Supplemental Rear Wheel Power Steering System for a FSAE Vehicle
(Technical Report)

Thesis Prospectus- Effect of the Consumer on Automobile Design
(STS Topic)

A Thesis Prospectus in STS 4500
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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Automobile companies are constantly redesigning their vehicles to meet consumer demands, consumer needs, and government regulations. Secondly, these vehicle redesigns also serve to test new technologies that consumers may find attractive (Wardlaw, 2020). Market analysts and engineers are continuously adapting vehicle designs and features by redesigning the body for aesthetics to developing new technologies that make vehicles safer or improve acceleration. The implementation of rear wheel steering (RWS) technology is a prime example of automotive companies identifying and acting upon consumer demands for higher performance and safer vehicles. In fact, rear wheel steering has been implemented by many automotive companies on past and current vehicle models including the Honda Prelude, Nissan 300 ZX, Porsche 918 GT3, and Lamborghini Urus (Autocar, 2020).

Automobiles typically struggle to make tight, low speed turns common in parking scenarios and in town driving. At high speeds, the ability to quickly change direction to avoid a collision with another vehicle or animal is critical to vehicle performance. Most cars today are equipped with a mechanical steering linkage from the steering wheel to the front wheels that allows the driver to actuate the wheels. While this setup is adequate for many common driving scenarios, front wheel steering vehicles are typically unable to make tight low speed maneuvers or provide the handling needed for emergency or performance situations at high speeds. Many vehicles equipped with both front and rear wheel steering have therefore been designed and sold at a large scale. It is common to refer to a vehicle equipped with both front and rear steering as a "rear wheel steering" vehicle. Generally, the goal of rear wheel steering is to facilitate difficult vehicle maneuvers at low speeds, such as navigating a tight parking garage, and improve handling characteristics at high speeds, such as quick lane changes on a high way. By improving performance throughout the range of vehicle operating speeds, rear wheel steering solves the problem of being unable to execute tight low and high-speed maneuvers. Rear wheel steering is the focus of my capstone project and will facilitate these improved performance characteristics.

The technical aspect of this project is focused on designing and implementing an electronically actuated rear wheel steering system on Virginia Motorsport's Formula Society of Automotive Engineers (FSAE) car. Virginia Motorsports is a large student run UVA organization that facilitates educational and recreational motorsports programs, one of which is FSAE. Formula SAE is an international collegiate design and race series in which teams fully design, build, and race their on-road race cars per FSAE rules. The annual competitions include technical and business presentations as well as multiple racing events. In the racing events, there are both high and low speed turns of varying radii and slaloms requiring agile car maneuverability. The technical project team is therefore developing a rear wheel steering system for our FSAE car in an effort to significantly decrease the car's minimum turn radius at low speeds and improve stability and maneuverability at high speeds. The fly by wire steering system must comply with all FSAE 2021 competition rules (SAE, 2020). Further, this project will analyze specific examples of how certain consumer demands have affected the design of automobiles.

Rear Wheel Steering

To understand the fundamentals of how a car equipped with four-wheel steering functions, it is necessary to understand steering geometry and tire deformation. When a vehicle turns, the outside wheels must travel a greater distance than the inside wheels due to the fact that the radius of the turn at the outside wheel is greater than the radius at the inside wheels. In its simplest form, steering geometry sketches are optimized to allow the vehicle to travel around a turn without dragging one or more wheels across the pavement due to the difference in turning radius between the outside and inside wheels (Milliken, 1995). When a steering geometry is designed such that all four wheels rotate about the same central point of the turn, a 100% Ackerman geometry is achieved as shown in Figure 1.

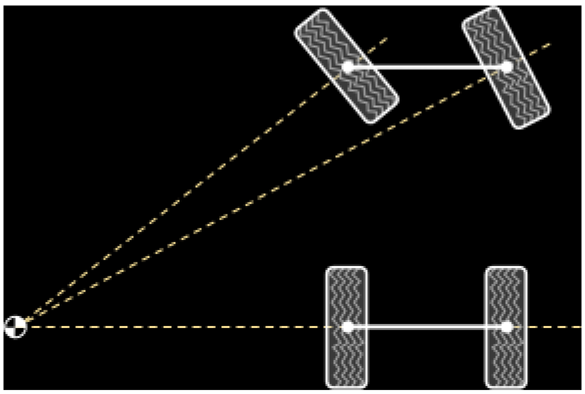

Figure 1: 100% Ackerman Steering Geometry. (Image Source: Ackerman).

