Thesis Portfolio

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

Engineering Education: Are Companies Having a Negative Impact?
(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering and Applied Science

Zachary Berman

Spring, 2021

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Sociotechnical Synthesis

Formula SAE (FSAE) is a collegiate design series put on by SAE International where students from all over the world can compete with the goal of designing and building an open-wheeled, formula style racecar. The competition includes many different events, both on and off the track, to test everything from the car's performance and the team's ability to explain their finances. For the first time University of Virginia (UVA) will have a team competing in FSAE under the name Virginia Motorsports. The team has experience designing cars for the Baja SAE collegiate design series, but this will be the first attempt at an FSAE vehicle. The goal of the technical project was to identify, design, and build a subsystem to aid in the performance of the vehicle, with a focus on the dynamic events. After identifying the needs, the team decided to create a supplemental rear wheel power steering (RWPS) system. The goals of the system are reduced driver fatigue, improved steering response, and better handling and stability. These goals are achieved by analyzing the steering geometry and using that along with competition rules to design an assembly that uses actuators to move a tie rod that in turns rotate the rear wheel to the desired angle, with hard stops welded in for safety. The movement is controlled using a microcontroller, encoders, and potentiometers to handle all data collection and control, with a PID control system as the main backbone. These systems combine to create a functional RWPS system.

None of the technical project would happen without collegiate design series like the ones hosted by SAE. These design series form a large basis for the experiential learning opportunities for engineering students at universities all over the world and allow for companies in the industry to see what students can do. The STS project derives itself from these competition experiences and looks at the way corporations form students' engineering education. When looking at the influence of corporations over the educational experiences, the paper will seek to determine if the influence is having negative effects on students, decreasing their abilities to be creative and participate in the things that interest them in favor of things that companies want, and overall if there is a negative impact on people's ability to be innovative. The basis for this paper will stem from autoethnography, highlighting the authors experiences as a student, both with the curriculum and their involvement in Virginia Motorsports, and seeing how they fit in the larger culture of engineering education. Part of the focus will be on looking at who and what defines success, and the different ways companies find ways to be involved and exert influence during a students' educational experiences in university. Using other literature on experiential learning opportunities and the experiences of other students, the author hopes to see if there are shared experiences and if any negative effects of companies' influence outweigh any positive aspects.

Supplemental Rear Wheel Power Steering System for a FSAE Vehicle

A Technical Report submitted to the Department of Mechanical Engineering

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Zachary Berman

Spring, 2021

Technical Project Team Members
Carolyn Wong
Connor Greene
Westin Recktinfeld
Lerene Palugod

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

Signature *Zachary Berman* Date 5/6/2021
Zachary Berman

Approved ______________________________________ Date __________
Natasha Smith, Department of Mechanical Engineering

Background Information

The Formula SAE Competition

Formula SAE (FSAE) is a competition put on by SAE (Society of Automotive Engineers) International. It 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 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). For the competition's static events, teams compete in presentation, cost, and design events that test teams' abilities in business, budget, and engineering knowledge. The competition's dynamic events which include acceleration, skid pad, autocross, efficiency, and endurance focus on teams' physical vehicles and their design, manufacturing quality, and overall performance. This year, the University of Virginia (UVA) team will be competing in FSAE as Virginia Motorsports.

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).

Identification of Need

With the current setup of the vehicle, certain areas were marked for improvement based on what would help in the competition's events the most. 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). Based on this and the general length of the competition, the team marked three areas of need: reduce driver fatigue, faster steering response, and better handling and stability. The first area will help both with the aforementioned length, but also better allow the driver's senses to not be overwhelmed by turning in any dynamic event. The other two will help improve times and performance in the dynamic events, allowing a better overall performance of the vehicle itself. A supplemental rear wheel power steering system was determined to best improve the demonstrated needs of the current vehicle.

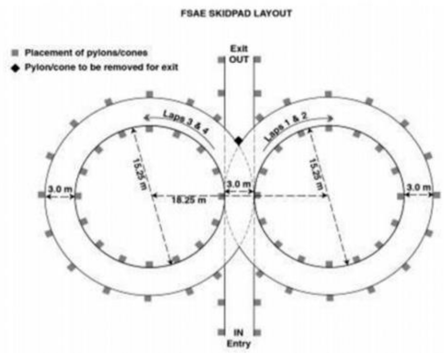

Figure 2: Skid pad test track layout. This image shows the track layout for the skid pad test where drivers will enter onto the track from the entrance at the bottom of the entrance, drive around the right-hand circle for two laps, turn and drive around the left-hand circle for two laps, and then exit 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).

The Current Vehicle's Steering System

The current design of Virginia Motorsports' 2021 competition car's steering system is front steer with a rack and pinion. As shown in Figure 3, our vehicle's steering wheel is connected to the steering column using a universal joint. From there, the steering column actuates the pinion gear inside the vehicle's steering rack which, in turn, actuates the vehicle's front wheels via the attached tie-rods to turn them left or right depending on the driver's input at the steering wheel. The chosen rack and pinion for our vehicle is one by KAZ Technologies that weighs 3 lbs and features 248 degrees of pinion rotation for a total travel of 3.25 inches and a steering rack ratio of 4.71" per revolution (see Figure 4).

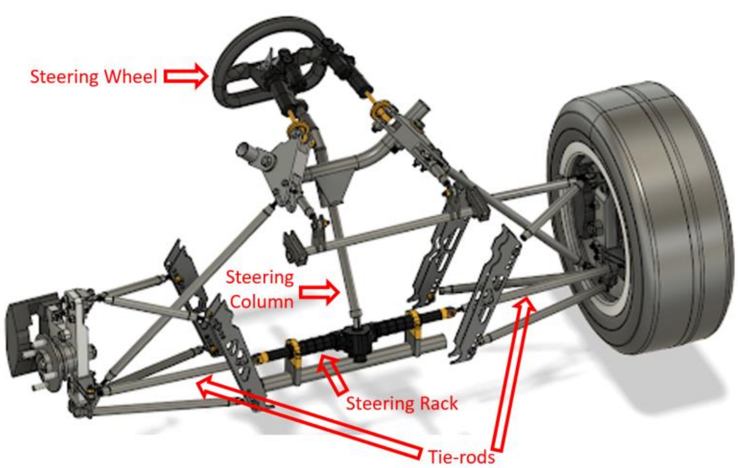

Figure 3: Virginia Motorsports' Front Steering System. This image depicts an isometric view of Virginia Motorsports' 2021 competition car's front steering system featuring the steering wheel,

universal joint, steering column, steering rack, and tie-rods that work together to take driver input from the steering wheel and turn it into actuation of the front wheels.

Figure 4: KAZ Technologies Steering Rack. This picture is of the KAZ Technologies steering rack that Virginia Motorsports' will be using for their 2021 competition car's steering in the front (KAZ Technologies, 2014).

Designing a Supplemental Rear Wheel Power Steering System

Related FSAE Competition Rules

There are multiple rules related to front and rear FSAE steering that must be adhered to. As discussed in section V.3.2 of the 2021 FSAE competition rules, the car steering wheel must be mechanically connected to the front wheels, and electronic steering actuation of the front wheels is prohibited. Rear wheel steering may be implemented if desired, and electronic actuation of the rear wheels is allowed. If rear wheel steering is implemented, hard stops limiting the rear wheel steering travel to a maximum of 6 degrees are required. Lastly, steering fasteners are classified as "critical fasteners", and thus certain bolt and nut grades as well as positive fastener locking mechanisms are required (Formula 2020). All rules have been followed throughout the design process of the front and rear wheel steering systems.

System Performance Metrics

The system was designed to meet several performance metrics that would enable it to be effective throughout all of the conditions it would face. At the highest level regarding handling, the low speed effectiveness can be demonstrated by decreasing the turning radius by 20%. High-speed effectiveness can be demonstrated by a lane-change maneuver and comparing stability to when the system is turned off. This is intertwined with the ability to turn the wheels under the maximum force experienced by the tires. Furthermore, as dictated by the FSAE rules the system must have hard stops which limit the wheel travel to 6 degrees in either direction. For robustness, we also required that our system be able to return to zero as a fail-safe condition. Finally, the entire system must be under 12 pounds and be IP54+ waterproof and shockproof.

Narrowing down the Design

A decision matrix was created to select the device providing the steering force. The choices included an actuator (electronic, hydraulic, or pneumatic) or rack and pinion (electronic or hydraulic). The actuators were compared to each other based on their cost, weight, force output, control, ease of use and compactness. Each category was weighted differently, that is, their significance was not equal to each other. Points are assigned under each category based on the benefit provided by it. Points range from 0 - 2, where higher numbers offered greater benefit.

Table I

Decision Matrix for Method of Implementation for Supplemental Rear Wheel Power Steering

Categories	**Cost**	**Weight**	**Force Output**	**Control**	**Ease of Use**	**Compact-ness**	**Total**
Options /**weight**	**1**	**2**	**3**	**3**	**2**	**2**	
Electronic actuator	1	1	1	2	2	2	20
Hydraulic actuator	0	0	2	2	0	0	12
Pneumatic actuator	2	1	1	2	1	1	17
Electronic rack & pinion	1	2	1	0	2	1	14
Hydraulic rack & pinion	0	1	2	0	0	0	8

The design using independent linear electric actuators had the highest total number of points after calculations. As the most beneficial choice, it will be used in the final design.

Rear Steering Geometry Design

Determining the Vehicle's Desired Steering Performance

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 measured 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 radii 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 5.

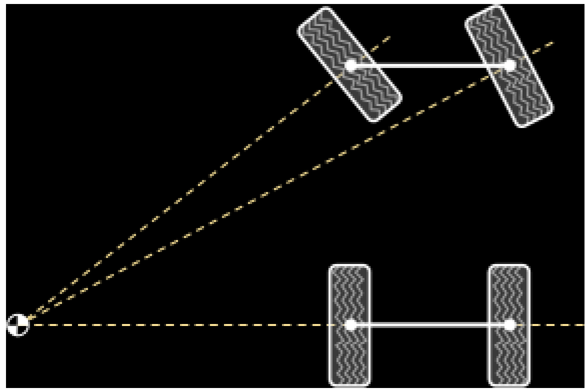

Figure 5: 100% Ackerman Steering Geometry (Ackerman Steering, 2016).

Greater complexity is introduced when the elastic deformation of the polymer tires due to the normal, lateral, and longitudinal loads on the tires is considered by the steering geometry. 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 (McRae, 2019). Parallel and Anti-Ackerman front wheel steering geometries are shown in parts b and c of Figure 6.

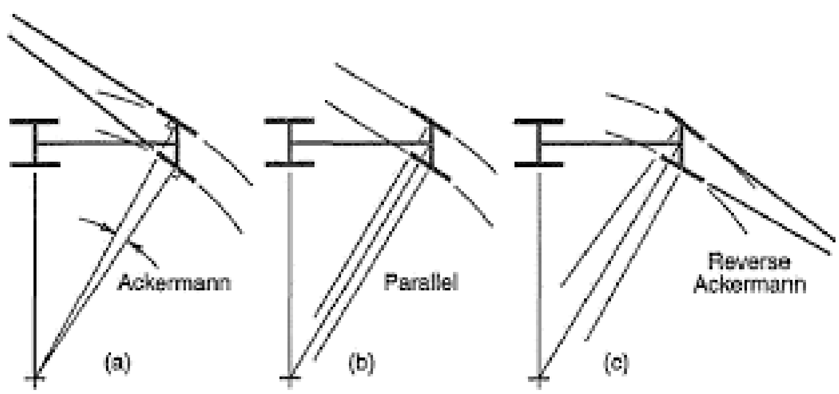

Figure 6: Ackerman, Parallel, and Anti-Ackerman Steering Geometries (Milliken, 1995).

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 7. This is done to achieve the shortest possible turning radius at low speeds and improve maneuverability at high speeds (Sparrow et al., 2016).

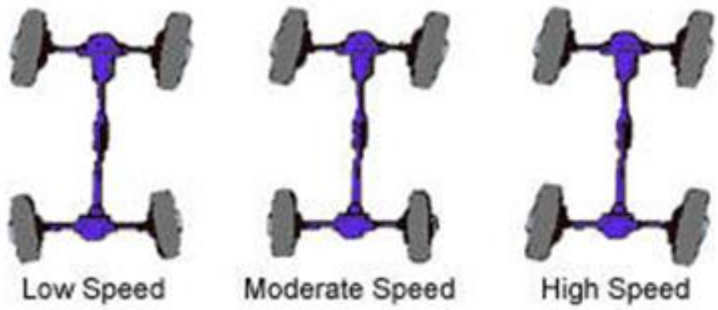

Figure 7: Speed dependent rear wheel steering (General Motors Quadrasteer Technology, n.d.).

Steering Geometry Decisions and Master Sketches

For the FSAE rear wheel steering designed for this project, a negative 100% Ackerman steering geometry is implemented at low speeds, and a positive Parallel steering geometry is to be implemented at high speeds. Due to the insignificant tire deformation induced at low speeds and the significant tire deformation induced at high speeds, Ackerman and Parallel rear steering geometries are implemented at low and high speeds, respectively. While ideally the rear wheels are turned at the same angle as the front wheels at low speeds to achieve the smallest turning radius geometrically possible (Arvind, 2013), the FSAE rules limitation of 6 degrees of maximum rear wheel travel constrains the allowable rear wheel angular travel to ±6 degrees. The following CAD screenshots, Figure 8 and Figure 9, illustrate our FSAE car's four-wheel steering geometry.

Figure 8: Virginia Motorsports' FSAE car's low speed negative rear wheel steering with 100% Ackerman rear geometry.

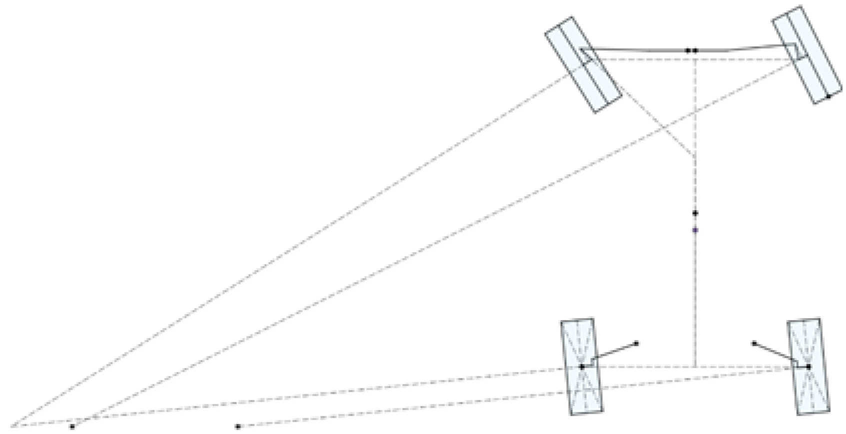

Figure 9: Virginia Motorsports' FSAE car's high speed positive rear wheel steering, Parallel rear geometry.

Examining the rear wheels more closely in Figure 10, the point circled in orange represents the steering tie rod's connection to the suspension upright. The point circled red represents the steering tie rod's connection to the RWS rocker. As the rear wheels are steered by driving the front steering rack position, the change in length of the rear tie rod directly corresponds to the change in length of the linear actuator needed to achieve the desired rear wheel angle.

