook should be clearly structured allowing for an easy user experience. Graphs and other visualisations should be visually appealing and easily understood by all users.

4.7 Latest News Updates Page

Users should be kept up to date with the latest F1 news updates providing a more engaging user experience. Subscribed users should be automatically notified when a news update occurs. The requirements are outlined below:

Functional Requirements:

News content should automatically be displayed to users and updated when updated content comes out using an automatic RSS feed. Users should be able to interact with any news story to learn more about it by clicking on the link. Users should be able to listen to the podcast linked on the page which should automatically update when a new episode comes out. All visitors should be able to subscribe to the website by inputting their email into the subscription box. The page should be easily navigated by all users for a smooth user experience.

Non-Functional Requirements:

RSS feed and podcast should automatically update when latest updates come out. All elements should be interactive and clearly stated on the page.

4.8 Feedback Page

Website visitors should be allowed to have their say on the content provided on the website. Therefore, polls and forms should be provided to the user to give feedback to the creator. The requirements for this are detailed below:

Functional Requirements:

Users should be provided with polls and forms to engage with to offer their feedback. Submission buttons should be provided to allow users to submit their answers. User feedback should be securely stored in a database and should be notified in the case of a return message. Users should be able to see the results of the polls.

Non-Functional Requirements:

Submissions by users should be sent quickly to the creator without error. Content should be visually appealing and engaging for the user. Data must be accurately and securely stored in WordPress database.

4.9 Analysis Conclusion

Functional and non-functional requirements have been identified for each aspect of the digital artefact providing insight into what is needed and not needed for the creation of each page. These requirements focus on what each website page should include, allowing the focus to be clear for what exactly is needed. The general problem was decomposed into sub problems by breaking them down into functional and non-functional requirements.

Design

This chapter of the project aims to explore the architecture of WordPress along with the front and back-end development required to design the digital artefact. This will be discussed in detail in this section.

5.1 WordPress Architecture

The architecture for a website hosted by WordPress is structured around various key components. The main components of the architecture include themes, plugins, database, core files and directories, content management system (CMS), and user interface (UI). Themes can be utilised to control the layout and aesthetic of the website. Plugins are additional features that can be added to a website, offering extra functionality and capabilities. All content related to the website including site content, setttings, storage, and other user information are stored within a MySQL database hosted by WordPress. Wordpress core files and directories are managed by WordPress to ensure the website runs properly and efficiently. The main files and directories include wp-content, wp-admin, wp-includes, index.php, wp-config.php, along with some other core files and directories. Together, these secure a smooth and seamless management of the site. The CMS in WordPress communicates with the MySQL database to store data and retrieve it. This allows users to manage, create, and edit any content on the website with ease. The UI which includes a main dashboard, acts as the main control hub for managing things across the site.

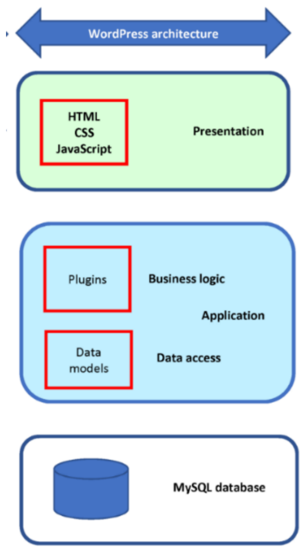


Figure 5.1: WordPress Architecture Diagram

5.1.1 WordPress Architecture Example

An example of the WordPress Architecture is shown below in Figures 5.2 & 5.3. These represent basic core structure and content structure code. Using the free version of WordPress for this project, the underlying architecture is managed by WordPress and not by the creator of the site. This includes site security, hosting, updates, backups and more. With WordPress managing the underlying architecture, this allows the creator of the site to focus on other aspects including creation and management of the site.

```
<body>
<div id="rap">
<h1 id="header"></h1>
<div id="content"></div>
<div id="menu"></div>
<p class="credit"></p>
</div>
</body>
```

Figure 5.2: WordPress Core Structure

```
<div id="content">
   <h2>Date</h2>
   <div class="post" id="post-1">
      <h3 class="storytitle">Post Title</h3>
      <div class="meta">Post Meta Data</div>
      <div class="storycontent">
         <p>Welcome to WordPress.</p>
      </div>
      <div class="feedback">Comments (2)</div>
   </div>
</div>
```

Figure 5.3: WordPress Content Structure

5.2 Back-End Design

The back-end design of the digital artefact hosted using WordPress is managed in a variety of ways. The website is managed through the main dashboard which offers customisation over all content on the site, appearance, plugins, users, tools, and settings. This allows the creator of the website to control user access, manage plugins and tools, and to handle the general settings of the website. The appearance of the website can be customised through theme options, offering vast customisation tools to the creator. A screenshot of this dashboard can be found below.

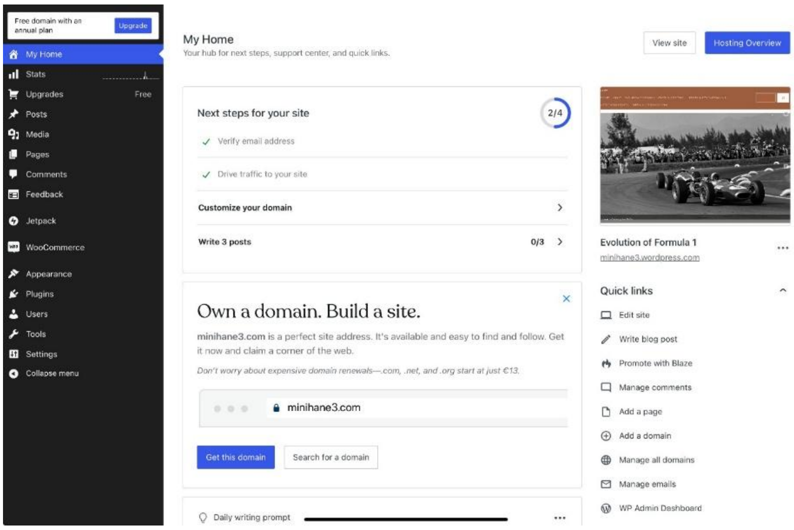


Figure 5.4: Dashboard Layout

5.3 Front-End Design

The front-end design of the website focuses on creating a visually appealing and user-friendly interface for users. This process begins with a well organised layout of the website with easy navigation for users. This allows users to navigate around the website with ease to find the information they need. Other aspects involved in the front-end design include customisable templates and themes allowing for creative colour schemes and typography. Ensuring the website has a great responsive design is vital in this process. Including various multimedia elements, interactive features and making the website accessible to all users is pivotal to the website's success. Presenting content in a tidy and appealing way is key for users engaging with the content. Screenshots of various front-end design aspects of the website are shown below.

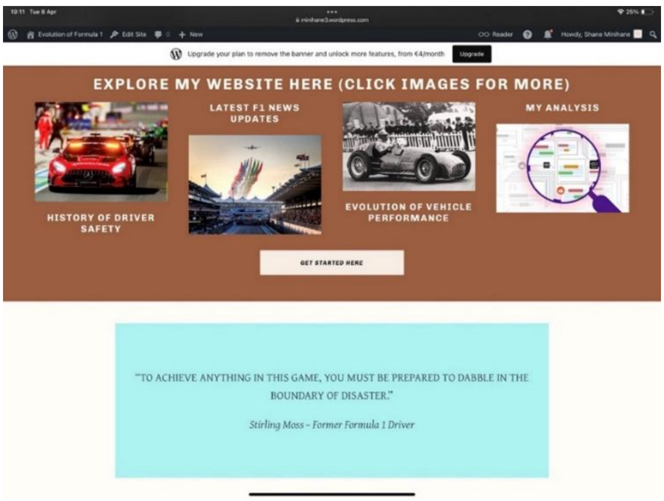


Figure 5.5: Home Page Layout: Theme

Figure 5.6: Navigation

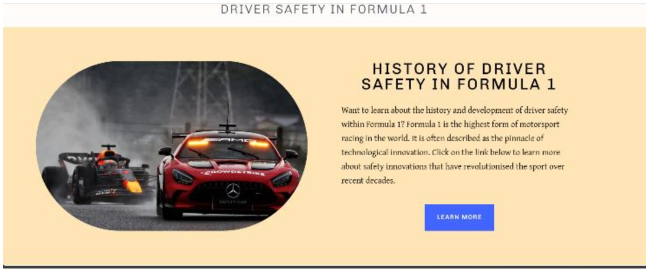


Figure 5.7: Typography and Colour Scheme

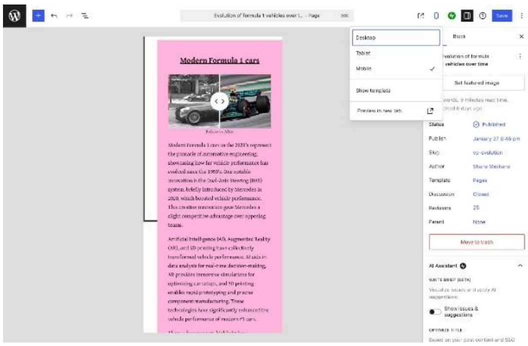


Figure 5.8: Responsive Design

5.4 Digital Artefact Requirements

A number of requirements were determined in the previous chapter. Functional requirements were outlined and are re-evaluated here with solutions demonstrated below.

5.4.1 Home Page

A website user can range from enthusiastic Formula 1 fanatics to casual visitors. Upon visiting the website, users are greeted by an automatic slideshow, taking users through the history of Formula 1. An efficient navigation menu along with a search bar are available for users to easily navigate the website. A user can scroll effortlessly throughout the page, making use of the variety of links and engaging elements the website has to offer. Users can engage with a brief introduction to the projects' outline and goals. A subscription block is available for users to subscribe to the site for further information.

5.4.2 Events Page

Web visitors are able to see all upcoming events in 2025 with key details included. Users are also able to search for specific events to find information more efficiently. If a user wishes to learn more about a particular event, additional event information is provided through the use of links, taking users to an external page with more in-depth information about that event.

5.4.3 About Page

Visitors can learn about the creator of the project and get introductions to vehicle performance and driver safety in Formula 1. Users are able to engage with an interactive world map showcasing all Grand Prix locations and other events around the globe. A user may scroll freely throughout the map and connect with the different elements.

5.4.4 Vehicle Performance Interactive Timeline

Upon entry to this page, users can engage with polls quizzing them on their current Formula 1 knowledge. Content along with other multimedia content is automatically displayed in an alternating fashion. Users can scroll seamlessly throughout the timeline without delay and can take part in a fun user experience including a variety of different interactive elements. Links are accessible to users through interactive features like buttons to GitHub and other pages.

5.4.5 Driver Safety Interactive Timeline

Users can scroll around the page with ease and take part in surveys to test their knowledge about the sport. Links are connected for users to visit the external timeline using the TimelineJS tool. The timeline offers an interactive experience to users as they have priority to navigate the timeline.