Greater complexity is introduced when the steering geometry accounts for the elastic deformation of the polymer tires due to the normal, lateral, and longitudinal loads on the tires. When a car travels around a turn, the outside wheels will be loaded more heavily than the inside wheels due to the force acting at the car's center of gravity due to the centrifugal acceleration experienced by the car. Under this higher load, the outside wheels deform more than the inside wheels. This causes the car's instantaneous center of rotation about each wheel to be different than a steering geometry not accounting for dynamic tire deformation would predict. Steering geometries used to account for tire deformation include Parallel and Anti-Ackerman geometries. In short, these geometries simply cause the outside wheel of the car to turn significantly more than the inside wheel, thus creating a common center point of rotation for the car when the outside wheels have deformed more than the inside wheels (McRae, 2019).

Rear wheel (also referred to as four wheel) steering geometries require very similar design considerations as front wheel steering geometries. The significant new complexity involved in rear wheel steering geometry is that at low speeds, the rear wheels are turned in the opposite direction as the front wheels, and at high speeds, all four wheels are turned in the same direction as shown in Figure 2. This is done to achieve the shortest possible turning radius at low speeds and improve maneuverability at high speeds (Wisniewski, 2016).

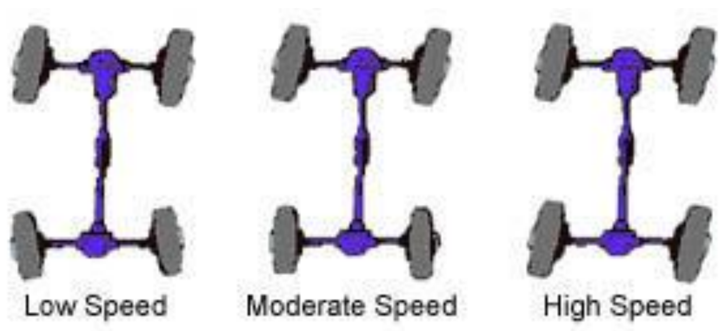

Figure 2: Speed dependent rear wheel steering. (Image Source: General, n.d.).

For the FSAE rear wheel steering currently being designed for this project, a negative 100% Ackerman steering geometry is to be implemented at low speeds, and a positive parallel steering geometry is to be implemented at high speeds. The following CAD screenshots, Figure 3 and Figure 4, illustrate our FSAE car’s four-wheel steering geometry.

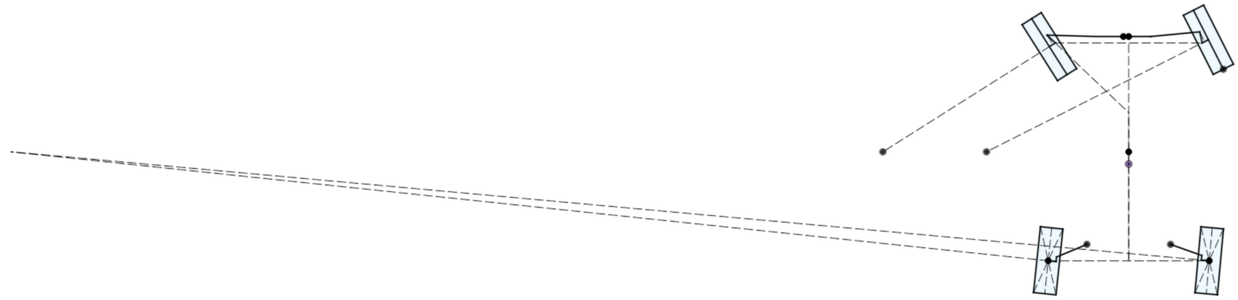

Figure 3: Virginia Motorsport’s FSAE car’s low speed negative rear wheel steering, 100% Ackerman rear geometry. (Image Source: Recktenwald, 2020).

