Designing an Assistive Rear Wheel Power Steering System for Improved Vehicle Dynamics and Handling of a Formula SAE Competition Car
(Technical Paper)

Analyzing Formula One's Role in Accelerating the Development of Hybrid Engine Road Car Technology and the Importance of Continued Participation
(STS Paper)

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Introduction

Racing competitions are crucial to the innovation and development of automotive technology (Budget Direct, 2015). Many incredible automotive innovations have been developed through the automotive racing world including the carbon fiber chassis which resulted in racecars becoming lighter and faster and the semi-automatic transmission which allowed drivers to become less dependent on the clutch pedal and thus shift faster (Budget Direct, 2015). These innovations develop because racing competitions push participating engineers to design better, more powerful technology so that they can give their team a competitive advantage and help them secure the prestigious title of champion (Eurosport, 2015). One such racing competition is an event put on by SAE (Society of Automotive Engineers) International called Formula SAE or FSAE for short. FSAE is an international, inter-collegiate student design competition that is centered around building and racing an open-wheeled, on-track race car much like the vehicle depicted in Figure 1 (Formula SAE, 2020, p. 5). This year, the University of Virginia (UVA) team will be competing in FSAE under the name Virginia Motorsports. Since many of the competition's dynamic events focus on vehicle handling and agility, our team's goal is to improve the competitiveness of our racecar through various design improvements in vehicle handling and steering response. Specifically, for our technical project, we will develop a custom assistive rear wheel power steering (RWPS) system to increase our vehicle's agility and help make our vehicle easier to steer. This enhancement would greatly improve our vehicle's performance in the upcoming 2021 competition.

Figure 1. The University of Western Ontario team's FSAE car. This image shows the University of Western Ontario's FSAE car competing in the dynamic events at the 2014 Michigan FSAE competition. (Brown, 2014)

As teams begin to show success with their new innovations in racing competitions, these designs will start to trickle down to the road car industry as manufacturers work to adapt these technologies to production vehicles (Eurosport, 2015). Unfortunately, due to the nature of the commercial industry and the need to build cost effective products, road car technology often develops at a slow pace. Racing competitions like Formula One, on the other hand, are not as constrained in regards to budget and foster fast-paced development that is fueled by the desire to win and gain prestige. As stated by Eurosport, "[Formula One] has continually either created new technologies or taken initial concepts and given them high-speed development" (2015). Without fast-paced development environments like Formula One that "feed into the learning journey that takes place in the road car world," industry objectives and vehicle capability goals would be more difficult to meet (Carney, 2019). For my STS topic, I will analyze how Formula One accelerates the technological development of hybrid engines in the commercial industry as this is one of the main areas F1 and the competing teams are currently focusing their efforts on.

This analysis will help companies better understand the advantages of participating in racing competitions like F1 and how they can best use these competitions to further business goals.

Technical Topic: Designing an Assistive Rear Wheel Power Steering System for Improved Vehicle Dynamics and Handling of a Formula SAE Competition Car

The FSAE competition is made up of many different events held both on and off the track that aim to test different aspects of the vehicle to "[give] teams the chance to demonstrate their creativity and engineering skills in comparison to teams from other universities around the world" (Formula SAE, 2020, p. 5). Many of the competition's dynamic events such as the skid pad test and autocross event test vehicles' handling and stability through tight turns and high-speed cornering as seen in Figure 2 (Formula SAE, 2020). To perform well in these events, "highly competitive field teams must build an extremely agile and lightweight vehicle" (Sparrow et al., 2016, p. 7). This means that the vehicle must have good steering abilities at both low and high speeds without compromising on weight in order to perform well. Currently, our team's 2021 vehicle design has a slow steering response, poor handling and stability, and heavy steering actuation forces resulting in increased driver fatigue. To improve the overall steering performance for this year's competition car, our team has decided to design and implement an assistive power steering system that will improve the turning capabilities of the vehicle. With this system, we aim to facilitate a tighter turning radius with greater maneuverability at low speeds and increased stability and responsiveness at higher speeds. This system must also integrate with the current vehicle design so as to require minimal redesign of existing components, not add excessive weight to the vehicle to reduce negative effects to the vehicle's handling, and meet the competition's rules for safety and performance.