5.4.6 GitHub & Google Colab Findings

Users can make their way to an open-source GitHub repository through the use of links on the website. Clear documentation is provided to users as they are able to browse through the datasets available and engage with the graphs and visualisations for a better overall user experience.

5.4.7 Latest News Updates Page

Up to date news content is given to the user through the use of an automatic RSS feed. This automatically updates every time a news update occurs. Web visitors can learn further information regarding the latest news in Formula 1 hy connecting with the RSS feed. A podcast is available for users to keep up to date with the most current and relevant news in the sport. Users are able to subscribe to the website to stay up to date with the latest information about Formula 1.

5.4.8 Feedback Page

Visitors can participate in polls and questionnaire forms to give feedback regarding the website. Submission buttons are available for users to click on when finishing their feedback forms to submit. Upon a user feedback submission, those details are securely stored in the MySQL database in WordPress. After engaging with the polls, users are able to see overall results of the polls to see feedback from other users.

5.5 Design Conclusion

The architecture of WordPress was discussed in detail here. The back and front-end design were analysed thoroughly here to ensure they met their goals. Screenshots were taken of the digital artefact to display the front and back-end design here. Having outlined the functional and non-functional requirements in the previous chapter, the design of each page and aspect of the website was clearly highlighted here. The capabilities of what users can and cannot do on each page were outlined in this section.

Implementation

The goal of this chapter is to illustrate how the data analysis for this project was conducted and how the interactive timelines were implemented. The implementation of the data analysis and interactive timelines on the website will be discussed in detail throughout this section. Python code is used to implement the data analysis for this project. Multiple tools were used to implement the interactive timelines on WordPress.

6.1 Data Collection

The first step when conducting data analysis is to collect the data first. Due to the lack of concrete data relating to the evolution of vehicle performance and driver safety in Formula 1 over time, data was gathered independently. Some data was collected from the main Formula 1 website containing some historical information regarding lap times from 1950 – 2024. This data was compiled and stored in an individual excel sheet along with other data relating to the evolution of vehicle performance and driver safety over time in F1.

6.2 Data Preparation

6.2.1 GitHub

GitHub is a cloud-based software development platform, which offers the distributed version control and source code sharing functionalities of Git [27]. For this project, GitHub is used to create a repository which stores all datasets used for the data analysis. The excel sheet filled with the relevant data was converted into a csv file so it was compatible with GitHub to load a dataset correctly. Other open-source datasets were imported using Kaggle and stored within the GitHub repository. A link to this repository can be found on the website under "My Findings" located beneath both interactive timelines. A screenshot displaying this GitHub repository can be found below.

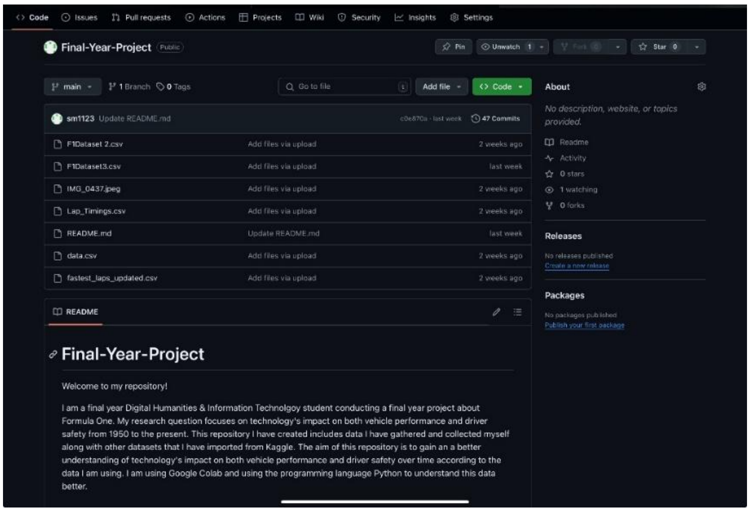


Figure 6.1: GitHub Repository

6.2.2 Google Colab

This GitHub repository is connected to a Google Colab notebook containing Python code for conducting data analysis to provide further data regarding the projects' goal. Google Colab is a computational environment ideal for data visualization, scientific calculation, and data processing [2]. Google Colab is a suitable environment for implementing Python code to conduct data analysis. Having the required datasets securely stored in the GitHub repository, they were now ready to be linked to the Google Colab notebook for data analysis. A screenshot showing this process can be found below.

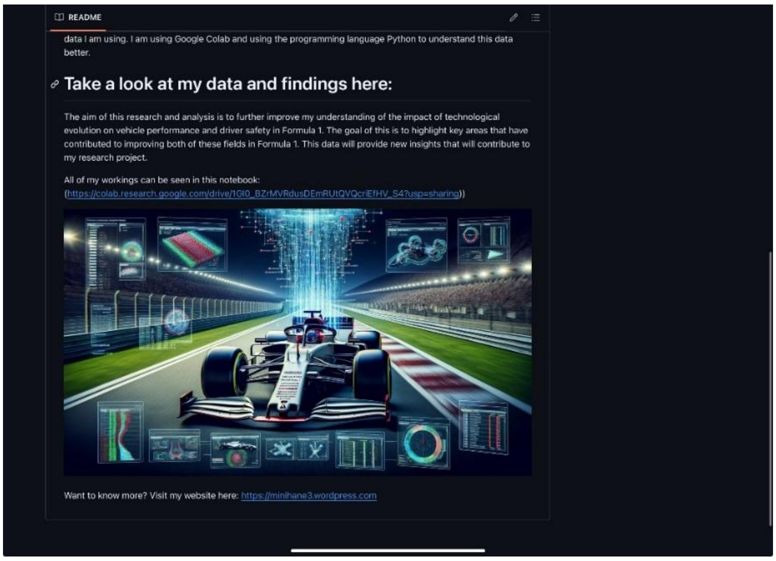


Figure 6.2: Google Colab Notebook Connected to GitHub Repository

6.3 Self-Gathered Data Analysis

6.3.1 Preparing Self-Gathered Data

The first step of this process was to connect the Google Colab notebook to the required dataset being used for data analysis. Having converted the individually collected data from an excel file to a csv, this dataset was uploaded to GitHub ready to be used. The raw csv file was copied into the Google Colab notebook so they could be linked together. A screenshot of this is found below.

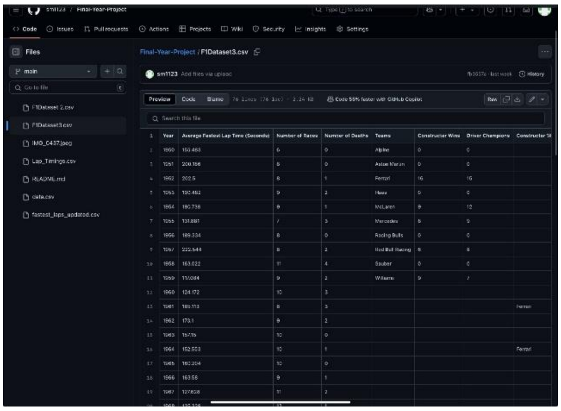


Figure 6.3: Dataset in GitHub Repository

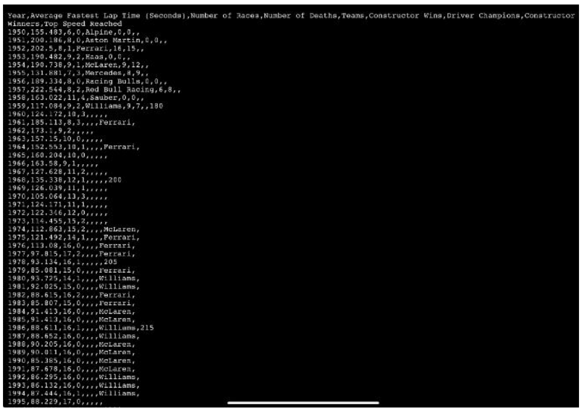


Figure 6.4: Raw CSV File for Dataset

6.3.2 Loading the Dataset

Connecting the dataset from the GitHub repository to the Google Colab notebook was completed through the raw csv file of the datasets' url which is shown previously. Having copied this link, the pandas library needed to be imported into the notebook. Pandas provides high-level data structures and functions designed to make working with structured or tabular data fast, easy, and expressive [18]. Using the pandas library makes the code more concise and readable. The code is provided below with a screenshot of this process also displayed below.

```
import pandas as pd
df = pd.read_csv("https://raw.githubusercontent.com/sm1123/Final-Year-Project/refs/heads/main/F1Dataset3.csv")
df.dtypes
```

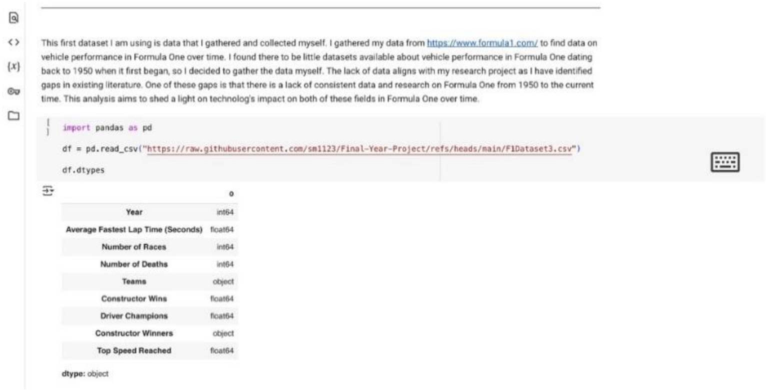


Figure 6.5: Loading the Self-Collected Dataset into Google Colab

This code block must be run before proceeding with any other code as the notebook will not work otherwise. This code imports the Pandas library and loads the relevant dataset.