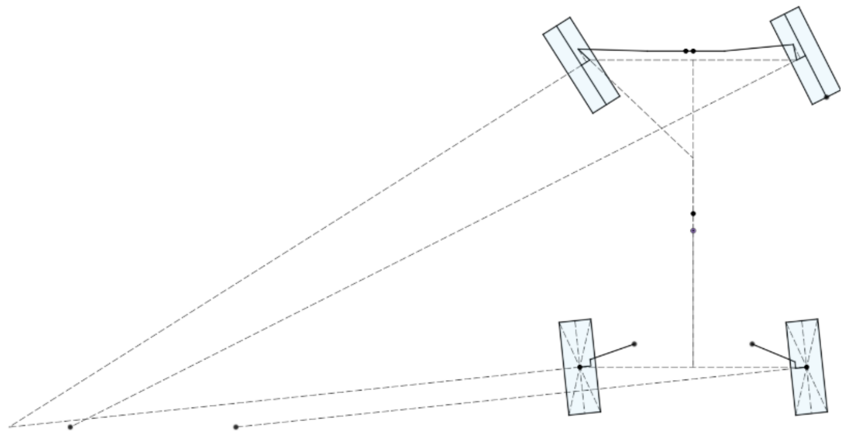

Figure 4: Virginia Motorsport’s FSAE car’s high speed positive rear wheel steering, parallel rear geometry. (Image Source: Recktenwald, 2020).

The front steering rack travel is the input to the steering geometry sketches, and the steering angles of all fours wheels is the output. In reality, the steering rack travel is actuated by the driver and measured using a potentiometer on the end of the steering column.

An electronic linear actuator attached to each of the rear suspension uprights as shown in Figure 5 will be controlled using an Arduino containing lookup tables of the steering geometry for any given car speed and front wheel steering angle. The output of the lookup tables is the desired linear actuator lengths needed to produce the desired steering angles of the rear wheels. The lookup tables will be obtained using an automated motion study script from the steering geometries shown in CAD in Figure 3 and Figure 4. A dynamic closed loop controller will independently actuate the two actuators to their desired position as dictated by the geometries.

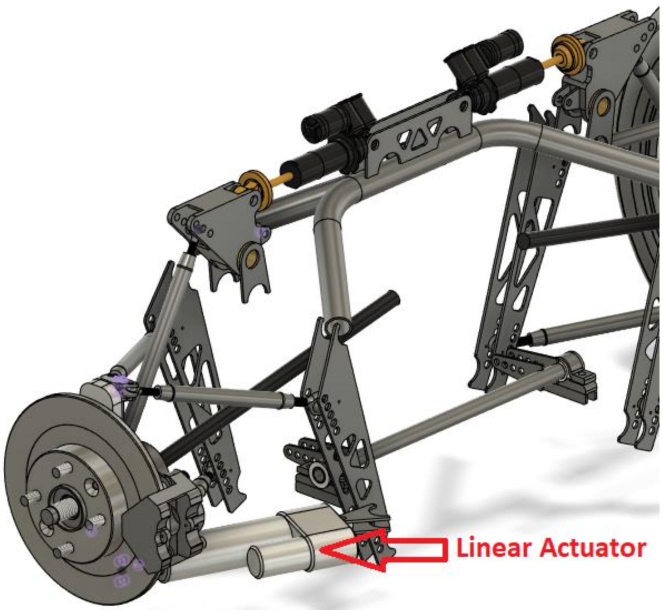

Figure 5: Virginia Motorsport's FSAE car's rear suspension CAD model including a linear actuator. (Image Source: Recktenwald, 2020).

The "ideal" RWS angle will be a combination the steering geometry designed in CAD and how agile and predictable the steering feels to the driver during racing. Specifically, a non-linear relationship between steering wheel angle as governed by the driver and the actual yaw (steer) angle of the car may be desirable from a purely theoretical geometry perspective, but will almost certainly be unsettling to the driver. This is because humans generally do not have an accurate sense of nonlinear system behavior, especially in a fast-paced racing environment. To design and implement a RWS system that improves overall car performance, it will be necessary to place great importance on how predictable the steering system "feels" to the driver through real world testing.

