Introduction

Formula One, also known as F1, is a prestigious international racing competition that features “the highest level of single-seat, open-wheel and open-cockpit professional” racecars (Tutorials Point, 2020). In 2014, the Formula One competition saw a drastic change to its rules that would alter not only the trajectory of the innovation within the competition and the standings of its competing teams, but also the direction of the automotive industry as a whole. Instead of running a “normally aspirated, 2.4-liter V8 engine”, teams would now run “1.6-liter turbocharged V6 power units integrated with complex, hybrid engine recovery systems”, solidifying Formula One’s decision to transition to more environmentally friendly technology (Manishin, 2018). This decision was met with a tremendous amount of backlash from both fans and critics alike. The following season’s testing and races featured “slow, unreliable and uncharacteristically quiet cars” that disappointed viewers all around the world (Manishin, 2018). Even with all the criticism, the Federation Internationale de l’Automobile (FIA), Formula One’s governing organization, stood by their decision for their choice was made not only with regards to the competition, but with consideration for the automotive market and its predicted course to move away from fully gas-powered engines and towards other methods of energy generation.

Recently, Honda, one of F1’s four power unit suppliers and an extremely important player in Formula One’s hybrid engine development, announced that it will be leaving the competition after the 2021 season. Their stated reason for leaving is that currently the monetary investment needed to continue their participation in F1 does not allow them to achieve their production business goal of becoming carbon neutral by 2050. This move by Honda to leave F1 brings into question the changes that F1 has made to make the competition more relevant to the production world and market desires, especially in terms of promoting hybrid engine development. Is it still worth it for other production company-backed teams to continue participating in the competition? If so, what are the tangible benefits of team participation? In this paper, I analyze the role of F1 in road car hybrid engine development and how knowledge transfer occurs between F1 and the road car industry to inform teams of the reasons continued participation is necessary and how teams can maximize their gains from this participation. Specifically, I focus on how this knowledge transfer occurs in Mercedes, the team that has been dominating F1's hybrid era. To do this analysis, I use Geels' Multi-Level Perspective (MLP) framework. From this research, I illustrate the importance of continued team participation in F1 by providing a better understanding of F1's crucial role in road car hybrid engine development based on F1's relevance to the automotive industry, F1's fast-paced development environment that encourages quicker technological innovation, and integrated company infrastructure between racing and production that facilitates knowledge transfer between F1 and the production industry. I also investigate how the MLP framework can best be applied to transitions in technology through the scope of F1's transition to hybrid engine development.

Part I: Changing the Rules of the Game

Formula One Enters a New Era

As mentioned in the introduction, Formula One is a professional racing competition for open-wheel, open-cockpit racecars (Tutorials Point, 2020). The competition is made up of 10 teams or constructors that race two cars each. As stated by Eurosport, "the ultimate aim in F1 is championship success" which is achieved by developing the fastest, most powerful competition car (Eurosport, 2019). Within F1, there are two annual championship awards: the Drivers' Championship Award and the Constructors' Championship Award (Tutorials Point, 2020). For the Drivers' Championship Award, the participating drivers compete with each other to accumulate the most points by driving faster and finishing higher than their competitors (Tutorials Point, 2020). While the drivers do not earn any prize money for their standing in the Driver's Championship, performing well allows them to negotiate with their teams for better contracts and higher salaries. The Constructors' Championship, on the other hand, is a competition between the 10 teams and does have prize money associated with it. Much like the Driver's Championship, teams earn points based on how well their two cars perform in each race. The better a team does in the Constructors' Championship, the more prize money that team receives. These funds, along with money from sponsors, is what fuels the teams' research and development and allows these teams to continue to compete.

Formula One's automotive technology and development is dictated by a set of rules determined by the FIA (Tutorials Point, 2020). According to these rules, teams are required to design and build their own chassis but are allowed to purchase certain components including the power unit from other suppliers (Tutorials Point, 2020). These suppliers can be outside companies or other teams. Because there are so many rules regarding power unit design along with the need for such high performance from these power units in order to be competitive, there are currently only four Formula One power unit developers: Mercedes, Honda, Ferrari, and Renault (Mitchell, 2020b).

