SAE Baja Front and Rear End

Final Proposal

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DISCLAIMER

EXECUTIVE SUMMARY

The SAE Baja is a collegiate competition that involves building a complete one-man, all-terrain vehicle that will be put through a series of tests; static and dynamic, to examine the engineering quality and the optimum potential of the vehicle. The competition will be held in Tucson, Arizona in April 2020. Based on the necessary deliverable and the intensity of work that goes into this project, the SAE Baja team for 2019-2020 is broken to four sub team divisions in order to provide optimum focus to all parts of the vehicle and merge talents and skills to produce an exceptional 4WD Baja vehicle.

The focus in this report is centered toward the front and rear end of the vehicle. The designs in these two sections have major differences that need to be highlighted. When looking into the front end, the design is comprised of the suspension, torque delivery to the wheels, steering and braking systems. The suspension geometry in the front end is delivered as a result of a series of LOTUS suspension geometry analysis that was used to understand that the vertical mounting of the shocks was necessary for optimum wheel geometry and performance. The shocks are mounted to the upper A arms to provide space for the 4WD system to input the front differential and the CV axles that attach to the wheel assembly. The steering system will be a closed type rack and pinion system that will be mounted horizontally to provide less Y forces and ease steering the vehicle. Finally, on the front-end design, the brake system will use an integrated master cylinder with custom made rotors which will be compressed for braking with a fixed caliper assembly comprised with dual pistons.

Moving on to the rear end, the trailing arms suspension system is focused on providing support for the section of the vehicle with the most weight. In order to provide accelerated mobility in the rear suspension area, the ball joint mounting points will be drilled and accommodated for before the trailing arm is fully functional for the vehicle. The suspension geometry will be hinged to the frame in order to provide variable movement during suspension compression and expansion.

As a result of a series of unanimous tests done on both sections of the vehicle, the teams have decided to move for with 4130 Chromoly as there material for both suspension geometries. The components will be tubed with 1 inch of OD and 0.049 inches of wall thickness. The shocks planned are King shocks with 20 inches in the Front End and 19 inches on the Rear End. In order to obtain best results with weight to performance ratios, other parts will be made using 4130 Chromoly or Aluminum.

After a series of research, analysis and testing via software, Front End and Rear End are ready full functional subsystems that have been made unanimously compatible with the entire Baja Team. The designs were modified after considering the failure modes and the testing procedures have been determined. The vehicle will be put through the optimum level of performance and tested in both forms of static and dynamics influences. The next steps moving forward will be taken towards building and assembling the Baja vehicle and performing the necessary modifications to have a high quality end product that would perform well at the competition.

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1 BACKGROUND

1.1 Introduction

SAE Baja is a collegiate competition that tasks students to design and build a single-occupant, off-road vehicle that will be put through a series of dynamic and static events. These events can consist of an acceleration test, braking test, hill climb, endurance race, and other various inspections and tests. These vehicles must also adhere to a strict set of competition rules and guidelines set by SAE. These rules and guidelines will ensure and show that the students on the team are able to function as professional engineers. Furthermore, this competition provides the sponsor and other stakeholders a large platform for advertising and it will also validate that the team is able to produce a functioning and reliable off-road vehicle.

1.2 Project Description

The Baja SAE intercollegiate competition is a unanimous engineering design competition among undergraduate and graduate students. The primary goal is to design, build, test, promote and compete a fully function mini Baja within the constraints provided in the Baja SAE 2020 rules booklet. Provided below is a vital portion of the project description provided by the administration of the Baja SAE 2020 intercollegiate competition.

"Each team's goal is to design and build a single-seat, all-terrain, sporting vehicle whose driver is contained within the structure of the vehicle. The vehicle is to be a prototype for a reliable, maintainable, ergonomic, and economic production vehicle which serves a recreational user market, sized at approximately 4,000 units per year. The vehicle should aspire to market-leading performance in terms of speed, handling, ride, and ruggedness over rough terrain and off-road conditions. Performance will be measured by success in the static and dynamic events which are described in the Baja SAE® Rules, and subject to event-site weather and course conditions." [1]

Based on this provided description, the Baja SAE 2020 team for Northern Arizona University has decided to fulfill the needed requirements by initiating a sub team division system. The sub teams are; Front-End, Rear-End, Drivetrain, and Frame respectively. Each sub team will initiate and design the allocated sections abiding by the rules of the competition. Based on the bonus point opportunity for this year, the teams will design their sections to facilitate a 4WD system. Once the sections are designed, the sub teams will combine their work and build the Baja merging the sections together while tweaking systems to be compatible with each other.