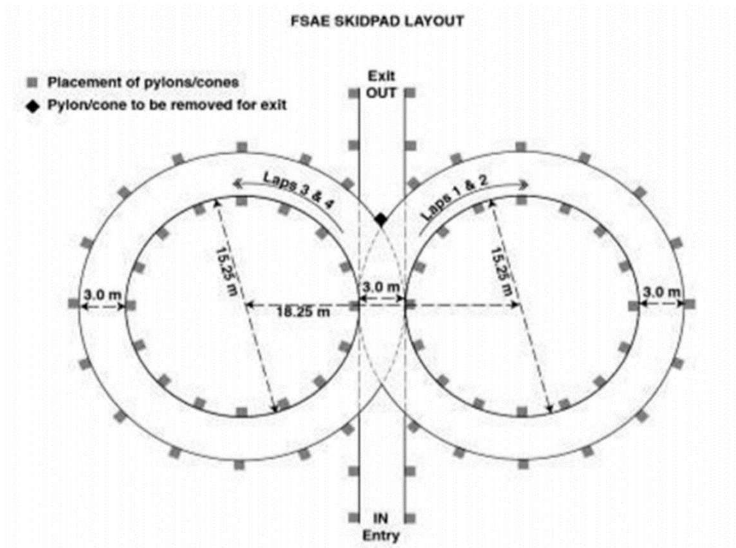

Figure 2. Skid pad test track layout. This image shows the track layout for the skid pad test where drivers will enter onto the track from the entrance at the bottom of the entrance, drive around the right-hand circle for two laps, turn and drive around the left-hand circle for two laps, and then exit the track using the exit shown at the top of the image. Since this track features continuous tight turns and teams are evaluated based on how fast they can complete this test, competing vehicles must be able to perform well under sustained high-speed cornering. (Formula SAE, 2020, p. 127)

There are many different methods for designing an assistive power steering system regarding placement and method of actuation. Currently, our vehicle is designed to be front steer, which means that the front wheels are responsible for steering the direction of the vehicle. When adding front wheel power steering to a front steer vehicle, the assistive power steering system senses the steering input from the driver and merely provides additional force or torque to the steering system to help the driver turn the front wheels of the vehicle to their desired position. In contrast, a rear wheel power steering system provides a force or torque to angle the rear wheels to supplement the driver's direct control of the front wheels. This implementation results in a four-wheel steering system that helps the vehicle turn more easily by changing the center of the vehicle's turning circle (see Figure 3). There are also many options to consider regarding the actuation of the wheels themselves. For these systems, the most commonly used types of actuators are pneumatic, hydraulic, or electronic. Each type offers its own advantages and disadvantages in terms of size, weight, actuation force, controllability, and cost.

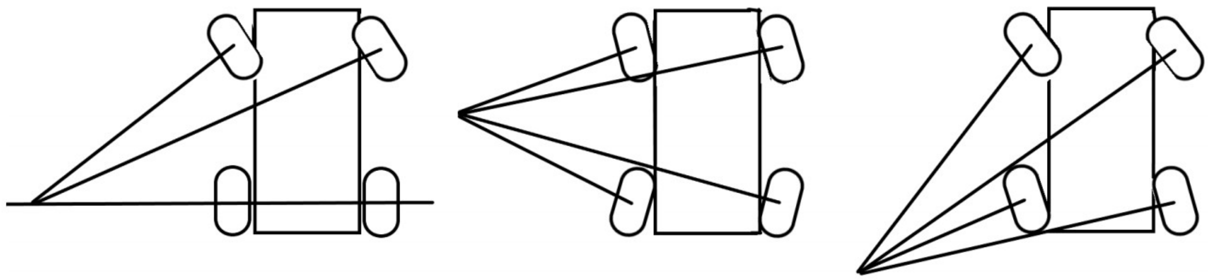

Figure 3. Two and four wheel steering diagram. This diagram depicts three different methods of steering and how they affect the center of the turning circle which is represented by the intersection point of the lines perpendicular to the vehicle's wheels. In the diagram, the front of each vehicle is at the top of the image. Front wheel steering, a form of two-wheel steering, is depicted on the left where only the front wheels are used in steering the vehicle. The middle and the right images depict two different methods of four-wheel steering which use both the front and rear wheels to help turn the vehicle. (Bremer et al., 2018, p. 3)