Figure 1. Formula One Hybrid Power Unit. As of 2014, Formula One racecars are powered by 1.6-liter turbocharged V6 hybrid power units with integrated energy recover units. This figure is an example of an F1 hybrid power unit with a Motor Generator Unit – Heat (MGU-H) and a Motor Generator Unit – Kinetic (MGU-K) as the methods of energy recovery. (Cassey, 2015)

In 2014, Formula One announced "the most significant rule changes in F1 history": racecars would now be powered by hybrid power units equipped with different forms of energy recovery units (shown in Figure 1) instead of the previously used normally aspirated engines (Manishin, 2018). The goal of this decision by the FIA was to "[give] the sport a much cleaner and greener image more relevant to developing road car technologies" (Manishin, 2018). Other associated rules changes included the lowering of the maximum amount of fuel each car could hold and the maximum fuel flow rate the power units could run in order to encourage power unit suppliers to develop greener, more fuel-efficient power units (Formula 1, 2020a). Since then, the FIA has continued to adapt their rules to direct F1 hybrid development towards improving the efficiency of this technology by decreasing the maximum fuel capacity and fuel flow for F1 power units, increasing the number of allowable energy recovery units, and increasing the percentage of required biofuel use with each season (Formula 1, 2020a).

One of the major players in Formula One's hybrid era has been Mercedes. Since the beginning of this era, Mercedes has dominated the competition, winning every Constructor's Championship since 2015 (Manishin, 2018). Behind these victories is a large, multi-million-dollar organization made up of many engineering teams. One of the most unique aspects of Mercedes' team structure is that their Formula One power unit development team based in Brixworth "is a part of the mainstream [Mercedes] R&D organization" (Youson, 2015, p. 39). At Mercedes, the power unit engineers on the F1 side and the production side frequently communicate and work together to provide assistance and improve one another's design.

Disruption to Formula One's Hybrid Power Unit Development

While the concept of hybrid engines has been around since the early 1900s, the technology was not widely adopted due to their complexity and impracticality. Recently, hybrid vehicles have seen a boom in popularity amongst consumers. As concern for the environment grows, more and more car buyers are pushing for lower emissions and greater efficiency (Hyundai, 2018). According to the Society of Motor Manufacturers and Traders, "the sale of plug-in hybrids were up 72 percent in May 2018" (InfiniGEEK, 2018). This increase in market demand for hybrid vehicles is being seen not only in the United States, but across the globe as countries become more stringent with their emission regulation standards (Mordor Intelligence, 2021). In response to this increasing demand for eco-friendly vehicles, companies are directing more of their resources to research on greener automotive technology including the development of hybrid engines.

In 2015, Honda rejoined the ranks of automotive companies in Formula One, this time as a power unit supplier instead of a constructor. As stated by Honda's CEO in 2015 Takanobu Ito, "Honda has a long history of advancing [their] technologies and nurturing [their] people by participating in the world's most prestigious automobile racing series" (Lamm, 2013). With F1's new environmentally focused regulation changes, Honda saw benefit to coming back to the competition as it would "inspire even greater development of [their] own advanced technologies" (Lamm, 2013).

