FH JOANNEUM - University of Applied Sciences

From Turbos to Hybrids:
A Comparative Analysis of Car Failures in Formula 1

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List of Abbreviations

The next list describes several abbreviations that will be later used in the thesis.

Aero	...	*Aerodynamics*
a.k.a.	...	*also known as*
ANOVA	...	*Analysis of Variance*
API	...	*Application Programming Interface*
DTM	...	*Deutsche Tourenwagen Masters*
DFV	...	*Double Four Valve*
F1	...	*Formula One, Formula 1*
F2	...	*Formula Two, Formula 2*
FIA	...	*Fédération Internationale de L'Automobile*
GP	...	*Grand Prix*
HANS	...	*Head and Neck Support*
hp	...	*horsepower*
KERS	...	*Kinetic Energy Recovery System*
MGU-K	...	*Motor Generator Unit-Kinetic*
MGU-H	...	*Motor Generator Unit-Heat*
MotoGP	...	*Grand Prix motorcycle racing*
VSC	...	*Virtual Safety Car*

Kurzfassung

Die Welt der Formel 1 hat sich seit den 1950er Jahren stark verändert. Der Sport entwickelt sich ständig weiter, mit verschiedenen Neuerungen wie der Aerodynamik, die den Sport in den 1960er bis 1970er Jahren zu seiner ersten Ära führte. In dieser Ära stieg die Bedeutung der Aerodynamik und die Teams nahmen viele Änderungen an den Autos vor, z. B. auch den Wechsel von Frontmotor- zu Heckmotorautos. Diese Ära entwickelte sich im nächsten Jahrzehnt weiter, als die Teams die Bedeutung des Abtriebs entdeckten. Die Ingenieure entwickelten Unterbodentunnel, die den Autos zu mehr Grip verhalfen, was wiederum den Fahrern ermöglichte, mit höherer Geschwindigkeit, ohne die Kontrolle zu verlieren zu fahren.

Eine der berühmtesten Epochen der Formel 1 war die Turbo-Ära in den 1980er Jahren, als Motorenhersteller wie Renault, Ferrari und Honda begannen, Motoren mit Turbolader zu produzieren. Aufgrund des höheren Verbrauchs und der höheren Leistung traten jedoch neue und häufigere Motorprobleme auf, wie z. B. Ausfälle des Turboladers, Probleme mit dem Kraftstoffverbrauch und viele andere, die zunehmend Sicherheitsbedenken aufwarfen, bis schließlich im Jahr 1989 Turbomotoren für den Sport verboten wurden.

Als sich der Sport weiterentwickelte, hielten innovative Technologien Einzug in die Welt der Formel 1. Einige davon waren die aktive Aufhängung, bei der der Fahrer die Einstellungen des Hydrauliksystems ändern konnte oder die aktive Elektronik, bei der verschiedene Optionen wie Traktionskontrolle, Antiblockiersystem (ABS) und Datentelemetrie in Echtzeit eingestellt werden konnten. Dennoch gab es Ende der 1990er Jahre einen weiteren Motorenwechsel, bei dem die V12-Motoren langsam aus dem Sport verdrängt und durch den V10 ersetzt wurden, gefolgt von einer weiteren Anpassung im Jahr 2006, bei der der V8 als einzige brauchbare Kraftquelle eingesetzt wurde.

Die letzte und größte Veränderung in der Formel 1 fand 2014 statt, als die Hybridmotoren in den Sport eingeführt wurden. Dabei handelte es sich um ein außerordentlich komplexes und effizientes Hybrid-Aggregat, das einen V6-Verbrennungsmotor mit Energierückgewinnungssystemen kombinierte. Er wurde entwickelt, um sparsamer und umweltfreundlicher zu sein.

Diese Studie zielt darauf ab, durch eine vergleichende Untersuchung der Ausschiedsgründen in den 1980er Jahren, auch bekannt als die Turbo-Ära, und den letzten zehn Jahren des Sports, in denen die Hybrid-Ära eingeführt wurde, ein tieferes Verständnis zu vermitteln. Darüber hinaus wird nach einer Korrelation zwischen den zeitlichen Abläufen und den versteckten Beziehungen zwischen mechanischen Ausfällen und den verschiedenen Grand Prix gesucht.

Abstract

Formula 1 underwent a lot of changes since its foundation in 1950. The sport is constantly evolving, with several innovations such as aerodynamics and underbody tunnels. Aero led the sport to its first era in the 1960s, and 1970s. During this period, aerodynamics became more important and innovations like spoilers and wings made an appearance. Due to the increased importance of such elements, constructors made bigger changes to the cars, such as the transition from front-engine to rear-engine cars. On the other hand, engineers developed underbody tunnels to increase the downforce of the cars. As a result, cars had more grip, which allowed drivers to drive around the track and take corners with higher speeds without losing control.

One of the most famous eras of Formula 1 was the so-called turbo era in the late 1970s and 1980s when engine manufacturers began to produce engines with turbochargers. Turbochargers helped the engine to produce significantly more horsepower and it led even to higher speeds. However, more horsepower meant increased fuel consumption and more frequent engine problems, such as turbocharger failures, engine bursts, and fuel consumption issues. As a result, these breakdowns increased the safety concerns of the sport and turbocharged engines were banned in 1989.

After the end of the turbo era, several other technologies made their way into the world of Formula 1. These innovations included the active suspension, where drivers could adjust the hydraulic systems. Furthermore, active electronic technologies made an appearance, for instance, the traction control and anti-lock braking system (ABS), that could be fine-tuned in real-time. In the late 1990s, another engine change occurred, where the V12 engines were pushed out of the sport and replaced by the V10. Later in 2006, the Fédération Internationale de L'Automobile (FIA) set the V8 engines as the only viable power source.

The last engine adaption in Formula 1 took place in 2014 when hybrid engines were introduced to the sport. This was an extraordinarily complex and efficient hybrid power unit that combined a supercharged V6 engine with energy recovery systems (ERS). It was developed to be more economical and environmentally friendly.

This study aims to provide a deeper understanding through a comparative study of the failure types in the 1980s, also known as the turbo era and the last ten years of the sport when the hybrid era was introduced. Furthermore, it analyses the hidden relations between mechanical failures and the different Grand Prix where all teams, cars and drivers are tested under unique conditions. However, this study does not aim to discuss car reliability, safety protocols or technological advances in Formula 1.

1. Present state of Formula 1

Formula 1, often abbreviated as F1, is an ever-evolving motorsport which has already attracted a lot of people over time and is one of the most prestigious motorsport competitions in the world. It was founded in the year 1950 by the FIA. "Over the years, 770 drivers representing 40 different countries have competed in the sport". ([Speedway Media 2023])

In the same year as F1 was founded, the first World Championship took place with the first official race at Silverstone, the British Grand Prix on the 13th of May. Spectators came to watch the single-seater cars, which had different liveries, bodyworks and engines, race around the circuit of Silverstone, which consisted of high-speed corners, which had to be approached very accurately. One single mistake could have meant the end of the Grand Prix weekend for that driver.
The most known drivers at that time were Guiseppe Farina, who also won the British Grand Prix and the first F1 World Championship, and Stirling Moss, who finished in three consecutive seasons behind his rival Juan Manuel Fangio. Juan Manuel Fangio was the greatest driver from Argentina of the 1950s, who secured multiple F1 World Championship titles with four different teams in the subsequent years. ([Bleacher Report 2013])

In the following 20 - 30 years the viewership has continued to rise and new F1 legends were born. Such drivers were Jim Clark, who was an outstanding driver with two championship titles, and Jackie Stewart, who won multiple championships and plays nowadays a key role in promoting safety standards. Other famous people were Niki Lauda, who is remembered for his comeback after a near-fatal accident, and James Hunt, who was the rival of Niki Lauda. Furthermore, Emerson Fittipaldi, who won two different motorsport competitions, F1 and Indianapolis 500, multiple times. Just as new constructors joined the motorsport at that time, such as Wiliams, Tyrell and Brabham who had a lot of success in that period by winning multiple Constructors' Championships and helping drivers win the title. The 1980's were especially challenging, because of the competitive intensity, and technological evolutions, like turbo and aerodynamic elements, but also because of fatal accidents, which all together raised safety concerns in the motorsport.

In the upcoming years old legends retired and new stars were born. Some names are Ayrton Senna, Alain Prost, Nigel Mansell, and Nelson Piquet from the 1990s and Fernando Alonso, Kimi Räikkönen, Michael Schumacher and Jenson Button from the 2000s. All these people contributed their whole lives to F1 and made the sport more enjoyable than it already was because of the new rivalries that were formed. One of the best rivalries in Formula One started in 1985 and lasted until 1993 between Alain Prost and Ayrton Senna. They share seven world titles, 92 F1 wins and multiple racing accidents. Although their relationship took a huge hit in 1989, when multiple accidents happened between the two because of the lack of respect, they became good friends in the years after 1993, when Prost retired. ([Autosport

Rivalries 2021]) There were also tremendous changes in regulations in and before this decade, which consisted of the turbocharger ban in 1989, the introduction of semi-automatic gearboxes, grooved tires in the 1990's and engine changes in the 2000s. These changes did not only have positive effects, but also negative ones, for instance, as a result of grooved tires, teams started to rely more on aero than on mechanical grip. This shift in focus resulted in an increased generation of “dirty air”, which is the turbulent air trailing the car. Consequently, turbulent air reduces the aero performance and downforce of the car behind, and it is more challenging to execute a successful overtake. Later they returned to slick tyres and more regulated aerodynamic parts to improve racing.

The latest regulation introduced in the 2000s was the kinetic energy recovery system (KERS). It was designed to help drivers overtake and defend positions.
It stored energy that was collected when the car was breaking and the driver, at the push of a button, accessed a burst of 80 horsepower on one or multiple points around the circuit. This was the first big step towards the hybrid power units that were later introduced in 2014, which also marks the beginning of the last Era. ([BBC KERS & DRS 2012])

In the next decades, Formula 1 underwent huge technical changes, when they first introduced Drag Reduction System (DRS), as already mentioned the V6 Turbo Hybrid Power Units and aerodynamics rules to increase the importance.
The DRS was introduced in 2011, where, if a driver is close enough to another car, he can press a button on the steering wheel and the top flap of the rear wing opens, which helps a lot at overtaking and makes the race more exciting. There are one or more segments of a circuit called DRS-Zones, where the driver can activate the DRS, which would reduce the aerodynamical drag of the car and can achieve a higher speed. "The statistical success of DRS cannot be questioned. For instance, at the Spanish Grand Prix between 2008-2010, there was an average of just two overtakes per race, but the introduction of DRS in 2011 saw a staggering race total of 51 overtakes, 29 of them enabled by DRS". ([BBC KERS & DRS 2012])

In this time a lot of drivers could prove themselves as one of the best, such as Sebastian Vettel, Lewis Hamilton, Max Verstappen, and Nico Rosberg. Lewis Hamilton was the rival of all the other three drivers in different years. At the beginning against Vettel, followed by teammate Nico Rosberg from 2013 until 2016. In the late 2010s one of the best and most exciting rivalries in recent decades was born between Max Verstappen and Lewis Hamilton. It reached its peak in 2021 when the title was decided at the last Grand Prix. It went down as one of the most controversial races in history, with Max Verstappen winning in the final lap to claim his first title. Despite the intensity of their on-track battles, both drivers expressed respect for each other in several interviews.

Max Verstappen just had his best and record-breaking season with Red Bull Racing, which will go down as the best season so far. He won 19 out of 22 races and he was on the podium at every race and achieved a record-breaking 575 points. He also broke the record for most wins from Pole, which was previously held by Mansell in 1992 and Vettel in 2011 which was nine wins and now it is twelve wins. He broke a lot of records from Vettel when he was racing for Red Bull Racing in the years 2010 to 2013. These records were the most consecutive wins, which was previously nine and is now ten wins, the biggest championship winning margin, which was previously 155 and is now 290 points and finally most laps led which was 739 and is now 1003 laps. This season was not only amazing for the Dutchman, but it was also a phenomenal season for Red Bull Racing with 21 wins of the 22 races and collecting 860 points, more than twice as much as the second team Mercedes. ([Formula 1 Season 2023])

Nowadays there are two types of Grand Prix weekends, Sprint and normal. If there is no Sprint race, then usually there are two one-hour practice sessions with a break between, also known as Free Practice 1 and 2 on Friday, which helps drivers get used to the track and gather data. On Saturday, the drivers start with the third Free Practice, which is followed by a break and after the qualification series starts. The qualification series is split into three stages, which last 18 minutes, 15 minutes and twelve minutes. "The five slowest drivers are eliminated in Q1, five more in Q2 (setting the grid positions from 11th-20th) before the top 10 grid slots – and pole position – are set by Q3". ([Formula 1 GP 2023]) The qualification series forms the grid, which will be used for the race.

With Sprint races on the weekend, the format changes. The new format starts with a one-hour practice session followed by a break and the qualification series, which was already mentioned above and sets the grid for the race on Sunday.
Saturday is all about the Sprint qualification and the Sprint race. The Sprint qualification has the same structure as the normal one but with less time for the stages. The first stage lasts twelve minutes, the second ten minutes and the last stage is eight minutes long. Due to the shorter sessions, each car can only do one or two runs, but not more. After the grid is set, the Sprint race is held. It is similar to the main race, but it is shorter (100 km), and points are only awarded to the top eight with the first place getting eight and every place getting one less. ([Red Bull 2023])

1.1. Importance of Safety Regulations

As a result of the high number of accidents in the early years of Formula One, technical regulations for driver safety were introduced continuously. As already mentioned, Jackie Stewart played a crucial part in promoting protection during F1's most dangerous years. He managed to introduce rules for mandatory seatbelts, and full-face helmets, as well as better barriers and much better-equipped medical teams.

The first safety regulations are often overlooked. These are the marshals, who are volunteers placed in various parts of the track. Marshals are first to an accident, and they are well trained in First Aid, fire safety and incident handling. Furthermore, they are responsible for alerting the track conditions during the Grand Prix, such as waving the yellow flag, if there is a hazard ahead or the blue flag to make drivers aware, that the driver is getting lapped, and they must let the faster car through.

The next safety introduction was the helmet, which was mandatory from 1952. Back in 1950 competitors wore cloth caps with goggles, which only protected them from dirt and insects. Finally, in 1952, cork helmets were made mandatory, and over the decades, new inventions such as Nomex, a synthetic fibre that is flame and heat resistant, and carbon fibre, which is more impact resistant, have been introduced. 20 years later the next driver safety rule was made mandatory, the fire-resistant race suits, which already saved some drivers from fatal accidents for example already mentioned Niki Lauda, who had a fiery crash at the Nürburgring in 1976. The race suit protected him from the flames and heat, preventing more severe burns. "The technology has continued to evolve over the decades and now race suits are made of lightweight and breathable material with Nomex coating." ([Autosport Safety 2022]) Nowadays these suits can withstand more than 600 degrees for more than 11 seconds. ([Autosport Safety 2022])

The next invention followed in 1981, was the introduction of the monocoque, also known as survival cell, which is the part of the car where the driver is seated. The monocoque is built out of a 6mm carbon fibre compound with a layer of Kevlar and is designed to be indestructible and to withstand every collision. Due to the importance of this part, it must undergo extensive testing before it is allowed to be built into the car. There were already a lot of accidents where the survival cell showed its significance. The most historic crash, which left a substantial impact on the sport, happened in 2020 at the Bahrain Grand Prix. In the opening lap the French driver Romain Grosjean, made contact with the Alpha Tauri driver Daniil Kvyat and crashed with high speed and broke through the safety barrier. Grosjean managed to free himself from the inside of the cockpit and climbed out of the fire. Miraculously, the medic report afterwards reported that he only suffered severe burns to his hands and a sprained ankle. ([RacingNews365 2020])

In the 1990s a lot of new rules were instigated to make racing safer. In 1993 the safety car was reintroduced into the sport, which slows the cars down and stops overtaking while there is a hazard on the track. In 1994, not one, but two new inventions came in place. The first was the pit lane speed limit, which is set to 60 or 80km/h, depending on the circuit. This was introduced to protect drivers, constructors' pit lane crew and pit lane staff. The other invention was the introduction of barriers and run-off areas after two fatal crashes in Imola in 1994. ([Autosport Safety 2022])

At the 1994 Italian Grand Prix in the second qualifying session, F1 lost Roland Ratzenberger, when he crashed at exceedingly high speed into the wall. The crash from Ratzenberger was one of the highest g-force crash in the history of Formula One. The other fatal crash happened in the race on the seventh lap, when Ayrton

Senna's car could not turn in a high-speed corner and struck the unprotected barrier. After that weekend, existing tracks started to be optimised and neutralise the danger of the high-speed corners. ([Formula 1 Imola ‘94 2019])

In the second half of the 1990s three other regulations met the sport. The first was the headrest in 1996, which helped drivers with the huge strain on the head and neck in a high g-force moment. The headrest consists of a material that is designed to help with energy absorption. The next device was not directly for driver safety, but rather for information collecting of the effectiveness of safety technologies. It is the accident data recorder, which, as the name already says, records data from the accident, which is again used to understand the usefulness of other safety devices and to use this information to improve those. The last safety introduction was the wheel tethers in 1999, which prevent tyres from flying off during an accident. This regulation came in place due to the 1998 Belgian Grand Prix, where several tyres became detached in an accident and caused threats to other drivers. ([Autosport Safety 2022])

In the next 20 years, new rules for driver safety were presented. In 2003, HANS, often abbreviated as Head and Neck Support, was introduced which limits the head and neck movement in the car to prevent severe injuries in the case of a crash. "It is thought to reduce neck tension in an accident by 72% and it is credited with saving the lives of countless drivers since it has been in use". ([Autosport Safety 2022])

In the 2010s several instruments were installed to measure data and safety technology effectiveness from crashes. One of them was the accelerometer, which are two earpieces that gather accurate data on the forces that act on the driver in a crash. Another device was the introduction of driver-facing cameras with high framerates to see everything that happens. It works in conjunction with the recently mentioned accident data recorder and it also gives a close-up view of the HANS device. The last big invention in 2018, the halo, was quite controversial, but it would have saved a lot of lives and injuries back in the years. For instance, the death of Jules Bianchi at the Japanese Grand Prix in 2014 or Felipe Massa's near-fatal injury caused by a loose spring at the Hungarian Grand Prix in 2009. "Many purists argued that it 'went against the DNA of single-seater racing' to move towards enclosing the cockpit and there was widespread concern that it could cause visibility issues for drivers". Race after race, people got used to the idea of the Halo as a form of cockpit protection and eventually it was rewarded as the most viable option, beating the idea of an aeroscreen, which is like a windscreen. ([Autosport Safety 2022]) The Halo has already saved many lives, helping in the Grojean accident and saving the life of Zhou Guanyu in an opening lap accident at Silverstone 2022.