Bump Steer Analysis

A vehicle's suspension system is simply a set of mechanical linkages. As such, they prescribe certain paths of motion in 3D space during suspension travel. The exact path the suspension will travel is a function of the many suspension parameters that define the location of the suspension linkages in space. As the rear suspension travels up and down due to bumps, potholes, and other dynamic driving scenarios, it is critical that the tires do not steer in or out as it travels. An unintended steering motion of the tires during the suspension travel is a product of a poorly optimized suspension geometry and can create very unpredictable and undesirable vehicle handling characteristics. Therefore, the suspension geometry must be optimized to ensure that steering of the tire due to suspension travel is minimized to a negligible magnitude. As shown in Figure 10, this optimization is done in the front view of the geometry. This front view CAD sketch shows the centerline of the wheel and well as the upper and lower ball joints and frame mounts. The suspension in this sketch is traveled up and down by redefining the dimension representing ground clearance. As the suspension is traveled, the length of the tie rod, which connects the suspension upright to the rear steering system's rocker, changes slightly (this dimension is boxed in green in Figure 10). Because in reality the tie rod is a solid steel tube that does not change length, this geometric "change in length" of the tie rod manifests itself as change in the rear tire's steering angle. The position of the tie rod's mounting points, both at the suspension upright and the rear steering rocker, is optimized by iterating through many different possible mounting locations and checking which locations amount to the lowest magnitude of bump steer. After optimization, the total "change in length" of the tie rod due to the full 2.5" of rear suspension travel is 0.01" for our suspension geometry. This small change in tie rod length produces a negligible change in tire steering angle throughout the suspension's full travel.

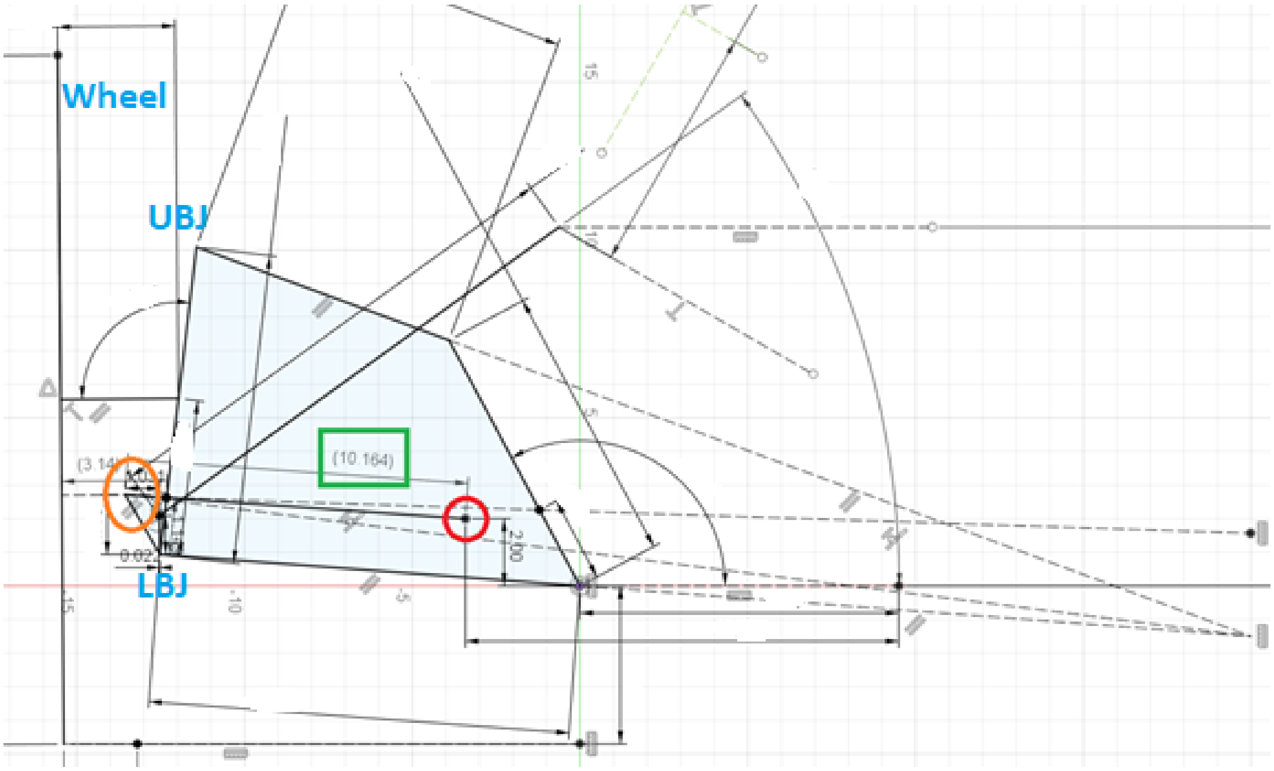

Figure 10: Virginia Motorsports' FSAE car's RWS bump steer analysis. Side view of suspension geometry shown.

For context of how the side view relates to the top view of the geometry, Figure 10 shows the mounting point of the rear tie rod at the rear steering rocker in red and the mounting (the point circled in orange in Figures 10 and 11).

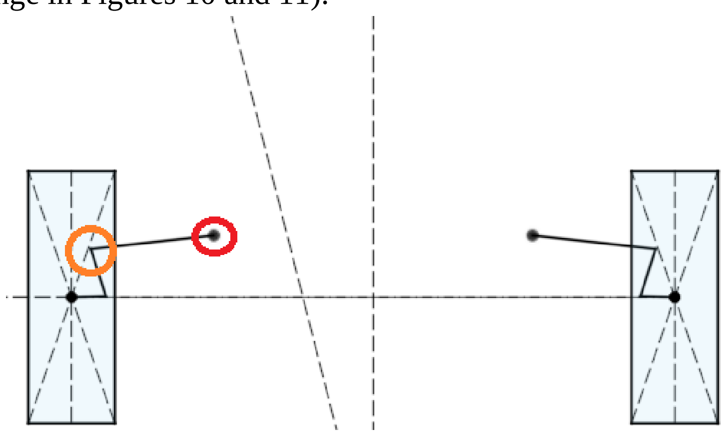

Figure 11: Virginia Motorsports' FSAE car's top down view of rear wheels. Tie rod outboard link circled in orange, inboard link circled in red.

Mechanical Design Overview

Analyzing the System's Loads in terms of Vehicle Performance

Tire performance is critical to understanding how a vehicle will perform because tires are the only contact that a vehicle has with the road surface. Creating grip with these contact patches allows vehicles to turn around corners, accelerate, and brake. Under load, a tire creates lateral friction through a phenomenon called "slip", in which the angle of the tire is different from the direction of its travel. This creates deformation of the sidewall, and the reaction force of this deformation gives grip to the vehicle. Fundamentally, a steering system counteracts a moment around the centerline of a tire. In most cases, the contact patch of a tire acts away from the centerline of the wheel, which creates this moment referred to as the pneumatic trail.

Choosing the correct actuator was one of the most important decisions made by the team, so it was critical to have data to back it up. Tire performance data obtained from the FSAE tire test consortium (FSAETTC) allowed us to determine the maximum force our actuator would experience. The conditions of one test matched those that would be experienced by our car under hard cornering. The results are shown in Figure 12, which indicate a maximum aligning moment of 98.9 N*m.

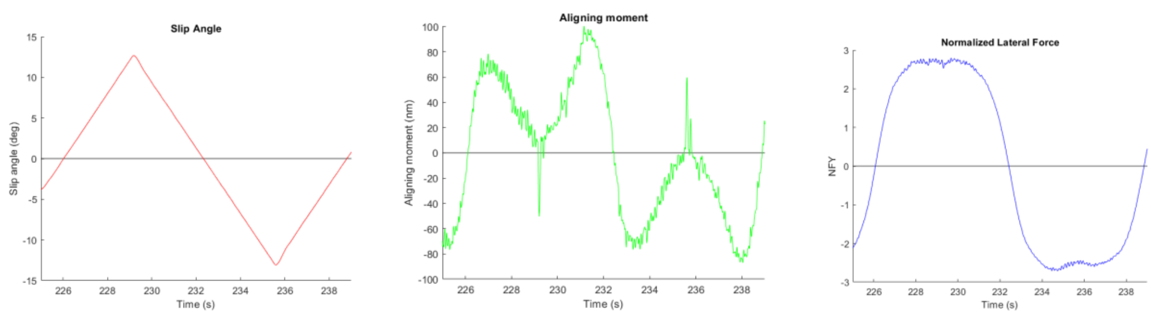

Figure 12: Coefficient of friction and Aligning moment with respect to slip angle.

Combining this information with a variable steering arm length, we were able to find the force required and thus create the decision matrix for the actuator.

Choosing the System's Components

As previously discussed, a decision matrix on the type of actuator determined an electronic actuator to be the most beneficial. In order to determine the best actuator for doing the job, market research was done to see what was available, which was then trimmed down using the specifications as listed in the *System Performance Metrics* section as applicable. It was found that actuators capable of mid-range forces, approximately 200 lbf, that had a built in potentiometer or encoder would be ideal. Issues arose surrounding the speed required of the actuator in order to provide a decent response time to driver input. After modification of the original mounting intent, an actuator was decided that was able to fix these problems. The team settled on the Linear Actuator PA-03 by Progressive Automations, which with proper packaging are able to quickly actuate through the full allowed range of motion of the rear wheels (*Linear Actuator PA-03*, n.d.).

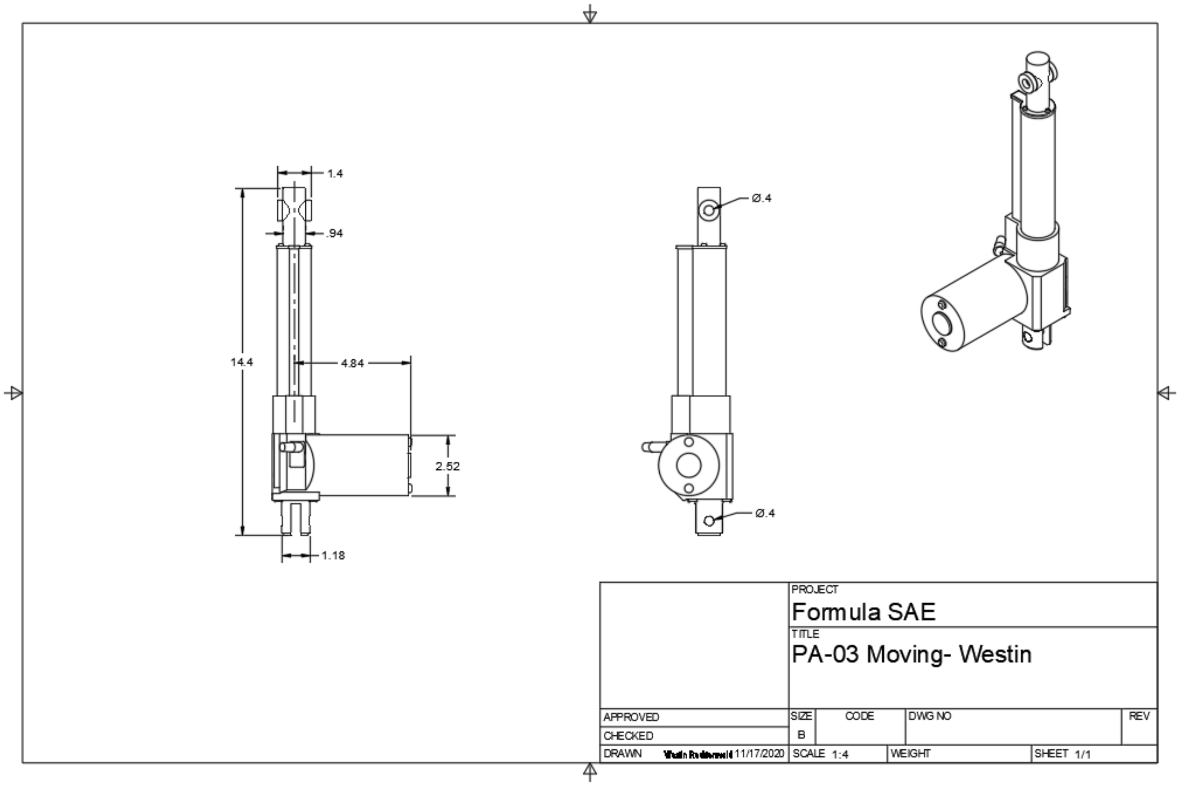

Figure 13: Dimensioned PA-03 actuator, unextended.

Figure 14: Image of PA-03 linear actuator (*Linear Actuator PA-03*, n.d.).

Another decision matrix was created to decide the type of sensor to use for data acquisition. The choices included an encoder, potentiometer or strain gauge. They were compared to each other based on cost, the accuracy of the data produced and whether there was much noise as well as ease of use. This decision matrix followed the same format as the one for actuator type (see Table II). The potentiometer had the highest total number of points and was selected for the design. Choosing a specific potentiometer was simple, because its travel needed to be matched to the steering column's travel of 248 degrees. A resistance of at least 1 kOhm was necessary to be compatible with the board voltage, and it needed to be mountable to our steering rack. Our final choice was the KAZ Technologies Steering Angle Sensor, a potentiometer that met all the above mentioned needs as it is designed for the steering rack the team used. As a result, this potentiometer would be easy to mount and have enough resolution for our steering rack's actuation.

Table II

Decision Matrix for Data Acquisition Sensors

Categories	**Cost**	**Noise**	**Accuracy**	**Ease of Use**	**Total**
Options/**weight**	**1**	**2**	**2**	**3**	
Encoder	0	2	2	1	11
Potentiometer	2	0	2	2	12
Strain gauge	1	1	1	0	5

The hall effect sensor was an even simpler selection as it only needed to read a digital signal for the vehicle's speed. Our choice was the 7674K25 from McMaster-Carr with an input voltage range from 15V - 34V and a max current of 150mA. This hall effect sensor was deemed more durable and robust than other options considered, and was easy to mount on the current setup. The presence of the castle teeth on the vehicle's half shafts will provide a sufficient magnetic field to activate the sensor's detection.

Encoder Analysis and Choice

Because the linear actuator's motor we chose does not have any motor feedback (such as a motor encoder), the linear actuator's position is not directly known and therefore cannot be used to calculate the rear wheel's steering angle. Thus, a sensor must be integrated into the system to provide the information necessary to calculate the wheel's steering angle. Specifically, a linear potentiometer or linear encoder could be mounted in line with the linear actuator, thus effectively yielding the needed information in the form of the linear actuator's change in length over time. This method of sensing was not pursued due to the high cost of a linear potentiometer or encoder with the needed accuracy. Alternatively, a rotary potentiometer or rotary encoder could be mounted in line with the steering rocker's central pivot. In this orientation, the rotary sensor measures the steering rocker's angle, which can be used to directly calculate the rear wheel's steering angle. The rotary encoder mounted in line with the pivot of the rocker's axis of rotation, as shown in Figure 15, was ultimately chosen due to ease of mounting and because the encoder chosen provided the high accuracy needed.

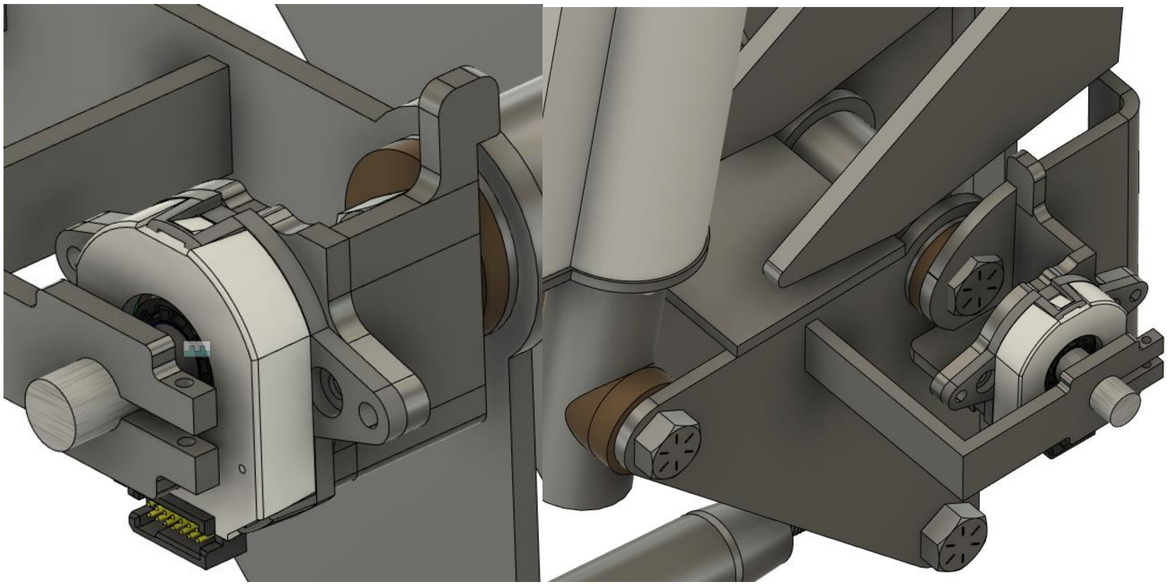

Figure 15: Virginia Motorsports' FSAE car's rotary encoder and encoder mounting.