6.3.3 Implementing Data Analysis on Self-Collected Data: Vehicle Performance

Focusing on the evolution of vehicle performance over time, Python code is used to display a variety of Python visualisation which are shown below.

```
df.plot.scatter(x = "Year", y = "Average Fastest Lap Time (Seconds)", 
marker = "x",
                title = "The Average Fastest Lap Time Per Year since 
1950",
                xlabel = "Year",
                ylabel = "Average Fastest Lap Time (s)",
                figsize = (11,7), color = "red")
```

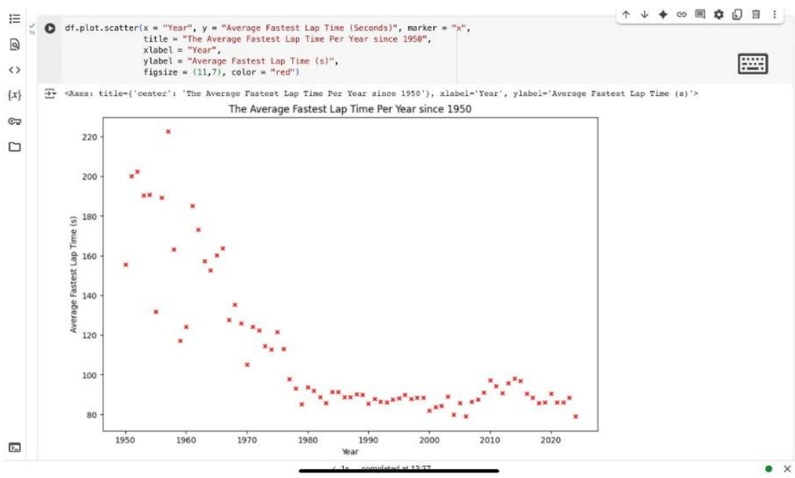


Figure 6.6: Python Visualisation Showing Improved Lap Times Over Time

This Python visualisation shows how lap times have improved from 1950 – 2025. A scatter plot was implemented to visualise the two variables over time. A strong trend is identified here as the average lap fastest lap time per year reduces exponentially over time.

```
df.groupby("Year").sum().tail(60).plot.area(y = ["Average Fastest Lap Time (Seconds)", "Top Speed Reached"],
                figsize = (9,6), alpha = 0.3,
                xlabel = "Year",
                ylabel = "Average Fastest Lap Time (s) and Top Speed Reached (mph) over time",
                title = "Area plot of the Average Fastest Lap Time (s) & Top Speed Reached (mph) over time in F1",
                stacked = False, color = ["tomato", "dodgerblue"])
```

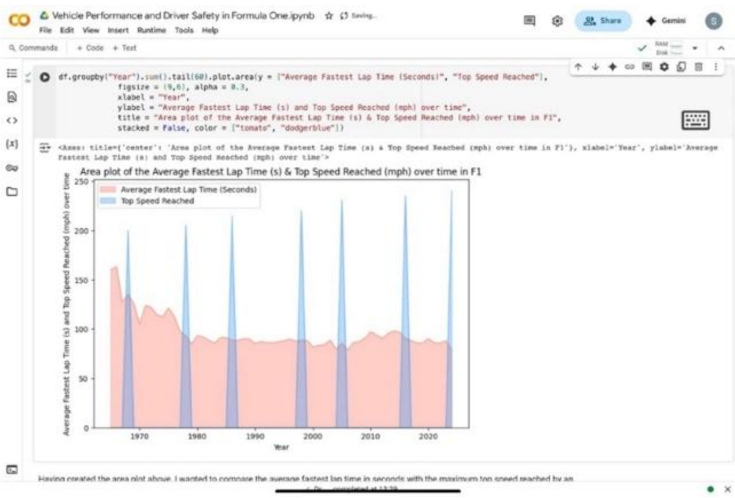


Figure 6.7: Python Visualisation Showing Lap Times in Correlation with Top Speed Reached

Python code is implemented here. Displaying the correlation between average fastest lap times and the top speed reached (mph) by an F1 car is represented using an area plot. As the average lap time begins to decrease, the top speed gradually increases over time, indicating a strong trend here.

```
df.plot.scatter(x = "Number of Races", y = "Average Fastest Lap Time (Seconds)", marker = "*",
                    title = "The Average Fastest Lap Time in relation to the Number of Races",
                    xlabel = "Number of Formula One Races",
                    ylabel = "Average Fastest Lap Time (s)",
```

```
                    figsize = (12,8), color = "blue")
df.describe()
```

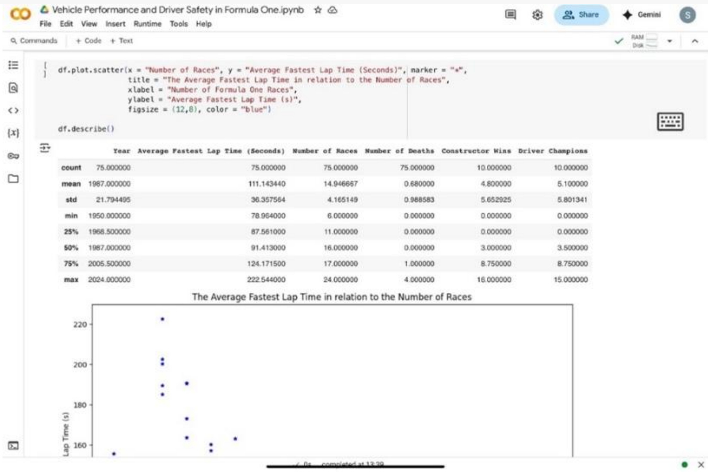


Figure 6.8: Python Visualisation Showing the Correlation between Lap Times and Number of Races in a Season

Python code is used here to implement and showcase the direct correlation between the average fastest lap times per year and the number of Grand Prix races in a season. This is implemented using a scatter plot to display the data.

```
df.groupby("Teams")["Average Fastest Lap Time
(Seconds)"].sum().sort_values().plot.pie(autopct='%1.1F%%',
                                                                          colors =
["skyblue", "gold", "lime", "coral", "violet", "mediumseagreen",
"blue", "cyan", "red", "pink"],
                                                                          title = "The
teams with the highest average fastest lap times in F1 since 1950",
                                                                          ylabel = "",
                                                                          explode =
[0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1],
                                                                          shadow =
True,
                                                                          startangle =
200,
                                                                          figsize =
(12,8),

labeldistance = None).legend(loc=(1.1,0.6))
```

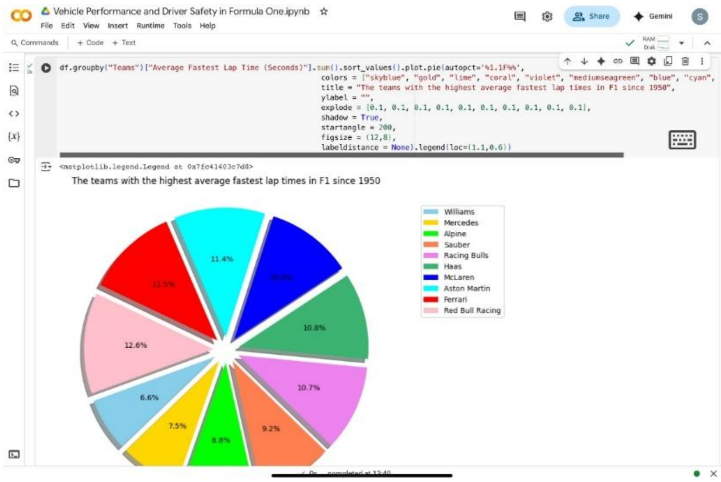


Figure 6.9: Python Visualisation Showing the Most Successful Teams in Terms of Lap Time in F1 History

Using a pie chart, the most successful teams in terms of fastest lap times earned are implanted using Python code here.

6.3.4 Implementing Data Analysis on Self-Collected Data: Driver Safety

The focus now turns to driver safety and analysing the impact of technology and how driver safety has evolved over time.

```
df.plot.scatter(x = "Year", y = "Number of Deaths", marker = "+",
                xlabel = "Year",
                ylabel = "The Number of Deaths",
                title = "The Number of Deaths Per Year in Formula 1",
                figsize = (10,7), color = "seagreen")
```

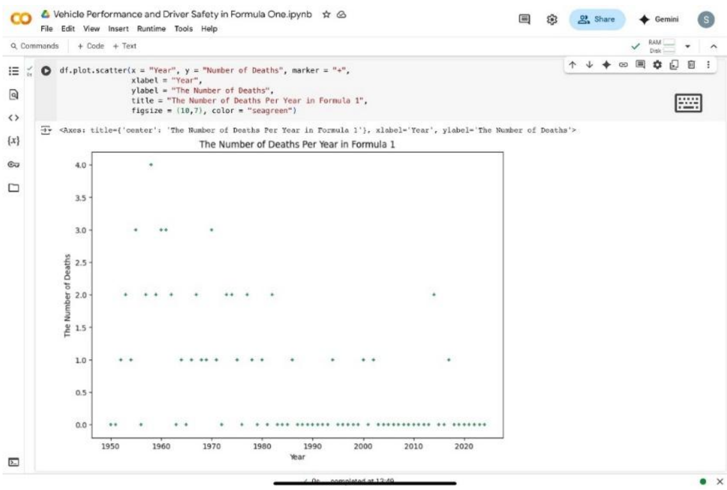


Figure 6.10: Python Visualisation of a Line Plot Showing the Number of Deaths Per Year in Formula 1

Python is used to implement a visualisation showing the number of driver deaths per year in Formula 1. This is represented as a scatter graph to visualise the data. Strong trends and outliers are identified here.

```
df.groupby("Year")[["Number of Deaths"]].sum().sort_values(by =
"Year").plot.bar(color = ['teal'],
                                                       title = "The
Number of Driver Fatalities in Formula One per year since 1950",
                                                       xlabel =
"Year",
                                                       ylabel = "The
Number of Driver Fatalities",
                                                       edgecolor =
"black",
                                                       rot = 90,
                                                       figsize =
(10,7))
```

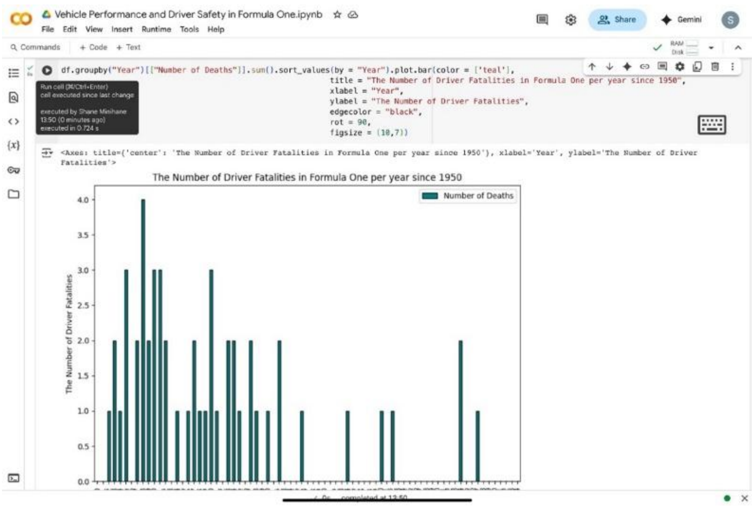


Figure 6.11: Python Visualisation of a Bar Chart Displaying the Number of Driver Fatalities in F1 Over Time

In order to display data relating to the number of driver fatalities per year in F1 over time, Python code is used to implement this. Using a bar chart, the data identifies strong tendencies and patterns.

6.4 Kaggle Dataset

Another dataset is imported from Kaggle and used here to conduct further data analysis.