2 REQUIREMENTS

The requirements that need to be met for this project is heavily based around the rulebook and our customer/client, Dr. Tester. After finding all the requirements needed, the team must convert those client needs to technical requirements that can be measured in a quantitative aspect.

2.1 Customer Requirements (CRs)

Part of the Baja competition is to pitch the design of the vehicle to a fictitious company for mass manufacturing. This company is our customer and requires that our vehicle can perform and pass different tests. These tests include an endurance race, a hill climb test, a braking test, an acceleration test, and others. From these tests, other requirements of the competition given in the rule book, and faculty advisors, a list of customer needs was generated and weighted. The weight of these requirements are from five, being the most important, to one, being the least important. Table 1 lists the needs as well as their weights. The weights for each customer need are out of five points with five being the highest.

Table 1: Customer Needs and Weights

Customer Needs	**Weights**
Reliable	5
Durable and Robust	5
Lightweight	4
Maneuverable	4
Low Cost (Within Budget)	5
Easy to Repair	3
Short Stopping Distance	4
Short Wheelbase	4
Ride Height	4
Track Width	4
Safe to Operate	5

A reliable design is one that will consistently pass repeated tests given to it. A durable and robust design will not break while performing the range of tasks it is designed for. Lightweight directly impacts the car's ability to perform well in the hill climb test. In addition, the maneuverability, the short stopping distance, wheelbase, ride height, and track width of the car will dictate how well it performs in the competition. Each of these requirements where found by comparing the winning teams' cars over the past few years of the competition. This data, from past years, was collected by students and provided to the team through one of our faculty advisors. Low cost for the car is crucial as the project is supplied with limited funds. In addition, the Baja vehicle is operated by a person inside the vehicle. Therefore, safety in operation is a customer need to ensure that the operator and others around the vehicle will not become injured. The last need to mention is for the vehicle to be easily repairable. This vehicle will be used by the SAE club on NAU campus for future years. Through this usage, it is inevitable that parts of the car will break over time or need to be replaced with upgraded models. Designing the car to be easily repaired will expand the overall life of the car and enable future teams to easily improve specific design components of the vehicle. Achieving these customer requirements, this vehicle that can exceed in the competition.

2.2 Engineering Requirements (ERs)

The engineering requirements found to be relevant for the sub-system suspension teams were based around the Customer Needs (CN's) given to us by the client and the competition rules itself. The purpose of the engineering requirements is to relate the CN's to technical requirements that can be measured. After discussing with both sub-teams, we concluded that our Engineering Requirements would include nine categories. Two of the more critical requirements include track width and ride height. These have become some of our technical requirements, because in order to achieve peak performance and maneuverability the team must design around a specific track width that can be measured in inches. For our specific purpose the track width goal is 53 inches. Ride height is also crucial to the entire vehicle, due to the axles and drivetrain, there is a required ride height of 10 inches. The Baja vehicle also needs to be able to stop within a certain distance of six feet, with a tolerance of 1-2 feet. For both front end and rear end, the total system is needed to stay within a budget of 7,000 dollars. The weight of the vehicle is another technical requirement, with more of a loose tolerance. As long as we stay within a weight of 450 pounds plus or minus 50 pounds. Another crucial requirement for the sub-teams involved in suspension is material properties to ensure the system does not fail when loaded during driving. The material being used can be measured by yield stress and tensile strength measured in Mega-Pascals or kpsi. Each of these engineering requirements directly relates to designing a system that will be both reliable and durable.