The rotary sensor's resolution necessary for desirable system performance was determined by first by using the CAD assembly of the system to determine the actuator's total length of travel necessary to actuate the wheel to $\pm 6°$ of steer. After knowing that the actuator must travel a total of 0.84", the steering rocker angles corresponding to maximum right and left steering directions were determined using the rear steering geometry. The total travel of the steering rocker is 16.36°. Therefore, the rocker (and thus rotary sensor) rotates 1.36° for every one degree of wheel steering angle (16.36/12 = 1.36°). To determine the sensor resolution needed, it was necessary to decide that inaccuracies in less than 0.1° of wheel steering angle would be unperceivable to the vehicle's driver and would cause no tangible change in vehicle performance. Thus, the minimum number of pulses per revolution of the rotary encoder is 2678 PPR ($\frac{1.36°}{10} \cdot \frac{365°}{rev} = 2678$ PPR). The rotary encoder chosen for our project was the AMT 203-V.

Hall Effect Sensor Choice and Mounting

The hall effect sensor needed to be mounted close to the rear axle's castle ring to receive the signal necessary to calculate wheel speed. To hold the hall effect sensor in a desirable location, a sheet metal bracket was designed that allows the sensor's position relative to the castle ring to be adjusted in order to ensure optimal sensing accuracy. This sheet metal bracket bolts onto the rear suspension upright using one of the same bolts that holds the brake caliper mount to the opposite side of the upright. This is shown in Figure 16.

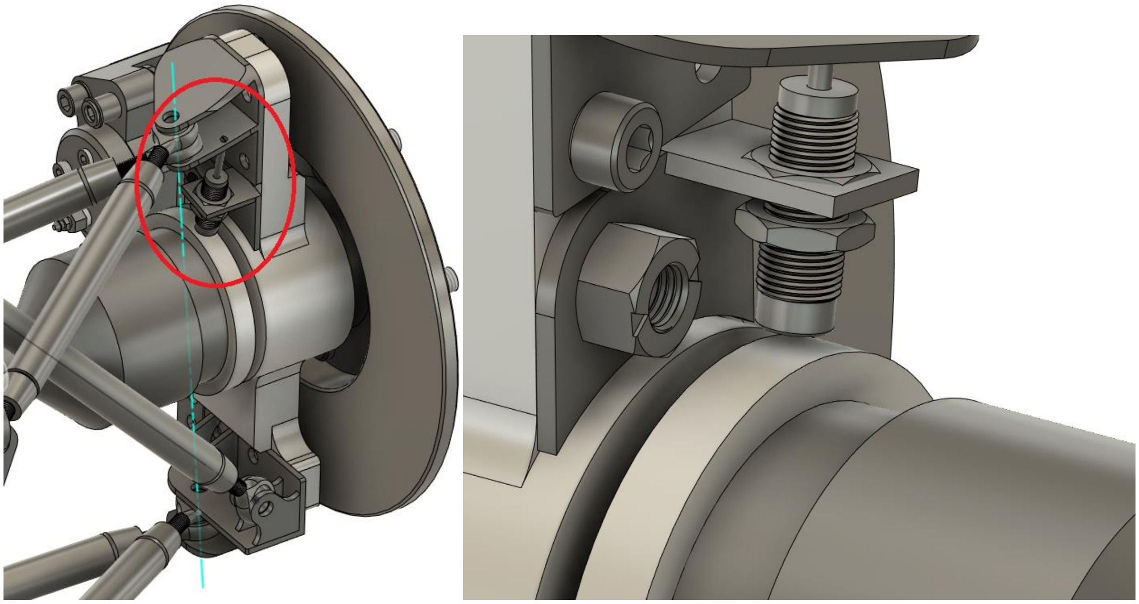

Figure 16: Virginia Motorsports' FSAE car's hall effect sensor mounting.

Mounting the Actuators

Packaging the actuators proved to be one of the most challenging aspects of the system's mechanical design. The trade-off between size of an actuator and the power it is capable of producing greatly affects the placement of its mounting points: smaller actuators require a longer steering arm to overcome the torque, but may not have the speed that is required for matching driver input. Since the team decided that a large and fast actuator was needed to meet the design requirements, a suitable mounting position directly to the steering arm could not be found. To overcome this a "remote" mounting system was devised so that the actuator could be located in a more desirable position. Taking cues from the inboard suspension which uses a pushrod and rocker to translate linear motion, a similar system was devised for the actuator. Figure 17 shows the subsystem with the actuator, rocker, and pushrod attached to the frame tabs and upright. Figures 18, 19, and 20 show dimensioned drawings of the rocker, tie rod, and their dimensioned placement in the overall system respectively. It is important to note that the rocker has a 1:1 ratio which means it provides a direct force translation from the vertical direction to the horizontal.

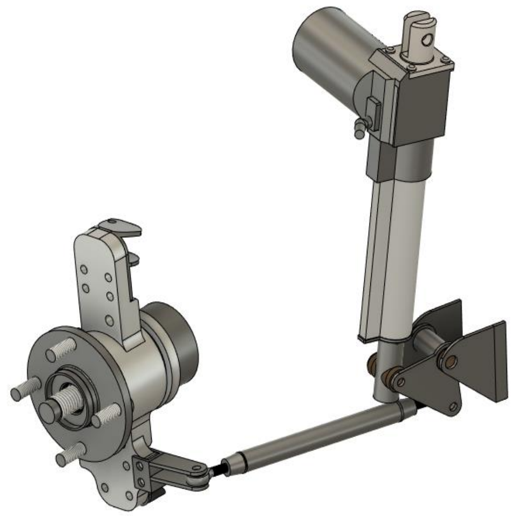

Figure 17: RWS subsystem CAD model.

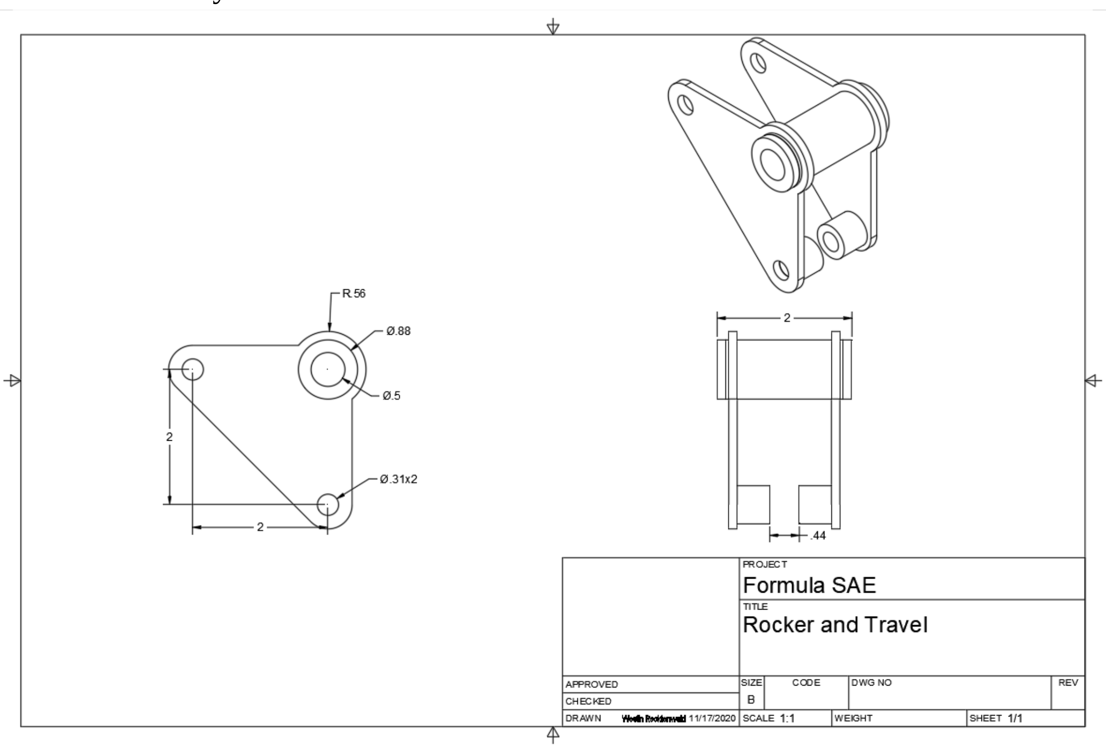

Figure 18: Dimensioned Drawing of Rocker in RWS subsystem.

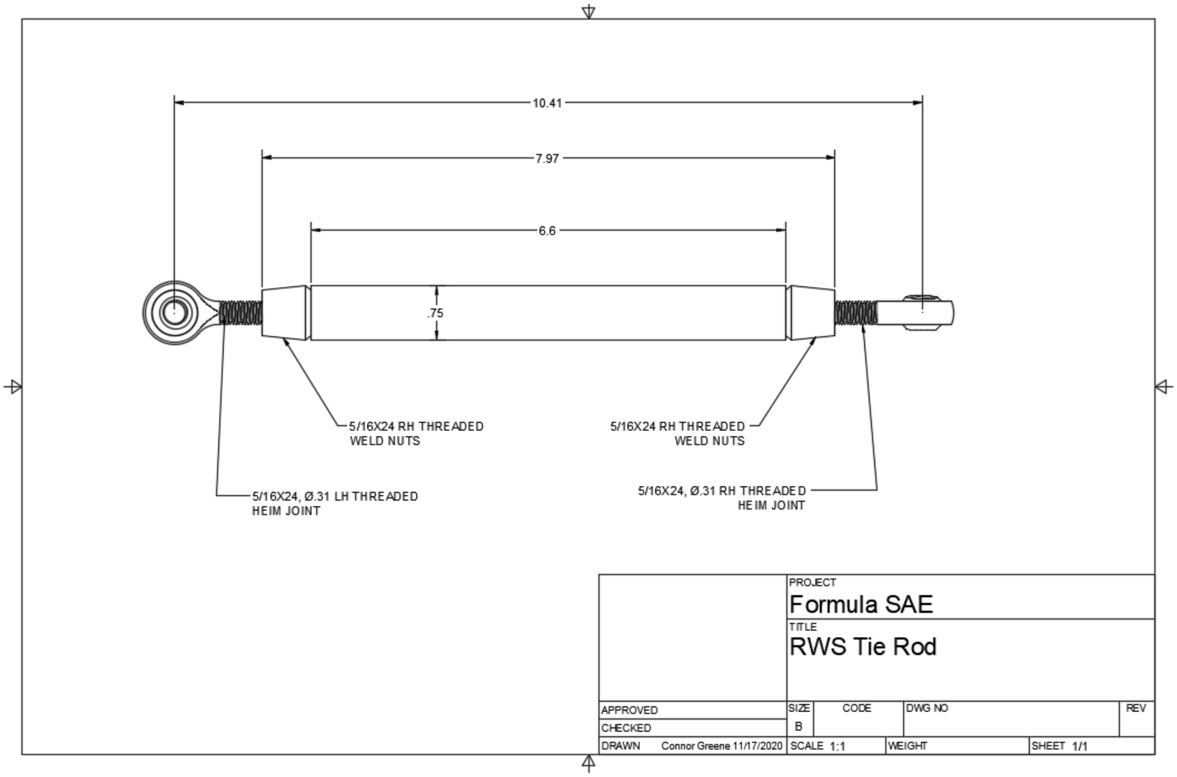

Figure 19: Dimensioned Drawing of Tie-Rod in RWS subsystem.

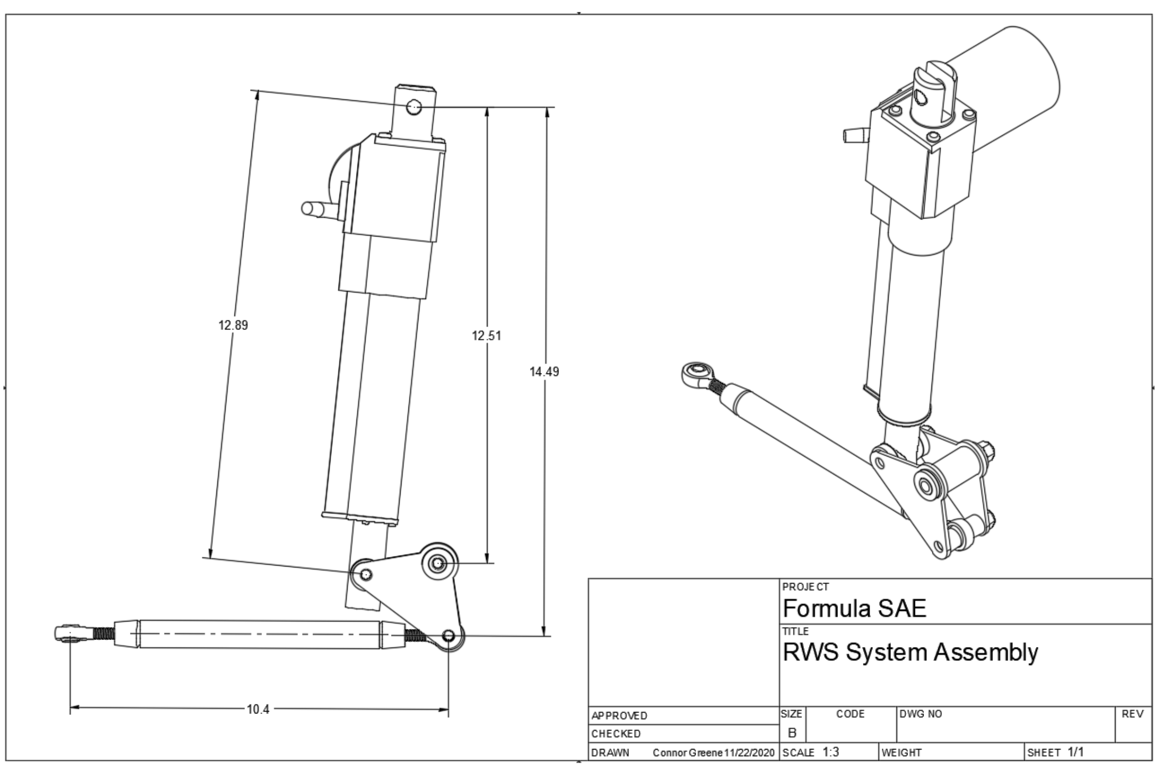

Figure 20: Dimensioned Drawing of RWS System Assembly.

Sheet metal will be used to construct the mounting tabs as well as the body of the rocker. We will use the waterjet to cut the profiles which will then be welded to the spacer cylinders on the rocker. Bushings will be purchased from McMaster-Carr and press-fit into the rocker. The tie rods will have McMaster-Carr weld-nuts and heim joints which are left- and right-hand threaded pairs as noted in Figure 19. This will allow us to adjust the length of the tie rod by twisting the body in one direction.

Analyzing the Design with Finite Element Analysis

Finite element analysis (FEA) is a method of predicting how a model reacts as a whole to various physical effects such as stress and displacement. A mesh breaks down the model into a finite number of smaller pieces known as elements. Predicting the behavior of each element, in turn, predicts the behavior of the model. Constraints and loads can be applied to simulate the environment. Computers are efficient at predicting behavior by analyzing mesh data. An FEA stress analysis was performed on the rear upright of the current car to see the effect of tire interaction. A more extreme case was considered in determining the loads applied as a precaution. 9000 N was applied in the vertical direction, 6000 N radially to where the wheel hub would attach and 6000 N laterally. The results of the study produced a model showing where the stress was concentrated. The most significant amount of stress, 36.78 MPa, occurred at the ends. With a safety factor over 7, the upright is not expected to fail under the extreme load case.