Although Honda struggled for their first couple of years back in Formula One, in the 2019 season, they scored four wins with their constructor partner Red Bull Racing (Gitlin, 2020). In 2020, however, Honda announced that they would be officially leaving the sport again after the 2021 season. There are currently many speculations as to the reasons behind Honda's decision, but they all seem to center around the same thing: money. According to the statement made by Honda's current President and CEO Takahiro Hachigo, Honda is leaving F1 in order to focus more of its resources on "the realization of carbon neutrality by 2050" and "electrifying two-thirds of [Honda's] global automobile unit sales in 2030" (Gitlin, 2020). Since Honda is just a power unit supplier and does not have a team competing in F1, Honda does not receive any prize money and has been relying solely on power unit sales to fund over £300 million (approximately $413 million) worth of development a year (Mitchell, 2020b). While Honda's situation is different from the other current F1 power unit suppliers, this announcement has increased the skepticism surrounding F1's technological relevancy. Best stated by Scott Mitchell for The Race, "Honda says its exit is about needing relevant, future-defining technology, so why is it abandoning an existing project with that exact development scope" (Mitchell, 2020a)? While it is known that Formula One has a strong relationship with the automotive industry, it is not well understood how exactly the two are connected or how they benefit from each other. Further analysis of the relationship between Formula One and hybrid technology in the automotive industry illuminates the importance of F1 participation to accelerating hybrid production development and informs teams of the benefits of their participation.

Part II: Examining the New "Hybrid Era" Through a Multi-Level Perspective

Strategy for Analyzing Transitions

This section utilizes the Multi-Level Perspective (MLP) framework from Geels (2011) to illustrate how Formula One facilitates the development of hybrid road car technology. The MLP framework is often used to analyze big transitions and shifts in technology by "focus[ing] in more detail on the various [involved] groups, their strategies, resources, beliefs and interactions" (Geels, 2011, p. 26). Specifically, the MLP framework is best for analyzing transitions towards sustainability because they are "goal-oriented" rather than "emergent" or related to new technologies and are influenced by many decisions from a variety of different groups (Geels, 2011, p. 25). As a result, this framework can be easily applied to the transition of F1 to hybrid technology because this transition was purposeful and involved many different actors.

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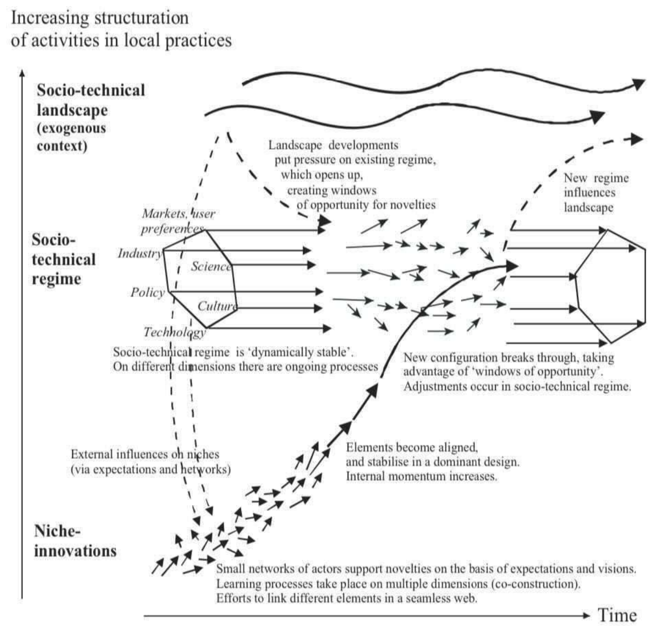

Fig. 2. Multi-level perspective on transitions.

Adapted from Geels (2002:1263).

Figure 2. A Visualization of Geel's Multi-Level Perspective Framework. Geels' Multi-Level Perspective framework is made up of three different levels – socio-technical landscape, socio-technical regime, and niche - shown on the left side of the diagram in order of increasing structure from bottom to top. The passing of time is shown from left to right as indicated by the arrow at the bottom of the diagram. This figure illustrates the influence certain actions taken at one level have on technology, policy, and society both within that level and across to other levels. (Geels, 2011, p. 28)

The MLP framework is made up of three distinct levels: the socio-technical landscape, the socio-technical regime, and the niche. As shown in Figure 2 on the left-hand side, these levels display varying amounts of structure. The socio-technical landscape listed closest to the top of Figure 2 is the most expansive and stable level of the three. It is defined as "an external environment that influences interactions between niche(s) and regime" (Geels, 2011, p. 27). Social-technical regimes are the next level down and form the "'deep structure' that accounts for the stability of an existing socio-technical system" (Geels, 2011, p. 27). Lastly, there are the niches which are the lowest, most specific level in the MLP framework. Niches are "'protected spaces' such as R&D laboratories" and are often where individual action and technological innovation occurs (Geels, 2011, p. 27).