Table 2: Engineering Requirements

Engineering Requirements	Desired Value	Tolerance
Track Width	53 inches	± 3 inches
Ride Height	10 inches	± 1 inch
Stopping Distance	6 feet	± 2 feet
Cost	$7,000	± $350
Weight	450 pounds	± 50 pounds
Material Strength	290 MPa	± 20 MPa

The table above summarizes the most crucial engineering requirements, along with the tolerances that are associated with each category. The table has an inaccurate tolerance for material strength due to it focusing on a lower tolerance but has an open-ended higher tolerance.

2.3 Functional Decomposition

2.3.1 Black Box Model

2.3.1.1 Front End

The primary function for the Front End subsystem of the Baja SAE vehicle is to control the displacement of the vehicle and support the vehicle weight. The driver must input Human Energy into the system to achieve this goal. Kinetic Energy due to shock forces translating suspension components (wheels, control arms, etc.) and Potential Energy due to vehicle weight forces must also serve as inputs. Visual and noise signals are interpreted by the driver as they operate the vehicle. These signals ultimately determine how the driver will proceed on the course and control the displacement of the vehicle. On the output end of the Black Box, Kinetic and Potential energies from the mechanical processes are conserved. In addition, noise and heat are also generated by braking, steering and dampening systems as they function. This model allowed the team to obtain a clear understanding of the end goal for the Front End geometry, including the vital physical concepts that achieve this goal. Figure 1 represents the Black Box Model for the Front End suspension geometry.

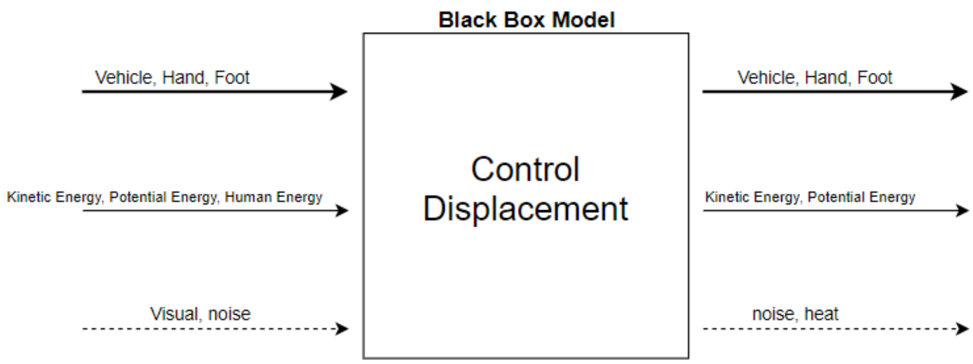

Figure 1 - Black Box Model for Front End Suspension Design

2.3.1.2 Rear End

The main goal for the rear end suspension system is to support the car. The kinetic energy of the movement of the car as well as its potential energy in relation to its position off the ground are inputted into the rear end suspension system. These energies are generalized to be a mechanical energy input as seen in Figure 2. The team also corrected the Black Box model to accurately show the car and obstacles the car experiences coming into and exiting the Black Box model.

Figure 2 - Rear End Blackbox Model

From the mechanical energy entering the system, the system produces mechanical energy to keep the frame of the car off the ground. There is also sound exiting the system. This sound signals the user on whether the system is working properly. Another change to the model from the preliminary report is the visual signals the user can see as obstacles enter and exit the system and the suspension system moves to support the car. This model demonstrated to the team that the objective of the rear suspension system was simple and that there would be many ways to accomplish this goal.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

2.3.2.1 Front End

The Functional Decomposition model allowed the front end design team to further analyze the goal of controlling the displacement of the vehicle. This was accomplished by dividing the inputs and outputs from the Black Box model into essential processes that serve to achieve this goal. The team then applied this model to existing concepts of automotive suspension geometry to determine an ideal design that best meets the Customer and Engineering Requirements [Suspension Geometry and Computation]. The driver must input Human Energy for this process to occur, and this energy is converted into mechanical energy in two ways. The driver actuates the braking system via a foot-operated pedal, and this pedal force is subsequently converted into hydraulic pressure. This hydraulic pressure must be stored to maintain consistent braking performance and prevent total system failure. The hydraulic pressure then displaces a piston, which forces the brake pads to clamp against the surface of the brake rotor. The friction forces generate heat and noise, decreasing the kinetic energy of the vehicle in the process. The driver's hands actuate the steering system to change the relative angle of the front wheels and direction of the frictional forces between the tire and ground. This process allows the driver to further manipulate the direction of the vehicle. Lastly, a dampening system must be implemented to control vehicle handling dynamics and shock forces from rough terrain. Figure 3 displays the Functional Decomposition Model for the front-end suspension geometry.