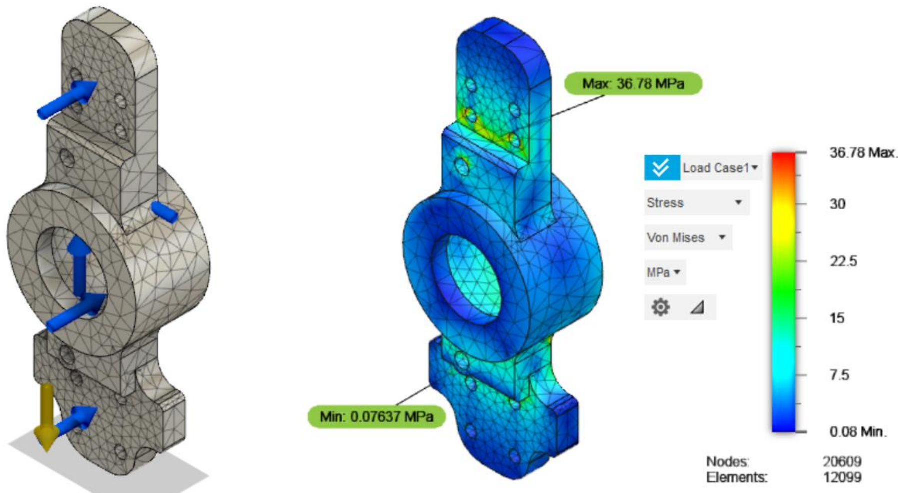

Figure 21: Rear upright with loads applied and the subsequent stress simulation.

Another stress analysis was performed on the rocker to see if it would be able to withstand the force output of the linear actuator. The maximum expected load was 300 lbs which was applied vertically to one end of the plates. The most amount of stress occurred around the bolt holes in the plates and was calculated to be 40.01 MPa. With a factor of safety of 5.1, the rocker is expected to be able to withstand the maximum force output.

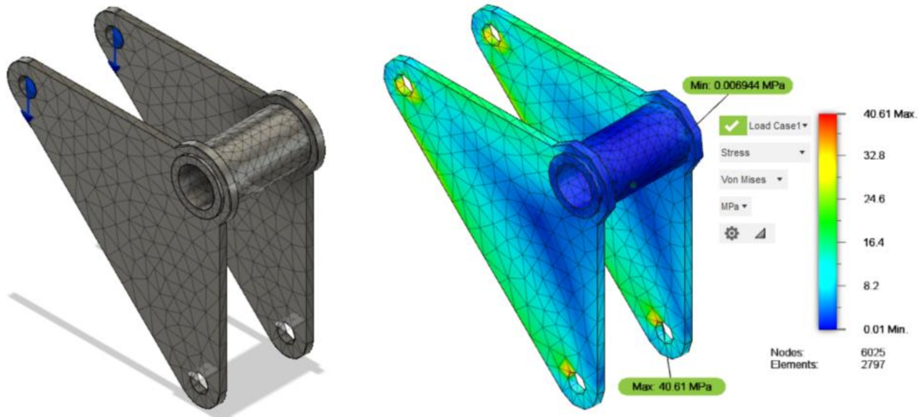

Figure 22: Rocker with loads applied and the results for the subsequent stress simulation. The left image shows the rocker CAD with the FEA mesh overlaid on top. The right image depicts the results of the FEA stress simulation highlighting the minimum and maximum points of stress measured in the component.

Electronics and Controls Design Overview

Developing the Controls Algorithm to Achieve the Desired Steering Performance

Once the desired high speed and low speed steering performance of the vehicle was determined, the team worked on designing the algorithm that would result in this performance using Matlab and Simulink. To start, the inputs and outputs of the system were identified and the controls algorithm was broken down into four main sections: the input signal section, the steering geometry section, the fail safe check section, and the control loop section. The inputs for the system include the steering rack potentiometer signal, the kill switch signal, and the vehicle's wheel RPM signals from its two rear wheels and the outputs of the system are the desired PWM voltage signals to actuate the right and left rear linear actuators.

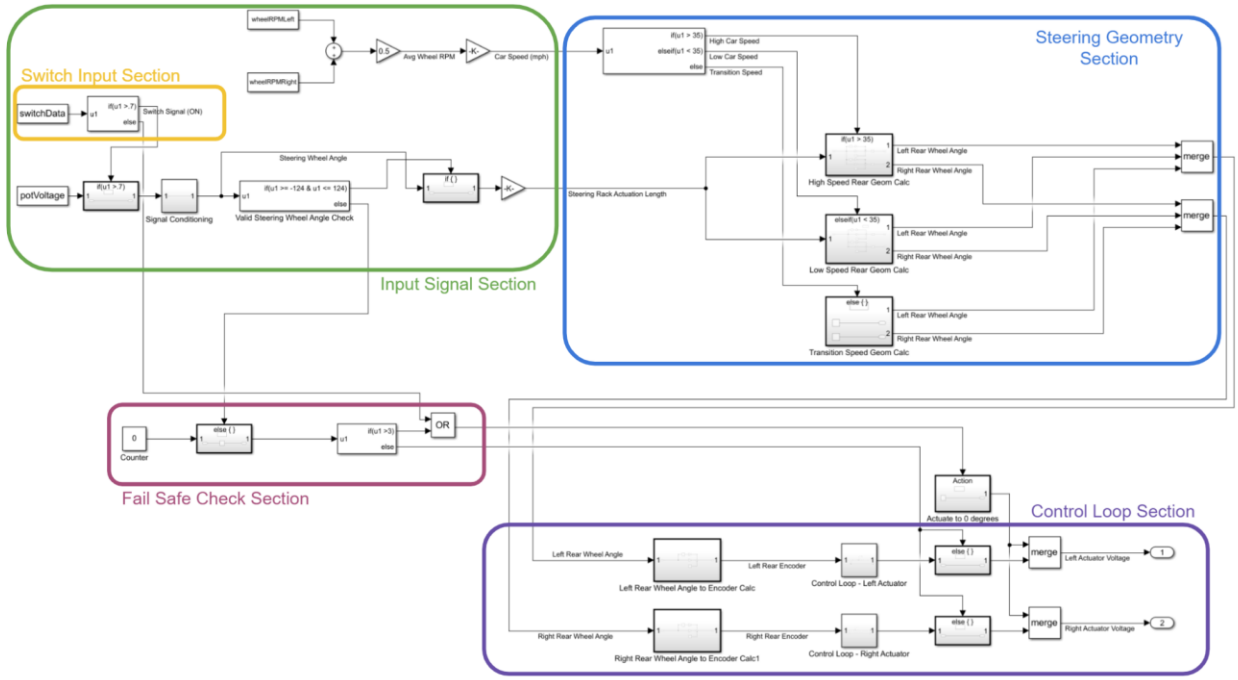

Figure 23: Overall System Block Diagram. This image shows the overall block diagram representation of the vehicle's control system algorithm. This algorithm takes in the steering rack potentiometer signal, the kill switch signal, and the vehicle's wheel RPM from its two rear wheels as inputs and outputs the voltage signals required for the left and right rear wheel linear actuators in order to actuate the rear wheels to their desired angles. It is organized into four main sections: the input signal section, the steering geometry section, the fail safe check section, and the control loop section.

As shown in Figure 23 above, the first section is the input signal section that takes in input from the kill switch, the steering rack potentiometer, and the vehicle's wheel RPM sensors and outputs the car speed and steering rack actuation length. This section is responsible for converting the voltage signal from the steering rack potentiometer into a steering rack actuation length value that can then be used in the steering geometry section, conducting input validation to ensure that the potentiometer signal being received is a valid value, and calculating the vehicle's speed based on the average of the RPM signals from the vehicle's rear wheels. This section also works with the fail safe check section to determine whether or not this supplemental rear wheel power steering system should be active by checking if either the kill switch is off or if the steering rack potentiometer has read too many invalid values. If either of these cases occurs, the system will turn off resulting in the rear wheels being actuated back to their neutral position.

After calculating the vehicle's current speed and steering actuation length, the steering geometry section then uses these two inputs to determine the vehicle's desired rear left and right wheel angles. To do so, the algorithm first determines if the vehicle speed is high, low, or at the transition and then feeds the steering rack actuation length to the appropriate speed's geometry calculation block (see Figures 24, 25, and 26). As determined previously, at high speeds, the vehicle will have Parallel costeer geometry where both rear wheels are actuated to the same steering angle (see Figure 24). At low speeds, the vehicle will have Ackermann countersteer geometry we calculate using a predetermined relationship between steering rack actuation length and rear wheel angles. Since the relationship for each of the rear wheels is different, different gains are used in the calculation as shown in Figure 25. Finally, at the vehicle's transition speed, the left and right rear wheels will be actuated to a zero degree angle, or to their neutral positions, which results in no rear wheel power steering assistance at this speed (Figure 26). This allows the vehicle to have a simultaneous transition from Ackermann to Parallel steering geometry and from countersteer to costeer. Since the competition limits the motion of the rear wheels to a maximum of 6 degrees, each of these geometry calculation blocks uses a Simulink saturation block to prevent the desired rear wheel angle signals from being more than 6 degrees away from the neutral position.

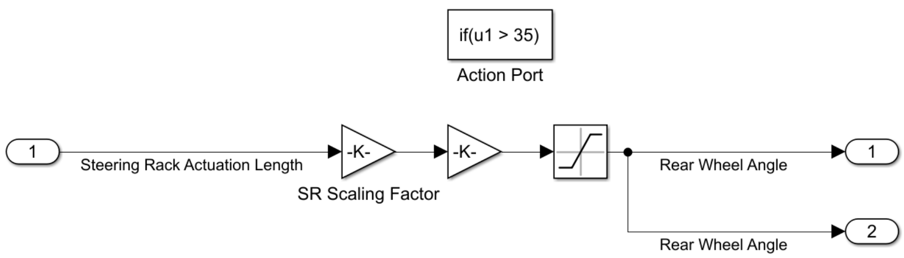

Figure 24: High Speed Geometry Calculation Block Diagram. This image shows the calculation of the desired left and right rear wheel angles from the left and right front wheel angles if the car is at a high speed using Parallel costeer steering geometry. The equations are based off of our steering geometry CAD sketches.

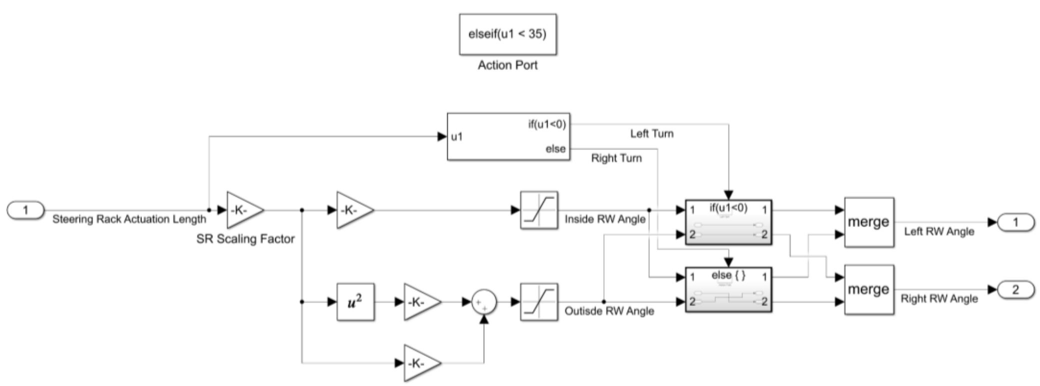

Figure 25: Low Speed Geometry Calculation Block Diagram. This image shows the calculation of the desired left and right rear wheel angles from the left and right front wheel angles if the car is at a low speed using Ackermann countersteer steering geometry. The equations are based off of our steering geometry CAD sketches.

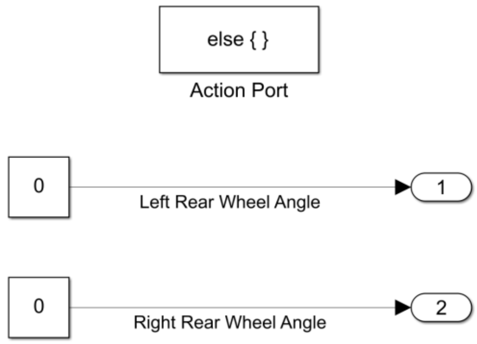

Figure 26: Transition Speed Geometry Calculation Block Diagram. This image shows the calculation of the desired left and right rear wheel angles from the left and right front wheel angles if the car is at the transition speed, resulting in the rear wheels being actuated to their neutral position (0 degrees of rear wheel steering).

To calculate the high speed and low speed geometry equations that relate the steering rack actuation length to the rear wheel angles, a coded script was used in conjunction with CAD sketches of 2D views of our steering geometry. Since our Fusion 360 CAD software's API has a built-in ability to run Python scripts, we used Python to write our script to allow us to interface with and iterate quickly through different dimensions in our CAD sketches. Using this script, we iterated through different rear wheel angles from -6 to +6 degrees and saved the corresponding steering rack actuation length. Finally, we plotted these points in Excel and found the best fit curve for the relationship between the rear wheel angle and the steering rack actuation length and the corresponding equations. Since only a small portion of the steering rack length was used in a 1:1 ratio between the front wheels and rear wheels for ± 6 degrees of rear wheel steering angle, we wanted to be able to scale the inputs to these equations. This would allow us to have the rear wheels change their steering angle over a larger range of the steering rack's actuation. In order to allow for accurate scaling of the steering rack actuation input, when determining the best fit curves for the relationship between steering rack actuation length and rear wheel angle, we set the intercept of the best fit curve to run through the origin. As shown in Figure 27, the resulting best fit curves were linear relationships for outside wheel angle at low speeds and the rear wheel angles at high speeds and a second degree polynomial relationship for the inside wheel angle at low speeds.

Figure 27: Delta of Rear Wheel Angle vs Actuation of Steering Rack for left and right rear wheels at low speed and high speeds.

Between the steering geometry section and the control loop section, the desired rear wheel angles are converted into desired encoder position values using a conversion value determined from our rear wheel steering CAD assembly. As explained within the **Mechanical Design Overview** section, the rocker (and thus rotary encoded) rotates 1.36° for every one degree of wheel steering angle. These signals are then used in this algorithm's last section, the control loop section. In this section, the desired encoder position values are put through two separate control loops which each output the required PWM voltage signal to actuate their corresponding actuator to the desired positions. Looking more closely at the control loops, Figure 28 shows this loop is a negative feedback loop with the controller and the physical system modeled in the feedforward portion of the loop. The controller is designed to be a PID controller in which we will use the proportional component to tune the control system's response, the integral component to ensure that the control system response has zero steady state error, and the derivative component to counteract the lag in the system's feedback loop.

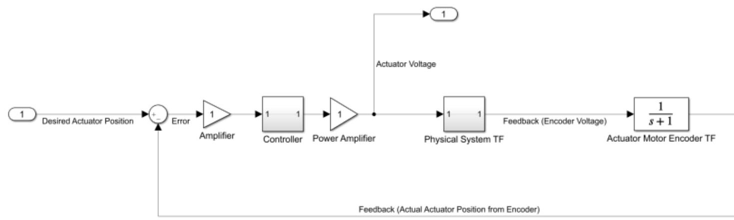

Figure 28: Control Loop Block Diagram. This image shows the control loop portion of the vehicle's control system algorithm which features a negative feedback loop with the desired actuator position as the input and the required voltage to actuate the actuator to its desired position as the output.

Interfacing with and Wiring of the Electronics

To measure the actuation length of our steering rack, we used a potentiometer mounted directly onto the bottom of our steering rack. This potentiometer converts the rotational motion of the pinion gear in the rack into a proportional voltage that we measure using our Arduino Mega microcontroller. Since the Arduino Mega has designated pins that can do analog-to-digital conversion (ADC), interfacing with the steering rack potentiometer was quite simple. The power and ground wires of the potentiometer were connected to 5V power and sensor ground respectively while the signal wire was connected to a ADC pin on the Arduino Mega. To read the voltage value of the potentiometer into the Arduino Mega, we used Arduino's analogRead() function that converts the 0-5V voltage to a value from 0-1023 proportionally.