6.4.1 Loading the Kaggle Dataset

```
import pandas as pd

df = pd.read_csv("https://raw.githubusercontent.com/sm1123/Final-Year-Project/refs/heads/main/data.csv")

df.dtypes
```

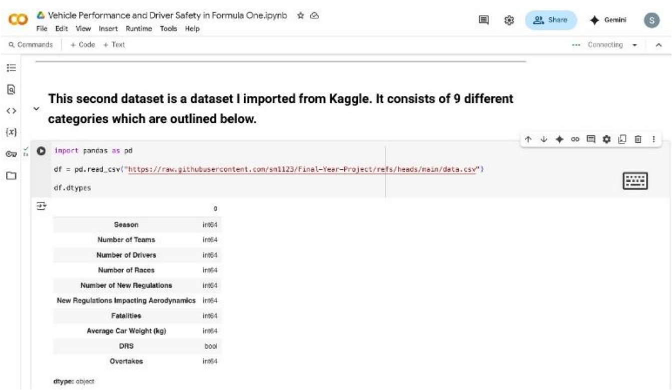


Figure 6.12: Python Visualisation Importing Pandas Library and Loading Kaggle Dataset

Using Python, the dataset from Kaggle is loaded up in the Google Colab notebook. This sets the stage for other visualisations to be made using Python as the programming language.

6.4.2 Implementing Data Analysis on Kaggle Dataset: Vehicle Performance

```
df.groupby("Season")[["Average Car Weight (kg)"]].sum().sort_values(by = "Season").plot.bar(color = ['steelblue'],
                                                            title = "The Average Car Weight (kg) Per Year since 1990",
                                                            xlabel = "Year",
                                                            ylabel = "Average Car Weight of an F1 Car (kg)",
                                                            edgecolor = "black",
                                                            rot = 90,
                                                            figsize = (7,6))
```

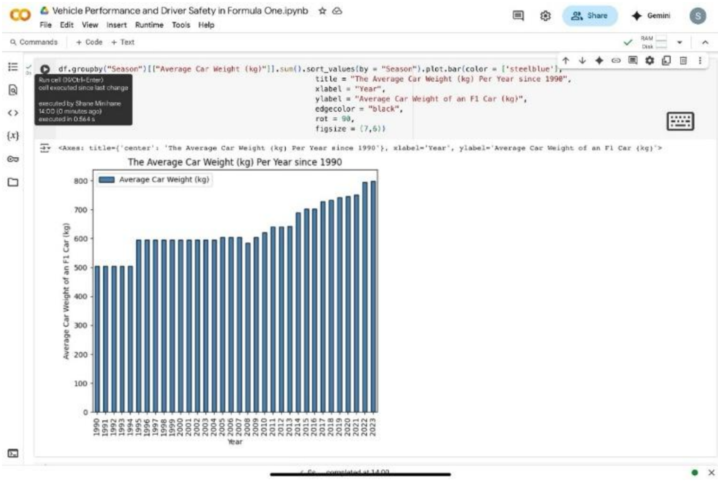


Figure 6.13: Python Code Displaying the Weight of F1 Cars Over Time

Focusing first on vehicle performance for this dataset, Python code is used to display the average car weight of F1 cars over time to analyse the different patterns using a bar chart.

```
df.plot.scatter(x = "Season", y = "New Regulations Impacting
Aerodynamics", marker = "+",
                xlabel = "Year",
                ylabel = "Number of New Regulations Impatcing
Aerodynamics",
                title = "The Number of New Regulations Impacting
Aerodynamics Per Year in Formula 1",
                figsize = (9,7), color = "black")
```

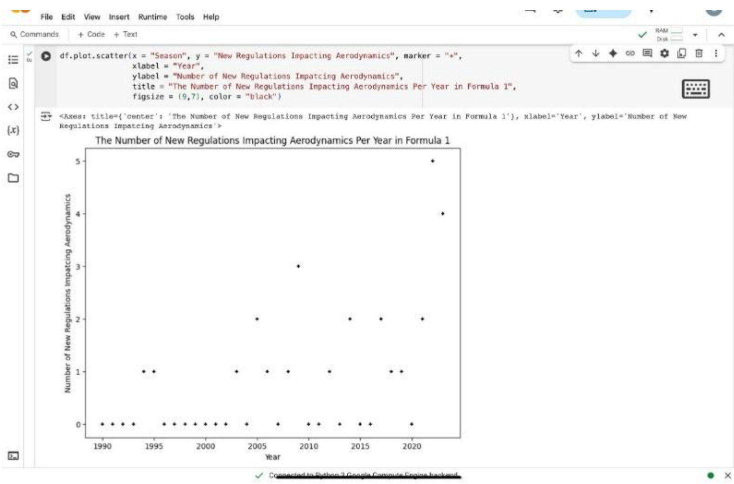


Figure 6.14: Python Code Showing Regulation Changes Affecting Aerodynamics Over Time

Python is implemented here to showcase the number of new regulation changes directly impacting aerodynamics per year in Formula 1. Implementing this using a scatter plot uncovers key data which identifies clear trends.

```
df.plot.scatter(x = "Season", y = "Overtakes", marker = "*",
                title = "The Amount of Overtakes Relative to the
Formula One Season",
                xlabel = "Formula One Season",
                ylabel = "Number of Overtakes",
                figsize = (9,7), color = "purple")
```

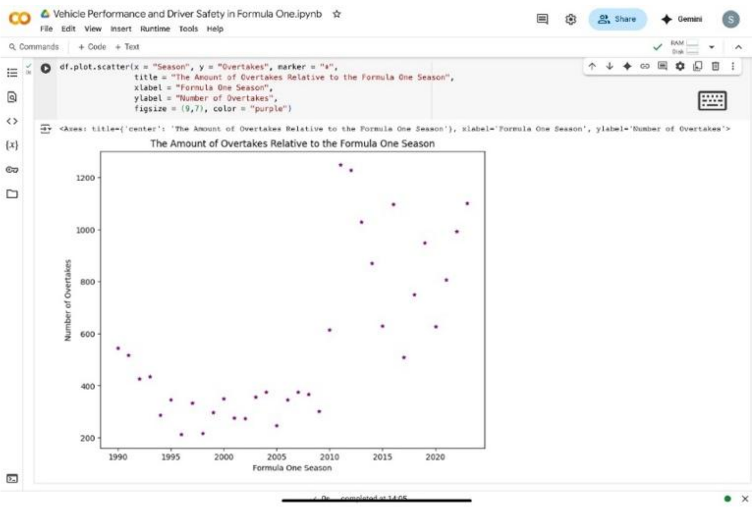


Figure 6.15: Python Code Outlining the Number of Overtakes Per Year from 1990 – 2023

Overtaking is a major part of Formula 1. It is a direct example of vehicle performance. Focusing on the number of overtakes per year from 1990 – 2023, clear patterns are identified here which are noted.

6.4.3 Implementing Data Analysis on Kaggle Dataset: Driver Safety

The focus now shifts to driver safety using the Kaggle dataset.

```
df.plot.scatter(x = "Season", y = "Fatalities", marker = "x",
                title = "The Amount of Driver Fatalities Relative to
the Formula One Season",
                xlabel = "Formula One Season",
                ylabel = "Number of Driver Fatalities",
                figsize = (9,7), color = "darkslategrey")
```

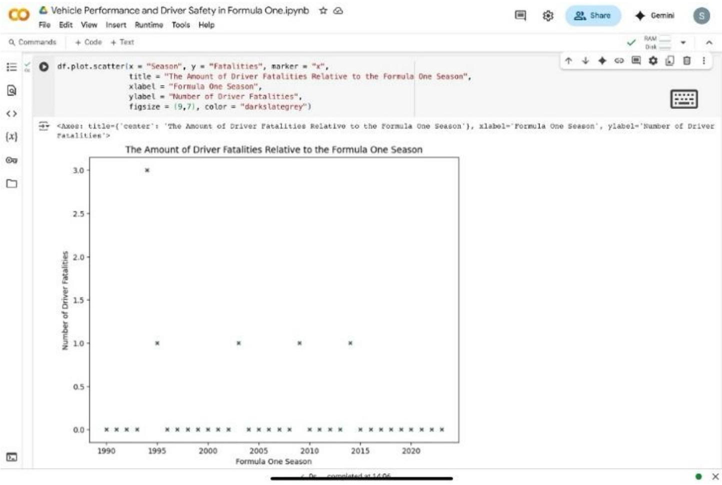


Figure 6.16: Python Code Showing the Number of Driver Fatalities Per Year from 1990 – 2023

Using Python to implement this as a scatter graph, noticeable patterns and trends are identified here relating to the number of driver fatalities per year in Formula 1 from 1990 – 2023.

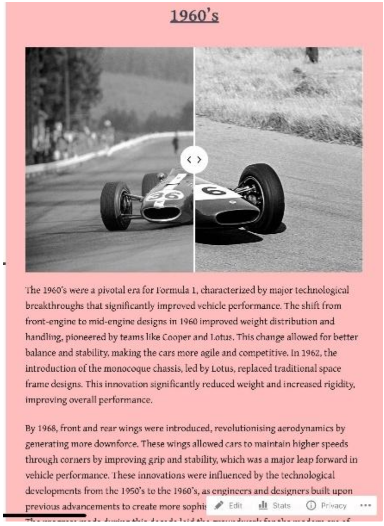
All trends, patterns, and outliers are noted here as key findings. An analysis relating to each Python visualisation can be found in the Google Colab notebook beneath eas visualisation, describing the key findings in more detail.

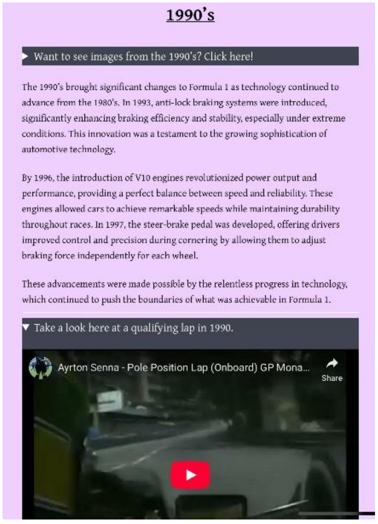
6.5 WordPress Interactive Timelines

The goal of these timelines on the website is to offer an interactive and engaging experience to all users about the evolution of vehicle performance and driver safety in Formula 1 and how technology has affected these fields over time.

6.5.1 Vehicle Performance Timeline

Using the free version of WordPress, internal WordPress blocks are used to implement an interactive timeline here to visually represent the evolution of vehicle performance in F1 over time. Without having access to plugins, engaging WordPress features are employed here to create an interactive user experience. A variety of features including automatic slideshows, live slider comparisons, YouTube videos, clickable images and more are employed here to enhance the user experience. The timeline block is configured to display a timeline block for each decade since F1's inception in 1950 in a visually appealing and chronological order. The timeline consists of timeline blocks alternating and appearing in an aesthetic fashion. Elements in the timeline are interactive, allowing users to engage more with the content. External links are setup for users to engage with if they wish to learn more about certain aspects of the project. Styling and content options are adjusted for users to ensure the timeline is easy to navigate and engage with. The result of this is a dynamic and interactive timeline effectively displaying the evolution of vehicle performance in Formula 1 throughout time. Screenshots of this are seen below.