Many rules and regulations as well as system requirements must also be considered when designing an assistive power steering system. Regarding the FSAE competition, the main rules that affect our design include the prohibition of electrically actuated steering of the front wheels as well as the requirements that "the steering wheel must be mechanically attached to the front wheels" and that rear wheel steering must "limit the range of angular movement of the rear wheels to a maximum of six degrees" (Formula SAE, 2020, p. 21). Additionally, the system needs to be lightweight and low cost, and offer responsive low-level control. After considering all of these factors, our team has decided to design an assistive rear wheel power steering (RWPS) system using independent electronic linear actuators along with a custom controls algorithm much like the system shown in Figures 4 and 5.

Figure 4. A RWPS design from the University of Washington's FSAE team mounted into the vehicle's frame. This image shows a rear view of the University of Washington's RWPS design featuring independent electronic linear actuators in place of the rear tie rods to enable control over the steering angle of each of the individual rear wheels (Sparrow et al., 2016, p. 46).

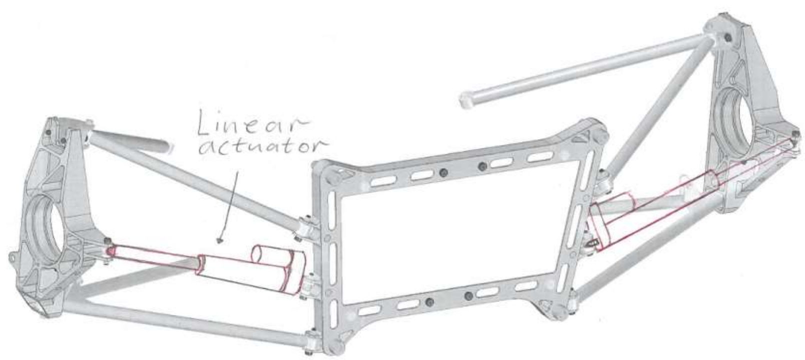

Figure 5. A RWPS concept design from KTH's FSAE team integrated with the vehicle's rear suspension CAD. This image depicts a sketched design for a RWPS system utilizing independent electronic linear actuators in place of the rear tie rods that clearly shows the use of the rear tie-rod mounting points for the mounting of the linear actuators in the vehicle's rear suspension (Bremer et al., 2018, p. 13).

This assistive RWPS design greatly improves the vehicle's steering capabilities thereby increasing the vehicle's performance. Using separate electronic linear actuators on each of the rear wheels enables us to independently set each wheel to its ideal steering angle. As a result, because "the [rear wheel steering] geometry is controlled entirely through software," we are able to design and tune the RWPS system to optimize the vehicle's maneuverability at low speeds while still maintaining stability and predictability at higher speeds (Bremer et al., 2018, p. 3). Unfortunately, this design is not very lightweight because it uses two electronic actuators and these actuators tend to be heavy due to the motors inside of them. To reduce the amount of added weight to the system, we will evaluate actuator options based on their weight as well as their performance. Although this design is expensive in cost and not optimal with regards to weight, the benefits of increased handling abilities, decreased driver steering forces, and overall improvement of our vehicle's competitiveness outweigh the cost and added complexity.

STS Topic: Analyzing Formula One's Role in Accelerating the Development of Hybrid Engine Road Car Technology

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). As stated by Eurosport, "the ultimate aim in F1 is championship success" which is achieved by developing the fastest, most powerful competition car (2019). To do so, teams recruit "some of the best engineering brains from vehicle dynamics to aerodynamics to materials [to] … the sport" (Eurosport, 2019).