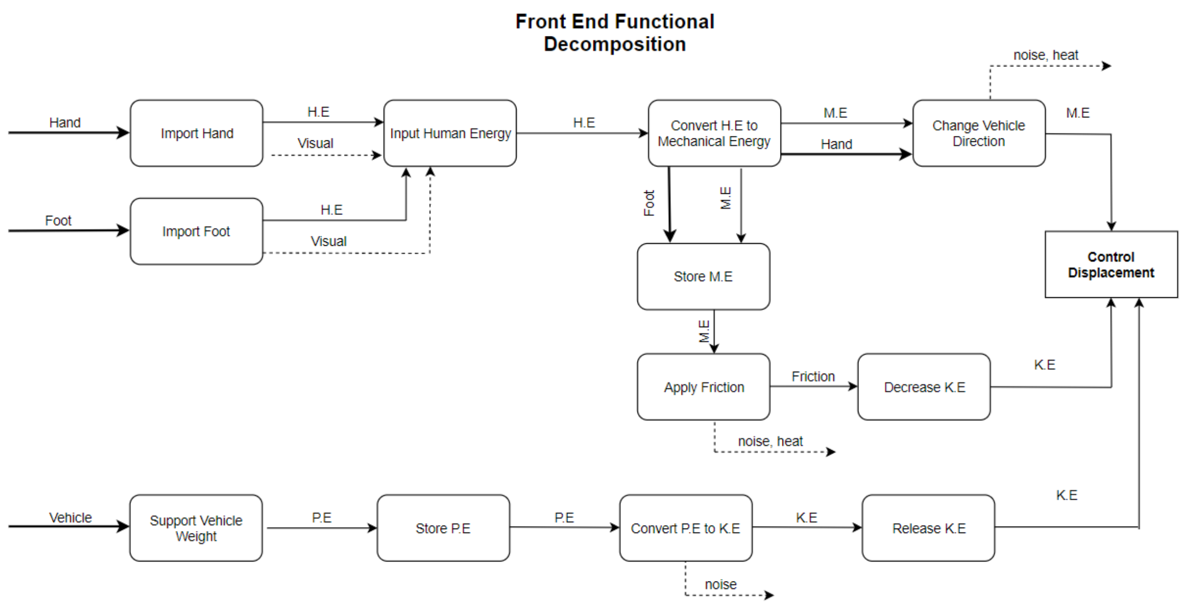

Figure 3- Front End Functional Decomposition Model

2.3.2.2 Rear End

The rear end functional decomposition model was created by expanding on the black box model of the rear suspension system. This helped the team narrow down what was a necessary function that the system needed to perform and expanded our view on how these could be accomplished. Figure 4 illustrates our functional model. Changes to this model from the preliminary report include the inclusion of the car and obstacles entering the system and visual signals both entering and exiting the system. The car and obstacles displace the control arms and generate mechanical energy.