There are a lot of other small instruments that increased driver safety over the years and are not mentioned in this thesis, but all these technologies still play a crucial role.

1.2. Current Regulations

As already mentioned, the nature of F1 was evolving with each year and so was the need for different regulations. In the 1950's these rules were relatively open and less standardized compared to present-day. Such rules are engine, fuel and chassis related, but there were also changes to race formats and new regulations for lap times. One of the most important non-technical rulings nowadays is the "one move" defending rule. This rule was introduced to stop drivers from swerving in an attempt to block the attacking car. Today drivers must maintain their racing line and are only allowed to make one change of direction while defending. If someone neglects this rule, they first get a warning and after several other occurrences in one race they get time penalties or they even get disqualified. ([Formulapedia])

Another important rule is the grid penalty if an engine part is changed. Constructors are now limited to three power units per car and season. If they change more, then they will be punished with a grid penalty. Sometimes teams are forced to swap more than one part, due to an accident and if they are already above the limit at those parts, then these penalties stack up. As a result of this regulation, teams tend to concentrate more on the reliability of the power unit. ([Formulapedia])

A new race regulation is the "1 Point for fastest lap", which was introduced in 2019 so teams and drivers push for the fastest lap during races. Although there are also some underlying factors that the driver who has the fastest lap has to be in the top 10, otherwise he wouldn't get the point, but they can still deny it from others. Another new race rule was presented in the past years, where drivers are required to change to another compound of tyre during the race in dry weather. If there are wet conditions, then this rule does not apply. A further race ruling was adopted in the last years. This was about the overtaking line after a safety car session, which is prohibited for drivers. In the new regulation, if the safety car left the track, then no overtake is allowed until the start/finish line. In the past ruling, it was another line further down after the pit straight. ([Formulapedia])

Some regulations are not well known. Such as the 107% rule, which was in effect from 1996 until 2002 and returned in 2011. The 107% rule requires each driver to set a lap time within 107% of the fastest lap time in the first qualification session to compete in the Grand Prix. If someone fails to be under 107 per cent, they will be not allowed to start the race without the permission of the race stewards, due to the lack of car quality. The last time someone was not allowed to race due to the 107% rule was in 2012 at the Australian Grand Prix, where both drivers from HRT qualified one per cent out of the limit. If a driver did not participate in any free practice or qualification sessions, then this driver is also not allowed to race in the Grand Prix. This was presented to ensure that drivers have equal opportunity and promote track safety, since missing a session could limit their preparation and a single mistake could endanger others.

A further regulation states that drivers are not allowed to force others off the track or endanger them. Violation of this rule results in warnings and after multiple occurrences in one race, they get time penalties or may even be disqualified. ([Formulapedia])

Flags in Formula 1

Regarding flags, there are several types in Formula 1. First, the green flag. It means that the track is clear of any hazard that was on the track or the start of a new session. The second is the blue flag, which has different meanings based on the current session. If a driver receives the blue flag during practice or qualification, then it is to inform him, that a faster car is approaching and is about to overtake. If the blue flag is shown in the race, then it indicates that the driver is getting lapped, and the following car must be allowed to pass at the earliest opportunity. If someone neglects this rule, they will get warnings and if they collect more than three warnings in one race, then they will be penalised. In connection with the blue flag, a white flag can be seen very often, which signals that there is a slower car ahead. The yellow flag indicates that there is danger ahead. If the flag is single-waved, then drivers need to reduce speed and are not allowed to overtake. They also must be prepared to change direction, due to a risk next to or partly on the track. If the yellow flag is double waved, then it means that they have to reduce speed significantly and overtaking is prohibited. Also, they must focus on the track since hazards could be blocking the track or marshals are working beside the track. If the risk cannot be solved quickly or weather conditions turned to bad, a red flag is waved to signal that the session is being stopped. Here all drivers have to reduce their speed and return to the pit lane. There are several types of black flags. If it has an orange circle in the middle, then it is used to inform a driver that their car has a mechanical problem, which poses a danger to themselves and others on the circuit. Here, drivers must pit as soon as possible, and the pit crew must fix the problem or retire the car. Another type of black flag is the black and white flag, which is parted in these two colours in a diagonal, which indicates a warning to the driver that they behaved unsportsmanlike. If they continue to drive with that behaviour, then further penalties will be issued such as drive-through, where a driver has to drive through the pitlane or a stop-and-go penalty, where drivers have to full stop at the garage in the pit, wait ten seconds and then they are allowed to drive off again. Last the full black flag, which signals the end of the race for the driver, due to disqualification, which can happen if the driver neglects another type of black flag. The chequered flag is the most known one of all, which means the end of the race and it is waved until all competing cars have reached the finish line. ([Formula 1 Flags 2023])

Tyres in F1

There are different compound tyres for different weather options. For dry weather, there are soft, which are marked red, and medium, which are marked yellow and hard tyres, which are marked white. They are also known as Compound 0 (C0) to Compound 5 (C5), where C0 is the hardest and C5 is the softest tyre. Additionally, the wet weather tyres, called intermediate, are marked green and wet tyres are marked blue. In theory, the slick tyres offer the most amount of grip, but they get outworn extremely fast. On the other hand, hard tyres have the least grip, but they last much longer, and mediums are between the two. In the 2023 season a qualifying format called "Revised Qualifying Format" (RQF) was tested twice, where in the first qualification session, drivers could only use hard tyres, in the second only medium tyres and the last session only soft tyres, if the weather is dry. In case of wet weather conditions, intermediate and wet tyres were allowed. ([Formula 1 Tyres 2023])

Driver Licence Regulation

Driver-specific regulations were introduced into the sport in the 1980s, such as formula driver licences. There are different types of licences issued by the FIA to be able to race in various FIA-sanctioned categories. Formula One has stringent requirements and the licence is labelled as the Super Licence. Some of these requirements were adopted in the last years as the minimum required age, which is now 18. “Beyond this, the driver will be tasked with completing a knowledge test on the International Sporting Code and F1 Sporting Regulations, while they are required to have completed at least 80% of two separate seasons from a range of certified single-seater championships”. ([Formula 1 Super Licence 2023])

Another condition is that the drivers need to collect 40 points in the last three- or two-year period preceding the year of application. In 2020 and 2021 the FIA considered the highest accumulated number of points in any three of the four years before the year of application. If any driver returning to Formula One has already held a Super Licence in the previous three years, then they will be considered for a renewal. ([Formula 1 Super Licence 2023])

1.3. General overview of F1 Failure types

Due to the complexity of the technical parts, there are several reasons why a car is not able to finish the race. Correspondingly, any technical intervention and innovation will change the reliability of the single-seater. In the public F1 dataset, which was collected using a Python package (pyErgast), which itself uses the Ergast API (Ergast), there are different types of failures. This data had to be filtered first, because for example for gearbox failures you can find "gearbox" as well as "transmission" in the data.
Another case would be for cars that finished the race under a chequered flag. Here data like "Finished", "Finisheds", "+X Laps", where the "X" represents a number, can be found. This means that someone got the chequered flag while being behind one or more laps. After cleansing the data, technical and logical groups had to be formed, since there are around fifty unique values. Therefore, we consider the following fifteen groups:

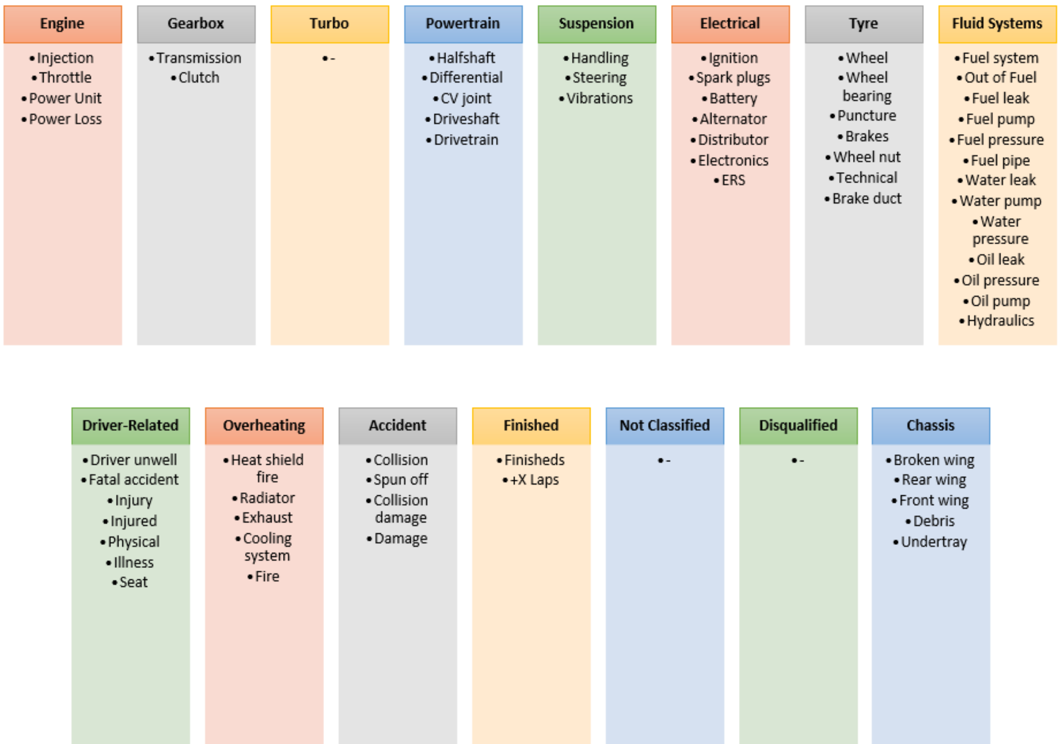

Figure 1: Grouping of Failure Types in the Dataset

Most of the breakdown types are contained in the logical group. Some groups do not even contain subtypes (which are marked with a "-"), but there are some that seem out of place and is very general, like "Technical" and "Mechanical".

There are some cases where data has been misclassified and ended up in a different status. For instance, there are only two records with the type "Technical" and those are from Red Bull Racing at the Malaysian Grand Prix in 2014 and from Alfa Romeo at the Singapore Grand Prix in 2023. In 2023, Alfa Romeo retired the car of Valtteri Bottas in the 51st lap, due to overheating issues on the other hand Red Bull retired

Daniel Ricciardo's car because of Wing damage in 2014. Due to the low amount of this type, those two cases have been changed to the significant group.
Another misclassification would be Alexander Albon's Monaco Grand Prix in 2022, where Albon reported "unexpected bouncing" in the straight, which was the cause of his retirement from the race, but in the data, the status “Mechanical” was entered. ([Williams F1 2022]) Due to the diversity of failures under “Mechanical” in the dataset and the medium amount of this failure type, these data records were not used in the analysis. There were other race statuses, which were not relevant in this analysis, because of the low amount or the type of the status, for example, rows like "Did not qualify", "Retired", "Withdrew" and "Did not prequalify", were dropped.

2. Era selection

Due to F1’s all-changing nature, such eras have been formed. The first couple of years are called the “Early Days” since the sport just was born. In this period only two types of engines were allowed. The first one was a 4.5-litre naturally aspirated engine and the second one was a 1.5-litre supercharged engine, which uses a technology to force more air into the engine to increase its power. The most dominant engine at that time was the second option, the 1.5-litre from Alfa Romeo. In the first two seasons, it won all races except one. ([Bhambwani F1 Era 2023])

The year 1954 was the beginning of the rise of Ferrari. They were struggling in the previous years to compete with Alfa Romeo, but due to another engine ruling, they came back with a new competitive engine. The FIA changed the engine rules to only allow 2.5-litre naturally aspirated or 0.75-litre supercharged engines. Ferrari’s engine was a 2.5-litre V12, which delivered around 250 horsepower and was called “the Lampredi engine", after its designer Aurelio Lampredi. With the power of this engine Ferrari managed to secure their first drivers’ and constructors’ championship in 1956. ([Bhambwani F1 Era 2023])

The era of Ferrari continued until the year 1967, when FIA changed the regulations banned supercharged engines and increased the maximum displacement for naturally aspirated engines to three litres. As a result, most of the team were required to develop new engines or modify existing ones. Lotus decided to look for a new supplier and they chose the British company called Cosworth. Cosworth was known for tuning Ford engines for racing, and they agreed to build a new engine for Lotus, which resulted in the Cosworth Double Four Valve (DFV) engine, which was a 3-litre V8. It made its debut in 1967 and it succeeded in the first race with a win. This engine was not only known for its power but also for its reliability, lightweight and cost. It was the most popular engine and was used by all teams except Ferrari. ([Bhambwani F1 Era 2023])

While the Cosworth DFV engine dominated, another innovative technology was becoming more popular which challenged its supremacy. It was the turbocharging, which had the same principle as the supercharger. Renault was the first team to experiment with turbocharging in F1 which introduced the nicknamed “The Yellow Teapot”, a 1.5-litre V6 Turbo engine. Over the years they improved their engine and by 1983 it was an unstoppable force winning race after race and challenging for the title with Alain Prost. The peak of the turbo era was in the mid-1980s when engines produced over 1000 horsepower in qualifying and 800 horsepower in race. Their power made these engines very fast but also extremely dangerous. As a result, FIA decided to limit the fuel per race to 150 litres and limit the boost pressure to 4 bar. The turbo era ended in 1988 when the FIA banned turbochargers. ([Bhambwani F1 Era 2023])

Until 2005, every manufacturer was given a range of possibilities for engines, such as different configurations and cylinder numbers, like V8, V10 or V12, where most of them chose the V10. The V10 dominated the field, because of its power, weight, and fuel efficiency. In the beginning, it only produced around 600 hp, but it steadily increased over the years to around 900 hp. Not only did they increase the power, but also the reliability, which increased the lifespan of these engines. Honda's engines were the most successful after the turbocharger ban but were directly challenged by the famous RS01, which was the engine from Renault. From 1992 to 1997 the RS01 won six consecutive constructors' championships with Williams and Benetton. ([Bhambwani F1 Era 2023])

In 2006 the 2.4-litre V8 was standardized for all teams, which also marks the beginning of the V8 era. Throughout the years the power of these engines decreased from around 800 hp at the beginning to around 750 hp in 2013, due to more restrictions like Revolutions per minute (RPM), fuel flow and development. The time of V8 ended in 2013 when the FIA announced new regulations for the 2014 season. ([Bhambwani F1 Era 2023])

The current era is the hybrid era, where teams are standardized to a 1.6-litre V6 turbo-hybrid engine. The engines became more efficient, with less fuel consumption and lower emissions and their power increased from around 750 horsepower at the beginning to over 1000 hp currently. ([Bhambwani F1 Era 2023])

2.1. Reason of the selection of specific Eras

In this thesis, two eras have been selected for comparison, where the evolution of technology made an enormous difference in race pace. These eras are the Turbo and Hybrid Era. As previously mentioned in point 2, the turbo era began in 1980 and ended with the ban of turbos in 1988 and the hybrid era started in 2014 and is still present in the sport as a consequence of the standardized regulations. The main difference between the two periods is in the power unit configuration. In the turbo era, turbocharging was a key technology for high power outputs. In the current era, engines are combined with ERS. Speaking of energy recovery, in past eras there was no systematic energy recovery or deployment system in place, but nowadays the ERS includes two major innovations the Motor Generator Unit-Kinetic (MGU-K) and Motor Generator Unit-Heat (MGU-H), which recover energy during braking and from the heat of the exhaust gases. [US Motorsport 2016]

Another main difference lies in the performance and efficiency. The turbo era is known for its high-power outputs and high speeds, but turbo lag, which is the delay between pressing the accelerator and feeling the turbo kick in and fuel consumption were huge challenges. Conversely in the hybrid era, ERS is helping the main focus, which is fuel efficiency, but also increases performance.

This emphasis is due to the regulations set in these eras, where in the 1980's they were less focused on environmental considerations, and there also were fewer restrictions on engine development. In the current era, environmental sustainability has become the main focus, with rulings aimed at reducing carbon emissions and increasing overall efficiency.