In the past few years, Formula One has implemented new rules that have "incentivized many more hybrid developments" and, in turn, led to many major improvements in hybrid engine technology in areas such as thermal and fuel efficiency (Delbert, 2019). Hybrid engine technology is defined by the use of "at least one electric motor with a gasoline engine to move the car" (Riswick, 2019). For the 2020 season, F1 has changed their rules so that "drivers can now use three Motor Generator Unit[s] … over the course of the season rather than two" (Formula 1, 2020). Motor Generator Units, or MGUs, are a new energy recovery technology that can take energy such as waste heat from a car's exhaust or the act of braking and regenerate it into electricity that can be used to power the engine (Honda, 2018). The 2020 season has also seen another decrease in fuel allowance rules which now "limit the amount of fuel allowed to course around the car outside of the fuel survival cell to just 250ml - down from two litres in 2019" (Formula 1, 2020). As environmental issues become a growing concern for businesses and consumers alike, industries are pushing to develop green technology; the automotive industry is no exception. With these rule changes, F1 is making itself more relevant to the desires of the automotive industry. In fact, according to Delbert in Popular Mechanics, "Formula One [has] announced concrete plans to be carbon neutral by 2030" (2019). F1 is able to accelerate the development of this green technology by encouraging the use and development of hybrid technology in competition.

While F1 has implemented many changes to its rules to better align the competition with industry goals and customer desires, not all teams see the benefits in continued participation. As Budget Direct states, "with every year that passes, and with every technological innovation, the cost of running a team in F1 increases" (2015). As a result, many participating teams and "manufacturers have wanted to see a more practical return on their investment" (Budget Direct, 2015). Unfortunately, Honda, a big power unit supplier in F1, has not been able to justify the costs of continuing to participate in the competition. In October of 2020, Honda's President and CEO Takahiro Hachigo announced that "the Honda Motor Company … has decided to leave the sport at the end of 2021" (Gitlin, 2020). As stated by Gitlin in ARS Technica, "instead of spending $164 million (€140 million) a year on an F1 engine program, Honda will instead devote those resources to carbon-free technology for road cars, including battery and fuel cell electric vehicles" (2020). If more influential teams follow in Honda's footsteps and leave F1, not only will the competition itself be negatively affected, but the transfer of technology between F1 teams and production companies will also be severely reduced. To prevent this from occurring, F1 must make its competition worthwhile for the participating teams and manufacturers. For my STS research, I will focus on analyzing how F1 accelerates the advancement of hybrid engine road car technology to show how this relationship can help further industry business goals and how teams can benefit from participating in this competition.

There are many factors that contribute to F1's ability to speed up the development of hybrid engine technology for its eventual adoption into road car technology. Through my STS research, I will utilize the technical, organizational, and cultural (TOC) organization presented by Neeley in "Toward an integrated view of technology" to better understand how F1 fosters a fast-paced development environment that consistently produces cutting edge technology by using these three perspectives to examine the involved actors, networks, and their interactions. From there, I will then use the Actor Network Theory (ANT) to analyze the major actors and networks identified by the TOC framework to better understand how their presence and interactions facilitate the transfer of knowledge and technology between F1 and the road car industry and affect the decisions made in each environment. This analysis aims to provide a better understanding as to why teams participate in F1 and the advantages of their participation.

Conclusion

Racing competitions like Formula 1 and Formula SAE play an important role in directing and accelerating the development of automotive technology. For the technical portion of this thesis project, the UVA FSAE team will design an assistive RWPS system using two independent electronic linear actuators and a custom controller algorithm. This new steering system will improve the maneuverability, stability, and responsiveness of the FSAE racecar and therefore increase the team's performance in the FSAE competition. The STS research paper will evaluate the impact of F1 on the development of hybrid technology in road cars by analyzing the main actors and networks involved from a TOC perspective and examining how their choices and interactions affect this transfer of technology through ANT. This analysis will help inform participating teams and companies of the benefits of participating in F1 as well as the downsides of not being involved. These projects, if completed successfully, will result in a comprehensive understanding of racing competitions like Formula One and FSAE as well as the technologies involved and their impacts.

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