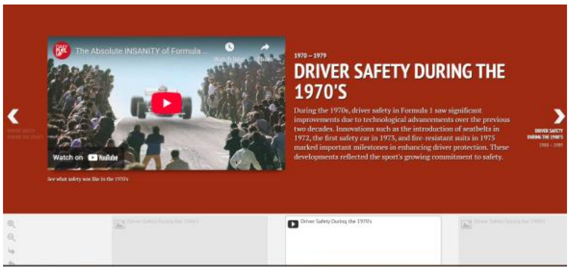




Figures 6.17 & 6.18: Interactive Vehicle Performance Timeline

6.5.2 Driver Safety Timeline

A separate tool is used to implement the interactive driver safety timeline. This tool is known as TimelineJS. This tool is open-source and is used here to build a visually appealing interactive timeline. It leverages a Google spreadsheet template to input data into the timeline, which is then converted into an aesthetically rich timeline using JavaScript. It allows for a variety of media types to be used including videos, text, and images, allowing for a better overall user experience. The timeline is configured to to display how driver safety has evolved in F1 from each decade since 1950. Using a separate tool to the other timeline, TimelineJS offers a more engaging experience to users allowing them to slide back and forth through the visually appealing timeline. Brief extracts of text are provided to users alongside interactive multimedia elements to create the most engaging and easy experience possible for users. It represents a dynamic timeline that utilises JavaScript to display the data in a timeline manner. The timeline is easily accessible via the website through the use of a link on the main driver safety page.



Figures 6.19 & 6.20: TimelineJS Interactive Driver Safety Timeline

6.6 Implementation Conclusion

The implementation of both interactive timelines on the website and the data analysis was discussed in detail in this section. The variety of tools and platforms used to implement these aspects are clearly outlined here. Both the process of the data analysis and interactive timelines are discussed in depth. Screenshots and code were provided to back up the text provided, offering a more comprehensive overview of the processes.

Testing & Evaluation

This chapter evaluates the website's unit testing, performance testing, and usability. A variety of tests are conducted to ensure the website is functional, user-friendly, and efficient.

7.1 Unit Testing

For unit testing of the website, a tool called Pingdom Tools was used to conduct a functionality test on the website. This evaluates the functionality performance of the site and offers feedback on individual things to fix on the website. Various metrics including server response times, user interactions, and load times of various aspects of the website are analysed to identify any issues relating to unit testing. Pingdom Tools generates detailed reports based on the website, highlighting areas for improvement. This ensures the efficiency and reliability of the website. A screenshot of the result is found below.

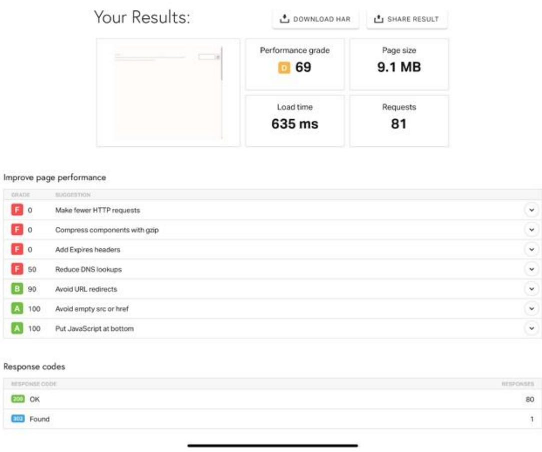


Figure 1: Pingdom Tools Functionality Results

The result of the functionality test using Pingdom Tools shows the website has a grade of 69. At first glance this may not appear to be great but when the grade is broken down, it is incredibly positive. Many of the issues relating to the website are connected to WordPress as the host of the website. There is little control over the performance and functionality issues relating to the website. Using the free version of WordPress offers limited control over the website in this aspect, therefore resulting in a slightly lower grade than anticipated. However, the functionality of the site's performance will be analysed next which will be a good indicator. Detailed reports were generated by Pingdom Tools, offering valuable insights for optimising the functionality of the website. The results were used to further improve the functionality and user experience of the website.

7.2 Website Performance

A tool was used to evaluate the performance of the website. The tools Is known as SE Ranking. It offers a comprehensive range of features that analyse the performance of websites. This tool provided insights into the functionality and performance of the digital artefact for this project. Using a separate tool compared to the unit testing tool offers a unique perspective in terms of feedback. A variety of different metrics were evaluated here. A screenshot of the website's overall performance can be found below.

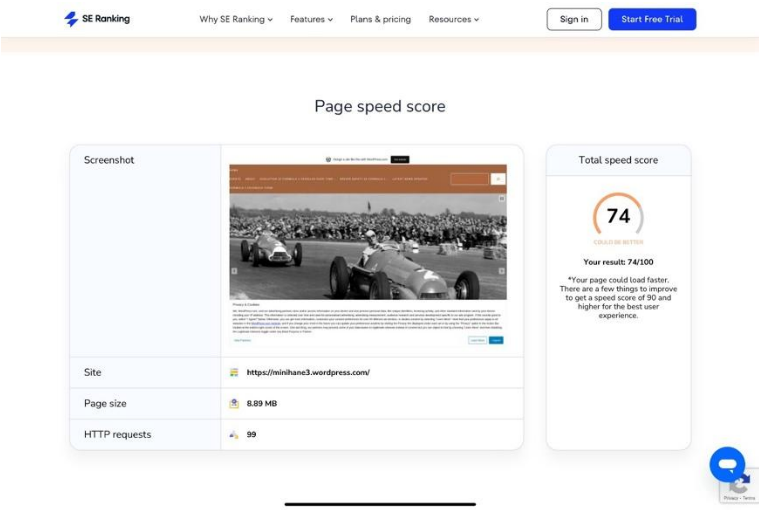


Figure 7.2: SE Ranking Tool Performance Results

This tool ranked the website's performance on a scale of 0-100. The website received a grade of 74, indicating its performance could be improved in small ways. A grade of 90 or above corresponds to the best user experience. This tool offers in-depth analysis of the performance, concluding that images and other interactive features took longer to load than the rest of the webpage. Some of the interactive elements on the website including automatic slideshows, YouTube videos, polls, and more were larger in size than other parts of the webpage which is expected. However, this meant it took a few milliseconds longer to load, therefore reducing its performance slightly. Having little control over these minor details as WordPress hosts the website and domain, the grade given reflected a particularly good result. Various metrics including website health, organic traffic, domain authority, backlink profiles, rankings of keywords and more metrics were evaluated during this process. Similar to the previous tool, SE Ranking offers a more comprehensive report outlining the strengths and weaknesses of the website's performance. This tool offered insights to optimise the user experience, search engine rankings, and overall performance of the website.

7.3 Usability

Surveys were carried out to analyse the usability of the website. A variety of users ranging from passionate Formula 1 fans to casual fans were given the link to the website to determine how usable it was. Users were told to evaluate all aspects of the website including interactive features and external pages and links. The website usability scale was used here to get feedback from the users on the website's usability. This identified any issues with the website from both a casual user and F1 enthusiast's perspective.

7.3.1 Website Usability Scale

The Website Usability Scale (WUS) is a tool for measuring the usability of a website [13]. This scale consists of 10 questions in which users rank their answers from 1-5, relating to how strongly they agree with the statement. 1 is the lowest ranking on the scale, representing "strongly disagree", while 5 is the highest ranking, representing "strongly agree". Users followed these guidelines when answering the questions. The 10 questions are as follows:

1. I think that I would like to use this website frequently.
2. I found the website unnecessarily complex.
3. I thought the website was easy to use.
4. I think that I would need the support of a technical person to be able to use this website.
5. I found the various functions in this website were well integrated.
6. I thought there was too much inconsistency in this website.
7. I would imagine that most people would learn to use this website very quickly.
8. I found the website very cumbersome to use.
9. I felt very confident using the website.
10. I needed to learn a lot of things before I could get going with this website.

This method for feedback was preferred as it has been used since 1986 [13]. The concept originates from the System Usability Score (SUS) but was later modified for the use of websites. This method offers users a quick and effortless way to evaluate the website's usability.

7.3.2 Desktop & Tablet Results

Websites can be accessed by a multitude of devices including mobile, desktop, and tablet. A tool was used here to evaluate the usability of the website on a desktop and tablet. A well-known tool called PageSpeed Insights was used to evaluate the website in terms of accessibility. A screenshot of the results is displayed below.

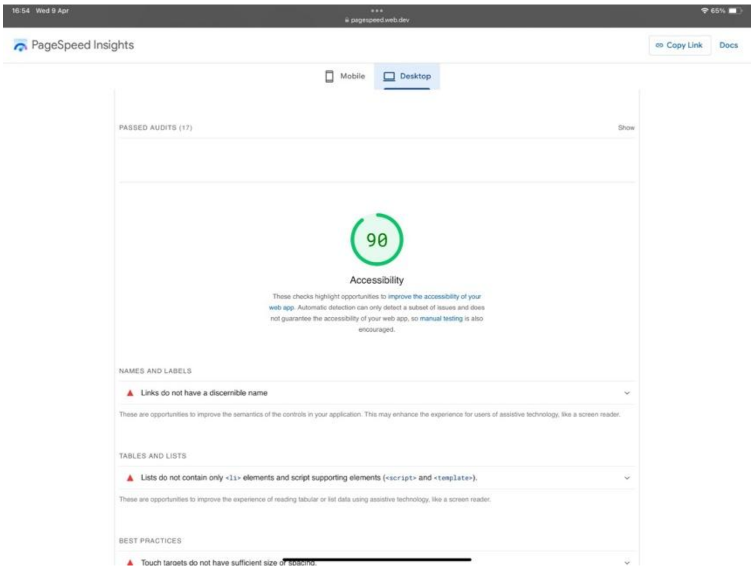


Figure 7.3: PageSpeed Insights Accessibility Score on Desktop & Tablet

7.3.3 Mobile Device Results

Another tool was used to analyse the usability of the website on a mobile device. This offered insights into its accessibility to a user accessing the website on a mobile device. The results of this can be found below. The tool used is SEO Site Checkup.