Figure 29: Front steering rack potentiometer placement, close-ups, and wiring diagram.

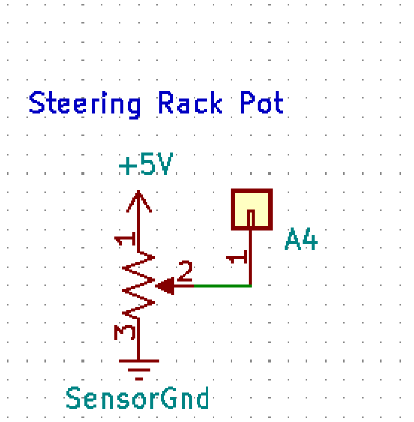

Figure 30: Wiring diagram for the steering rack potentiometer.

To read the vehicle speed from our hall effect sensors, we wired the sensors so that they received the necessary 12V power source, but only provided up to a 5V signal. As shown in the figure below, we limited the signal output of the hall effect sensor to 5V by using a pull-up resistor connected to the Arduino Mega's 5V power source. Since the hall effect sensor uses its grounding wire as a ground reference for its signal wire, we had to connect the battery ground with the sensor ground to ensure that the Arduino Mega and the hall effect sensors were using the same ground reference. As mentioned previously, the hall effect sensors are mounted above the rear axles' castle rings. As the rear axles rotate with the motion of the wheel, the hall effect sensors will measure the passing of the castle rings' teeth and can extrapolate the vehicle's wheel speed based on how many teeth the hall effect sensors measured passing by during a given period of time. Hall effect sensors work by sensing a change in the magnetic field surrounding it and as the teeth of the castle rings pass underneath it, the hall effect sensors' signals get pulled low. This pull to a low signal is what the Arduino measures and counts using digitalRead() to determine how fast the vehicle's wheels are moving.

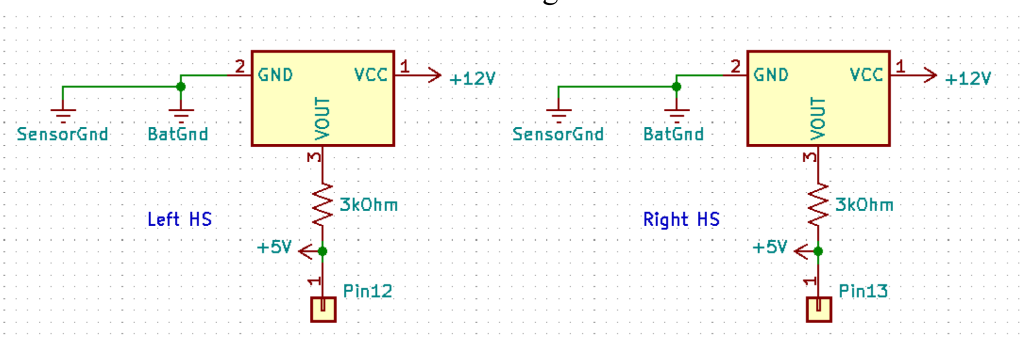

Figure 31: Wiring diagram for the left and right hall effect sensors.

To control the linear actuators, we used BTS7960 motor control units with integrated H-bridges to simplify the wiring. We chose this particular motor control unit because it's input voltage range included the 12V operational voltage of our actuators and because it allowed for forward and reverse pulse width modulation (PWM) motion control in a compact packaging. Since the Arduino Mega has designated pins capable of producing a PWM signal if given a value from 0-255, we elected to use those pins as part of our wiring as shown in Figure 33. Then, to send a PWM signal through the Arduino Mega, we used the built-in Arduino function analogWrite(). Besides PWM inputs for the forward and reverse directions as well as the expected power and ground inputs, our chosen motor control units also have inputs for enabling forward and reverse motion as well as side current alarm outputs for the forward and reverse directions. To control the activation of the motor control units, we also connected the inputs for enabling forward and reverse motion (R_EN and L_EN) to digital output pins on the Arduino Mega as shown in Figure 33. For enabling the motor control units to send power to the actuators, we set the output of those pins to HIGH in the setup section of our code. Because we did not need to use the alarm outputs on the motor control units, we left those unconnected.

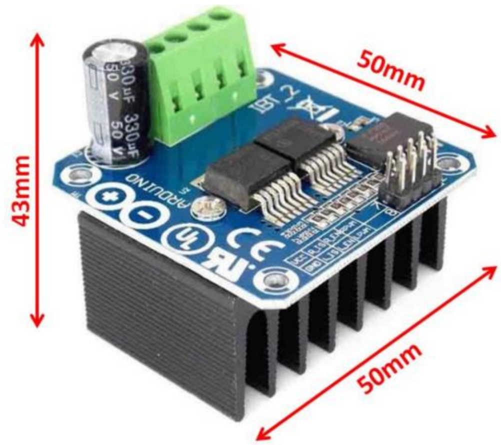

Figure 32: Motor control unit used to help control our linear actuators (Handson Technology, n.d.).

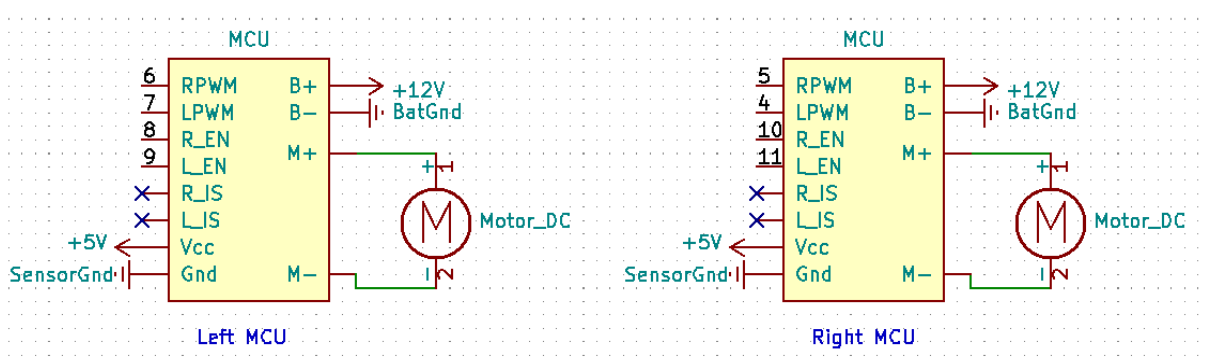

Figure 33: Wiring diagram for the left and right motor control units.

For our encoder, we chose to purchase the AMT 203-V quadrature encoder with absolute encoder capabilities programmed in. Since we wanted to be able to read our position definitively everytime, we chose to use the encoder's absolute encoder function. This required communicating with the encoder using Serial Peripheral Interface (SPI). Fortunately, the Arduino Mega has built-in pins for handling SPI communication. To read from both of our encoders, we used the designated SPI pins on the Arduino Mega and an additional digital pin for our second encoder's chip select. When programming the Arduino Mega to read from these encoders, we developed a helper method based on sample code provided by CUI Inc (Kelly, 2016).

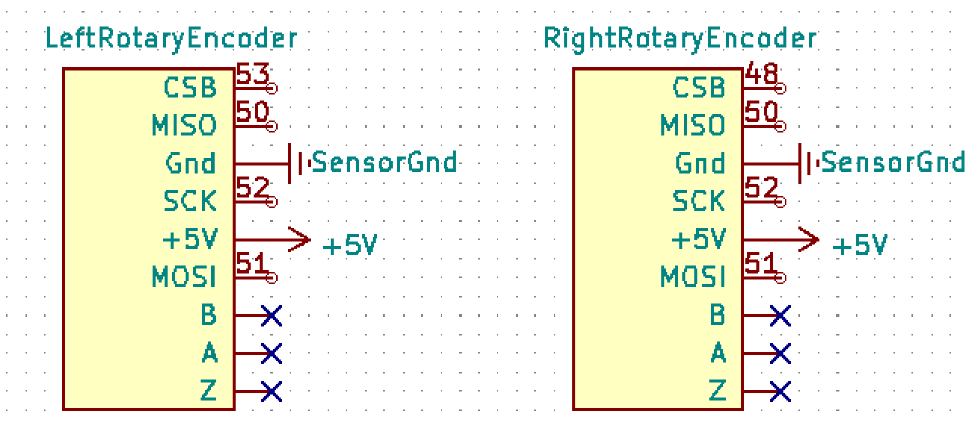

Figure 34: Wiring diagram for the left and right encoders.

To allow for the driver to activate and deactivate the supplemental rear wheel steering system, we also included a switch as part of our design. If this switch is on, our RWS system would be activated and the rear wheels would be actuated to their appropriate positions according to the driver's steering input. However, if this switch is ever turned off, our RWS system would be deactivated and the rear wheels would be actuated back to their neutral position. To read the signal from our switch, we wired it to 5V power and a digital input pin on the Arduino Mega as shown in Figure 35. To ensure that the pin always read a low signal when the switch was open, we incorporated a pull-down resistor as part of the circuit.

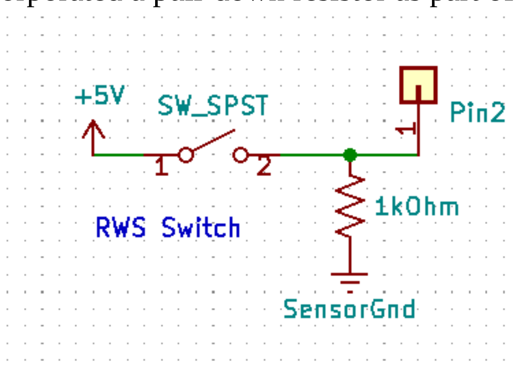

Figure 35: Wiring diagram for the RWS switch.

Implementing the Controls Algorithm on Arduino

The key to implementing the controls algorithm is the microcontroller used, the Arduino Mega. The block diagram developed in Matlab's Simulink provided the basic logic for the Arduino's code. With the setup of the block diagram in matlab to create the algorithm itself and do the tuning as needed, the Arduino can provide the implementation in two different methodologies. One method is to embed the Arduino capabilities within the Simulink model through the Simulink Support Package for Arduino (*Arduino Support from Simulink*, n.d.). The functionality of this setup allows the control logic of the block diagram to run on the Arduino board instead, which achieves a faster run rate for the controls algorithm and allows for faster sampling rates. The option the team went with was to code directly into Arduino's software system using Arduino IDE.

After developing helper methods to interface with each of the different sensors and actuators (steering rack potentiometer, hall effect sensors, encoders, and linear actuators), the next step was to directly code the pre-loop and main loop of our controls algorithm onto our Arduino Mega. For the pre-loop, we update all of our values for steering rack actuation length and vehicle speed based on our values from our steering rack potentiometer and our hall effect sensors. The pre-loop is also where we calculated our desired position values for our encoder based on these updated input values. Using the equations determined earlier for the relationship between steering rack actuation length and rear wheel angle, we first converted our updated steering rack actuation length to desired rear wheel angle. Then, using the conversion value we determined earlier for rear wheel angle to encoder angle, we convert our desired rear wheel angle to a desired encoder position. This desired encoder position value is the driving input for our control loop to move our linear actuators accordingly. For the main control loop, we used an Arduino library called Custom PID that helped simplify the coding of our PID control loop. With this library, we were able to define the values we wanted for our proportional, integral, and differential control as well as utilize its update function that takes in the actual error measured in the system and returns the adjusted PID error. This adjusted error is then used to determine the percent PWM to actuate each of the linear actuators in order for the actuators to best reach their desired length. As more testing was conducted, these PID coefficients were adjusted so as to provide a better response time and performance for the actuators.

Failure Mode and Effects Analysis (FMEA)

FMEA was performed on our system to attempt to predict the components with the greatest risk of failure. Table III shows the results of the analysis, with each category being rated from 1 to 5, 5 greatest.

Table III

FMEA chart for each component in the RWS system

Component	Severity	Occurrence	Detection difficulty	RPN

Actuator	5	2	2	20
Steering angle sensor	2	1	1	2
Wheel speed sensor	3	2	3	18
Microcontroller	4	2	2	16
Wiring	4	2	1	8

As an overview, the components with the highest Risk Priority Number (RPN) are the actuators, the wheel speed sensors, and the microcontroller. The actuator has the highest severity because it is the only component which is an output from the system, and if it were to fail unexpectedly the driver's control would be unpredictable. The wheel speed sensor has the second highest RPN because it would be fairly difficult to detect when the vehicle is stationary, and there is no visual confirmation of its function unlike the potentiometer which can turn. The microcontroller has the third highest RPN because while it is the interface between all of the other components, it would be fairly easy to detect and there is a low chance of failure. In summary, the group must be cognizant of the possibility of failure in those components and impose contingency plans for each should they fail. This may be difficult with the actuators as they make up a large portion of our budget, but when designing our system and selecting our actuators, we used an absolute worst-case scenario actuation force.

Manufacturing

Manufacturing of the rear wheel steering system required use of machines in Lacy Hall, our machine shop at the University of Virginia, including the waterjet, 3-axis CNC mill, manual lathe, bandsaw, and TIG welder. The manufacturing processes for each component of the system are described in the subsections below.

Tie Rods

4130 steel tubing, outer diameter 0.75", wall thickness 0.065", were used as the tie rod's main structural member. The tubes were cut to length on a bandsaw. Weld nuts purchased from McMaster Carr were welded to each end of the tube, with one of them being left-hand threaded and the other right-hand threaded. Matching threaded heim joints purchased from McMaster Carr were then screwed into the weld nuts.

Rockers

The 2D profile of the rocker was cut using a waterjet from 0.125” thick low carbon steel plate. The cylinder that houses the pivot bushings was CNC milled from a 1” outer diameter low carbon steel cylinder. The spacers allowing the tie rod’s heim joint to be mounted to the rocker were manually turned from 0.75” outer diameter low carbon steel cylinder stock. The bushing housing and rocker profile plates were then welded together, using the bushing sleeves and heim joints as pins to ensure geometric accuracy was maintained. The final rocker assembly is shown in Figure 36.

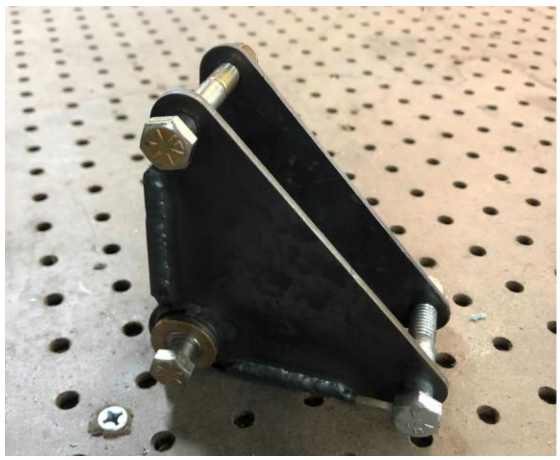

Figure 36: Rocker assembly with bushings and hardware

Actuator and Rocker Mounts

The profile of the mounts attaching the rocker to the frame were waterjet from 0.125” thick low carbon steel plate. The tabs were bent using a metal brake and then welded to the car’s frame. Bump stops were also produced in a similar way and welded to the frame. The upper mount for the linear actuator needed to be 0.4 inches, so 0.5 inch thick steel plate was faced with the CNC mill, waterjet to final size and shape, and then welded to the frame. Figure 37 shows the welded mounting features on the frame with no components attached.