As actions are taken and decisions are made within each of the different levels, aspects of them influence the other levels. Depicted as dotted lines in Figure 2, these influences often indicate transitions that result in significant technological change. Other transitions, albeit slower ones, can also be seen forming at the niche level. As time passes, smaller actions at the niche level build up until a threshold is met and the niche level influences the regime level, resulting in a major shift in technology, policy, or society. Lastly, actions made within each level can affect other aspects of that level as illustrated in Figure 2 by the small arrows going in multiple directions at the socio-technical regime level and the wavy lines at the socio-technical landscape level. While these actions and decisions do not result in notable transitions, they provide a better, more holistic understanding for how the overall shift the MLP framework is being used to analyze occurred.

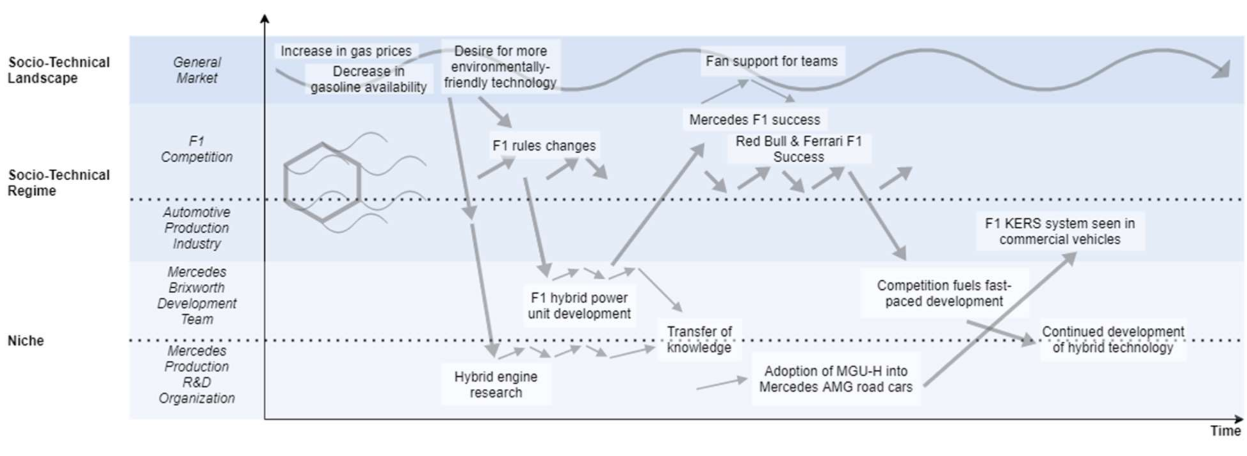

Figure 3. A Visualization of the MLP Framework Applied to Formula One's Relationship with Hybrid Road Car Technology Development. This figure illustrates how I will be using the MLP framework to analyze the influence of Formula One on the development of hybrid engine technology. (Created by Author)

Applying the MLP Framework to F1 and the Automotive Industry

In the context of F1's role in hybrid engine development, I identified the broadest socio-technical landscape as the general consumer market as shown on the left of Figure 3. For the next, more specific level of socio-technical regimes, I identified the F1 competition and the automotive production industry as two specific regimes that played a large role in hybrid engine development and where many influential decisions were made (see left-middle of Figure 3). Finally, for the niche level of the MLP framework, I chose to focus my analysis on one Formula One team – the Mercedes team – and within that, their Brixworth F1 power unit development team that focuses on their Formula One power unit technology development and their research and development organization that handles their development for Mercedes' production side. Both of these Mercedes development groups can be seen in the bottom left of Figure 3.