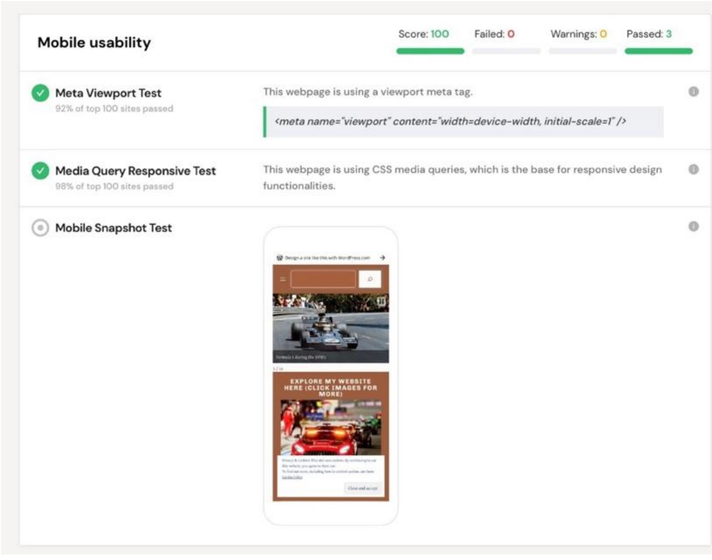


Figure 7.4: SEO Site Checkup Mobile Usability Results

7.3.4 Website Usability Scale Results

Screenshots of the results from users answering all questions from the Website Usabiltiy Scale (WUS) are provided below. These figures clearly show the website was functional, easy to use, and would browse this website often to stay up to date with cutting-edge technology in Formula 1. All users expressed they would visit this website often. The majority of users found the website was not complex and had an easy user interface, but one user said it was slightly complex for them. Most users felt comfortable navigating the website themselves, but a couple of users added they may need technical help. All users found the website to be highly interactive and and well integrated. They all felt comfortable whether they were a beginner to Formula 1 or not that the website tailored to all parties.

Users were asked to browse the website using a variety of devices including a mobile device and/or tablet, or a mobile device and/or desktop, to offer feedback on the website's accessibility. Some users had difficulty reading text on the phone but due to the adaptiveness of the website, it allows for zooming to occur which may tailor to users with poor eyesight. Collecting data on its usability from users provided valuable feedback which will benefit the overall performance of the website.