2.2. Turbo Era (1977 – 1988)

Looking back, it can be said that ground effects were less important to the long-term development of Formula 1 technology than supercharging - although both were introduced in the 1977 season and eventually later banned. In 1977 Lotus was developing the ground-effect principle and Renault re-entered with the “Yellow Teapot” the RS01 turbo. Although Renault’s first turbo engine was incredibly fast, it suffered from "turbo lag" during acceleration and was very unreliable. In the same season, several other technical inventions were introduced like the skirts of the car and radial tyres, first by Michelin and later followed by Goodyear and Pirelli. ([F1 Turbo Era 2018]) In 1977 and 1978 there were several new rulings to ensure driver safety. In 1977 FIA set standards for helmets and they were to meet in the following year, where the licence qualification requirements were introduced. ([F1 Rules 70s 2009])

The development of turbo engines progressed slowly. In 1979 Renault secured the RS01’s first Grand Prix win in France, where the title contenders waged a fantastic duel behind in second place. After the French Grand Prix, the new Williams car won five of the last seven races including a stretch of four in a row and Renault recorded six poles. In the end, Ferrari’s reliability had won them the title. In 1979 a new safety regulation was introduced the life support system. ([F1 Turbo Era 2018])

The turning point for turbocharging happened in 1980 when Williams dominated the season. In the same year at Imola, the Italian Grand Prix, Ferrari introduced their turbocharged car, which did not see much achievement that season. On the contrary, Renault won at Interlagos, Kyalami and the “Österreichring”. Although in 1981 and 1982 Cosworth DFV-powered teams won the championship, the field was increasingly dominated by the turbos. ([F1 Turbo Era 2018])

Despite the turbo advantages, there were still eleven teams in 1982 that were using the Cosworth engine, including Brabham for whom Nelson Piquet won the 1981 championship by only one point. In the following years, the nature of Formula One lost several legends. Gilles Villeneuve died while trying to improve his grid position in the qualifying session at the Dutch Grand Prix. Four weeks later Ricardo Paletti died at the start of the Canadian GP. ([F1 Turbo Era 2018])

In those three years from 1980 until 1982 new regulations met the nature of F1. In 1980 several medical service rules were introduced, such as the permanent medical centre and a fast rescue car. Additionally, from 1981 onwards the survival cell had to be reinforced and extended in front of the driver’s feet. ([F1 Rules 80s 2009])

The turbo era came to its peak in 1983, when Nelson Piquet won his second title with a turbocharged BMW engine. In the same year, McLaren introduced the TAG-

Porsche engine, which secured them three Grand Prix wins and runner-up in the title contention, despite leading for most of the season. The highlight of the year was the Belgian Grand Prix, which returned after a 13-year break. In 1984 McLaren with the TAG-Porsche engine won twelve out of sixteen races and took the constructors championship. The driver’s championship was decided by a half of a point, where Niki Lauda came out on top in front of his teammate Alain Prost, even though he only won five and Prost won seven races. ([F1 Turbo Era 2018])

Many thought that McLaren’s dominance was only in 1984, but it continued until a close title fight in 1986. The following year was the dominance of Williams, where their driver, Nigel Mansell won the home Grand Prix. However, Piquet won his third World Championship after Mansell had a qualifying accident in Japan. ([F1 Turbo Era 2018])

In those five years, Formula One had a couple of big changes. On the safety side, they introduced the “Super license”, which was already mentioned under point 1.2. Furthermore, medical helicopters were obligatory and several changes to circuits have been made. On the technical side, refuelling was banned in races in 1984 and in 1985 new car test, the frontal crash test was added. ([F1 Rules 80s 2009])

The last season of the turbo era was a special one for McLaren as they shattered their record of Constructors points. Their drivers, Alain Prost, and Ayrton Senna secured fifteen out of sixteen race wins and 167 points combined. The driver’s championship was won convincingly by Senna with a 16 points difference. ([F1 Turbo Era 2018]) In the same season, new rulings like permanent FIA race director and another crash test for the survival cell and fuel tank have been introduced. Additionally, from 1988 on, the driver's feet had to be behind the front wheel axis. ([F1 Rules 80s 2009])

2.3. Hybrid Era (2014 – present)

In the year 2014, the most significant rule change in F1 history shocked the scene. It was the normally aspirated 2.4-litre V8 engines replaced by the 1.6-litre turbocharged V6 “power units” - no longer officially called engines - with the ERS, that recovers energy. Another crucial rule change was the decrease in fuel usage per race, which is 100 kg now. As a result of these changes, the cars were slow, unreliable, and uncharacteristically quiet. In the first year, some new circuits were added, and some were removed. Not only GPs changed but also driver lineups, where Ferrari replaced Felipe Massa with Kimi Räikkönen and Red Bull replaced Mark Webber with Daniel Ricciardo as the second driver. Red Bull and Ferrari came out of the box with a huge horsepower disadvantage to Mercedes and not even one constructor could figure out how to match the Germans for speed and efficiency. ([F1 Hybrid Era 2018])

The two Mercedes pilots, Lewis Hamilton and Nico Rosberg battled the whole season without team orders. Hamilton took the point lead early, but Rosberg battled his way back and took the lead after some races. Over at Red Bull, however, Sebastian Vettel had a dreadful year, often overshadowed by second driver Ricciardo, who took a number of podiums and Grand Prix wins. At the last race of the season, double points were awarded. In the qualifying session, Rosberg took the Pole, but during the race, he encountered numerous technical problems and finished in 14th place, while Hamilton won the race. Hamilton won the drivers’ championship and the also-called Silver Arrows captured 16 Grand Prix wins, 18 pole positions and the most constructors’ points ever that year. ([F1 Hybrid Era 2018])

In the same year, several new regulations came into place. Such as the penalty point limit on super licences, which is set to twelve and if a driver reaches the limit then he will get a race suspension. Other technical regulations focused on the chassis and power unit. ([F1 Rules 2010s 2019])

In 2015 Sebastian Vettel switched from Red Bull to Ferrari and Alonso from Ferrari to McLaren. Daniil Kvyat took the place of Vettel in Red Bull, but the season played out as the last season. Complete domination of the Silver Arrows. The Duo collected 16 out of the 19 possible wins and yielded more points than Ferrari in the second place and William in the third place combined. Lewis Hamilton stayed consistent in the whole season by winning races and he only finished twice out of the podium. Sebastian Vettel collected some podiums in the new Ferrari, but he could not challenge the Mercedes in points. “Sadly, it was almost impossible to track how many rule changes had come and gone in Formula One over recent seasons. Refuelling and traction control in and out. Wing and nose sizes big and small, high and low. Brake bias only manually adjusted, but then electronic-assisted rear braking systems allowed.” ([F1 Hybrid Era 2018])

A fantastic addition to the rules was the virtual safety car (VSC), which means that drivers must drive to a targeted lap time, which is a bit slower than the race pace. Another addition was the new Mexican Grand Prix, which has a new stadium section in the last turns, but as new circuits come, old circuits go. After 59 years the German GP left the F1. The season in 2016 introduced some new teams and new drivers. The entry of Haas was a historic point in F1 because it was the first American F1 team in three decades. Nonetheless, Azerbaijan GP was added to the F1 calendar, and the young sensation Max Verstappen was promoted from Toro Rosso to Red Bull. During the pre-season testing at Circuit de Barcelona-Catalunya in Barcelona, Ferrari was consistently the fastest, but in the first four races, they still struggled to put it in the race pace. Conversely, Nico Rosberg won the first four races and had a decent lead coming back to Barcelona. At the Spanish Grand Prix, one of the dramatic highlights of the season happened, when the Mercedes Duo did not leave space for each other and collided on the track. As a result, the rookie Max Verstappen secured his first Formula One win. In the following races, Hamilton fought his way back to a 19-point difference, but then Rosberg won at Spa, Monza, Marina Bay, and Suzuka. In Malaysia Hamilton’s car had an engine failure and retired from the race, which again increased the gap between the two. Meanwhile, Ferrari had a horrible season, struggling for pace and could not even secure a single race in the season. The car was unreliable, and strategies were full of errors. Throughout the season not only Ferrari was inconsistent, but so were the Stewards with penalties and licence points. The last four races of the season ended up 1-2 for Mercedes with always Hamilton topping Rosberg. At the last race in Abu Dhabi, Nico needed only a podium finish to win the Drivers' Championship, and he did just that. Toto Wolff’s crew won 19 out of the possible 21 races and secured another constructors’ championship for Mercedes. ([F1 Hybrid Era 2018])

The beginning of the 2017 season, was similar to the previous ones. Yet again legends left the sport and got replaced by other drivers. After his title win in 2016, Nico Rosberg retired from F1, and ex-Williams driver Valtteri Bottas took his place. At the beginning of the year, Vettel and Hamilton were in a close fight finishing 1-2 in four of the first five races. Unfortunately, racing was difficult at that time due to the amount of “dirty air”, which made overtaking impossible. “Rules and penalties problems that had plagued the sport in recent seasons stayed messy. The unloved engine token development system was shelved, leaving teams free to design enhancements during the year so long as they did not exceed a reduced four engines per driver limit for the 20 races.” ([F1 Hybrid Era 2018])
For instance, Stoffel Vandoorne was hit with a 35 grid-spot at the Mexican GP alone, while Ricciardo, Alonso and newcomers Brendon Hartley and Pierre Gasly were hit with a 20 grid-spot penalty on other GPs. The season continued with Mercedes dominance and Hamilton secured his fourth World Championship with 46 points lead. ([F1 Hybrid Era 2018])

The season 2018 had some circuit changes as the Malaysian Grand Prix left F1, but the French GP was introduced, and the German GP came back. There were also fresh faces in F1 with Toro Rosso signing Pierre Gasly and Sauber Ferrari signing

Charles Leclerc. Nonetheless, the result of the 2018 season was the same as the previous ones. Lewis Hamilton had a weak performance in the first 3 races, but then he secured at least a place on the podium of every remaining GP except three. He finished the year with 408 points and an 88-point margin to Vettel. ([F1 Fandom 2018 Season])

The following season did not start any different from the previous ones. A lot of driver lineups met changes, for instance, the switch from Räikkönen and Leclerc, where Leclerc got promoted to Ferrari from the sister team. Another newcomer made an appearance in 2019, the 2018 runner-up Formula Two champion Lando Norris, who replaced Stoffel Vandoorne at McLaren. None of this made a change in the season. The first eight races were won by Mercedes, where Hamilton got the better start for the title. After those races, it was clear that Mercedes would win the championship again if they continued their brilliance. More interesting was the fight for third place in the drivers' championship. The podium was decided between Sebastian Vettel, Max Verstappen, and Charles Leclerc. At the halfway mark of the season, Max leads the duo with a 21-point difference to Vettel and a 42-point difference to Leclerc. The third place was decided in Brazil, where Vettel and Leclerc finished out of point and Verstappen meanwhile secured a GP win. The Season ended with Hamilton in front of his teammate Bottas and Max Verstappen in third place. ([F1 Fandom 2019 Season])

There were no big driver-lineup changes for the 2020 season. Scuderia Toro Rosso was renamed to Scuderia AlphaTauri and Nico Hülkenberg was replaced by Esteban Ocon at Renault. As a result of COVID-19, the season calendar was reduced to 17 Grand Prix’s. Those 17 races were held at 14 different tracks, meaning some circuits for instance Red Bull Ring and Silverstone held two f1 weekends. Despite the changes, the season did not start any different. Hamilton won five out of the first seven GPs, but he was constantly challenged by his teammate Bottas and by the young talent over at Red Bull called Max Verstappen. Regardless of the five retirements over the season for Verstappen, he nearly clinched second place in the drivers' championship from Bottas, who only ended the German Grand Prix early. Hamilton secured his seventh world title, equalling Micheal Schumacher’s record. ([F1 Fandom 2020 Season])

The 2021 season was the most exciting season with a controversial finish. The year already started with Renault rebranding to Alpine and Sebastian Vettel leaving Ferrari to join Aston Martin. The Mexican driver Sergio Perez, who was replaced by Vettel, later joined Red Bull as second driver. Albon who was driving for Red Bull remained in the team as their reserve driver. Haas completely changed their driver lineup from Grosjean and Magnussen to Nikita Mazepin and Mick Schumacher, Micheal Schumacher’s son. Due to COVID slowly fading away the F1 calendar was filled with 22 race weekends. The season started with a lot of battles on the track between Verstappen and Hamilton. At the halfway mark of the season, Verstappen was leading the Drivers' World Championship by eight points ahead of Hamiton. There was a lot of heat on the track between the two and they even crashed into each other, for instance, at the British Grand Prix or even at the Italian Grand Prix. The Grand Prix in Abu Dhabi in 2021 was the most controversial race. It was the last race, and the title was decided in the last round. Due to the crash of Latifi at the end of the race, there was chaos. Mercedes decided to not pit Hamilton from the hard tyres, meanwhile, Verstappen was running on more fresh soft tyres, which gave him the grip advantage in corners. Before the last lap, the safety car exited the track and Verstappen had only one lap chance to overtake Hamilton who was in pole position in front of him. In turn five Verstappen took the lead and later he was crowned the world champion. Mercedes won the constructors' championship thanks to a 36-point difference between the secondary drivers. ([F1 Fandom 2021 Season])

In the following season, a lot of changes were happening. Aston Martin and Alpine announced their new team principals, Ferrari and Haas dropped sponsors because of varied reasons and drivers switched places. For example, Bottas switched from Mercedes to Alfa Romeo and was replaced by George Russel from Williams. The empty seat at Williams was filled with Alex Albon from Red Bull. Due to the conflict between Russia and Ukraine, the Russian Grand Prix was cancelled, but the Miami Grand Prix was added to the calendar. The Turkish Grand Prix was expected to be on the schedule, but due to monetary issues, they could not afford to host an F1 weekend. After a horrible first race for Red Bull, where both of their cars had technical issues, they came back stronger. Charles Leclerc was a possible contender after the first six races for the title, but later he started struggling in the team and with the car and at the halfway of the season he was down 38 points off Verstappen. The Dutch driver continued his brilliance and won eight out of the last twelve races. He secured the Drivers' World Championship title back-to-back. ([F1 Fandom 2022 Season])

3. Case Study & Data analysis

In this section of the thesis, a comparative analysis and correlation between the two eras has been completed. Here the focus was on the car failures during the race. Furthermore, six tracks have been selected for comparison between the two periods to demonstrate any correlations between the eras and to highlight the underlying types of failures related to each track.

Red Bull Ring

One of the selected circuits is the Austrian Grand Prix, also known as the Red Bull Ring. This racetrack welcomed F1 from 1970 until 1987 and was called “Österreichring” at that time. The following year they shortened, rebuilt, and renamed it to the A1-Ring, and it hosted the Austrian GP from 1997 until 2003. Later it was purchased and rebuilt by Red Bull’s Dietrich Mateschitz. He also renamed the track to Red Bull Ring and reopened it on the 15th of May in 2011. In the same year, DTM and F2 could test the track in race conditions. Later in 2014, at the beginning of the new era, Formula One returned to the Austrian Grand Prix and in 2016 MotoGP also made its comeback. The current track has a maximum uphill gradient of around twelve per cent and a point three per cent downhill gradient. It is one of the shorter tracks with just 4 318 meters.

Circuit of Spa-Francorchamps

Another selected circuit is the most famous track, the Belgian Grand Prix also known as Spa-Francorchamps or shortened Spa. The first official Formula One race was in the first year of the Formula Championship in 1950 and in the following year, the track was extended with the creation of the Stavelot bend. From 1971 until 1984 F1 left the track due to its length, which was around 14 000 meters but in 1979 the circuit was dramatically shortened to create the track today.

F1 returned to the track since 1983. It is around 7 000 meters long, and it has one of the most famous corners called the Eau Rouge. Over the years, the circuit has been modified for safety reasons, but in 2019, during a Formula 2 weekend, tragedy struck when Anthoine Hubert had a fatal accident at the Eau Rouge. As a result, in 2022 alterations were made to the track, including extra run-off areas and gravel pits.

Silverstone Circuit

The third selected Grand Prix is the British GP, also known as Silverstone. It hosted the first round of the first Formula Championship in 1950 and since 1987, it has been the permanent home of the British Grand Prix. The first layout of the track was made out of runways, where in World War Two Wellington bombers used to take off. These runways and their perimeter were quickly converted for use as a racing circuit. Nowadays, the circuit is 5 891 meters long and a vintage part of F1.

Circuit Gilles Villeneuve

The Canadian Grand Prix is one of the most consistent circuits. It was introduced to Formula 1 in 1978 and since it only was left out in 1987, 2009, 2020, and 2021. The circuit was initially called Circuit Ille de Notre Dame, the island on which the track was located, but in 1982 after the tragic death of home-grown hero Gilles Villeneuve, it was renamed Circuit Gilles Villeneuve. The circuit is nowadays 4 265 meters long, and it is also one of the shortest tracks in F1.

Autodromo Nazionale Monza

A further selected track is the Italian Grand Prix, which was one of the original races of the first Formula Championship in 1950. The track of Monza was only left out in two years since 1950. In those two years, several parts of the track were improved and rebuilt, such as the podium, paddock, and pits complex. Monza is the fastest track in F1 with maximum speeds of around 350 km/h and a track length of 5 793 meters. Monza is often mentioned as the “Temple of Speed”.