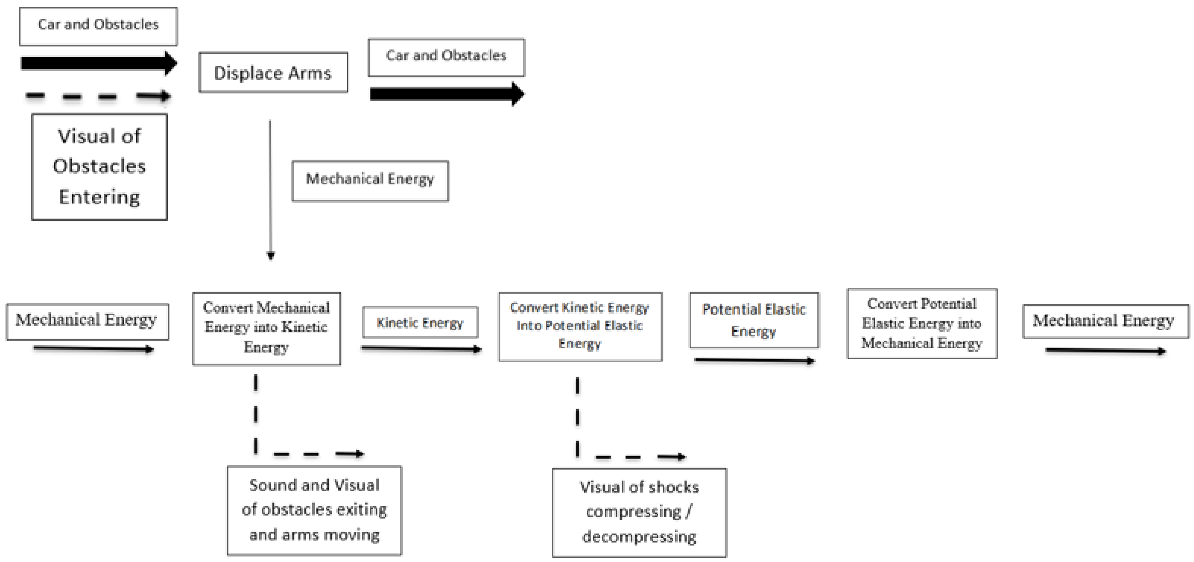

Figure 4 - Rear End Functional Model

After the mechanical energy of the car enters the system it is converted into kinetic energy. This kinetic energy is then transformed into potential elastic energy and leaves our system as mechanical energy. The system converts the mechanical energy into kinetic energy through the displacement of the control arms or links when the tires experience an obstacle. When these arms move, they compress shocks and created elastic potential energy. As these shocks decompress, kinetic energy and potential energy in the displacement of the car is what leaves the system as mechanical energy.

2.4 House of Quality (HoQ)

The house of quality is a major part of the initial design stage. The Baja team has generated customer needs and engineering requirements in Sections 2.1 and 2.2. Those customer needs span the left side of the house of quality as seen in Table 3. The engineering requirements or technical requirements are listed at the top of the house of quality. With both the customer needs and engineering requirements generated they can then be compared to how well they align. The weighting for this includes values one, three, and nine. For example, if the vehicle is very reliable then it would have high cycles till failure, which awards the correlation with a nine. Whereas obtaining an optimal track width does not depend on decreasing the number of fasteners, which leaves that correlation blank.

Table 3: House of Quality

		Technical Requirements								
Customer Needs	**Customer Weights**	Cycles till Failure -->	Material Properties -->	Weight <--	Wheel Base <--	Cost <--	Fasteners <--	Stopping Distance <--	Ride Height *	Track Width <--
Reliable	5	9	9	1		3	3	9	3	3
Durable	5	9	9	1		3	3	3		
Lightweight	4		3	9	3	9	9	3		3
Manuverable	4			9	9	1		1	1	9
Low Cost	5	1	3	3	1	9	3			3
Easy to Repair	3	3		3	1	3	9			1
Short Stopping Distance	4							9		3
Short Wheel Base	4			9	9			3		
Ride Height	4			3					9	
Track Width	4			1				1		9
Safe to Operate	5		3	3	1			9		
Technical Requirement Units		#	kpsi	lbs	inches	$	#	feet	inches	inches
Technical Requirement Targets		150	50	450	60	7000	N/A	6	10	53
Absolute Technical Importance		104	132	169	97	124	108	169	55	93
Relative Technical Importance		5	2	1	6	3	4	1	8	7

The next step in completing the house of quality is creating target values for each of the engineering requirements. The targets were obtained through experiences at SAE competitions. For example, when in the rosy areas of the track it is optimal to have a high ride height and high material properties in case a rock makes contact with the suspension systems. If the vehicle does not have all wheels on the ground then there might be an increase in the impact taken by the shocks once it lands. This creates the target value of 450 pounds for the vehicle. The house of quality was able to assist the team in tabulating which engineering requirements are important in order for the team to do well at competition. For example, it is very clear from previous competitions that the lower the weight of the vehicle the better the team places. For that reason, the primary goal is to decrease the weight of the vehicle. Another important goal is to make the vehicle cost effective. To find the absolute importance the customer needs weights and how well they relate to the engineering requirements are multiplied and summed. The relative importance is simply which engineering requirement had the highest absolute importance in relation to the others.