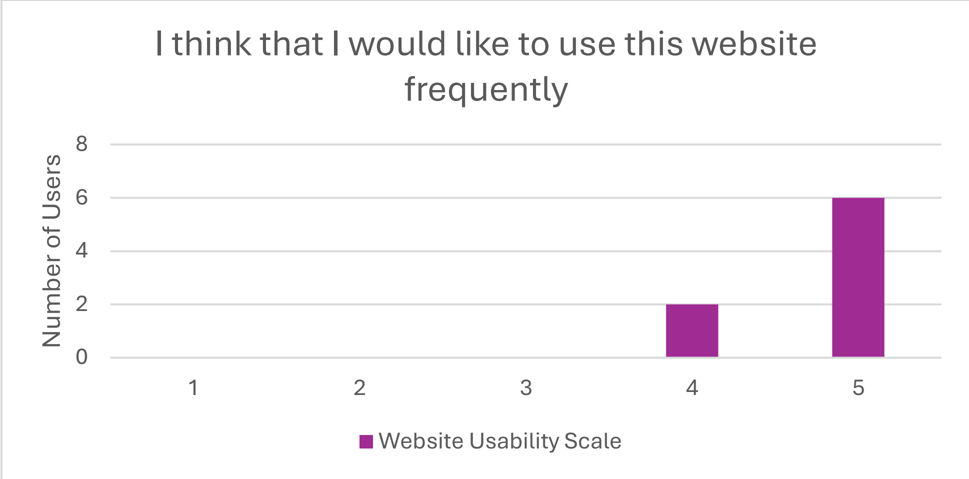


Figure 7.5: Website Usability Scale: Question 1 Results

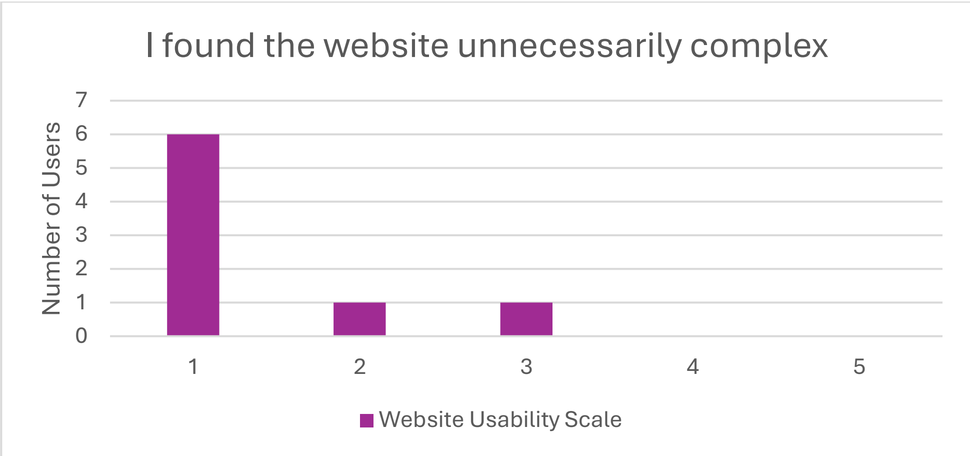


Figure 7.6: Website Usability Scale: Question 2 Results

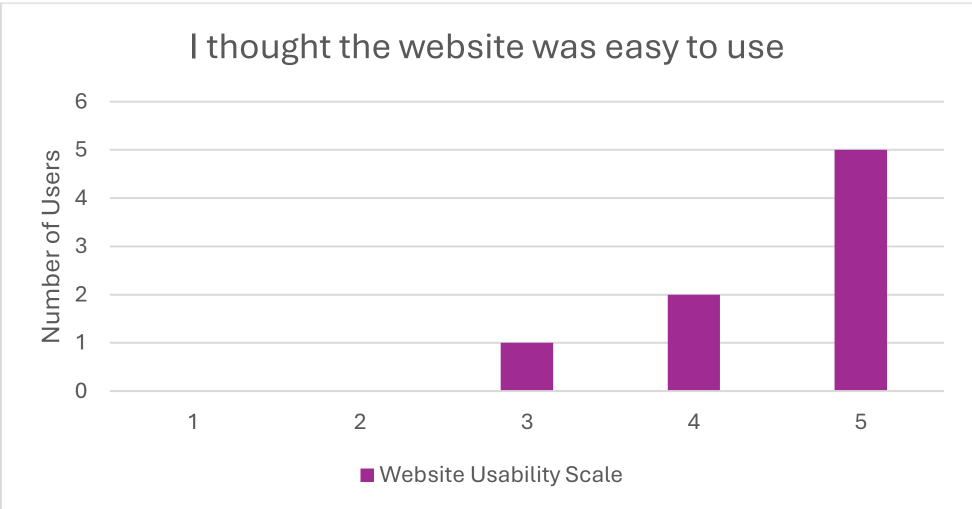


Figure 7.7: Website Usability Scale: Question 3 Results

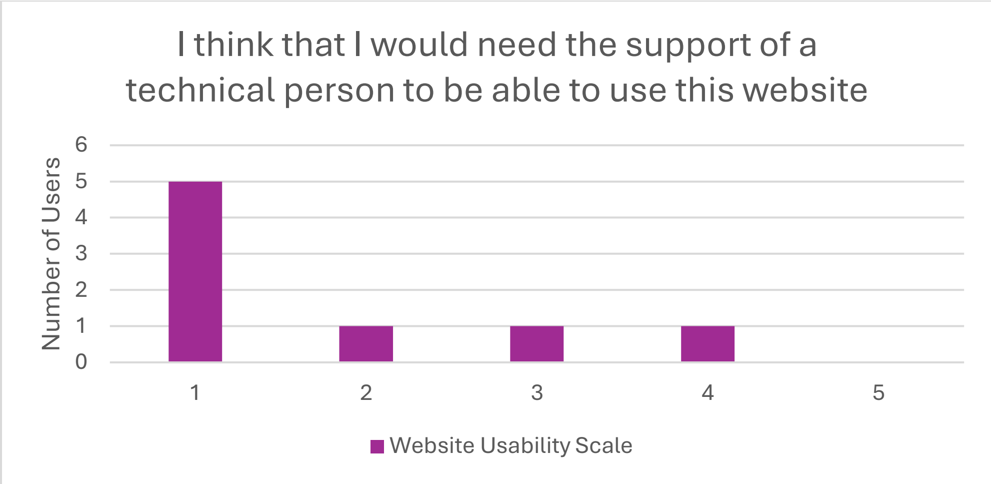


Figure 7.8: Website Usability Scale: Question 4 Results

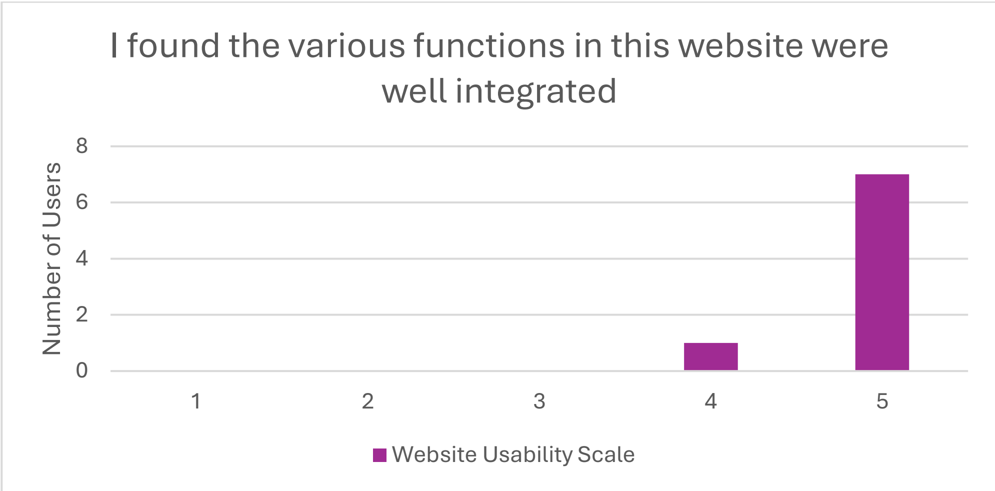


Figure 7.9: Website Usability Scale: Question 5 Results

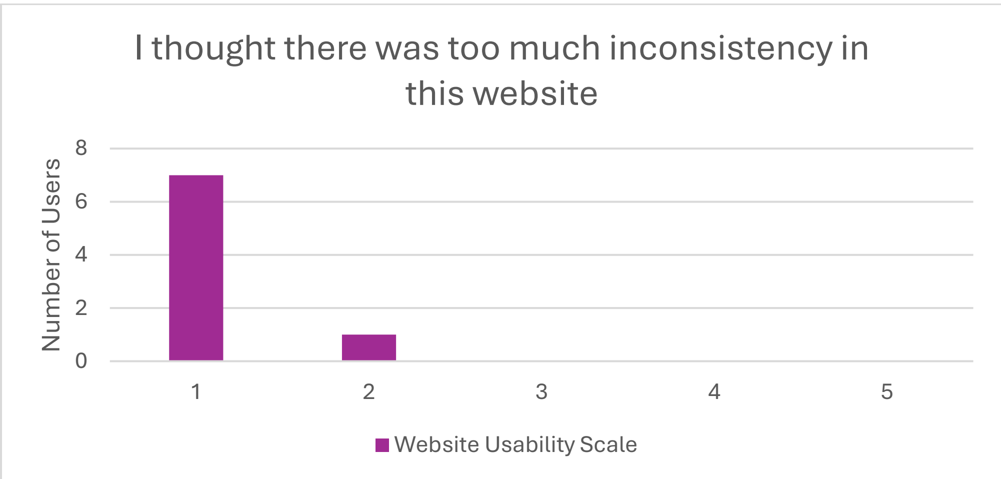


Figure 7.10: Website Usability Scale: Question 6 Results

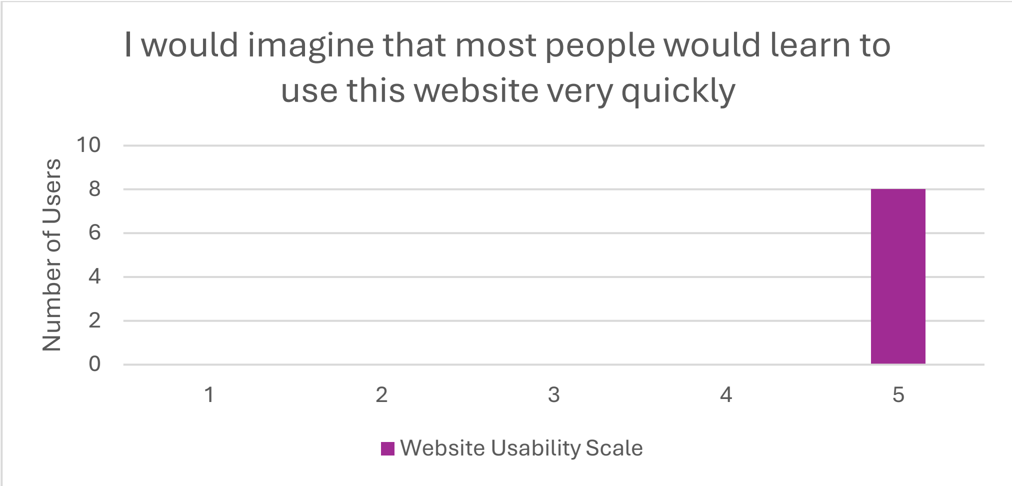


Figure 7.11: Website Usability Scale: Question 7 Results

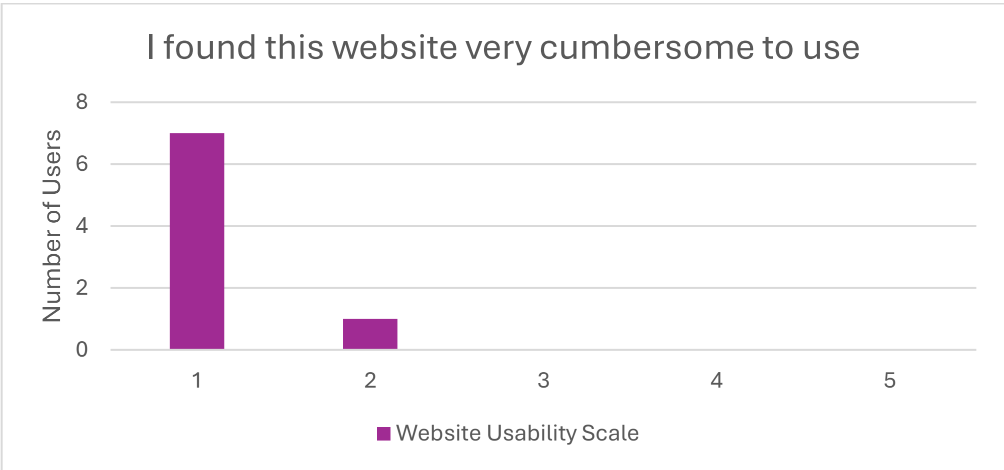


Figure 7.12: Website Usability Scale: Question 8 Results

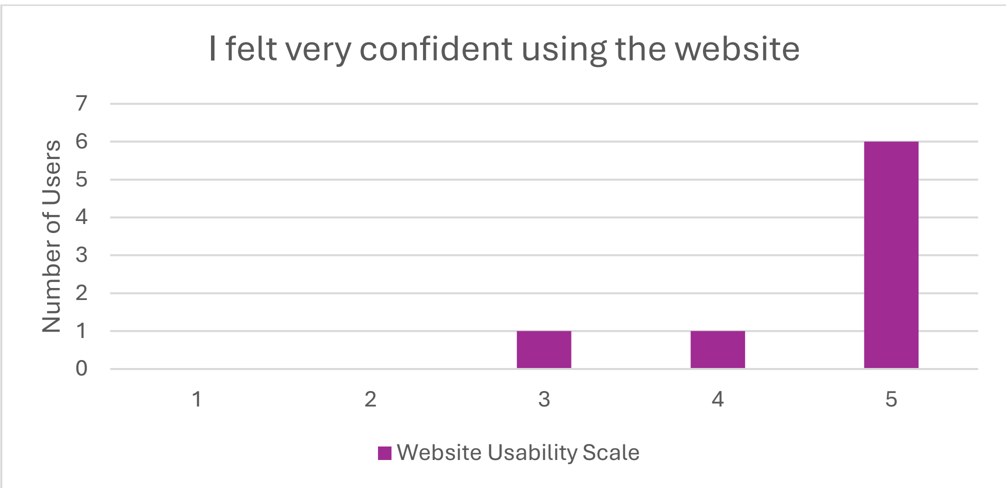


Figure 7.13: Website Usability Scale: Question 9 Results

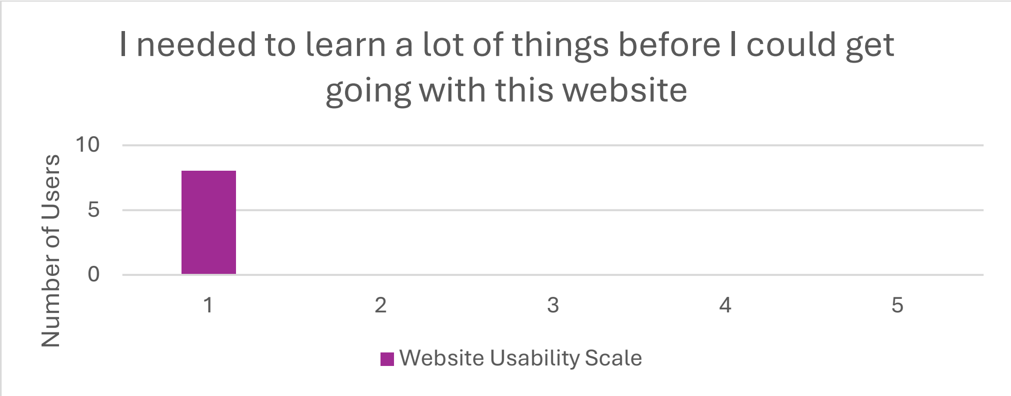


Figure 7.14: Website Usability Scale: Question 10 Results

7.4 Testing & Evaluation Conclusion

The unit testing, performance, and usability of the website were evaluated in this section. The unit testing examines the functionality of each aspect of the website which provided valuable feedback as to how the website's functionality performed. This test was conducted by a tool known as Pingdom Tools. A separate tool was used to examine the overall performance of the website, offering a unique perspective in terms of feedback. This offered varied feedback in comparison to the previous tool, highlighting different things that need to be improved. Using a variety of tools provides a wide range of feedback, offering different insights. Finally, using the WUS, the usability of the website was evaluated. The WUS consists of 10 questions which were given to a variety of different users to give feedback on the website's usability. The results of each these questions were visually presented in this section, providing valuable feedback.

Conclusion

8.1 Summary

In conclusion, a comprehensive digital artefact was created in the form of a website. This website offered an easy learning experience to users regarding the evolution of vehicle performance and driver safety in Formula 1 over time. Interactive features such as interactive timelines and other engaging elements such as podcasts, polls, and YouTube videos were added to improve the overall user experience. Alongside that, a GitHub repository was connected to the website through the use of links, which contains datasets relating to both vehicle performance and driver safety. A Google Colab notebook is also connected to that particular GitHub repository which contains Python graphs and visualisations conducted for data analysis on these topics. This offered a different approach to other projects as this has the addition of data to back up the key findings on the website.

The implementation was successful, having performed data analysis on both data collected individually and open-source datasets imported from Kaggle. The results based on unit testing, performance, and usability provided valuable feedback which was used to improve the website and the data backing it up. The general consensus from the feedback given was incredibly positive. Users found the website and datasets to be user-friendly and interactive. Some confusion regarding technical ability was oversized and noted during this process. All users stated they would visit the website regularly for updates on Formula 1 which is significant.

8.2 Reflections

Throughout the duration of this project, I developed new skills and techniques along with learning many valuable lessons. I will reflect on the skills that were developed and the lessons that were learned during the course of this project in this section. I will offer insights as to what I would have changed during this process also.

Skills Developed

Before beginning this project, I had little previous experience using WordPress and had some experience using Python. During this project I honed my technical skills on WordPress as I used a different version of WordPress compared to what I had used in the past. Things like adding custom HTML and JavaScript to the website, integrating external features and tools to seamlessly embed into the site, and adding various interactive elements tested my technical ability. Achieving what I set out do in these aspects gives me confidence in my technical ability as it has expanded considerably throughout this process. I was exposed to a variety of modern technologies during the course of this project. Being exposed to technologies like TimelineJS, GitHub, & Google Colab whilst honing my Python ability and achieving what I have done with these tools, gives me great confidence to achieve greater things in the future.

Valuable Lessons Learned

Thinking back to the beginning of the project, there are a number of things I learned. Having used WordPress in a different manner to before, it would have been beneficial to begin developing the digital artefact sooner to understand the limitations and capabilities of WordPress as a platform. This meant that I had lots of confusion deciding what I could and could not do due to the limitations of the free version of WordPress. I considered using HTML and CSS to develop my interactive website but felt it would have added complexity to the project where there was no need. This would have given me the control of certain aspects that are lacking on WordPress but would have taken a significantly longer period of time to develop. If I could talk to my previous self before this process, I would have advised myself to keep things simple and to not over complicate technical parts of the project.

8.3 Plan for Future Work

Throughout this process, multiple areas were identified for the website that could be improved. Due to the limited time available to complete the project, these improvements were reviewed beyond the projects' time constraints. The additionally considerations for improvement are detailed below.

8.3.1 Improving Dataset Capacity and Accuracy

To further validate the data relating to vehicle performance and driver safety in Formula 1, collecting more precise data would enhance the accuracy of the datasets and would provide better visualisations to draw on. There is a lack of concrete data relating to both of these areas in Formula 1 as to how they have developed over time. This led to the self-gathering of data which provided more accuracy. Continuing to collect additional data on these topics and integrating it with the existing data would enhance the data accuracy, allow for better insights, and would provide more meaningful visualisations.