Circuit de Monaco

The last selected track is the Monaco Grand Prix, which is the most famous and prestigious race of Formula One. This is one of the most difficult street circuits, because of its narrow routes and high speeds. The track of Monaco is the shortest circuit of Formula One with only 3 337 meters.

3.1. Analysis of Turbo Era

The turbo era was the first that was analysed in this thesis. First, the data was collected through the Python package. For caching purposes, the data was saved as a separate file. After analysing the raw data, it was sure that it needed cleansing and grouping. The logical groups that were chosen, were already presented in chapter 1.3. Next, the data was visualized in a stacked bar chart with unique colours.

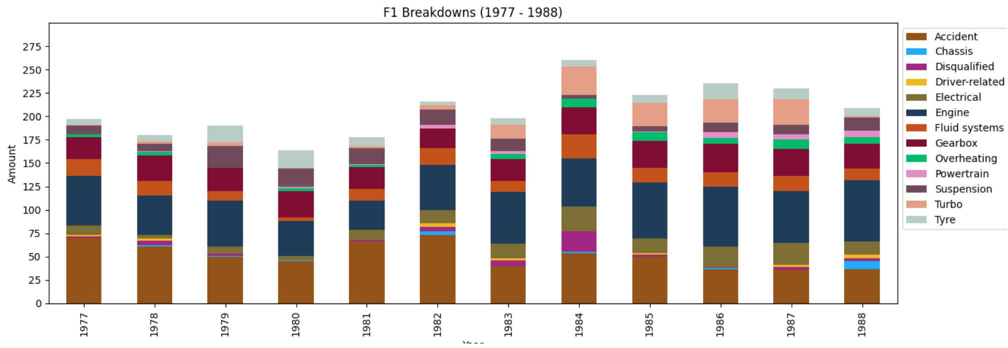

Figure 2: Turbo Era Failure Types throughout the years

Upon closer examination of Figure 2 conclusions can be drawn that racing accidents were always present in F1 through the years of the turbo era. In 1986 was the lowest and in 1982 was the highest number of accidents. Another big part of the breakdowns through the years is the engine problems. The amount of engine problems was almost constant throughout the year, except in 1981 when it was around half of the highest amount. A further constant failure type was the gearbox. Looking at the turbo failures, it can be seen that from 1983 until 1987, it had higher counts than usual. This was due to the rising interest in turbocharged engines. The rise of turbo failures in 1983 and 1984 a similar rise in disqualified cars can be seen. A similar effect was visible in the failure-type fluid systems, which include the whole fuel system. Overall, the year 1980 had the lowest amount and the year 1984, when the turbo era began to flower, had the highest amount of car failures.

Austrian Grand Prix

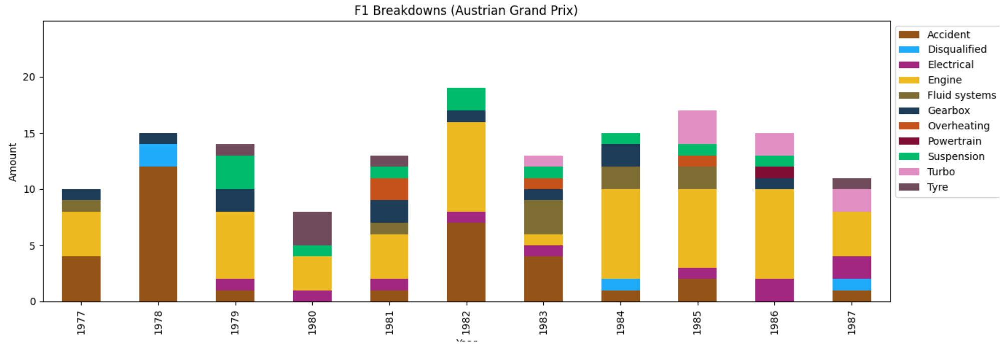

Figure 3: Car Breakdowns at the Austrian Grand Prix in the Turbo Era

In the next section, the Austrian Grand Prix was analysed in the turbo era. After further examination of Figure 3, it can be seen that accidents are very fluctuating. In 1978 there were around 12 cars that could not finish the race due to an accident. Another outstanding failure type is the engine. Engine problems were present every year at the Austrian GP, except in 1978. The highest amount of engine failure was in 1982 when around 8 pilots could not reach the black and white flag. Looking at turbo failures there was only from 1985 constant such malfunctions. In 1988 the Austrian GP was not held due to safety concerns with the Österreichring.

Belgian Grand Prix

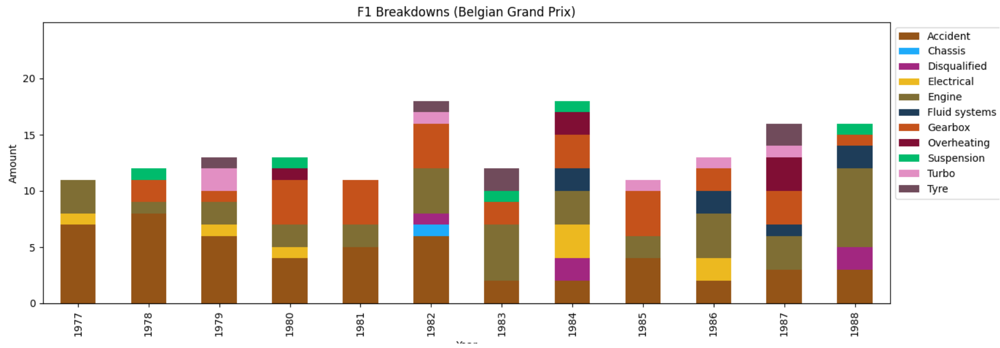

Figure 4: Car Breakdowns at the Belgian Grand Prix in the Turbo Era

Next, the Belgian GP will be examined. In the first half of the turbo era, there were more accidents than in the second half on the Circuit of Spa. Another dominant failure type is the engine. In the years 1982 and 1983 there were excessive amounts of engine malfunctions, but the highest count was in the last year of the turbo era in 1988. Unlike other tracks, gearbox problems were almost every year an obstacle in the field, especially in the years from 1980 until 1982. In the turbo era on the Belgian GP, only twelve out of the fifteen groups made an appearance.

British Grand Prix

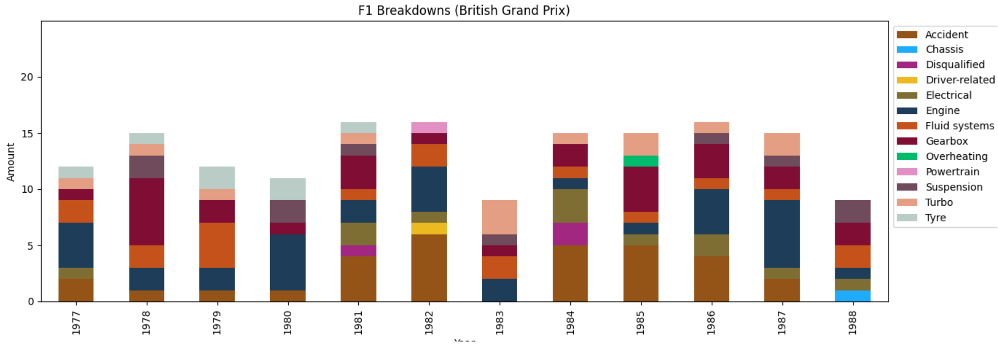

Figure 5: Car Breakdowns at the British Grand Prix in the Turbo Era

Coming to the British GP almost all groups were present in the turbo era on this track. One of the predominant failure types was again engine, which fluctuated very strongly throughout the years, with a maximum count in 1987. Different from other tracks gearbox failures were almost as prevailing as accidents. Gearbox malfunctions reached a peak of six in 1978 and the most accidents on the British GP occurred in 1982. Especially focusing on turbo malfunctions, almost every year, except 1980, 1982 and 1988 there was at least one car, which had to be retired due to this problem. The peak of turbo failures was in 1983 when the turbo era was at its prime.

Canadian Grand Prix

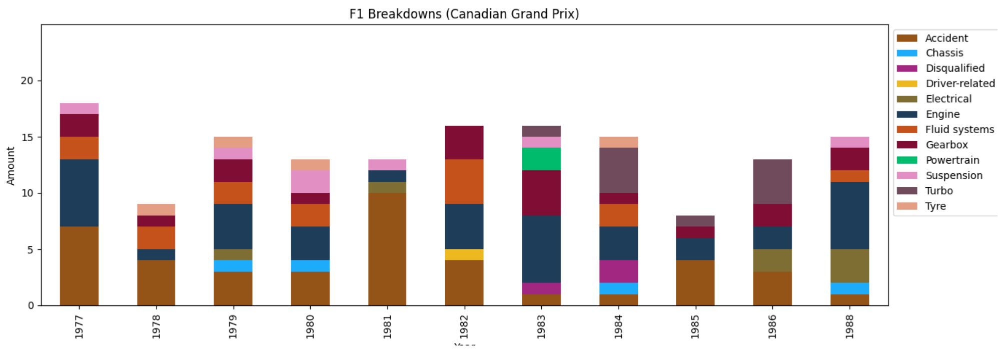

Figure 6: Car Breakdowns at the Canadian Grand Prix in the Turbo Era

The Canadian Grand Prix has a different split between the failure types than any other track. Similar to other track accidents, engine failures and gearbox malfunctions were the dominant breakdown types. Accidents peaked in 1981 with ten and gearbox malfunctions in 1983 with four cars exiting early. Engine problems reached its maximum three times throughout the years, in 1977, 1983 and 1988. Alike to other tracks, turbo breakdowns were predominant in the peak years of the turbo era. In 1987 the Canadian Grand Prix was cancelled due to a court case, which was later resolved before the 1988 season.

Italian Grand Prix

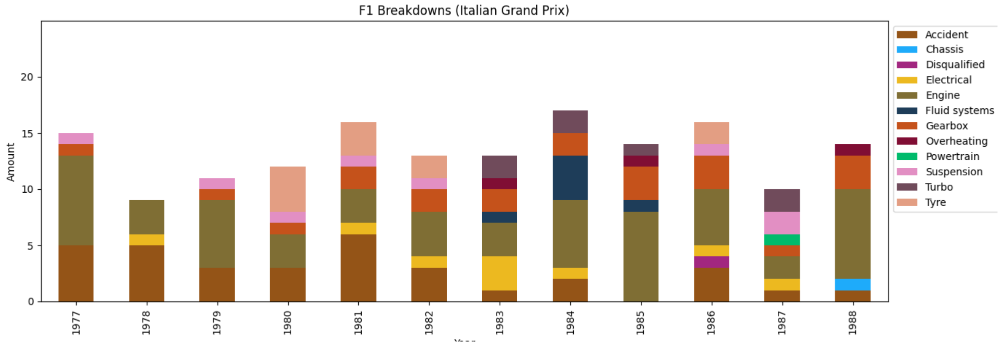

Figure 7: Car Breakdowns at the Italian Grand Prix in the Turbo Era

Further moving onto the Italian GP, Figure 7 shows that the most predominant failure type on this track was the engine problems. Every year at least two pilots could not finish their race due to an engine malfunction. It reached its peak three times over the twelve years, in 1977, and 1985 and in the last year of the era in 1988. Accidents were almost always a factor in the race. Throughout the years, only in 1985 were no accidents, else in every other year at least one driver exited the race early. Turbo failures only made an appearance in the prime years of the turbo era.

Monaco Grand Prix

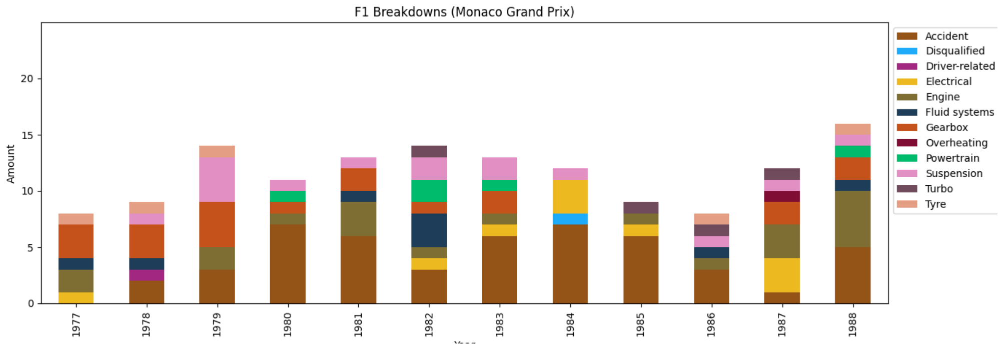

Figure 8: Car Breakdowns at the Monaco Grand Prix in the Turbo Era

Coming to the last selected Grand Prix, which is the track of Monaco. This street circuit is famous for accidents, because of its narrow streets. As a result, number of accidents is the most dominant problem. It reached its peak in 1980 and 1984 when seven cars could not finish the race due to this issue. Unlike other tracks, turbo malfunctions occurred rarely, with only four cases throughout the twelve years. On the other hand, suspension issues had a higher amount than on the other selected tracks. This could be because of the elevation change, which is 42 meters between the highest point in turn four and the lowest point in turn seventeen. It reached its peak in 1979 with four early exits and made an appearance in almost every year, except in 1977, 1985 and 1986.

3.2. Analysis of Hybrid Era

Next, the hybrid era was further examined. Here again, because of caching purposes the data was collected, cleansed, grouped, and saved as a separate file.

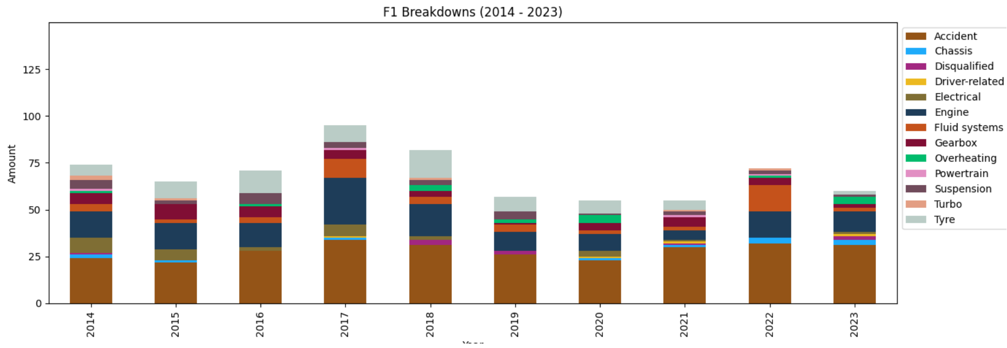

Figure 9: Hybrid Era Failure Types throughout the years

By further analysis of Figure 9, it can be seen that accidents are a predominant cause of early exits. Another dominant breakdown type is the engine, which is similar to the turbo era, but unlike the tyre failures. From 2014 until 2021 there were almost constant amounts of tyre failures. Throughout the years suspension issues decreased to only some cases. Gearbox problems have been fluctuating since the beginning of the hybrid era. It could be because of the continuously innovating parts around and in the gearbox. The years with the lowest number of unfinished cars were 2020 and 2021. The main difference between these two years is the number of accidents, where 2021 has around fifteen more, and overheating issues, where 2021 has none, unlike the season of 2020.

Austrian Grand Prix

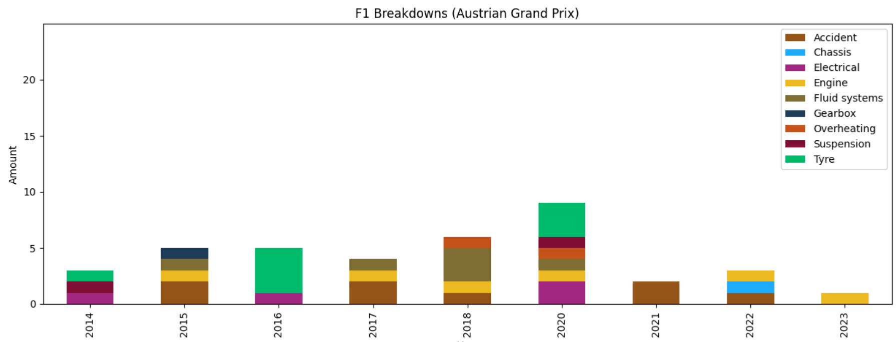

Figure 10: Car Breakdowns at the Austrian Grand Prix in the Hybrid Era

Coming to the first track in the hybrid era, the Austrian Grand Prix. The maximum breakdowns in the last nine years on this track were in 2020, which was plagued by tyre issues. Although there was only a small number of failures, it can be said that accidents, engine issues and fluid system breakdowns were the most common breakdown types. The two peaks of tyre failures in 2016 and 2020 were because of brake breakdowns, which are caused by the kerbs of the circuit. The Austrian Grand Prix in 2023 had only one engine malfunction and was one of the cleanest races on the circuit in the hybrid era.