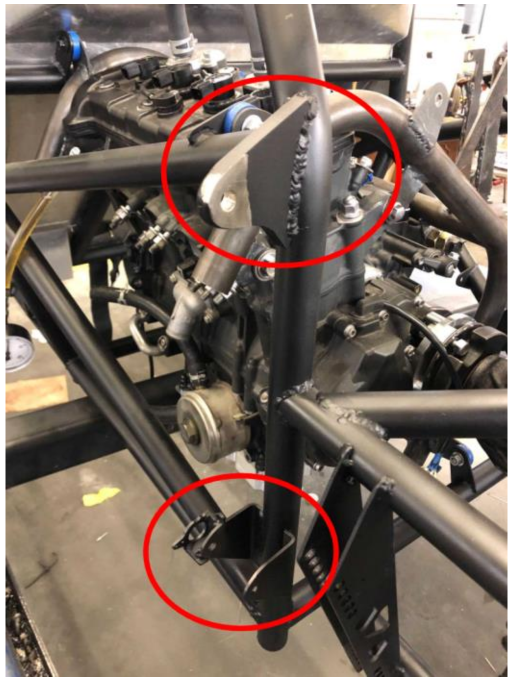

Figure 37: Welded mounting tabs for the rocker and linear actuator

Electronics Board

A custom circuit board was designed using a solderable busbar board and header pins. After iteratively testing our circuit board design using a breadboard to ensure all the wiring was correct (see Figure 38), we then transferred the design onto our solderable busbar board as shown in Figure 39.

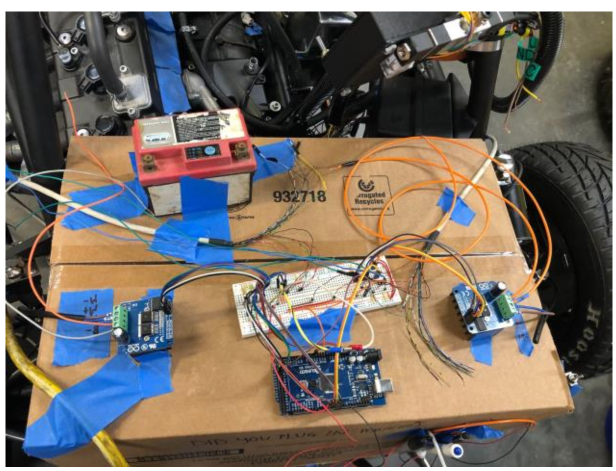

Figure 38: Breadboard set-up of our custom circuit board. This set-up was used to iteratively test each of our separate components' wiring.

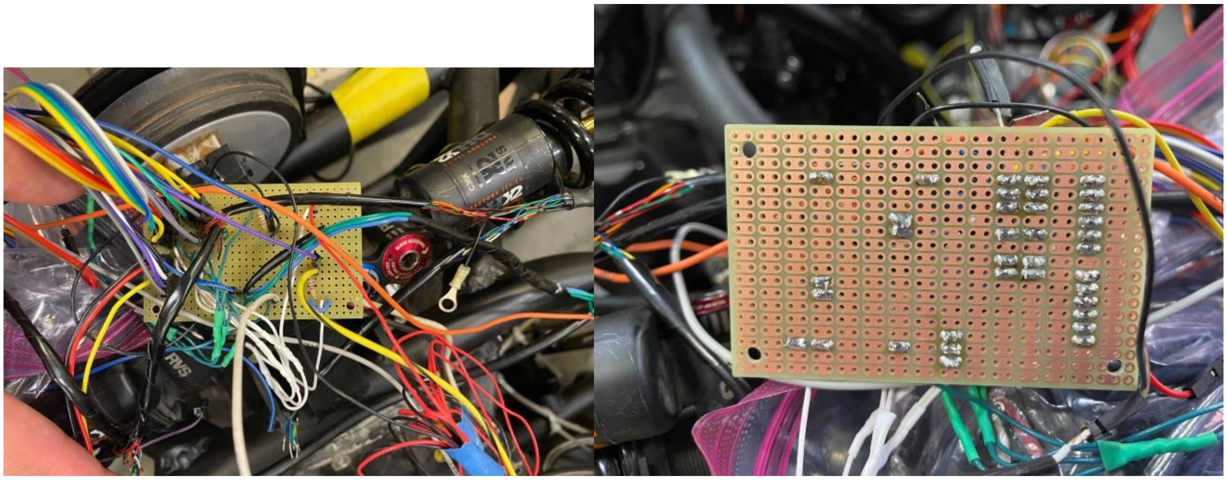

Figure 39: Custom circuit board design. Top view (left) and bottom view (right)

Challenges

The team encountered several challenges when manufacturing the RWS assembly. Most notably, distortion experienced in welding the rocker led to a far greater amount of tacks necessary than would be expected. Using hardware as aligners as explained above was necessary to ensure the parts would line up again once the part had cooled down. Another challenge was maintaining consistency across both assemblies: since tabs were “floating” on frame members, jigs were necessary to make sure they were placed at the right height and angle. Overall we were able to deal with the challenges quickly and effectively, resulting in a smoothly actuating mechanical system.

Testing Plan

Controls Algorithm Testing Plan

For the controls system, we hoped to test our controls algorithm through simulation both with real-world data and hypothetical, edge-case scenario data to ensure the robustness of the controls algorithm. To collect real-world input data, the team would have recorded data from the steering rack potentiometer and vehicle wheel RPM sensors while a driver conducts practice laps both under normal circumstances and under scenarios with rapid steering changes. This would help test how the controls system performs under real-world operating conditions as well as determine how good the signal conditioning portions of the system are at reducing the noise in the input signals. To test edge-case scenarios for system robustness, the team would have developed hypothetical input data for the steering rack potentiometer and vehicle wheel RPM sensors. This hypothetical data would help test how the controls algorithm will react to various invalid input signals and other potential hardware or software errors. Unfortunately, our team ran into time constraints with this project and was unable to complete this portion of our testing plan.

Whole System Testing Plan

The steering system will be tested dynamically once it is installed on the FSAE car. Testing will be broken into two categories: low vehicle speed and high vehicle speed performance. Low speed performance of the steering system will be quantitatively evaluated by slowly driving or pushing the car through a corner at maximum steering actuation. The turning radius of the car can then be measured from the centerpoint of the turn. The test will be conducted both with the electronic rear wheel steering system activated and with the system deactivated. Turning radius achieved with and without the rear wheel steering system activated will then be compared.

The high vehicle speed test will measure the car's ability to make an agile high speed lateral "lane change" on a course similar to that shown below in Figure 40. The vehicle will be driven though the course both with and without the rear wheel steering system activated. Vehicle speed during each test will be recorded and will continue to be increased until the vehicle hits a cone marking the course boundaries. The maximum speed achievable without traveling outside the prescribed course will be compared between the tests done with and without the rear wheel steering system activated to determine the high speed performance benefits of the rear wheel steering system.

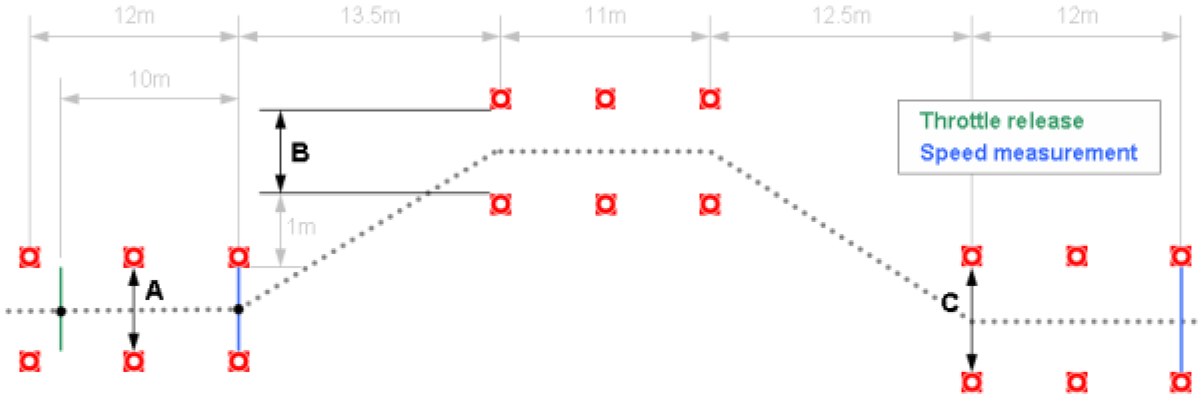

Figure 40: ISO Double Lane Change Test (ISO, n.d.).

Testing Results and Analysis

The effectiveness of the low speed steering geometry was tested by conducting a turning radius test both with and without RWS activated. The test was conducted a total of four times: twice with and twice without RWS activated. The average turning radius between the two tests is reported here. High speed performance has not yet been tested due to testing and tuning of our FSAE car's engine not aligning with this project's timeline. The low speed turning radius test setup can be seen in Figure 41. The frame of the vehicle was aligned to be parallel with a string marking a constant datum defining the starting position of the car. Yellow tape was also used to mark the centerline of the car's rear axles and the middle of the car to ensure consistency between each test.

Figure 41: Turning radius test starting setup.

For each test, the steering wheel was turned completely to the left and held at this position for the duration of the test. The vehicle was slowly rolled around a 180 degree arc beginning and ending along the string taped to the ground shown in Figure 42. To quantify the effectiveness of the RWS system, the turning radius test was conducted both with and without RWS activated. Without RWS activated, the vehicle's turning radius was 3.38 m. Figure 42 also shows the vehicle's path, marked with yellow tape, during this test without RWS engaged.

Figure 42: Turning radius test without rear wheel steering. (3.38 m turning radius).

With rear wheel steering activated, the vehicle's turning radius is 2.89 m. The vehicle's path with rear wheel steering engaged is marked with blue tape in Figure 43.

Figure 43: Turning radius test with rear wheel steering (blue tape marks path with rear wheel steering engaged). (2.89 m turning radius)

A 14.5% decrease in the vehicle's turning radius was achieved by the rear wheel steering system utilizing the low speed geometry. A close-up of the end of the vehicle's path with and without rear wheel steering activated is shown in Figure 43. While this 14.5% decrease in turning radius is not the 20% decrease our team was looking to achieve, this decrease is still substantial and will greatly improve vehicle agility and speed during low speed maneuvers. A much larger decrease in turning radius could be achieved if the rear wheels were able to be actuated beyond the ±6° of wheel angle allowed by the FSAE competition rules.

Figure 44: Close up view showing vehicle path with rear wheel steering activated (blue) and without RWS activated (yellow).

While care was taken to ensure consistency between tests, a more robust testing procedure would have increased accuracy. Specifically, it was difficult to position the vehicle in the exact same location at the beginning of each test. As shown in Figure 43, the blue (RWS activated) path initially swings out in a larger radius than the yellow no RWS path, thus indicating that the car was slightly misaligned relative to the string datum between the tests. Accuracy could have been improved by taking greater care to initially align the car before each test, and wheel casters could have been used to more easily manipulate the car into a consistent starting position. In total, this RWS system adds roughly 10 pounds to the vehicle, and thus we remained within our goal of adding less than 12 pounds to the net vehicle weight. We did not meet our weatherproofing and shock proofing goals due to time constraints and the nature of our prototype testing setup.

Table IV

Comparison of our Results and our System Requirement Goals

Specification	Plan	Actual	Did we meet it?
Low Speed Turning Radius	Decrease current vehicle low speed turning radius by 20% (currently 3.3m)	Low speed designed and works, 20% decrease in turning radius was not achieved	✗
High Speed Maneuverability	Improve high speed maneuverability, measure with "lane change" or obstacle avoidance test	High speed designed and works (test to be completed)	✓
Stay within $950 budget	Stay in budget and consider costs when purchasing items	Spent approx. $900	✓
Fail Safe System	Incorporate a fail-safe system to return rear wheel angles to 0 in case of unacceptable sensor values or driver choice	Fail safe system designed and functionality confirmed	✓
Weather/Shock Proofing	Be weatherproof (IP54+) and shockproof	Products rated as low as IP 43, but is plenty weatherproof for our competition	✗
Weight	Add < 12 lbs to the vehicle weight	Approx. 10 lbs added	✓

Project Schedule

The initial plan for the project was to spend fall semester focused on research and conceptual development for the RWPS system, and in the spring semester start to manufacture and install the hardware of the car then test the system as a whole before the FSAE competition in May (as seen in Figure 45). This whole process was estimated to take twelve weeks each semester to complete, for a total of 24 weeks for the entire project. This schedule allowed for some leeway in case the team came across any difficulties. Alongside manufacturing, the controller was to be designed and programmed in addition to the wiring and programming of the individual sensors during the spring.

During the fall semester, major decisions were made in regards to the design and the preliminary design was drawn and assembled in CAD. The team was on track in terms of our pre-determined schedule throughout the semester, meeting deadlines as needed, with slight delays caused by design iterations later on in the semester when problems arose with actuator mounting. At the end of the fall semester, a new schedule was drafted up with more detail to better represent the plan for the spring semester, as seen in Figure 46. The start of the spring semester followed the plan to some accuracy, but issues arose with delays in the coding and manufacturing of the vehicle as a whole. This, paired with an unequal distribution of responsibilities, led to the schedule being shifted in certain areas, with controller tuning and full-system testing not starting until the start of May. Overall, despite not staying completely on schedule, the RWPS system was still completed and tested by the end of production on May 7th.

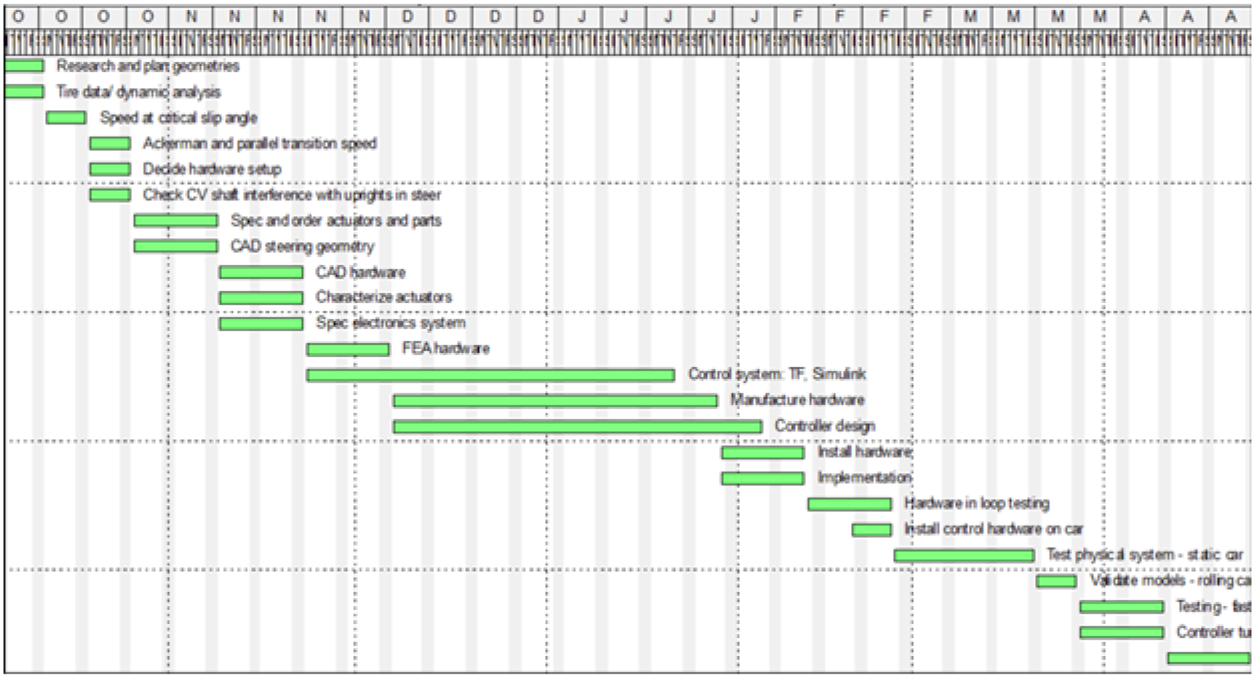

Figure 45: Whole Year Gantt Chart for Virginia Motorsports' Supplemental Rear Wheel Power Steering Project.