8.3.2 Consistently Updating the Website

As the website currently highlights the evolution of technology in Formula 1 and emphasises its impact on both vehicle performance and driver safety, continuing to add key innovations and other major details relating to these areas would keep users well informed about the cutting-edge innovations being added to F1. Adding to the existing interactive timeline and other engaging elements of the website would further improve the overall user experience. Integrating other external tools is also a possibility to keep the content fresh and updated for users to browse through. The main aspect of the digital artefact is to give users an engaging and user-friendly learning experience about technology's impact on vehicle performance and driver safety in Formula 1. These additions would continue to align with the philosophy of his project.

References

[1] Arya, B., Yao, J., Davy, J.L. and Fard, M. (2025). A novel and fast crash simulation method: Revolutionising racetrack safety barrier analysis. Results in Engineering, 25, p.103870. doi:https://doi.org/10.1016/j.rineng.2024.103870.

[2] Baptista, L. (2021). Using Python and Google Colab to Teach Physical Chemistry During Pandemic. *chemrxiv.org*, [online] 1. doi:https://doi.org/10.26434/chemrxiv.13656665.v1.

[3] Bell, A., Smith, J., Sabel, C. and Jones, K. (2016). This is an author produced version of Formula for success: Multilevel modelling of. Formula for success: Multilevel modelling of Formula One Driver and Constructor performance, 1950-2014, [online] pp.99–112. doi:https://doi.org/10.1515/jqas-2015-0050.

[4] Demirel, H.O., Jennings, A. and Srinivasan, S. (2022). An Early Design Method to Quantify Vision Obstruction: Formula One (F1) Halo Case Study. Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management. Anthropometry, Human Behavior, and Communication, pp.32–44. doi:https://doi.org/10.1007/978-3-031-05890-5_3.

[5] Dhanvanth, S., Rajesh, R., Samyukth, S.S. and Jeyakumar, G. (2022). Machine Learning-Based Analytical and Predictive Study on Formula 1 and Its Safety. Lecture Notes in Electrical Engineering, 915, pp.257–266. doi:https://doi.org/10.1007/978-981-19-2828-4_25.

[6] Ekanem, I.I., Essenubong Ikpe, A. and Sunday Abia, E. (2024). EVOLUTION OF FORMULA ONE (F1) MOTORSPORTS AND ITS TOP-NOTCH ADVANCEMENT IN ENGINEERING INNOVATIONS ACROSS THE RACING INDUSTRY. In: ResearchGate. [online] New York, USA: Liberty Academic Publishers, pp.108–109. Available at: https://www.researchgate.net/publication/378040222_EVOLUTION_OF_FORMULA_ONE_F1_MOTORSPORTS_AND_ITS_TOP-NOTCH_ADVANCEMENT_IN_ENGINEERING_INNOVATIONS_ACROSS_THE_RACING_INDUSTRY [Accessed 24 Mar. 2025].

[7] Erruas, V., Supervisor, M., Javier, R. and Rubio, P. (2024). FORMULA 1 CAR AERODYNAMICS Report and Annex. [online] Catalunya: Universitat Politècnica de Catalunya, pp.11–93. Available at:

https://upcommons.upc.edu/bitstream/handle/2117/420071/TFG%20-%20VICTOR%20ERRUAS%20-%20FINAL.pdf?sequence=2 [Accessed 28 Feb. 2025].

[8] Formula 1® - The Official F1® Website. (2024). *F1 - The Official Home of Formula 1® Racing*. [online] Available at: https://www.formula1.com/en/results/1950/races/94/great-britain/race-result [Accessed 9 Apr. 2025].

[9] Gazaneo, D. (2022). Configuration optimization for a HANS device attachment system in a frontal crash scenario. [PDF] pp.40–112. Available at: https://www.politesi.polimi.it/bitstream/10589/208538/3/Tesi_Gazaneo.pdf [Accessed 27 Mar. 2025].

[10] Hardik Inani, Prajapati, Y., Mehta, V., Bhavsar, D., Bhagat, D. and Kiran, M.B. (2024). The Intersection of Industry 4.0 with Formula 1 and Other Motorsports: Future of Racing. Lecture notes in mechanical engineering, pp.171–192. doi:https://doi.org/10.1007/978-981-97-3173-2_12.

[11] Heimbs, S., Strobl, F., Middendorf, P., Gardner, S. and Key, J. (2009). Crash Simulation of an F1 Racing Car Front Impact Structure. 7th European LS-DYNA Conference. [online] Available at: http://www.heimbs-online.de/Heimbs_2009_Formula1Crash.pdf [Accessed 28 Mar. 2025].

[12] Hou, X. (2024). Evolution of the Formula One front wing assembly. Theoretical and Natural Science, [online] 53(1), pp.159–168. doi:https://doi.org/10.54254/2753-8818/53/20240191.

[13] Isabelle, R. (2019). *What is the Website Usability Scale? | Indulge*. [online] Indulge. Available at: https://indulge.digital/blog/wus-score [Accessed 9 Apr. 2025].

[14] Kallimogiannis, V. and Massouros, C. (2023). Predictions on the impact of the budget cap on Formula 1 teams' performance. Ratio Mathematica, [online] 47(0), pp.445–468. doi:https://doi.org/10.23755/rm.v47i0.1179.

[15] Kazemi, A., Boyd, M., Choi, F., Tai, A.M.Y., Tsang, V.W., To, T., Kim, J., Jang, K., Shams, F., Schreiter, S., Cabanis, M. and Krausz, R.M. (2024). Architecture and Development Framework for a Web-Based Risk Assessment and Management Platform Developed on WordPress to Address Opioid Overdose. *JMIR Formative Research*, [online] 8(1), p.e49759. doi:https://doi.org/10.2196/49759.

[16] Kempema, J.M. (2024). Formula One: a ‘crash’ course in motorsports medicine. Trauma Surgery & Acute Care Open, [online] 9(Suppl 2), p.e001402. doi:https://doi.org/10.1136/tsaco-2024-001402.

[17] Lippi, G., Salvagno, G.L., Franchini, M. and Guidi, G.C. (2007). Changes in technical regulations and drivers’ safety in top-class motor sports. British Journal of Sports Medicine, 41(12), pp.922–925. doi:https://doi.org/10.1136/bjsm.2007.038778.

[18] McKinney, W. (2022). *Python for Data Analysis*. [online] Google Books. Available at: https://books.google.ie/books?hl=en&lr=&id=EAKBEAAAQBAJ&oi=fnd&pg=PP30&dq=pandas+library+python&ots=PJXuPvah40&sig=A8ZDnCdb-EPjwJATSl0uHLxPR8w&redir_esc=y#v=onepage&q=pandas%20library%20python&f=false [Accessed 9 Apr. 2025].

[19] Papachristos, G. (2014). Technology, performance and team adaptation to regulation in Formula 1. In 32nd International Conference of the System Dynamics society., [online] pp.1–25. Available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=9630e19c906ee18d05cabeee17be96f7381ae68f [Accessed 24 Mar. 2025].

[20] Savage, G. (2008). Composite Materials Technology in Formula 1 Motor Racing. G. Savage Honda Racing F1 Team. [online] Honda Racing F1 Team, pp.109–139. Available at: https://f1-forecast.com/pdf/F1-Files/Composite%20Materials%20Technology%20in%20Formula%201%20Motor%20Racing.pdf [Accessed 27 Mar. 2025].

[21] Savage, G. (2010). Development of penetration resistance in the survival cell of a Formula 1 racing car. Engineering Failure Analysis, 17(1), pp.116–127. doi:https://doi.org/10.1016/j.engfailanal.2009.04.015.

[22] Schneiders, C. and Rocha, C. (2022). Technology Innovations and Consumption of Formula 1 as a TV Sport Product. Sport Marketing Quarterly, 31(3), pp.186–197. doi:https://doi.org/10.32731/smq.313.0922.02.

[23] STĘPIEŃ, Z. (2016). A new generation of F1 race engines – hybrid power units. Icm.edu.pl, [online] pp.22–37. Available at: https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-9616df86-6562-49ed-9396-d9e3cfb7d486/c/stepien_a_new_ce_4_2016.pdf [Accessed 27 Mar. 2025].

[24] Sturm, D. (2021). The Formula One Paradox: Macho Male Racers and Ornamental Glamour 'Girls'. Sport, Gender and Mega-Events, pp.113–130. doi:https://doi.org/10.1108/978-1-83982-936-920211012.

[25] Suarez, F.F. (n.d.). Organizational exploration, exploitation, and performance differential: A simulation model of Formula 1 competition 1970-2013. PDF. pp.1–43.

[26] Tanaka, H. (2006). Transition of Regulation and Technology in Formula One. Honda R&D Technical Review F, [online] pp.5–13. Available at: https://www.f1-forecast.com/pdf/F1-Files/Honda/F1-SP2_01e.pdf [Accessed 24 Mar. 2025].

[27] Tiwari, S., Rathore, S.S., Farooq, S.U. and Patani, P. (2022). How Students Are Using GitHub? A Survey. *15th Innovations in Software Engineering Conference*, pp.1–5. doi:https://doi.org/10.1145/3511430.3511454.

[28] Toet, W. (2013). Aerodynamics and aerodynamic research in Formula 1. The Aeronautical Journal, [online] 117(1187), pp.1–26. doi:https://doi.org/10.1017/S0001924000007739.

[29] Ugle, S., Kate, S. and Dolas, D. (2015). Formula One Safety: A Review. International Research Journal of Engineering and Technology, [online] 2(7), pp.433–437. Available at: https://www.irjet.net/archives/V2/i7/IRJET-V2I766.pdf [Accessed 24 Mar. 2025].

[30] Wright, P. and Matthews, T. (2001). Formula 1 Technology. [online] Google Books, SAE International, pp. xi–xiii. Available at: https://books.google.ie/books?hl=en&lr=&id=o3Z0EAAAQBAJ&oi=fnd&pg=PR7&dq=formula+1&ots=mpAX_hAj1p&sig=nLPYkLsJsPx6msBIqEBC-wkvt-I&redir_esc=y#v=onepage&q=formula%201&f=false [Accessed 24 Mar. 2025].

[31] Young, S. (2012). Formula One Racing: Driver vs. Technology. Intersect: The Stanford Journal of Science, Technology, and Society, [online] 5, pp.1–11. Available at: https://ojs.stanford.edu/ojs/index.php/intersect/article/view/349/165 [Accessed 24 Mar. 2025].

[32] Zhang, Z. (2023) 'Study on aerodynamic development in Formula One racing', Theoretical and Natural Science, 14, pp. 38–41. Available at: https://doi.org/10.54254/2753-8818/14/20240875.