Belgian Grand Prix

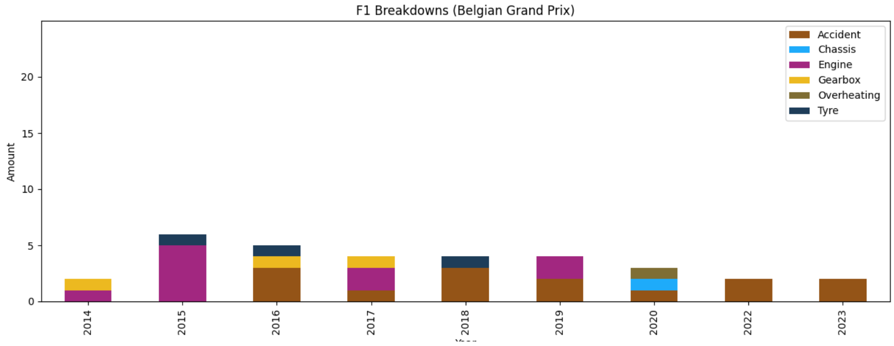

Figure 11: Car Breakdowns at the Belgian Grand Prix in the Hybrid Era

The Belgian Grand Prix had a dwindling number of breakdowns throughout the last years, similar to the Austrian Grand Prix. The maximum was in 2015 when five drivers could not finish the race due to engine problems. Although engine failures did occur in several seasons, it was not the most dominant breakdown type. Accidents were almost in every season except in 2014 and 2015. In the last two years at the Belgian GP, there were only two accidents each, which also marks the years with the lowest breakdowns. In the graph 2021 is missing, because there were no accidents since the race was red-flagged after the third lap due to bad weather conditions.

British Grand Prix

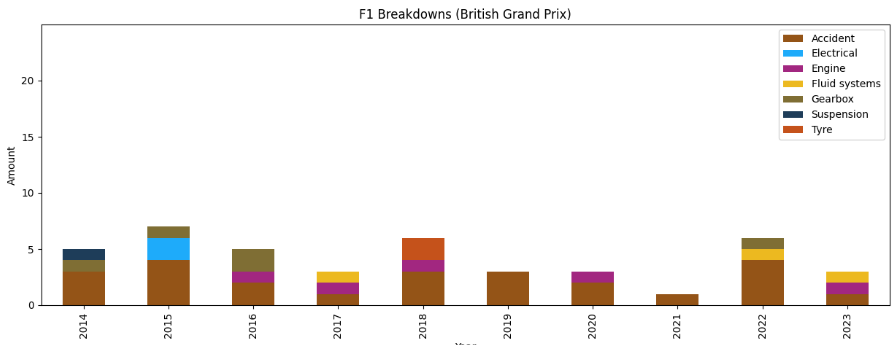

Figure 12: Car Breakdowns at the British Grand Prix in the Hybrid Era

Unlike the other selected GPs, the Circuit of Silverstone had multiple higher number of accidents, throughout the hybrid era. Every year at least one car could not finish the race due to an accident and it is also the most dominant failure type on this track. Engine and gearbox breakdowns also made some appearances, but the amount of those cases is low. In the season of 2021, one of the cleanest British Grand Prix was witnessed with only one accident, which occurred in the first lap of the race.

Canadian Grand Prix

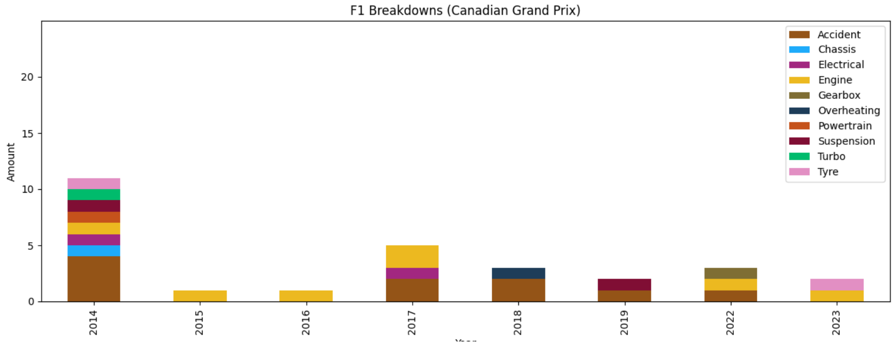

Figure 13: Car Breakdowns at the Canadian Grand Prix in the Hybrid Era

Coming to the third selected track, the Canadian Grand Prix. The race in 2014 was full of different car breakdowns. It had already eight different unique failure types. Eleven cars exited the race early due to issues like accidents, chassis, electrical and much more. Even though accidents brought more car retirements, engine breakdowns were the most dominant failure type. Engine problems occurred in every year since 2014, except in 2018 and 2019. The Canadian Grand Prix's in 2015 and 2016 were only plagued by one engine failure each. Due to the COVID-19 pandemic, the Canadian GP did not make an appearance on the 2020 and 2021 F1 calendar.

Italian Grand Prix

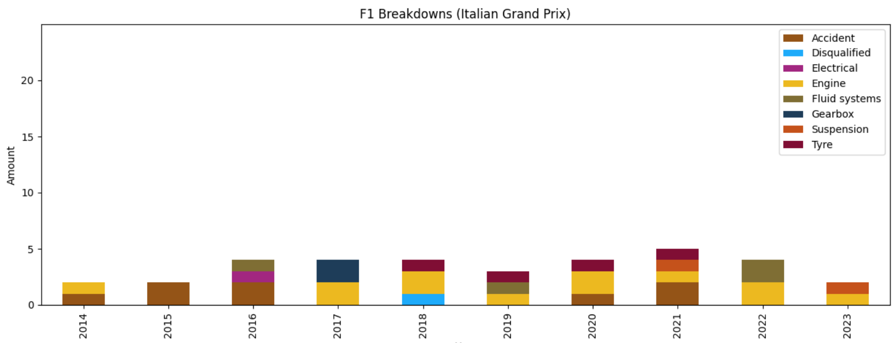

Figure 14: Car Breakdowns at the Italian Grand Prix in the Hybrid Era

The Italian Grand Prix had a variety of failure types over the years since 2014. The predominant one was engine failure which always retired at least one car, except in the season of 2015 and 2016. Accidents were also happening on the track, but there were only eight cars that could not finish the race due to them. It is interesting to point out the gearbox failure from 2018 until 2021, which always forced a driver to not be able to finish the race under the chequered flag. The cleanest Italian Grand Prix's occurred in 2014, 2015 and 2023, where always two cars had different breakdowns.

Monaco Grand Prix

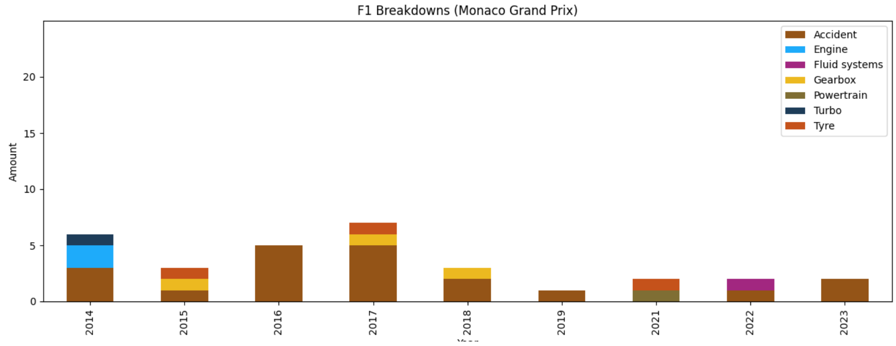

Figure 15: Car Breakdowns at the Monaco Grand Prix in the Hybrid Era

The breakdowns at the Monaco Grand Prix decreased throughout the years of the hybrid era. The most dominant failure type at the circuit of Monaco is the accidents. In the years 2016 and 2017, five cars each could not finish the race due to collisions or crashes. Since the year 2018 breakdown went to do maximum of three per race and in 2019 only one car had an early exit. Other failure types do not occur much at this trick. Tyre and engine malfunctions only happened three times each over the last nine years.

3.3. Correlation Analysis of Eras

In the following section of this thesis, a correlation analysis in and between the two eras was conducted. A correlation analysis is a statistical method that identifies the strength and direction of a linear relationship between variables and returns a number between minus one and one. Positive values are an indicator of a positive relationship, which means that as one variable increases, the other will increase. In contrast, a negative value, which points to a negative relationship indicates that as one variable increases, the other tends to decrease. Based on the value there are different levels of correlations. If the absolute value is one, this means that there is a perfect correlation between the variables. A high correlation exists if the absolute value is between 0.75 and 0.99. If our absolute result is between 0.74 and 0.5 then it has a moderate correlation and everything below 0.5 has a weak correlation. If the correlation is zero then there is no linear correlation between the variables.

Correlation in the Turbo Era

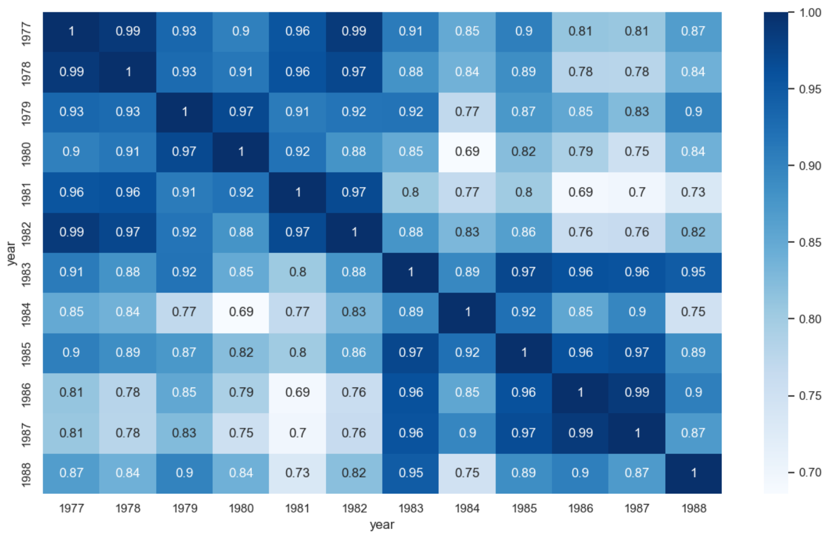

Figure 16: Correlation Analysis between the years in the Turbo Era

By further examining Figure 16, which represents the correlations between the years of the turbo era, a value range between 0.69 and 0.99 is visible. Furthermore, the matrix is only filled with positive values, which indicates that the seasons in the turbo era have a positive relationship with each other. The most significant correlations, with a value of 0.99, occur between the years 1977 and 1978, as well as between 1977 and 1982, and between 1986 and 1987 in Figure 16. The lowest relationship is between the 1980 and 1984 and the 1981 and 1986 seasons with a value of 0.69. Upon closer inspection of Figure 2, the year 1980 was the year with the lowest number of breakdowns and especially turbo failures, unlike 1984. The season of 1984 had around 265 breakdowns, which is almost 100 more than in 1980. Additionally, 1984, the peak year of the turbos, had the most turbo failures with around 30 cases. These two factors explain the correlation value observed between these two years. Between the years 1981 and 1986, the main differences are in the frequency of the failure types. Furthermore, the season of 1986 had much more turbo and powertrain failures than the 1981 season. In Figure 16 the correlation of the year 1981 with 1985 and 1986 has a difference of 0.11. Upon closer inspection of Figure 2 and by comparison between the years 1985 and 1986 the amount of powertrain issues is the main difference. In Figure 2 it can also be seen that the years 1986 and 1987 are almost identical, which explains the 0.99 correlation.

Correlation in the Hybrid Era

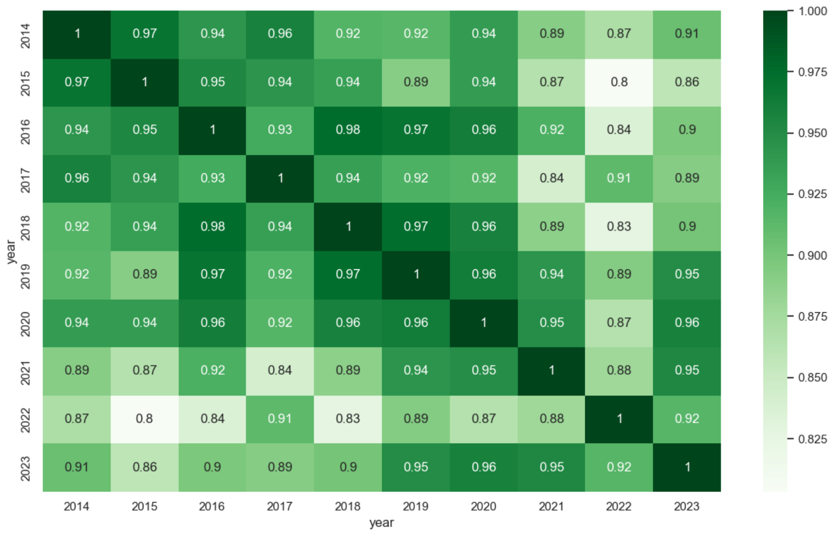

Figure 17: Correlation Analysis between the years in the Hybrid Era

Coming to the hybrid era, in Figure 17 we have values ranging from 0.8 to 0.98. In the matrix, only positive values can be found, which indicates that we only have positive relations. The most and least important correlations are unique, which means we only have one year pair, where this value occurs. The least significant correlation is between the year 2015 and 2022. The main differences between the season of 2015 and 2022 are already shown in Figure 9. The year 2015 was plagued by tyre and gearbox issues, unlike the year 2022, which had zero tyre failure cases and only some gearbox issues. On the other hand, 2022 had the most fluid system issues. These failure-type differences explain the correlation value between these two years. Upon closer inspection of Figure 9 and a comparison between the 2016 and 2018 seasons, a notable similarity is evident, except there is a noticeable increase in the occurrences of each type of failure in the 2018 season.

Correlation between the Eras

For the correlation analysis between the eras the first ten years of each era were compared. The reason behind this selection is that it should give a better understanding of the evolution of the technologies and the corresponding risk of failures.

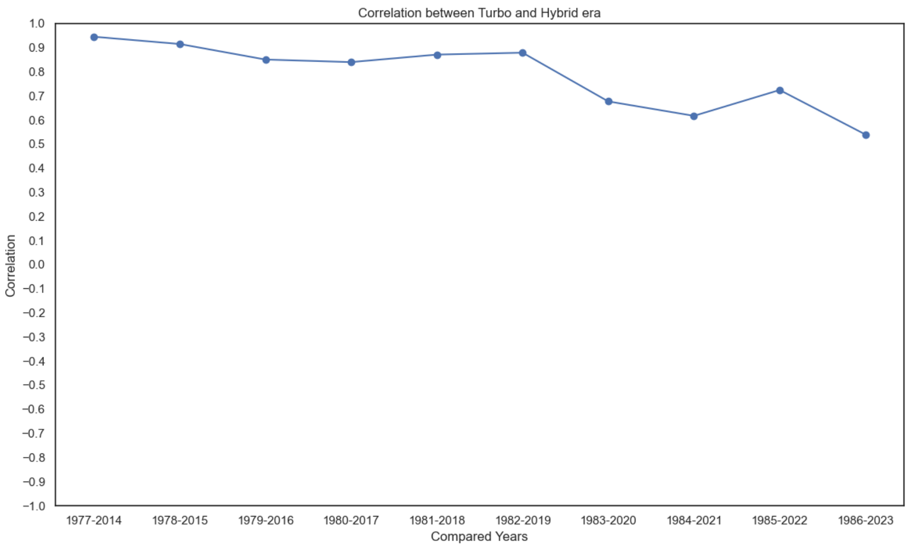

Figure 18: Correlation of the first ten years of the Turbo and Hybrid Era

In Figure 18, as the label already says, the first ten years of each era were analysed for correlation. It shows that the first six years have a strong positive relationship. From the seventh year, the correlation value goes back to around 0.7 and further down in the eighth year, which marks the peak of the turbo era, to a moderate correlation valuing 0.6. The correlation's lowest value is in the last analysed year which is the 1986 and 2023. Upon closer inspection and comparison of Figure 2 and Figure 9, it is evident that in the beginning years, only the frequency of the failure types was the main difference. The key dissimilarity between 1983 and 2018 are three breakdown types. One of them is the tyre failures, which were low in 1983 and remarkably high in 2018. The other two are the gearbox and suspension malfunctions, which were relatively high in 1983 and low in 2018. On a more thorough inspection, the key difference between 1986 and 2021 is that in 1984 there were a lot of overheating issues, unlike in 2021 where there were zero cases in the whole season. Furthermore, as already mentioned under point 3.1 the year 1984 was the peak of the turbo era and therefore it had the greatest number of turbo breakdowns. In 2021, there were only some cases of turbo breakdowns. Coming to the lowest correlating years, the dissimilarities are overall the number of breakdowns of each type. In 2023 there was an overall lower number of cases, unlike 1986 which had the second highest number in the turbo era. The key difference between these two years is the turbo and overheating issues. The season of 1986 had a lot of cases of turbo malfunctions and some cases of overheating problems, unlike 2023, where these breakdown types did not make an appearance at all.

3.4. Correlation Analysis of Circuits between Eras

In this part of the thesis, the correlation analysis for the selected tracks will be further investigated.