Influence of the Consumer on Automobile Design

The implementation of rear wheel steering by automobile companies is a direct result of the companies meeting consumer demands for high performance and safer vehicles. Rear wheel steering therefore exemplifies the consequential relationship present between consumers and automobile manufactures that is being investigated. Characterizing the influence of consumers on vehicle design decisions requires an analysis of both the consumer wants that automotive companies cater to directly as well as the technologies that automotive companies anticipate a customer will benefit from or need but is not currently aware of.

The direct response of automobile companies to consumer demands, in an effort to increase sales by satisfying the consumer, is exemplified in new and updated vehicle models each year. The new lineup of vehicles that automotive companies release and showcase annually are an embodiment of the technologies and styles that they believe consumers demand. For example, the marketing surrounding the 2020 Lexus GS sedan high lights the many safety features engineered into the car's design (Lexus, 2020). The argument being made by Lexus is that their engineers have designed the GS model to be extremely safe and accommodating to driver demands. Lexus understands that the consumers of their vehicles place a high value on safety, which is therefore reflected in many of the GS's features. The GS has a 10-airbag system, GPS based roadside assistance, a dynamic backup camera, and dynamic variable traction control among many other features. Lexus is obviously attempting to persuade to consumer to be confident in their GS sedan by appealing to importance of safety.

Another example of automotive companies designing for consumer demands is the shift away from mechanical rear wheel steering, which typically yields minimal performance benefits, to electronically actuated rear wheel steering, which is very effective in increasing vehicle performance. Specifically, Wan argues that this shift from mechanical to electronic steering is due to consumer demands for greater performance (Wan, 2013).

General Motor's 2020 C8 Corvette has many features that cater to consumer demand. While many engineering decisions for the C8 were made to satisfy their targeted consumer, features such as magnetic ride control and different operating modes, such as eco and race, particularly stand out. GM has obviously considered many consumer demands that affect the development of the C8, and the performance benefits and creature comforts gained by features such as magnetic ride control and driving mode selection significantly benefit the consumer. The different driving modes allow the driving characteristics of the car to be easily adapted instantaneously according the experience the consumer demands, whether that demand is a cruise through town or laps on a race track (Tracy, 2019).

Automakers also implement certain technologies in their vehicles, the implementation of which is not directly motivated by current consumer wants but rather what the automaker believe could be necessary given the consumer's driving skill level or predominant demographic. The 2020 C8 Corvette also exemplifies many engineering decisions that account for the general consumer's driving skill level and age. As pointed out by John Fitzgerald, the marketing manager for Chevy performance cars, one in five buyers of the Corvette are age 65 and older (Chappell, 2013). This means that a significant portion of Corvette consumers will have slower response times to situations requiring fast reflexes, such as pushing a race car to its limits on a track of highway, compared to the average, middle aged automobile consumer. Also important is that the C8 Corvette is a mid-engine, high horsepower, race-oriented car starting a relatively low starting price of $59,995 compared to other vehicles with similar specifications (Cenizo). A significant portion of C8 consumers may have little to no experience driving, let alone racing, such a capable car due to its entry level price point. While engineering the C8, GM obviously considered the large portion older and unexperienced consumers present. For example, the new mid-engine C8 Corvette is intentionally designed to understeer, meaning it tends to not steer as sharply as the driver tells it to from the steering wheel during cornering (Fenske, 2020). The engineers did this largely because if they designed a car that oversteered (turns into the corner more sharply than commanded), or even if they designed a car that didn't over or understeer, the average consumer of the car would be very likely to crash because large amounts of racing experience is required to control such agile and aggressive steering setups.

I will structure my analysis using ''The Social Construction of Facts and Artifacts'' framework discussed by Pinch and Bijker. The idea that social groups and individuals have a large and continuous impact on the development of technology is central to the SCOT theory and is in contrast with technological determinism. Through their primary example of the development and evolution of the bicycle, Pinch and Bijker discuss how various groups of people influenced almost every aspect of the bicycle's design over time. Pinch and Bijker emphasize that often the technical workings and merits of a technology can be irrelevant to the success and adoption of that technology within society. They argue that for a technology to be accepted by society and therefore successful, many different forces, such as governmental regulations and different social groups' perception of the technology, must act in favor of integrating the technology onto their society (Bijker, 2012). I am primarily focusing on how consumers affect the automotive industry's design and engineering decisions, and the SCOT theory will be helpful in explaining the influence of different consumer groups. Specifically, the automobile is the artifact whose development will be analyzed in the context of influential consumers' demands and needs.