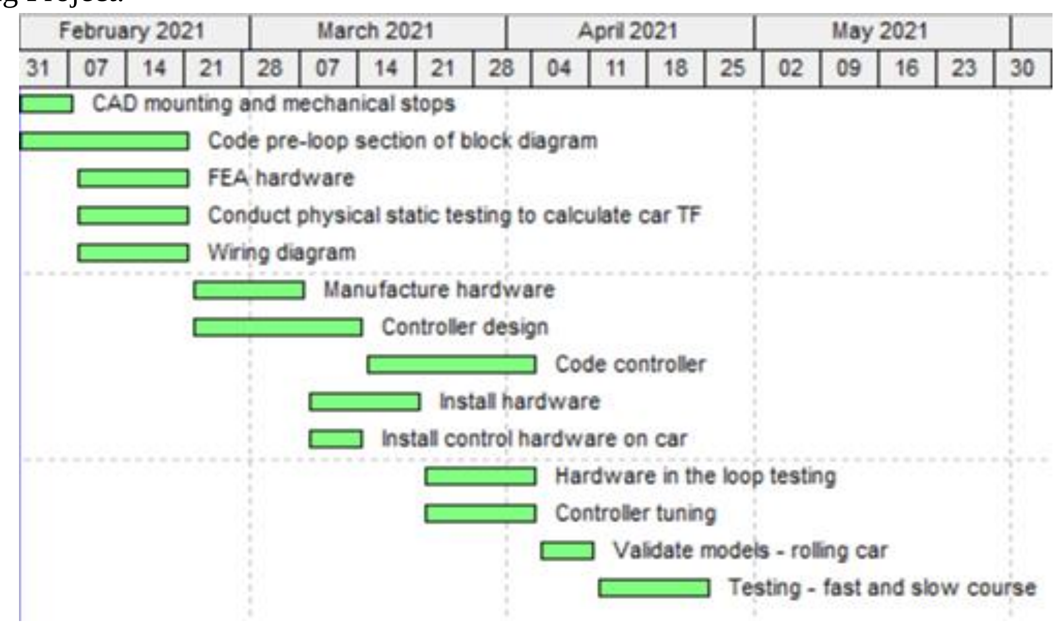

Figure 46: Updated Spring Semester Gantt Chart for Virginia Motorsports' Supplemental Rear Wheel Power Steering Project.

Project Budget

The main sources of funding for this project come from the Capstone Discretionary Funding ($450) and the Student Engagement Funding ($500), totaling up to $950. The Student Engagement Funding was applied for by the members of the Capstone group under the name of the Virginia Motorsports organization and the Capstone Discretionary Funding is allotted to the group by the university. A large portion of the budget will go towards the electronic linear actuators, the PA-03 Actuators provided by Progressive Automation, and another larger portion of the budget will go towards other necessary electronics such as the microcontroller, steering rack potentiometer, encoders, and hall effect sensors. The remaining budget will be mainly used for additional electronics supplies including the busbar boards for manufacturing our custom circuit boards as well as other various hardware and materials needed to construct the system as shown in Table V.

Table V

Virginia Motorsports' Budget for Supplemental Rear Wheel Power Steering Project

Assets				Amount
	Capstone Discretionary Funding			$450.00
	Student Engagement Funding			$500.00
Total Assets				$950.00
Expenses		Quantity	Per Part Cost	Cost
	PA-03 Actuators	2	$137.33	$274.66
	Arduino Mega Microcontroller	1	$64.38	$64.38
	Steering Rack Potentiometer	1	$145.33	$145.33
	Hall Effect Sensors	2	$47.48	$94.96
	Encoders	2	$50.31	$100.62
	Encoder Cables (purchased from different locations due to availability and price)	2	-	-
		1	$51.18	$51.18
		1	$15.80	$15.80
	Toggle Switch	1	$4.81	$4.81
	Busboards and Header Pins (more expensive due to additional shipping costs)	1	$14.31	$14.31
	Stock Metal, Bolts, Nuts	1	$104.75	$104.75
Total Cost				$870.80
Margins				$79.20

Future Work

There are many opportunities for improvement regarding our supplemental rear wheel steering system. One of the main aspects of our system that can be improved is the optimization of our PID controller. Instead of tuning the controller based on only real-world testing, we would recommend characterizing the physical system and using Simulink to help optimize the PID coefficient values through iterative testing and simulation. This is something we wanted to implement, but unfortunately didn’t get a chance to accomplish due to time constraints. Another opportunity for improvement would be to explore other controller designs beyond PID such as using root locus to develop a controller and evaluate their performances.

In terms of the mechanical portion of our RWS system, many improvements could be made on reducing the play or slop in the assembly as well as improvement alignment. In particular, one of the biggest issues we had with regards to manufacturing was warping of our welded components due to the heat generated by the welding process. By developing more accurate methods for manufacturing the different components, the team would be able to greatly improve the alignment of encoder and actuator mounts as well as decrease the amount of backlash in the system as a whole. Both of these improvements would help increase the accuracy of the rear wheel actuation with regards to instruction from the Arduino Mega microcontroller.

Lastly, we would recommend conducting tests on the system as a whole with regards to its functionality and durability under various conditions. This would include conducting the high speed functionality test we were unable to complete due to time constraints as well as running it through several FSAE endurance race set-ups. By testing the system under race-like conditions, the team would be able to analyze its performance and durability much more accurately. Overall, while we were able to produce a working prototype of our supplemental rear wheel steering system, there are still many different ways to improve the system for future work.

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Engineering Education: Are Companies Having a Negative Impact?

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Zachary Berman

Spring, 2021

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

Signature *Zachary Berman* Date 5/6/2021
Zachary Berman

Approved ____ Date __________
Sean Ferguson, Department of Engineering and Society

Engineering Education: Are Companies Having a Negative Impact?

How would you interpret this phrase if you were in an experiential learning experience: "don't rock the boat." Among mechanical engineering students who have some leadership in the major at the University of Virginia, a conversation ensued with a professor about the mechanical engineering curriculum. During the meeting, discussion turned towards suggesting some innovative ways to improve the major, and the professor's response was don't rock boat, with an implicit statement after of: don't do anything that might mess with ABET recertification at this time. Student's education is influenced greatly by corporations, both in classes and extracurriculars, which can lead to a stifling of creativity, and this is just one example. In a world where there is such a drive for innovation and change, engineers are often at the forefront of that. The education and experiences they receive in university can be crucial for the change society tries to enact; thus, one must think about who seems to be controlling and deciding the education of these students and if the creativity and ability to innovate is something they are learning. Just like ABET above, various companies are able to have a heavy hand in the educational opportunities and objectives being taught to students using their money, and that is having a negative influence on the engineering education students receive, which I will show through evidence gathered from autoethnographic research of my own and others' experiences and comparisons to other scholarship on the matter. Other authors have looked at the effects of various competitive project teams that students participate in and how it effects their education. They tend to claim positive aspects due to the differences they offer from the classroom, with general hands-on experience and teamwork, and based on their ideas, I will look at the negative aspects and narrowing of student's experiences and new knowledge, on a larger scale societal basis, instead of just their education (Gadola & Chindamo, 2019). By this I mean, the negative effects on students' academics and how money and resources, mainly provided by companies, play a large part along with how success is defined in these competitions narrows the design options and the ability for students to explore innovative designs.

Companies can exert their influence on education in many ways, from the money they donate to schools for facilities, their connections to coursework, and most drastically their connections and monetary influence on extracurricular opportunities of students, especially competitive teams. Good engineering schools are determined by ABET certifications, which in turns determines the curriculum of various engineering programs if they want to maintain their certification. When it comes to the competitive project teams of different schools, the success and competitive abilities of different schools can be determined by the influence of corporations on 2 fronts: what counts as success and the money the teams have. People want to win, and corporations are looking.

Where the Ideas Are Coming From

For this investigation, I will be focusing on the idea of innovation, and how companies are negatively influencing students' education, leading to a stifling of innovation. To do this, first how innovation is being defined, I will be looking to Hill and Martin's (2005) evaluation framework to do so. Their framework focused on what they called "radical innovation," meaning things that can change society as a whole, not the small innovations and improvements seen on a daily basis, and thus radical innovations will be the focus going forward. They incorporate stakeholder theory, innovation management concepts, and Popper's evolutionary learning methodology of science and its extension to social issues. The use of their framework is to look at radical technology and their unintended and negative impacts on society, mainly environmental, health, and social side effects. Based on their framework, I am going to look at engineering education and the influence of corporations and use similar ideas of stakeholder theory and unintended consequences to identify the societal impact of the way the education system is currently setup.

The primary evidence for the following research was based on autoethnography. This is the process of looking at one's own experiences in a bigger picture, pulling the key experiences of the author to indicate how their position on a matter has evolved over time. Interviewing other members of a certain culture that "inhabit a different position" confronts the author with "new perspectives from insiders" that can help improve upon the author's own ideas. Research of this nature requires reflexivity of the author; thus, when new or confronting information is presented, the author must be able to force themselves to rethink what they know (Tombro, 2016). In this way, an ultimate answer can be found on the author's position amongst the larger culture they belong to.

Journey of An Engineering Student

Towards the end of each semester, students start to stress not just about exams, but also about selecting their courses for the next semester. There are many options to choose from; however, for many engineering students, especially at UVA, the choices are simpler because most of their coursework is determined when they are a first year deciding their major. A prime example is the Mechanical Engineering 2021 curriculum where most semesters students have room for only 1 or 2 classes of their choosing (*ME & AE Undergraduate Curriculae*, 2017; *MECHANICAL ENGINEERING - 2021 Graduation.Pdf*, n.d.). This leads to one of the largest negative impacts on students, as they now have little to no room to explore their interests through their curriculum. This doesn't change much until a student's last year when they have less required courses, but they are still expected to take multiple electives that are still focused on technology, math, or science in some way (*ME & AE Undergraduate Curriculae*, 2017; *MECHANICAL AND AEROSPACE ENGINEERING MATH SCIENCE TECHNICAL ELECTIVES - Class 2019_2020_2021.Pdf*, n.d.). All the set courses are decided based on meeting this ABET certification that engineering schools are looking to keep.

If students don't get to explore their interests and be creative until their last year through the pre-determined curriculum, that just leaves other extra-curricular activities as the solution. There are caveats to this too; students need to select activities that incorporate their interests while balancing that with ones that will teach them hands on skills earlier than their courses would; therefore, allowing them to be competitive when looking for jobs and internships, something very crucial for engineering students (Kim & Bastedo, 2017). This is when the influence of corporations really starts to appear.

When It's Time to Race

Top engineering schools across the nation offer a wide variety of extra-curricular activities for students to join such as: student government/networking groups, undergrad research, and collegiate competition teams. The competition teams are some of the most popular and largest as it allows students to get the hands-on experience employers like, as well as allow students to explore some interesting projects. These experiential learning opportunities are seen as crucial to the development of an engineer, with some calling these opportunities the "ideal playground for the application of this innovative teaching method," referencing experiential learning through competing against other universities (Gadola & Chindamo, 2019). However, one must wonder if the competitions are teaching students to be creative and innovative, or if they are actually narrowing the mind of the engineering students. Companies sponsor the competitions and various teams, deciding not only what constitutes success in the competitions, but also what teams can do.

One of the main collegiate designs I have been involved in is the Baja SAE design series, which is just one of many design series competitions hosted by the Society of Automotive Engineers. Teams are expected to build an off-road vehicle, also known as a Baja car, with rules stemming mainly from safety and the use of a 10 hp engine. Success in the competition stems from static events, based on design, costs, and presentations on the car, and dynamic events, such as acceleration, maneuverability, and the main endurance race. According to SAE, this all results in achieving the goal of teaching students the challenges of a "project that involves the design, planning and manufacturing tasks found when introducing a new product to the commercial industrial market," and gathering financial support is a part of this (*Baja SAE*, n.d.). So essentially, they are trying to prep students for going to work for the companies that sponsor the competition.

If this is the objective of SAE, I think looking at results and the cars created by the teams involved says regarding if this objective is met. In the rankings from 2017-2019 at the Midwest Baja SAE competition, only 22 teams have placed in the top 10, with the stipulation that some of those 22 were not in the race every year (*Baja SAE*, n.d.). These same teams can be found to place in the top 10 for other Baja SAE competitions during that year, and this trend can be found in other collegiate design series. The University of Michigan's MRacing and Baja Racing are two different teams that place in the top year to year for their respective competitions. Each year, their vehicles don't look very different and have very little changes and innovations added to them (*Student Organization | Michigan Baja Racing | United States*, n.d.). From my experience, for Baja SAE competitions, they build their car as light as possible without worrying if parts break as they make multiple part replacements. This highlights the amount of funding they have, so they can do something like this. Some of the top sponsors for Michigan's FSAE and Baja teams are Ford (*MRacing*, n.d.) and GM (*Student Organization | Michigan Baja Racing | United States*, n.d.) respectively, along with other top companies. Compare this to a team from Birmingham, Alabama whose entire budget was approximately 5k. They were barely able to get the money to travel to competition in Tennessee and did not compete due to not passing technical inspections, a result of car manufacturing delays caused by financial hurdles. This highlights the disparity between teams. The companies and the money they give to already top teams, creates a barrier for many schools to do well in the competition as defined by SAE, and the companies that help organize it. In fact, the teams with less financial resources have to be creative and find innovative ways to still compete in some sense. A team can't get more money without having some positive results; consequently, creating a cycle.

Michigan is not the only school that has a large influx of cash and company influences. The Oregon Racing team competing in FSAE partnered with a German corporate university counterpart competing in FSAE Electric, which means they partner with a Formula team for learning. This has allowed both universities to rank in the top 10 or 20 both domestically and internationally for their respective competitions for the past decade (*Home*, n.d.). The resources they have compared to a brand-new team would essentially mean that the new teams don't actually have a way to properly "compete" in the rules of the competition. This can be a turn off for new teams trying to get in as well as prevent those at the top schools from trying to find new ways to create large scale innovations to their cars.

There are benefits to experiential learning opportunities of competitions as they do provide a collaborative area where "authentic experience is made possible" as students learn within the confines of the university. Gadola and Chindamo (2019) claim they "promote creativity, clever problem-solving and innovation," using the University of Brescia Motostudent team's first year into the competition as a case study. They ended up placing 5th overall despite it being their first time in the Motostudent competition; however, their members had a few years of experience in the FSAE competition and a large amount resources and manpower available. Gadola and Chindamo (2019) go on to claim the "cognitive feedback" is a major positive and the project as a whole "promotes emotional interest, motivation and involvement." There is still the acknowledgement that these competitions can be an "all or nothing affair", and that it can actually negatively impact students academically because the projects have "higher resource demands" compared to regular lectures. The experiences of the authors do highlight the benefits of student competitions, showing in particular how it helps students learning the soft skills many companies also value, and it provides an environment similar to that of the automotive industry. This means that former team members of UniBS "are usually recruited within a few weeks after graduation or even before." It is clear that companies want those involved in these team competitions, and it shows why they might have the heavy involvement they do; however, is replicating the automotive industry and catering to their wants beneficial to creativity and innovation, or does it just create more employees that do as the company wants?

How the Industry Works

With innovation always comes risk, and many companies are careful with any kind of innovation they might bring to their industries because of this. Even on smaller scales, trying to be creative and innovative can lead to major problems. Toyota introduced their Toyota Production System, TPS, to great success and became an industry leader in car manufacturing; however, when they tried to innovate and change their cars to allow for something as simple as more seat options for clients, with plans to introduce new models in the near future, they had massive problems in their US factory with the seats. If the man in charge, Doug Friesen, just followed the company mold as they had been, this problem would've grown exponentially once these new models were introduced; and in fact, that is what happened for several months as all the engineers at the factory just used the TPS methods and didn't think to update them. This is the problem Doug faced (Mishina, 1992). This is just one example of what happens when people don't learn to be innovative and creative in the world of engineering.