Austrian Grand Prix

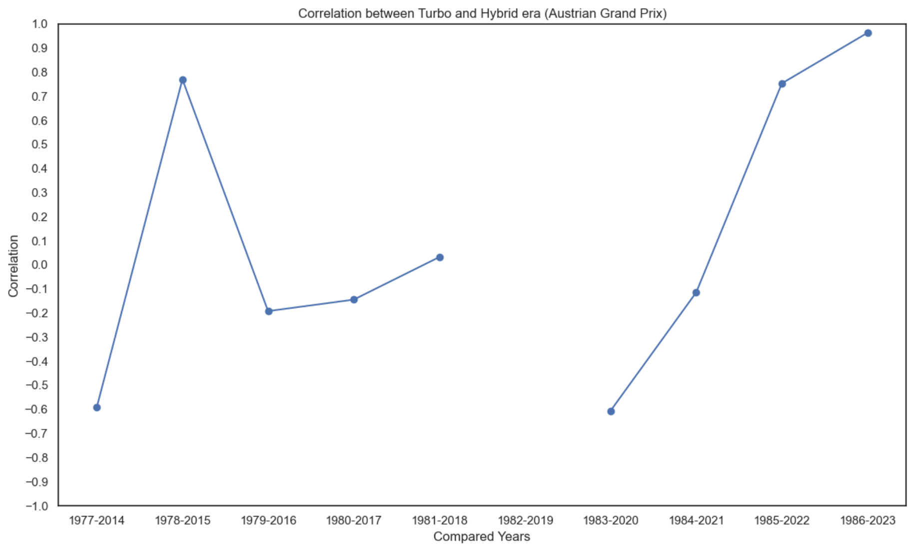

Figure 19: Correlation of the first ten years of the Turbo and Hybrid Era at the Austrian GP

The Austrian GP has a variety of correlation values ranging around -0.65 and up to 0.95. The correlation of the first year in Figure 19 has a value of -0.6, which means a negative relationship. Comparing Figure 3 and Figure 10, it can be seen that the seasons 1977 and 2014 do not share one failure type. Unlike the years 1978 and 2015, which has a correlation coefficient of around 0.75. They share engine and gearbox malfunctions, but also other different breakdowns, which explain the intensity of the value. The next three years have a weak relationship, which is the result of partly the same, but for the most part different failure types. In 2019 there were no early exits of drivers, thus no correlation between the year 1982 could be calculated. Coming to the maximum negative correlation happened between the years 1983 and 2020 with a value of -0.65. If we further analyse Figure 3 and Figure 10, the key differences are in two breakdown types. The first are the accidents, which were zero in 2020 and in 1983 the majority exited early due to accidents. Further difference is the tyre problems, which were high in 2020, but in 1983 there were zero cases. The year 1984 and 2021 had a weak correlation, which is reasoned by the different numbers of breakdowns. In 2021 only two drivers finished the race early due to accidents, but in 1984 there were around seven times more early exits, which were non-identical failure types. Coming to the years with a highly positive relationship. The year 1985 and 2022 has a correlation of around 0.75, which is explained by the shared failure types, accidents, and engines. The highest value is between the years 1986 and 2023. Upon closer inspection and comparison of Figure 3 and Figure 10, the following conclusions can be drawn. The year 2023 had the lowest breakdowns, except in 2019, which was only one engine failure and 1986 had several reasons for an early exit, but the majority was because of engine failures.

Belgian Grand Prix

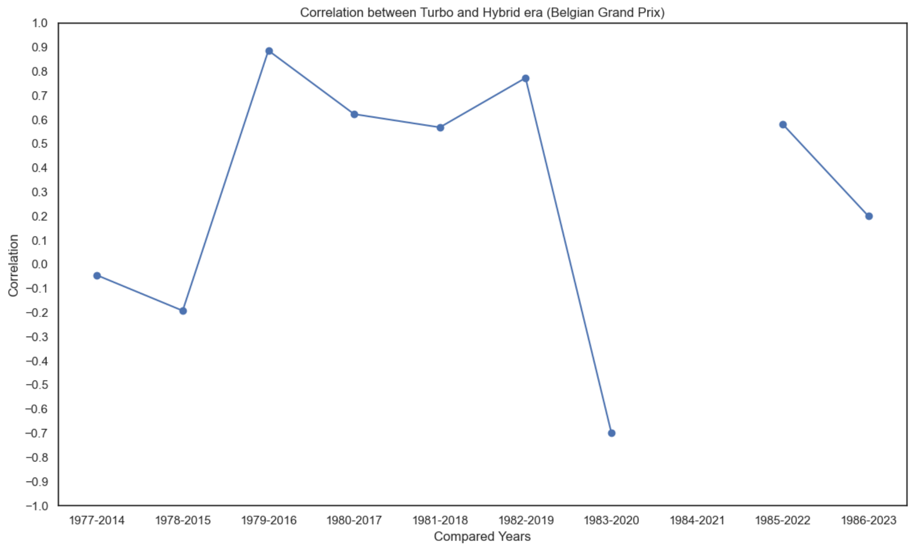

Figure 20: Correlation of the first ten years of the Turbo and Hybrid Era at the Belgian GP

Further, the Belgian GP was analysed for correlation between the turbo and hybrid era. The values of the relationships range from around -0.75, which represents a strong negative relation, up to around 0.9, a strong positive relation. The first two years have a low negative value. The key difference can be drawn from the figures Figure 4 and Figure 11 and it is that there were no accidents in 2014 and 2015. They only share engine malfunctions with their year-pair, thus the low relation. The correlations for the following four years were moderately strong, especially the year 1979 with 2016 valued at around 0.9. The key failure types for this strong relationship are all three presented in Figure 11, which are accident, gearbox, and tyre. 2017 and 2018 had around the same correlation with their pair, which was around 0.6. On the other hand, the pair 1982 with 2019 has a strong relation with a value of 0.75, because of the shared breakdown type, accident, and engine. It is followed by the highest negative correlation between the years 1983 and 2020. The value -0.7 is explained by the dissimilarity of the malfunctions. The Belgian GP in 2020 was the only one in the entire hybrid era, where one car had to end the race early due to chassis issues and another one with overheating issues. Additionally, the years only share one failure type, which is an accident. In 2021 the race was red-flagged early due to weather conditions, thus there were no accidents. The last two year-pairs have a positive correlation, which is explained by the shared breakdown, which is an accident.

British Grand Prix

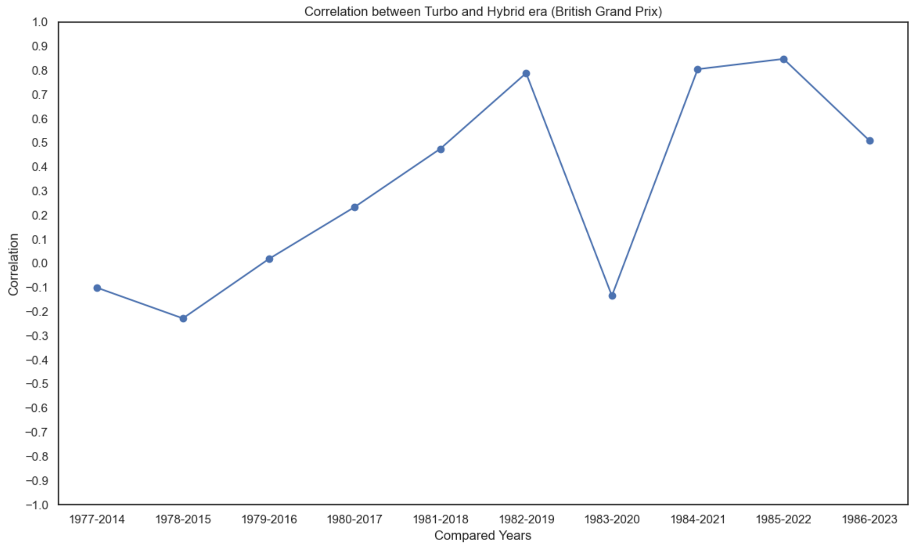

Figure 21: Correlation of the first ten years of the Turbo and Hybrid Era at the British GP

The British GP has predominantly only positive correlations. The value ranges from the lowest value of -0.25 to the highest value of 0.85. The first four years have a weak correlation, of which the first two are negative. By closer examination of the figures Figure 5 and Figure 12, the following conclusions can be drawn. The first five year-pairs have a weak correlation due to the dissimilarity of their pairs, where the number and frequency of the failure types vary. The pair 1982-2019 has a strong relation, due to 2019 only having one breakdown type, which is accident. As a result of zero accidents in 1983, the correlation with its pair is almost zero. The years 1984 and 1985 are dominated by the number of accidents, which is the basis for the correlation value. The difference between the pairs 1984-2021 and 1985-2022 is the extra breakdown types, fluid system and gearbox, that it shares with its pair, thus the higher correlation. Although the year 2023 shares all its categories with its pair it has a relation value of 0.5, which indicates that either one or both additional failure types are working against a positive correlation.

Canadian Grand Prix

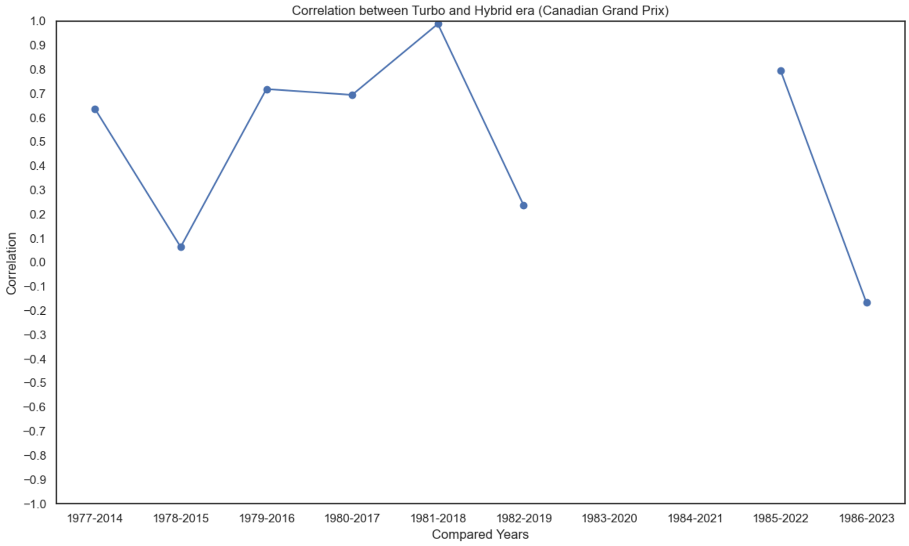

Figure 22: Correlation of the first ten years of the Turbo and Hybrid Era at the Canadian GP

The correlation value range of the Canadian GP is mainly positive and is between -0.2 and 0.99. By comparing the figures Figure 6 and Figure 13, the relation value of 0.65 between the years 1977 and 2014 can be explained by the several failure types they share. The value of around 0.05 at the pair 1978 and 2015 is due to 2015 only having one failure type, engine, which number is low in 1978. On the other hand, the year 2016 also only had one engine failure, but its pair, 1979, was dominated by engine malfunctions. The following year-pair has a slightly lower correlation, due to the breakdown type electrical, which did not appear in both years. Coming to the highest value is between the years 1981 and 2018, where the high correlation is explained by the high number of accidents in 1981. Between the years 1982 and 2019, the relationship is low due to the different distribution of breakdown types. In 2019 only two cars could not cross the finish line under the chequered flag, due to an accident and a suspension issue. On the other hand, the year 1982 had three predominant failure types, which were accident, engine, and fluid systems. Due to them only sharing one dominant failure type is the correlation value relatively low at 0.25. As mentioned under point 3.2, the Canadian GP was not on the F1 calendar in 2020 and 2021 due to the COVID-19 pandemic. Nevertheless, it returned in 2022 and its correlation with its pair is moderate. The high relation is explained by the shared categories, which are accident, engine, and gearbox, but it is not as high as in 2018 due to the distributions between these. Last the years 1986 and 2023 share a low correlation, which is reasoned by the different breakdowns, where they only share one, which took one of the lowest distribution parts in the year 1986.

Italian Grand Prix

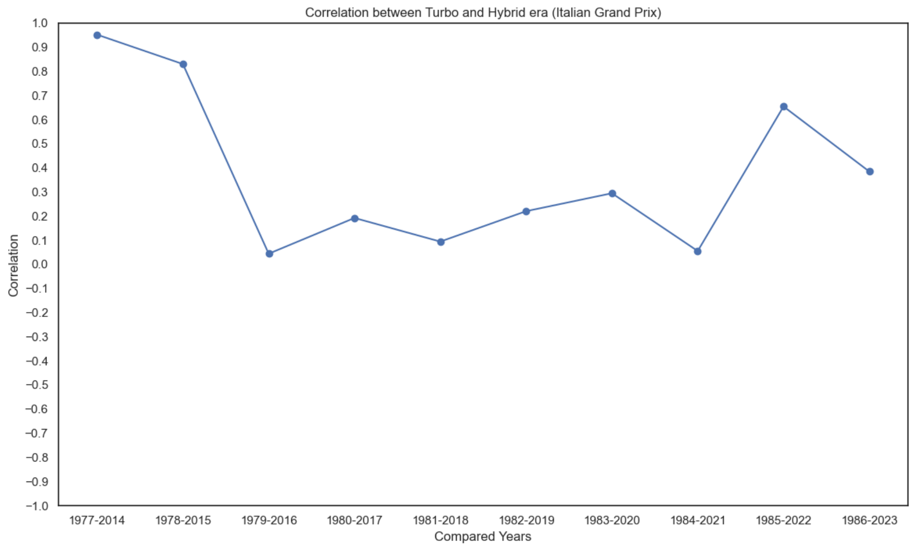

Figure 23: Correlation of the first ten years of the Turbo and Hybrid Era at the Italian GP

The Italian Grand Prix had only positive correlations throughout the years. The values range from around zero to 0.95, which represents a weak to strong relationship between the years. Unlike other selected circuits, the first two year-pairs have a very high correlation. By comparing the figures Figure 7 and Figure 14, the following conclusions can be drawn. The key similarities are the only two breakdown types, that happened in 2014, engine and accident, which is predominant in 1977, thus the high correlation. In 2015 only two cars could not finish the race early, due to accidents, which failure type again is dominant in 1978. The next six year-pairs have a weak relationship. It can be explained by the dissimilarity between these year-pairs. The pair 1979-2016 only share one of the many failure types and it is not the main breakdown type in both years. By closer examination of Figure 7, the years from 1980 until 1982 were dominated by tyre failures and accidents, which are the key differences between their pairs. Unlike any other year at the Italian GP, in 1983, electrical failures were the main reason for exiting the race early, which is the reason for the low correlation. The years 1984 and 2021, have a low value, which can be explained by the number of failure types they share. The pair only has two common breakdown types, but due to the different distributions, the connection between them is not significant. Coming to the last two year-pairs, 1985 and 2022 have a moderate correlation, which is reasoned by the similar malfunction types, which are engine and fluid systems. In 2022 only these two categories appeared with the same distribution, unlike 1985, where engine malfunctions were predominant followed by gearbox problems. The key dissimilarities between the last analysed year-pair are the different distributions of the failure types between the years, thus the weak relationship.

Monaco Grand Prix

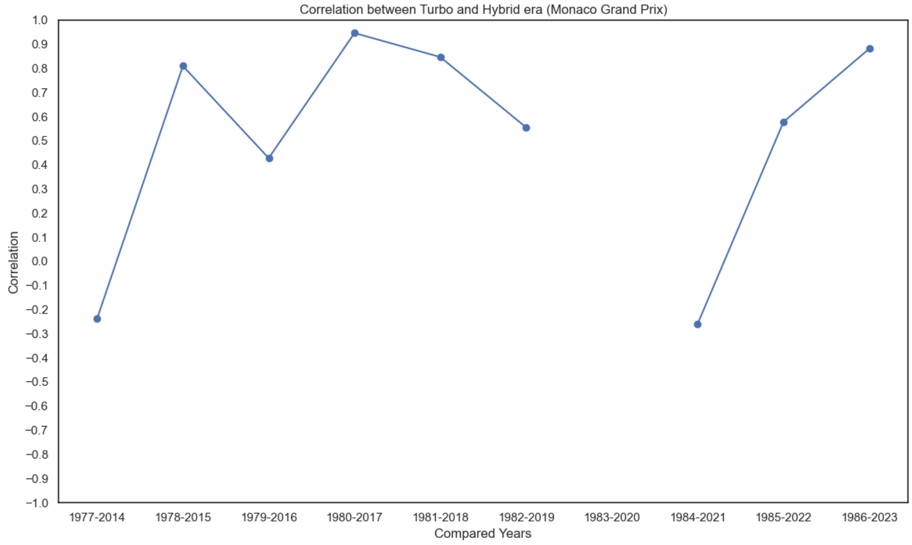

Figure 24: Correlation of the first ten years of the Turbo and Hybrid Era at the Monaco GP

The Monaco Grand Prix mainly only has positive correlations, where the values range from -0.25 to 0.95. The first pair has the second highest negative correlation, which can be explained by further comparing the figures Figure 8 and Figure 15. The key difference is the different distribution of the categories and that the only shared category is the engine. Followed by the year-pair 1978-2015, which has a strong connection. The failure types in 2015 were also present in 1978, in almost the same proportion, which explains the high value. Accidents were the only breakdown type in 2016, unlike 1979, where accidents were only on rank three, led by suspension and gearbox malfunctions, which explains the moderate correlation. Throughout the analysed ten years, the highest value was achieved between the years 1980 and 2017. After further comparisons and analysis of the figures Figure 8 and Figure 15, the following conclusions can be drawn. Both years were dominated by the failure type accident, followed by other single breakdowns, where they share another category, gearbox. Nevertheless, the year-pair 1981-2018 had a high correlation as well, which is explained by the common categories and their different ratios of them. In addition, there is a moderate correlation between the years 1982 and 2019, which is attributable to the only type of failure in 2019, namely accidents. Due to COVID-19, there was no Monaco GP in 2020, thus there is no value for the relationship between 1983 and 2020. The lowest correlation was achieved between the years 1984 and 2021, where the key differences lay in the number of failure types. In 2021 there were only two early exits, one due to an accident and another due to tyre malfunctions, unlike 1984, where twelve drivers, due to four different failure types, ended the race early. The last two year-pairs have a moderate or strong correlation due to the high ratio of accidents in their year-pair.