Research Question and Methods

The research question I will be answering is: what influence do automobile consumers have over engineers' decisions throughout the vehicle design process? Understanding how consumers affect automotive design decisions is important due to the large impact this influence has on automotive engineering decisions. These engineering decisions then affect the lives of millions of vehicle owner every day.

The identification of consumer needs and potential demands by automotive companies and how this identification affects design decisions will also be presented and analyzed. Rear wheel steering in particular will be discussed from an STS perspective as a technology that satisfies consumer demands for increased performance (Kasliwal, 2019) and safety (The Pros, 2019). The design decisions that automobile marketing teams and engineers make with consumer demands in mind typically affect the features and capabilities of their vehicles. I will therefore investigate the nature and magnitude of the influence consumers carry on automobile design.

Evidence to support the analysis of this research question will be gathered from multiple sources, including automobile engineering literature, economics and business databases, and other consumer reports and surveys published online. To understand past and current consumer demands, consumer reports and surveys will be most useful. Analyzing the effects of these consumer demands is complicated due to the large number of factors affecting automotive design, including manufacturability, R&D budget constraints, and of course consumer demand. Therefore, consumer wants and needs gathered from consumer reports and surveys, while a critical factor affecting vehicle designs, must be interpreted from a holistic perspective considering the other factors influencing vehicle design decisions, such as annual automobile company budgets and long-term company goals. While companies do not directly publish their design decision justifications, engineering literature communicating design features of specific vehicles and in some cases postulating why the company made such decisions will be useful in constructing an understanding of how consumer demands are satisfied by the final design. For example, a consumer survey I will use in my analysis focusses on the preferences of Swiss customers in fatal accident situations involving self-driving cars and changes in self driving car algorithms that may need to be made as a result. Pugnetti and Schlapfer conclude that the Swiss tend to attribute roughly the same value to the lives of children and the lives of adults, which conflicts with the more geographically diverse studies that generally find a higher value attributed to the lives of children (Schläpfer, 2018). The effect of this geographically specific consumer demand on automobile design can be understood through engineering design documentation on different car models and features for different geographic regions.

To analyze this topic, I will view consumer influence on automobiles through the lens of the SCOT theory because it is useful in investigating the continuous and substantial impact that social groups and individuals have on the development of technologies. Using the SCOT framework, a model of the consumer's influence on automobile design will be developed. Specifically, the multidirectional model of artifact development Pinch and Bijker advocate in favor of is directly applicable to the artifact-influencer relationship between automobiles and consumers (Bijker, 2012). Also, any case studies or content analysis articles related to this topic will also be useful in analyzing the effects of consumer demands on vehicle design. Specifically, the influence of government regulation on vehicle design and the consumers' reactions to such regulation is discussed in "Review of European Regulations and Germany's Action to Reduce Automotive Sector Emissions" (Kotak, 2016). Another source of analysis focused on the automotive industry is by Santos and Paganotti. They argue through conducting case studies, interviews, and analyzing secondary sources that the direction of engineering R&D of new automotive technologies is typically influenced heavily by specific market demands (Santos, 2019).

I will gather the remainder of the sources I need for this analysis, including surveys, consumer reports, and engineering literature during January 2021. I will then conduct my analysis in February and write my final report in March.

Conclusion

The technical aspect of this project involves designing, building, and testing an electronically actuated rear wheel steering system for an FSAE car. Four-wheel steering geometries, FEA analysis, feedback control system design, and real-world testing are some of the major deliverables. With the completion of this project, our FSAE car will be capable of making much tighter turns at low speeds and will have greater maneuverability at high speeds.

Because vehicle designs impact millions of people every day who interact with vehicles, understanding how consumers affect design decisions is important. The main deliverables for this analysis will be an investigation of certain vehicles whose designs have been significantly affected by consumer demands and analyses of certain design decisions made for the benefit of the consumer but not explicitly demanded by the consumer. With the completion of this investigation, examinations of consumer influence relevant to specific vehicles will be synthesized to develop an overarching understanding of how consumers affect automobile design decisions.

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