To analyze the shift of Formula One to hybrid technology, I used this high-level overview of the MLP framework that focuses on the interaction between these three layers. The multi-level aspect of this framework showcases the relationship between the F1 and production worlds which, while separate, are very closely intertwined and are constantly affecting each other. Identifying the different organizations that make up each layer for Formula One and the automotive production industry allows for the clear illustration of the interaction that occurs between both sides on different levels as well as how decisions made by each side affected the other across levels. While Geels's MLP framework also allows for analysis of the different sectors within the socio-technical regime level and how they interact, this specificity was not needed for this study.

Overall, the MLP framework lends itself to examining the relationship between F1 and road car hybrid engine development. The MLP framework is most useful for analyzing transitions and the development of hybrid engine technology is made up of several different transitions. By identifying critical transitions throughout hybrid technology development, I was able to examine F1's role in this development more closely and truly determine its value. This framework also enabled me to individually pick out the aspects that perpetuate the close relationship between F1 and the automotive industry and ultimately contribute to the crucial knowledge transfer that occurs between these two development environments.

Part III: The Three Keys to Faster and More Innovative Hybrid Engine Development

As mentioned before, although it is understood that Formula One plays an important role in the development of automotive technology, there is not a good understanding as to why participation in this competition is so crucial. This section illustrates which aspects of the competition are the most instrumental in facilitating the development of road car hybrid engine technology. Using the MLP framework, this section analyzes three major transitions that have occurred during the development of hybrid engines and the role that the Formula One competition played in each.

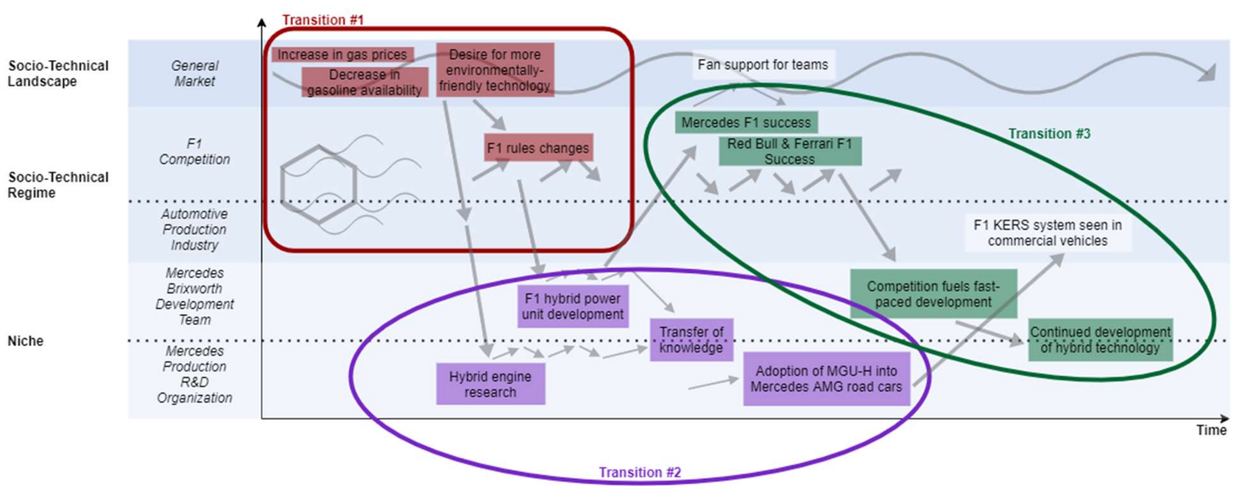

Figure 4. A Visualization of the MLP Framework Applied to Formula One's Relationship with Hybrid Road Car Technology Development with Major Transitions Identified. This figure identifies the three major transitions that occur during the shift of Formula One from combustion engine to hybrid engine technology with respect to the MLP framework. (Created by Author)

Transition 1: The Effect of Growing Environmental Awareness at the Socio-Technical Landscape Level