4. Comparison between the two Eras

In the following segments of the thesis, the selected eras were compared with two different models. The first model is called analysis of variance, and it is also known as ANOVA. The results of the ANOVA tests show if there is a statistically significant difference in and between the eras. The second model is called the Shapiro-Wilk Test, which analyses the groups of the eras for its distribution. If the resulting p-values are below the significance, which is 0.05, then the group has a normal distribution within the era.

4.1. Comparison with the ANOVA Model

First, the results of the ANOVA model within the eras, for the whole era will be examined and after for the selected circuits only. The reason behind the selection of ANOVA and t-Test is to determine whether there are statistically significant differences between the mean values of the failure groups in and between the eras. The first era, that was analysed for its variance is the Turbo era.

ANOVA for Turbo Era

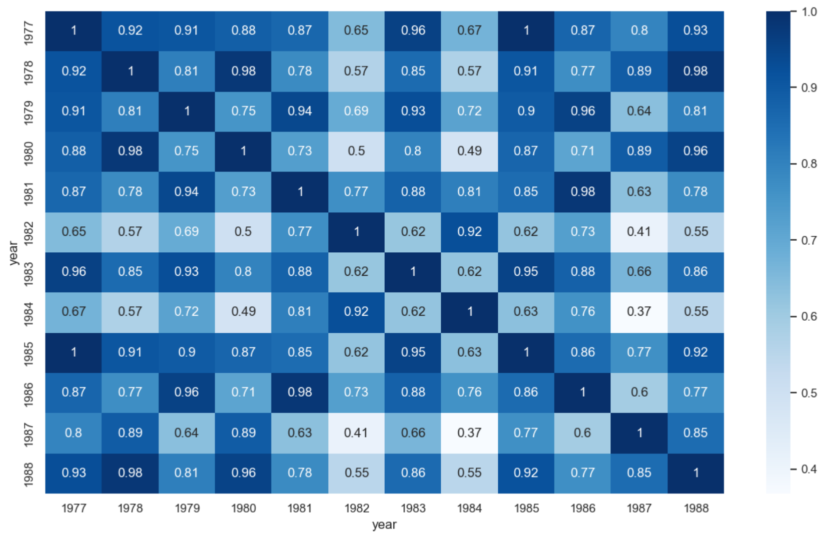

Figure 25: ANOVA Matrix of the Turbo Era

Figure 25 is a matrix of the years in the turbo era. The values between the years are the so-called p-values, which we get from the ANOVA tests between them.
Upon closer inspection of Figure 25, the following conclusions can be drawn. The lowest value in the matrix is 0.37, which is not even close to our significance level of 0.05. Therefore, it indicates that there is no statistically significant difference between the years in the turbo era.

Austrian Grand Prix

Figure 26: ANOVA Analysis in the Turbo Era for the Austrian Grand Prix

Next, the ANOVA analysis was conducted on only the data from the Austrian GP. After closer examination of Figure 26, the following information can be concluded. The lowest value is 0.0052, which is a false value because in 1988 there was no race in the Austrian Grand Prix. Due to this, the correct lowest value is 0.27, which reveals, that there was no significant difference between the years statistically.

Belgian Grand Prix

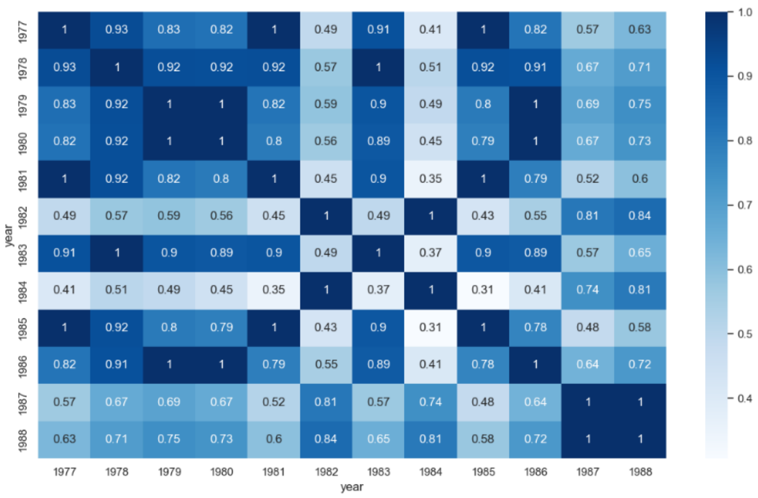

Figure 27: ANOVA Analysis in the Turbo Era for the Belgian Grand Prix

The ANOVA analysis for the Belgian GP was no different than the other two before, which can be seen by looking at Figure 27. The lowest value is 0.31 between the years 1984 and 1985, which is six times the significance level, which means, that there was no significant difference between the years on the Belgian GP in the turbo era.

British Grand Prix

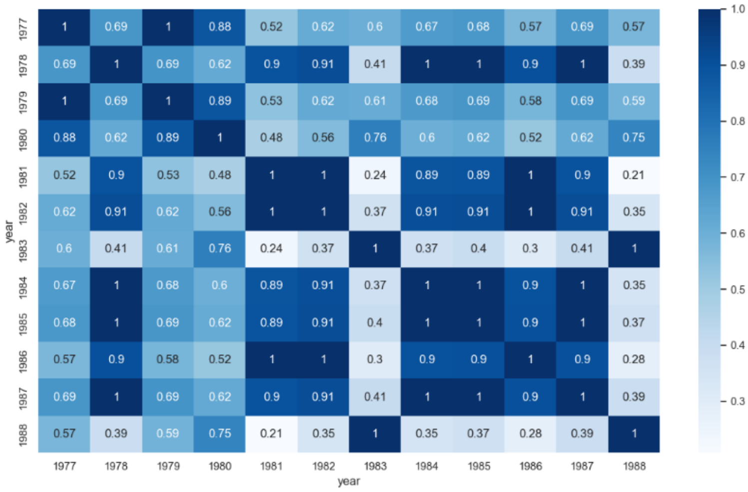

Figure 28: ANOVA Analysis in the Turbo Era for the Belgian Grand Prix

The British GP is remarkably similar to the other tracks. By taking a closer look at Figure 28, it can be seen that the lowest value, which is between the years 1981 and 1988, is 0.21. This value is too high for our significance level, which indicates that there were no statistically significant differences between the years at the British Grand Prix.

Canadian Grand Prix

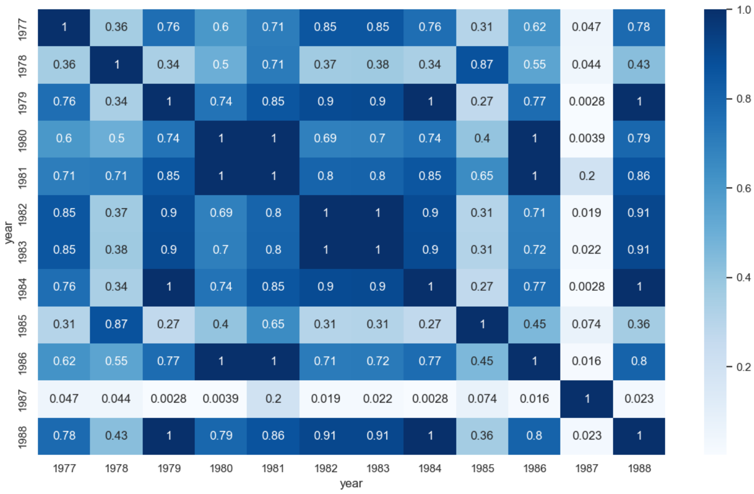

Figure 29: ANOVA Analysis in the Turbo Era for the Canadian Grand Prix

The fourth GP that was analysed is the Canadian GP. By taking a look at Figure 29, it can be seen that the year 1987 has a lot of low values. This is due to the fact, that the Canadian GP was not held due to a sponsorship dispute in 1987. Therefore, the correct lowest value can be found twice in the matrix, and it is between 1979 and 1985 and between 1984 and 1985, valued at 0.27. The value is over our confidence limit, as a result, we can say that there is no statistically significant difference between the years.

Italian Grand Prix

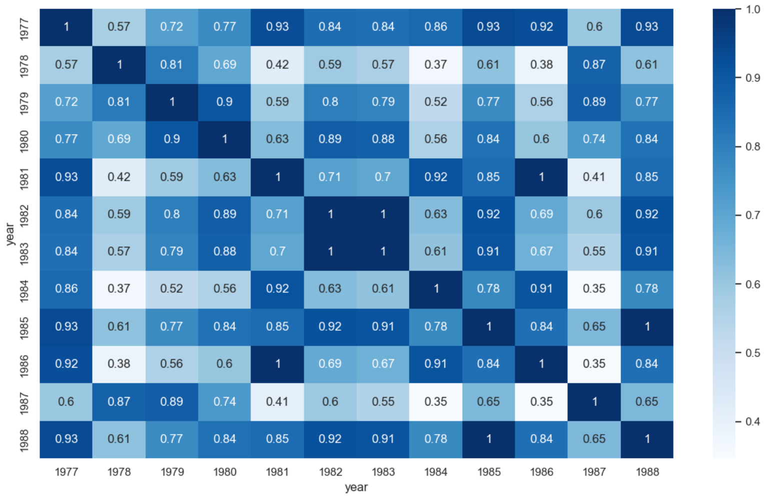

Figure 30: ANOVA Analysis in the Turbo Era for the Italian Grand Prix

Next, the Italian Grand Prix was analysed and the matrix in Figure 30 only has some low values and the lowest occurs twice. It can be found between the years 1984 and 1987 and between 1986 and 1987, valued at 0.35. The value is way above our significance level, as a result, it can be said that there was no significant dissimilarity in the turbo era at the Italian GP.

Monaco Grand Prix

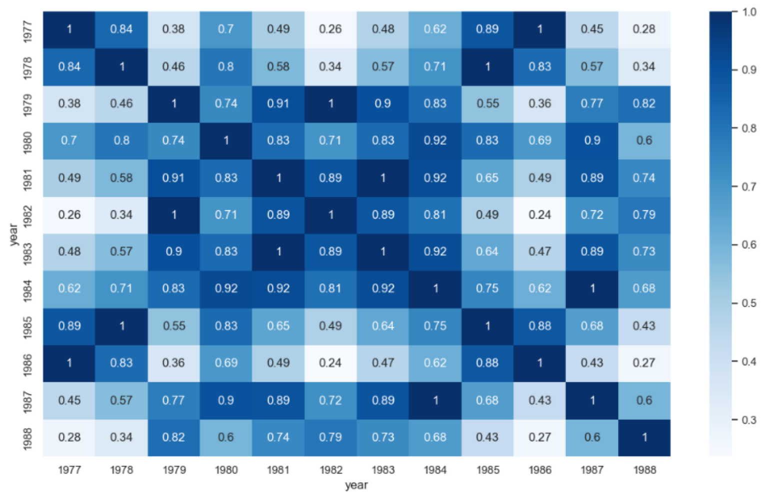

Figure 31: ANOVA Analysis in the Turbo Era for the Monaco Grand Prix

At last, the Monaco GP was analysed. Figure 31 shows that the lowest value can be found between the years 1982 and 1986, valued at 0.24. This p-value exceeds our significance limit therefore, it can be said that there was no significant difference between the years of the Monaco Grand Prix.

ANOVA for Hybrid Era

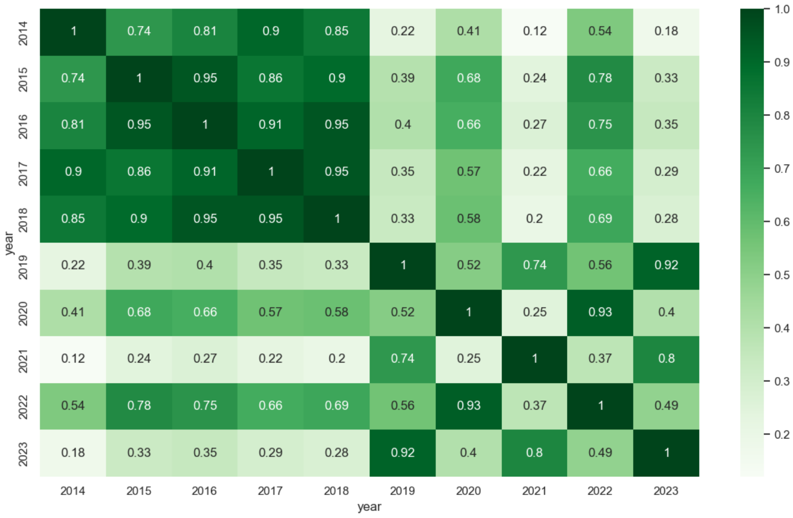

Figure 32: ANOVA Matrix of the Hybrid Era

The ANOVA Analysis for the Hybrid Era in Figure 32 shows, that the first five years were similar to each other. Similarly, the last five years had a similar variance, which can be seen in the figure above. The highest difference and the lowest p-value can be found between the years 2014 and 2021, valued at 0.12. Although this value is still above the significance level, it can be said that there was a minor change from 2019, but not enough.

Austrian Grand Prix

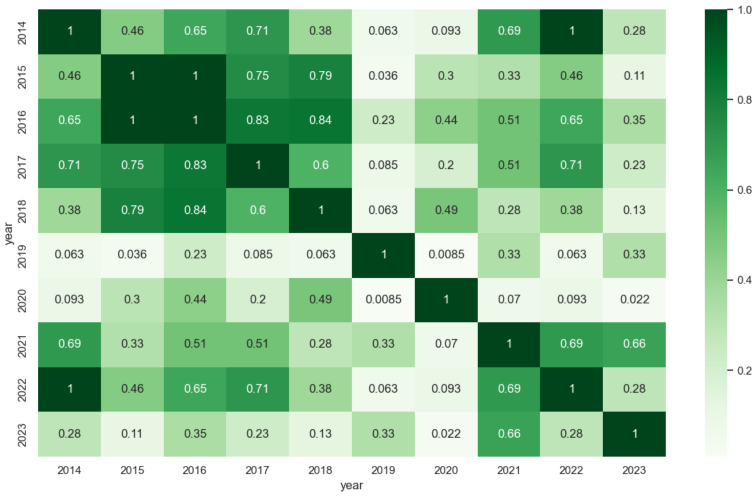

Figure 33: ANOVA Analysis in the Hybrid Era for the Austrian Grand Prix

In Figure 33, the ANOVA Analysis for the Austrian Grand Prix is presented. From the figure, the lowest value is p=0.0085, which is well below our significance level, and it occurred between the years 2019 and 2020. By further analysis of Figure 10, it can be seen that the race in 2019 was clean because there were no breakdowns, unlike in 2020 where almost ten cars exited the race early, which is the reason for the low p-value between the years. There are two more year-pairs, where the value was well below the limit, which were 2015-2019 and 2020-2023. Again, the reasons were already presented above, which is that 2019 had the lowest and 2020 had the highest number of breakdowns.

Belgian Grand Prix

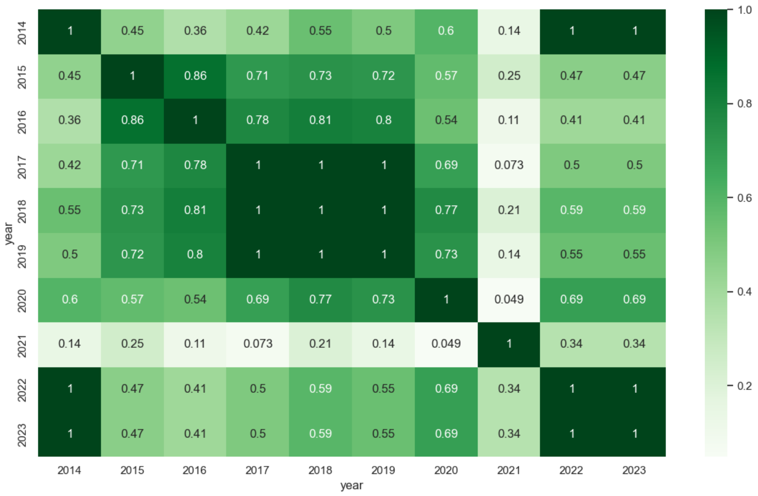

Figure 34: ANOVA Analysis in the Hybrid Era for the Belgian Grand Prix

The ANOVA analysis for the Belgian Grand Prix in the hybrid era was similar to the turbo era, except for one year. The values of 2021 are significantly lower than the others in the matrix of Figure 34. This is due to the fact that the race in 2021 was red-flagged after one lap due to weather conditions, which is why there were no breakdowns in Figure 11 for that year. Although there were no failures in 2021, the lowest p-value in Figure 34 is p=0.049, which happened between 2020 and 2021, which is barely under our significance limit.