Ferrari on the other hand faces a world of different problems despite still being in the automotive sector. They are trying to maintain the Ferrari Way and deliver the Ferrari experience to clients that they do their best to maintain, so they use their small teams to innovate and deliver their cars, with changes happening even when delivering pre-series vehicles. One example is the LaFerrari, which was a hybrid vehicle and the electric engines' sole purpose was to produce more horsepower; thus, the car did not function like a normal hybrid. They spent several months on just the sound of the engine to deliver what they considered the Ferrari experience to their clients (Thomke, Corsi, & Nimgade, 2018). When Porsche delivered their electric vehicle, the fake sounds they had playing through the speaker had many claiming it was soulless. This again highlights the importance of creativity and innovation in the automotive industry.

As a student, I look more to the methods of Ferrari than Toyota, yet more often Toyota is going to be involved in engineering education and be looked to as a standard in the automotive industry. People are expected to do as they are told and produce the work higher ups in a company want, even if the engineers do not have the passion for it. A trickle-down type effect can be seen in engineering education because of this. Some students from top, well placing teams may end up at companies like Ferrari, where they can be innovative and follow through with their passions, but most will not. Your average student is just looking to get a job working for companies such as Toyota and Ford; therefore, these companies donate to teams with the intent to train students in their ways before they are employed at their companies.

What do the Students Experience?

To confirm what I have found from my own experiences and research, I looked at other students, both in my major and other engineering majors at the University of Virginia. For anonymity purposes, only their initials will be used. The goal was to see if the same feelings and experiences were had about both the curriculum and extra-curricular classes and how they affected students' overall education and abilities to be creative, as well why they thought this happened, i.e. if companies were involved, and if they felt like they were prepared to go work for these companies.

One such student was BG, a 3rd year mechanical engineering major. He was involved in Virginia Motorsports, working on both the Baja and FSAE teams, while having certain leadership roles. He had similar experiences and feels "frustrated" and "confused" as to why he had to take certain mechanical courses, citing Intro to Mech as "it felt like many aspects, particularly the drawing, was not relevant to learn." He cited his experience in Virginia Motorsports heavily, saying he "learned more there about CAD and engineering" than the intro course, and he also had experiences learning things he never imagined such as carbon fiber. BG believes that there are definitely issues with the curriculum, and in terms of competitions, feels very frustrated knowing that other teams have such large backings and companies doing things for them that he "learned how to do through multiple attempts" like the carbon fiber. From his experiences at competitions, he mentioned feeling "punished" for trying new things because there are inevitably problems which result in a lower performance. He sees the money that corporations put behind some teams and how little choice he has in his courses and is curious to "Why does it happen?" but knows that he just needs a job in the end.

Another student was JS, a 4th year computer science engineering student. During his time as a student, JS has had little freedom in the courses he had to take, with only 15 credits that were up to him with everything else "mapped out" for him. With CS, he says "If you don't do other projects to support the coursework" many companies won't care. People are pushed towards individual projects or teams, with extra-curriculars assisting this. The projects can let them be "as creative as you want" with companies just wanting to see if students can apply their knowledge. JS notes the benefits that because CS is done mainly on 1 laptop, there are more avenues to explore his creativity and be innovate in different ways, or as he put it "Do anything I [JS] needs to. He views the degree as "teaching foundations" and because the field is so broad, no one has specifics needed for most companies. JS believes he has a foundation, but he also doubts the usefulness of a college degree in his field with only the "structured environment" being the important part for him; others with the motivation could find similar results on their own. He does note that in "higher level CS, a lot of classes focus on understanding higher level concepts, like processors or memory, which is not practical." These courses seem irrelevant for most jobs, and the reasons JS can think that he must take them is because of a higher-level understanding of the whole picture and also ABET. As he put it, many are just "part of the requirements."

The final student interviewed was ZK, a 3rd year system engineering student. Unlike other majors, systems engineering tends to have some of the most flexibility in course requirements for graduation, allowing for some extra field specialization in the major when compared to other engineering majors at UVA. From ZK's perspective, many system engineering students end up in consulting, so the requirement that systems requires students to take courses in other concentrations allows students to explore the interest prior to working. The flexibility allows "space for technical electives", so people aren't "tied down to one major," and ZK is double majoring in economics while doing an economic systems course. There is a decent exposure to various companies, with a networking class called "SE Design Colloquium." There students could learn what companies do and ask questions about which courses they should take if that is a track they wanted. He has never felt pressure to join anything just for a company but has been involved in a networking club. The systems engineering curriculum adds another way for students to explore their own interests by giving the option to make up their own concentration. Systems engineering is not everywhere, but industrial engineering is a similar program at other universities; however, the freedom offered by the program at UVA while still being ABET accredited differs from other engineering programs.

Time to Talk

Corporations have a reason to want engineers that fit their mold and do what they need, so it makes sense why large companies will support programs that allow engineering students to get the hands-on experience and skills, as well as supporting the teams that are most capable of properly training their members. As Gadola and Chindamo found, there is a positive psychological effect from design competitions, on top of many hard and soft skills learned for actual jobs. Even if students' academics can drop due to the time intensive nature of the competition, Kim and Bastedo (2017) found a positive correlation between job related extra-curricular activities and job prospects, and this could offset the academic issues. It is clear that involvement in design competitions and similar activities, even if it prevents exploring one's own interests, is beneficial for getting a job, and similarly would help for graduate school opportunities, which is most students' objective after university. But then the question becomes, is the heavy involvement of companies in this area moral? Looking at teams at Oregon and Michigan, it is clear that they have massive financial resources and years of success to go with it thus allowing their students to learn a lot and get jobs at these top companies that back them; however, at schools like the one in Alabama previously mentioned, their students face a much more difficult time and are most likely not gaining as much of a benefit. With top teams just keeping their same designs and lower teams struggling to make a car and get involved, where does the creativity and innovations come in? Thus, with the influence of companies and many just focused on doing well in the competition or making it there, it forces students to not look for fun and innovative ways to design and build their competition vehicles. A job is great, but it is clear people are so focused on what companies are looking for that they aren't trying to be different in any way.

There is no denying the innate advantages of ABET accredited programs and involvement in extra-curricular activities when looking for a job. In terms of its effect on creativity and innovation opportunities for students, there does appear to be a clear difference depending on the type of engineering the student is majoring in. Depending on the major, there can be a lot more chances for creativity and exploring interests, as in CS students can work on any type of project on their own to eventually add to their resumes and with Systems Engineering students have freedom to choose many of their courses and still be in an ABET certified course. However, certain majors still have a very rigid class structure and don't easily allow students to do projects on their own to explore their interests, and this is where issues of innovation and creativity start to show, and in the end most students are still making choices because they are mostly thinking about their future working for various companies. It is clear that there is a heavy influence of industry leaders on engineering education, and it is not always to the benefit of the students, but depending on the nature of their major, students can sometimes still have the freedom to explore their interests and creative side. Toyota and Ferrari highlighted why creativity is an important soft skill for students to have, and without it being an important part of all types of engineering there could be issues down the line when people try to discover the radical innovations that will be crucial to an ever-evolving society.

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

Engineering Education: Are Companies Having a Negative Impact?
(STS Research Paper)

A Thesis Prospectus Submitted to the

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Zachary Berman

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Technical Project Team Members
Carolyn Wong
Westin Recktenwald
Connor Greene
Lerene Palugod

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

Signature *Zachary Berman* Date 5/6/2021
Zachary Berman

Approved ____ Date __________
Natasha Smith, Department of Mechanical Engineering

Approved ____ Date __________
Sean Ferguson, Department of Engineering and Society

Introduction

Virginia Motorsports Education is working to develop their first vehicle for the Formula SAE collegiate design series. As members of the team, my capstone group is working to design, build, and test a rear wheel power steering (RWPS) system for the vehicle to improve handling and stability at both low and high speeds. One of the crucial parts of the SAE collegiate design series is the involvement of various companies in the automotive, energy, and manufacturing industries, both through sponsoring the competition as well as sponsoring certain teams. Teams are sponsored to help support the education of their members for the industry, thus allowing training before being on the job; however, it tends to just be top teams that are directly sponsored, and this creates a pattern of what determines "success" at competition. Many of these companies are at the top of their field and claim a drive for innovation and to set themselves apart from their competitors, yet truly innovative companies are rare. Using Hall's and Martin's radical innovation framework as a base, I will evaluate the automotive industry and highlight the similarities between the industry and experiential learning opportunities at universities, and the damage this causes to creativity and innovation (2005). I will track the way that the automotive industry stifles radical innovation. I will then pivot to track how they influence experiential learning, mainly SAE collegiate design series, and might be recreating that same effect on a college level.

Technical Prospectus

The objective of the RWPS system is to facilitate a tighter turning radius and greater maneuverability at low speeds and increase stability and responsiveness at higher speeds without adding excessive weight to the vehicle. The system will focus around the automatic control of linear actuators using a feedback loop. For this project, the members of my capstone will work with the other members of the FSAE team, a subsection of Virginia Motorsports Education, to ensure the vehicle is the best it can be, as well as be ready for testing. The Student Engagement Fund will be supplying a majority of the funds required for the project.

The system will use an Arduino Uno microcontroller to act as an interface between a potentiometer that gathers data about the steering angle and the linear actuators which have a built-in encoder to send data back to the Arduino. These 3 main parts will form the basis for the feedback control loop that will be designed in MATLAB & Simulink R2020a and embedded using the Arduino Support from Simulink package (*Arduino Support from Simulink*, n.d.) or coded onto the with the microcontroller using PJRC encoder library (*Encoder Library, for Measuring Quadarature Encoded Position or Rotation Signals*, n.d.). This control system will make it so the rear wheels are adjusted properly according to the angle of the steering wheel as well as the speed of the car constantly, even under maximum cornering forces. The system, as a whole, will also have a built-in fail-safe in case of unacceptable sensor values or power failure. In order to help meet the standards the team is looking for, I have worked on carefully researching and selecting the actuator that is able to meet our needs and will be heavily focused on the electronics and coding necessary to use the Arduino to gather our needed data, as well as embed the control loop. We will use a similar process as described by a controls lab at the University of Michigan, which makes use of the available Simulink and Arduino libraries (*Control Tutorials for MATLAB and Simulink - PI Control of DC Motor Speed*, n.d.).

The use of RWPS is common on day to day cars; however, it is not something normally seen in the FSAE competition. Using RWPS helps reach a more ideal steering geometry at various speeds, a symmetric counter steering at low speeds and co-steering at higher speeds, which has a basis in Ackermann steering geometry. Ackermann steering is a concept where the inside wheel turns more than the outside, with a central point of rotation based off the intersection of lines perpendicular to each wheel. This does not account for slip angle differences between inner and outer front tires, which is important at higher speeds (Arvind, 2013). Our car will use 75% Ackermann geometry, meaning the central point where the lines meet is a bit farther out. We are also not the first university team to investigate the use of the system on the car. The Washington University in St. Louis FSAE team prototyped a four-wheel steering system of a similar design in 2016, but the documented design was not fully implemented due to errors in the system centered around the control system (Wisniewski et al., 2016). Their research will help form a solid basis for comparison throughout our own design process.

STS Prospectus

How would you interpret this phrase if you were in an experiential learning experience: “don’t rock the boat.” Among mechanical engineering students who have some leadership in the major at the University of Virginia a conversation ensued with a professor about the mechanical engineering curriculum. During the meeting, discussion turned towards suggesting some innovative ways to improve the major, and the professor’s response was don’t rock boat, with an implicit statement after of: don’t do anything that might mess with ABET recertification at this time. ABET sets the “educational standards” for professional engineers with their criteria focusing on “what students experience and learn” and then uses their standing to determine which engineering programs meet that (*About ABET | ABET,* n.d.). That experience led me to consider what is the role of innovative education experiences on students’ education. Upon entering college many young engineering students are excited about the chance to learn and explore their fields of interest through both coursework and experiential learning as well as research opportunities. Experiential learning opportunities, especially the design competitions, are crucial to the development of an engineer, touted as the “ideal playground for the application of this innovative teaching method”, and when combined with the coursework, can produce great engineers (Gadola & Chindamo, 2019). However, throughout the development of an engineering student, there can be sense of stifling of creativity and individualism. Companies have an influence on both deciding what constitutes a “proper” engineering curriculum and “success” in the realm of experiential learning opportunities, mainly competitions. I want to show that the influence of these external industries has played a negative role on the growth of innovative engineers.

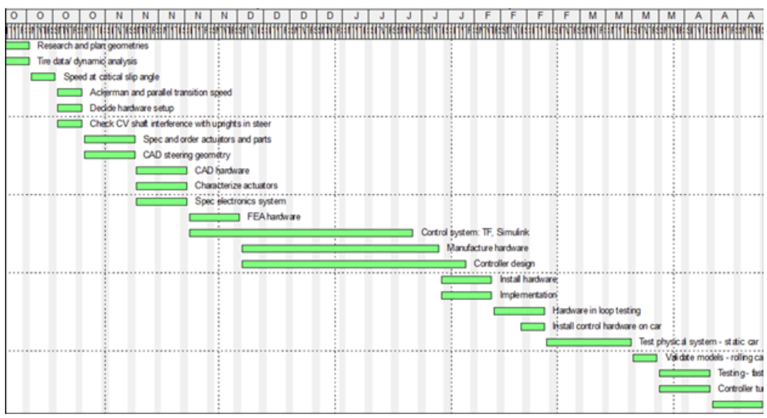
In the SAE collegiate design series, the top ranks tend to be consistently filled with many of the same universities on a year to year basis, with only slight changes over the years. When looking at the rankings over the last 3 years (2017-2019) at the Midwest Baja SAE competition, only 22 teams have been in the top 10 overall, with some of those 22 just not being in the race the years they didn’t place (*Baja SAE*, n.d.). Similar trends can be found in other collegiate competitions, such as the SAE Aero Design competition and FSAE. Often, designs amongst these teams vary little year to year, as noted when looking at University of Michigan’s MRacing team’s website, and their FSAE team, where their cars look minimally different year to year. At the same time, one of their top sponsors is Ford (*MRacing*, n.d.). The influx of money has a drastic effect on the results at competition. Another example is the Oregon Racing team which has partnered with a European counterpart that also works closely with a company in the industry (“About Us,” n.d.). They follow the advice from the pros and the companies, instead of trying to try new things.

The key part of my analysis falls around what is defined as a technological innovation. I will be addressing not the small innovations or improvements, but the drastic ones. The central framework for my assessment revolves around Hill and Martin's (2005) evaluation framework for radical technology development, which I am considering the basis for a technological innovation. Their framework incorporates stakeholder theory, innovation management concepts, and Popper's evolutionary learning methodology of science and its extension to social issues. Ideally, this framework is used for "controversial innovations that may have undesirable consequences" that have "complexities" that contemporary frameworks don't address. The ultimate goal of this framework is to address the "unintended and unforeseen consequences" of technology and their potential benefits.

I intend to incorporate this framework by addressing the similar failures in the education system to properly adjust and account for all stakeholders, the students, and the social effects it has the students, mainly their creativity and innovativeness as a result of the curriculum and experiential learning opportunities which have been influenced by external forces. A portion of my analysis derives from autoethnography of my own experiences in the SAE competitions. Autoethnographic research is done by analyzing one's own "position in the subculture" and the position of others the effects they have on attitudes about the subject (Tombro, 2016). Sources used for this will come primarily from first-hand experience from 3 years of Baja and Formula SAE, in addition to similar research published about students' experience in other collegiate design series, such as the Motostudent contest written by Gadola and Chindamo (2019). I will also be discussing ABET certifications and other influences on UVA's engineering curriculum and resources. The 3 essential stakeholders coming into play are the companies, the university, and most importantly the students. Some of the controversies addressed will fall around the common placements of certain teams in competition and how ABET certification leads to a less beneficial educational path for students.

Conclusion

For the technical portion of the project, the team created a Gantt chart at the start and has been following it from the beginning. The intent is to follow the below chart in order to complete the RWPS system and test it before competition in May.



For the STS topic, I will prepare for conducting autoethnographic research and forming a paper based on this method. I will start developing a journal that will include my own insight as I go through the whole process. I will also use old notes as I try to extrapolate my experiences. I aim to do 3-5 interviews of students in various degrees to get other viewpoints that act as crosscheck on my own experiences to develop greater validity. The goal will be to have the material and background needed to complete the paper without issue.

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