As seen in Figure 4, the catalyst for this transition towards hybrid engine technology was the increasing research regarding pollution, the increasing gas prices and decreasing availability of gasoline, and the growing concern for the well-being of the environment (InfiniGEEK, 2018). This change in mindset amongst the general public in the broader socio-technical landscape led to an increased desire from consumers for more environmentally friendly technology in the market. This desire filtered down to influence several different socio-technical regimes including the automotive production industry and the FIA's F1 competition, resulting in the first major cross-level transition. In the automotive production industry, there was an increase in hybrid engine research and hybrid production car sales starting in 2005 (Davis & Boundy, 2020, p. 182). The FIA also felt this influence from the public and in 2014, issued a major rules change for their racecars to switch from internal combustion engines to hybrid power units with the goal of making the F1 competition more relevant to the production world's needs.

By changing the power unit technology of the Formula One racecars from internal combustion engines to hybrid power units, the FIA redirected the path of Formula One technological development so that it was more useful and applicable to technological development occurring in the production world. For example, by lowering the allowed fuel flow rate within the power units, the FIA guided the development of hybrid technology to focus on increasing efficiency. Although at the start of the hybrid era, "F1 systems were no better than those found in hybrid road vehicles" and the first system that Mercedes designed "was just 39 percent efficient", the rapid development inherent to Formula One has drastically improved hybrid performance (Eurosport, 2015). By 2017, Mercedes' F1 power unit was shown to have a “thermal efficiency of over 50 percent, making [the Mercedes power unit] one of the most efficient internal combustion engines ever” (Mercedes, 2020). By participating in Formula One, teams ensure that their development stays aligned with market desires and that their technological innovations developed for F1 will be applicable to their commercial vehicles.

Transition 2: Crucial Transfer of Knowledge between Formula One and Production at the Niche Level

The second critical transition that illustrates F1’s influence on hybrid technology development occurs within the niche layer. As a result of F1’s rules change, all F1 power unit developers had to change gears and redirect their research towards hybrid technology. Since these F1 power unit developers were also production car companies, a lot of knowledge transfer occurred between the production side of these companies and the F1 racing side during this time. In the beginning, a majority of the knowledge transfer went from the production side to the racing side, allowing developers to quickly design a functional racing hybrid power unit. By building off the foundation of knowledge from production engines, developers were able to focus their efforts instead on adapting the power unit’s capabilities to a race setting. As the first couple seasons of the F1 hybrid era passed, developers quickly learned more about the capabilities of their designs through testing and use during races. From this, the racing side of these companies rapidly iterated and improved upon hybrid technology, greatly surpassing the capability of that found in road cars both in efficiency and power in a matter of just a couple of years. With all of this development, racing development teams gathered a wealth of knowledge that they were then able to pass on to the production side.

The sharing of knowledge between the Formula One power unit developers and the research and development organizations for road cars has been pivotal in the development of hybrid technology. As a result of this knowledge transfer, companies have been able to take what the Formula One power unit developers have learned and apply it their road vehicles. Developed in 2014 for the Formula One competition, Mercedes' Brixworth team designed the Motor Generator Unit – Heat (MGU-H) that "recover(s) or store(s) energy from, or to, the turbocharger in an F1 car" (Formula 1, 2020b). Using the knowledge gained through the development of this technology by their Brixworth team, Mercedes is applying it to their road car vehicles in the form of a new electric exhaust gas turbocharger (Noble, 2020). By having such an integrated company structure between its racing and production sides, Mercedes is able to facilitate the collaboration between the two that is necessary to increase knowledge transfer and speed up development on both sides.

Transition 3: The Influence of the Formula One Competition Structure on Hybrid Engine Development

As the development period of F1 closes and teams start to prepare for the coming season's races, the hybrid power units that these developers have designed are put to the test. The competitive environment of these races fuels the rivalries between the different teams and pushes each of them to constantly improve their designs in order to out-perform the other. The structure of the competition also facilitates faster iterative development through the constant testing that each scheduled practice and race provides. These two aspects of the competition represent the foundation for the third major transition that showcases F1's role in hybrid technology development. The constant competition created by the Formula One environment on the socio-technical regime level translates to fast-paced development on the niche level within each development team.