British Grand Prix

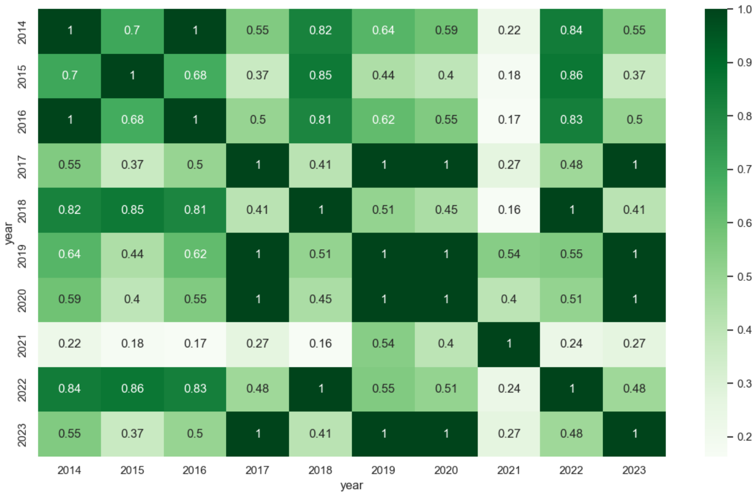

Figure 35: ANOVA Analysis in the Hybrid Era for the British Grand Prix

The British Grand Prix in the hybrid era was remarkably similar overall and this is also reasoned by Figure 35. The only year that has overall lower values is 2021 and it is due to the fact that there was only one accident in 2021 in Silverstone. Thus, the lowest value in Figure 35 is between 2018 and 2021, valued at p=0.16, which means that the races on the British GP in the hybrid era were similar.

Canadian Grand Prix

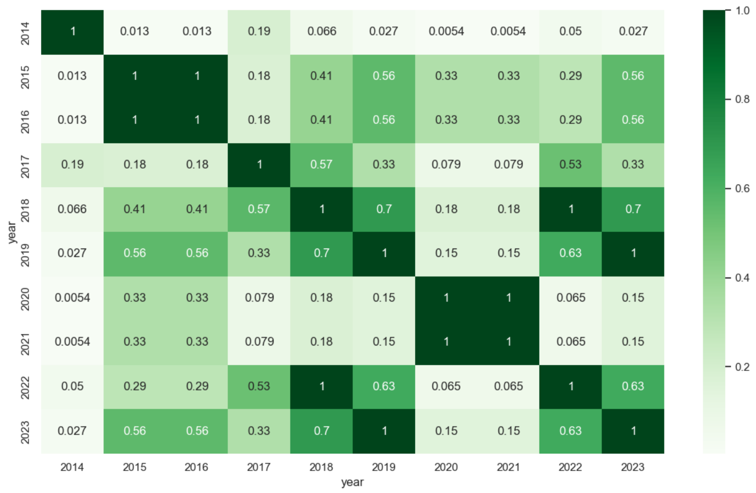

Figure 36: ANOVA Analysis in the Hybrid Era for the Canadian Grand Prix

The Canadian Grand Prix had overall low breakdown counts throughout the years in the hybrid era, except in 2014, which also can be seen in Figure 13. Similarly, the ANOVA p-values were exceptionally low in 2014, due to the high dissimilarity in the breakdown amounts. The lowest value can be found between the years 2014-2020 and 2014-2021, but these are false values because the races in 2020 and 2021 were not held due to COVID-19. Thus, the correct lowest value can be found between the years 2014-2015 and 2014-2016, valued at p=0.013. Several other year-pairs that have a value below the limit, for instance, 2014-2019, 2014-2022 and 2014-2023. Due to the values being under our significance limit, it can be said that there were dissimilarities between these years.

Italian Grand Prix

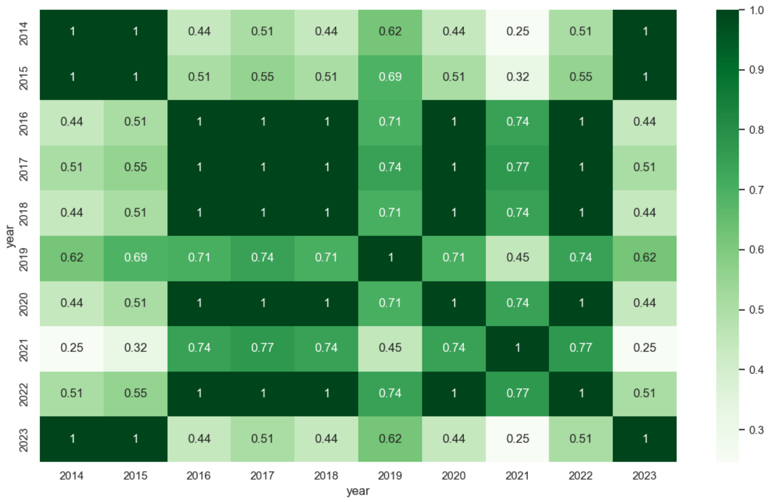

Figure 37: ANOVA Analysis in the Hybrid Era for the Italian Grand Prix

The Italian Grand Prix was very similar throughout the years in the hybrid era, which also can be seen in Figure 14 and Figure 37. The lowest value in the matrix of Figure 37 can be found twice and it is between the years 2014 and 2021 and between 2021 and 2023 with a value of p=0.25. Thus, the value being well above our significance level, it can be said, that there was no statistically significant difference between the years of the Italian GP in the hybrid era.

Monaco Grand Prix

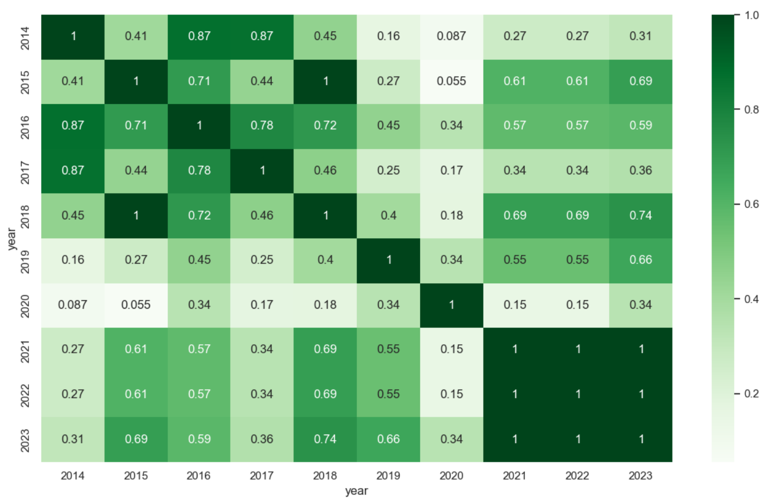

Figure 38: ANOVA Analysis in the Hybrid Era for the Monaco Grand Prix

The ANOVA analysis of the Monaco Grand Prix in the hybrid era is remarkably similar overall. The only year with overall lower values is 2020, but again these values are false, due to the fact that in 2020 the race in Monaco was not held, because of COVID-19. Thus, the correct lowest value can be found between 2014 and 2019, valued at p=0.16. The value is above the significance limit for our dissimilarity check, as a result, it can be said, that the races of the Monaco GP in the hybrid era were statistically similar.

Fisher's t-Test between the Eras

After the ANOVA analyses, a t-Test was conducted between the eras. The data for the eras were built in a dataframe, which is a table alike, where the only column was the mean of the amounts over the years and the y-axis was the name of the breakdown type. This data preparation segment was done for both eras. The t-Test returns three different results. One result is the statistics, which is not important in this case. The second result is the p-value, which is one of the interesting values to look at and the last result is the degrees of freedom, which is another interesting product.

The calculations of the t-Test presented the following results. The value for statistics is around $t(26)=2.2756$, for the p-value we got $p=0.0314$. Since the p-value is below the 0.05 significance level, this means that there is a statistically significant difference between the two periods, which can be explained by the changes in regulations and standardisation of technologies.

4.2. Comparison with Shapiro-Wilk Test

In the next segment of the thesis, the results of the Shapiro-Wilk test will be presented and discussed. The Shapiro-Wilk test is usually used to analyse the distribution of the given data, in this case, the distribution of the failure types in both eras. If the resulting p-value is below the usual significance level of 0.05, then it means that the failure type in that era has a normal distribution.

Breakdown Types	p-values (Turbo)	p-values (Hybrid)
Accident	0,47216025	0,15831615
Chassis	**0,00053365**	**0,00004713**
Disqualified	**0,00012539**	**0,00000010**
Driver-related	**0,00001251**	1,00000000
Electrical	0,24492961	**0,00127995**
Engine	0,33070448	0,51401591
Fluid Systems	0,25893679	0,05622289
Gearbox	**0,04408208**	0,08687962
Overheating	**0,04141548**	**0,00000467**
Powertrain	**0,00162346**	**0,00000467**
Suspension	0,72537690	**0,00189488**
Turbo	**0,02246206**	**0,00000010**
Tyre	0,05482976	0,24801846

Table 1: Shapiro-Wilk Test from both Era

In Table 1 the result from the Shapiro-Wilk Test is presented. Several breakdown types are over the limit in one and under the limit in the other era. For instance, Driver-related and Gearbox problems had a normal distribution in the turbo era, but not in the hybrid era. Another example is electrical and suspension failures. Both categories were over the limit in the turbo era, but in the hybrid era, they had a normal distribution. The reason for these changes could be regulation changes or even innovations in different technologies. Something worth noting is that the two predominant failure types, Accident and Engine, both were over the limit in each era. Several breakdown types, such as Chassis, Disqualified, Overheating, Powertrain and Turbo have a normal distribution in both eras.

It is important to note that the validity of an ANOVA and a t-test requires the assumption of a normal distribution of the data. For those breakdown types that have a significant value in both eras, meaning the p-value being under the significance level, the results can be interpreted. For the other breakdown types, there could be a different effect that requires a critical and more precise review.

5. Explaining Methods

The analysis for this thesis was written in Python. Python is a programming language, which is intuitive and easy to learn. It is also supported with several packages, which provide some extra functionalities. The code is composed of two files. One contains the data collection and data cleansing as a function and the other is the main file, where the data is read, analysed, and visualized.

F1data.py

This is the first file, which, as previously mentioned, is for gathering the data through a Python package from an external Application Programming Interface (API). The API is public and accessible at ergast.com/mrd and the Python package which acts as a wrapper for this endpoint is accessible at github.com/weiranyu/pyErgast.

The f1data module, which was written by the author of this thesis, has only one function, which accepts a start and end year as a number. Then the data will be read from race to race throughout the years and added to a such called dataframe. A dataframe is a two-dimensional tabular data, which has differently labelled columns and rows. For instance, here the columns are the name of the constructor, the status of the car at the end of the race, the date of the GP, the circuit where the race was, then the year and the race number.

After the data had been collected for the selected period, then statuses like “Did not qualify”, “Did not prequalify”, “Retired”, “Withdrew”, “Excluded”, “Mechanical” and “Not Classified” were dropped, because it is not a specific breakdown which occurs at the race. The status “Mechanical” was dropped due to the misclassifications. After the impractical data had been dropped, a dictionary was created for the grouping of the data. Dictionaries in Python are collections of key-value pairs, where the key is unique, but it can have many pairs. The groups were already presented under point 1.3. Further, all status values which were similar to “+X Laps”, where the X represents a number, were changed to the status “Finished”. After all the values are grouped based on the groups that were defined in the dictionary.
The last step of the function is to return the data as a dataframe.

Main.py

This is the code, where the analysis and visualization of the data take place. The script can be started with different parameters. The parameters are “u” for updating the data, “p” for only plotting the statuses of the selected year range “a” for analysing and visualizing the correlations between the saved data and lastly “t” for all the tests, including ANOVA, T-Test and Shapiro-Wilk Test. All variations of parameters are accepted. If parameter “a” was selected, but there is no data to analyse then it will exit the code and give a corresponding error message, unlike at parameter “p”, where nothing would happen, since the data is only processed sequentially in a loop, which directly reads from the folder.

As mentioned the parameter ”u” is to update or gather the data. Here we call our imported function from the f1data python script, and we save the data in a folder for caching purposes. This will take the most time when starting the code since it has to loop through all the races of all the years.

The parameter “p” is for visualizing the distributions of the failure types of the selected data ranges. After visualizing the breakdown types of the data, it saves the plot and at the end of it saves the same plot for each circuit separately.

The analysis for correlation in data only happens if the parameter “a” is given. At the beginning of the analysis segment, failure types like “Finished” and “Not classified” are dropped, since they are irrelevant. After, the correlation between the years in the eras is calculated, followed by the correlation between the eras. Finally, both data are grouped by the circuits and the correlation between the eras on the selected circuits is calculated.

Last the parameter “t” is, as already mentioned, for the ANOVA, T-Test and Shapiro-Wilk Test. It happens sequentially, but first, we read the data and remove rows that contain the failure type “Finished” and “Not classified”, since it is not needed in this case. The ANOVA test is conducted first, which gives us the era values and then the values for each circuit in each era. Followed by the T-Test which is a simple code segment to get a better understanding if there is a statistically significant difference between the eras. Lastly, we form the data, so we can conduct the Shapiro-Wilk test and since we cannot plot it logically, we save the data as a file, which can be used in Excel or other programs.

6. Conclusion

In this segment the research question will be answered by the found information in this thesis.

Which failure types were predominant in these time series?

The two eras share only two different predominant failure types. One of them is the category “accidents”, which was the most common reason for an early exit in the hybrid era and the second most common in the turbo era. The second failure type is the engine malfunctions, which was a usual breakdown type in both eras, but especially in the turbo era. Nonetheless, another conclusion can be drawn from the figures, that the reliability of the cars got much better throughout the years, since the maximum car breakdowns in hybrid era was around 100 in 2017 and the lowest amount in the turbo era was around 165 failures, which is a significant difference. There are three more breakdown types that was inconsistent in one of the eras, but it plagued some seasons. These are the tyre, fluid system, and gearbox failures. Tyre failures were more common in the hybrid era, but it also made some appearances in the turbo era, especially in the years 1979, 1980 and 1986. Fluid system however was more common in the turbo era, but it showed sign of problems in the hybrid era, mainly in the years 2017 and 2022. Additionally in the turbo era, gearbox failures were another challenge, unlike in the hybrid era, where it only plagued the first four seasons. Speaking of turbo era, it had two breakdown types, that were common that time, but not in the hybrid era, which were the turbo and suspension malfunctions. Suspension issues were main obstacles in the late 1970s and the early 1980s, but when the turbo era reached its prime, the turbo failures spiked.

To what extent is there a correlation between the two eras?

The correlation between the two eras is mostly a strong positive correlation. The highest was between the year first year of each era with around 0.95. It shows that the sport after new innovations behaves the same. The next five year-pairs until 1982-2019 has still a strong positive correlation with the lowest value 0.85 between 1980 and 2017. The average value in those five year is around 0.9, which indicates, that the evolution after a new innovation is very alike. The correlations after the five years, where the turbo era had its peak fell down to around 0.65, which is only a moderate correlation. This can be explained by the high turbo problems that every team faced, which was a predominant failure type in 1983. The following year the correlation value got lower to around 0.6, due to the high disqualification number, which again could be reasoned by turbo changes, that were out of the guidelines. Between the years 1985 and 2022 the correlation value got higher to around 0.75. The main difference between the year-pairs 1984-2021 and

1985-2022, is the high disqualification number in 1984 compared to 1985 and the high fluid system malfunctions in 2022 compared to 2021. Another difference is that in 2022 there were no tyre problems, unlike 2021 where tyre failure was the second most dominant breakdown type. The correlation between the last analysed years, 1986 and 2023 has the lowest value in the selected correlation period with a value around 0.55. This is due to the different distributions of failure types between the years and also due to the high turbo failures in 1986.

Are there any correlations or patterns between specific tracks and failure types?

The selected circuits for this analysis were the Austria, Belgian, British, Canadian, Italian and Monaco Grand Prix. At the Red Bull Ring the number of overheating issues and engine malfunctions is frequent in both eras, which could be a specific issue for this track. Engine problems were predominant in the turbo era, however it still shows up frequently in the hybrid era. Coming to the second circuit, Spa-Francorchamps. The Belgian Grand Prix was always famous for the Eau Rouge, a corner, where F1 drivers can reach up to 300 km/h. A loss of control in this corner could result into a heavy crash. Thus, the circuit of Spa has a frequent accident count in both eras, which can be an underlying connection. The third track that was analysed, was the Circuit of Silverstone, the British Grand Prix. It has two failure types that were mainly frequent in both eras, engine issues, and accidents. There were only two years in the analysed twenty-two, where there were no accidents. Additionally, although engines got standardised in the hybrid era through strict rulings, several teams still struggle with engine problems on this track, which could be an underlying challenge of the circuit. The fourth track is the Canadian Grand Prix also known as Circuit Gilles Villeneuve, which had an incredibly low count of failures in the hybrid era, which shows that the track is well built and safe for drivers. The most frequent breakdown type in both eras were the engine failures, which led at least one driver almost every year to an early exit of the race. Unlike other circuits, the Grand Prix of Italy, a.k.a. Circuit of Monza, has a different failure type, which is frequent in both eras, which is tyre issues. In the 1980s' and the hybrid era teams struggled with the tyres at Monza, which also forced some drivers to finish the race early. Next to tyre issues, constructors faced another challenge, which were engine problems. Every analysed year except two was plagued by at least one engine breakdown. Coming to the last track, the Grand Prix of Monaco. Since it is a street circuit with narrow streets, the number of accidents in both eras is predominant and frequent.

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