Because F1 is a competition where teams are fueled by the desire to be named the best in the world by winning the F1 championship title, these engineers push their technology to the absolute limit in order to maximize performance. Coupled with the ability to regularly test their designs and collect data by participating in the races, Formula One often results in many innovative designs that would not have necessarily have been discovered in a production research and development setting and at a pace that is much faster than what occurs in the production world. For example, in response to the competitiveness of the Mercedes team, Honda has pushed its F1 development team to speed up the integration of many of their updates to their power unit (Mitchell, 2021). As stated by Honda's F1 managing director Masashi Yamamoto "Mercedes' performance was really good and also stable, and considering that we thought we should make changes for the power unit" (Mitchell, 2021). Analyzing this transition has shown that Formula One plays an important role in accelerating the development of hybrid engine technology by providing a competitive environment with regular opportunities for testing that encourages quicker innovation.

The Importance of Continued Participation in Formula One

By analyzing each of these three main transitions regarding hybrid engine development identified by the MLP framework, it has been found that the F1 competition currently plays a crucial role in speeding up hybrid engine development in road cars for three main reasons: the relevance of F1's rules to the desires of the production industry (transition 1), F1's fast-paced development environment (transition 3), and the implementation of good company infrastructure that facilitates knowledge transfer between F1 and the production industry (transition 2). However, these factors are heavily dependent on the participation of many top F1 power unit developers in the Formula One competition to foster this increased development pace of hybrid engine technology. With the exit of one of F1's main power unit developers, this relationship between F1 and hybrid road car development is threatened. Fewer power unit developers in F1 means that not as many ideas are being generated and less competition is fostered which could lead to a decrease in pace of road car hybrid engine development. As a result, it is crucial that the other developers continue their participation in the F1 competition to allow for faster technological advancement and improved knowledge transfer between these racing teams and the production industry.

The Effectiveness of the MLP Framework in Analyzing Transitions

The MLP framework was extremely useful in analyzing Formula One's transition to hybrid technology. In using this framework, the most important actors in this transition were isolated through the identification of the different groups that made up the multiple levels of this framework: the socio-technical landscape, the socio-technical regimes, and the niches. Then, by classifying the key events that led to this transition under these three levels, this framework showcased the interaction between these influential actors. Specifically, I was able to clearly see the interplay between the racing and production industries on both the regime and niche level. Finally, by analyzing the smaller transitions made up by these key events, I was able to identify which aspects of their relationship were most important to the development of hybrid engine technology. Even though this transition of F1 to hybrid technology was incredibly complex, the use of the MLP framework made it easier to pinpoint the most significant players and events through its method of categorization and visualization.

Conclusion

Formula One plays an integral role in speeding up the development of hybrid road car technology as found through the analysis of three major transitions using the MLP framework.

By directing technical development according to market desires, cultivating a competitive fast-paced development that encourages faster technological iteration, and improving the transfer of knowledge between racing development environments and road car production facilities through increased communication and collaboration, Formula One both advances the development of hybrid road car technology and introduces cutting-edge, competitive designs to the production industry. Although Honda may no longer see the value in participating in Formula One with regards to balancing it with their production side, this research showed that there are tangible benefits to participating in F1 for road car technological development. However, these benefits can only be realized if teams continue to participate and innovate within the competition. Therefore, with regards to the development of hybrid road car technology, it is imperative that the remaining three F1 power unit developers – Mercedes, Ferrari, and Renault – continue their participation in the competition. This research also demonstrated the effectiveness of the MLP framework in the analysis of transitions through the identification of these integral aspects of the F1 competition. Overall, the results of this study provide a better understanding of F1's importance in hybrid road car development to inform teams of the benefits and necessity of their continued participation and confirm that the MLP framework is a useful tool for analyzing major changes in technological development.

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