2.5 Standards, Codes, and Regulations

For this type of project, many codes and standards may be referenced and used when creating the various subsystems of the Baja vehicle. Based on the predetermined rules set by SAE, this list can be further refined for codes and standards that comply with the competition rules. In Table 4 below, a list of these relevant and potentially helpful codes and standards can be found. For the entire Baja team, this list would be much longer, however, the standards below are most applicable to the front and rear end systems being presented.

Table 4: Standards of Practice as Applied to this Project

Standard Number or Code	Title of Standard	How it applies to Project
SAE J98	Personal protection for general purpose industrial machines	This standard determines what the driver of the buggy must wear while operating the baja vehicle
SAE J429	Mechanical and material requirements for externally threaded fasteners	This standard provides requirements for the hardware used with any components/systems that will be secured using bolts, studs, or other threaded fasteners.
SAE J512	Automotive tube fittings	This standard will provide relevant information for any fittings in the braking system, shocks, and/or steering system
SAE J1703	Motor vehicle brake fluid	This standard will be relevant for the braking system, as it will need brake fluid when in use
SAE 1739	Potential failure mode and effects analysis in design, in manufacturing and assembly processes, and for machinery	This standard can provide useful information for FMEA's that may be done by the team

In general, these standards and codes will not greatly affect the vehicle being created. This is because most of these standards have already been implemented into industry and the products being created. This means that any products the team may buy from aftermarket sources are, theoretically, already up to par with the codes/standards mentioned above. Furthermore, the rules and guidelines set by the SAE Baja competition also ensure that the vehicles being made are up to code and overall safe to operate for all involved.

3 Testing Procedures (TPs)

The following sections describe the necessary testing procedures that will be conducted in Spring 2020 to ensure the final design of the front and rear suspension geometries satisfy the engineering requirements outlined in section 2.2.

3.1 Testing Procedure 1: Shock Absorber Testing

To test the abilities of the shock absorbers used on the front and rear suspension geometries, the completed vehicle will travel over a course pre-designed by the competition team. The testing course will consist of an uneven road surface, including obstructions such as boulders and logs. These obstructions and surface irregularities determine the damping response of the shock absorbers at competition speeds, where the durability, or cycles to failure, for the shock absorbers, control arms, hub assembly, steering knuckle, wheels and fasteners will be examined. In addition, sections of jumps will be implemented to analyze the stresses of a hard impact on the suspension system and ensure a robust suspension design. Repeated trials on this course will be conducted to simulate the conditions of a four-hour endurance race hosted at the competition.

3.1.1 Testing Procedure 1: Objective

The objective of this testing procedure is to ensure the shock absorbers and suspension components of the front and rear end are reliable and robust to successfully endure the reaction forces from travelling over rough terrain in a four-hour endurance race. The vehicle will complete as many timed laps as possible within a time limit of four hours to accurately replicate the competition event and ensure the vehicle's suspension can withstand high stresses and reaction forces for an extended amount of time. This will also measure the cycles to failure for each subcomponent. This procedure is critical to the success of the Baja competition vehicle because analyzing failures will allow the design team to acknowledge unforeseen failures on essential subcomponents and change them to mitigate potential modes of failure. In addition, this procedure allows the team to gain exposure to trackside maintenance in the event of component failure, which will improve repair times in competition.

3.1.2 Testing Procedure 1: Resources Required

The design team must first utilize the Finite Element Analysis (FEA) feature found in SolidWorks to conduct a stress analysis on the geometry. In addition, a large area of open space on a gravel or dirt surface is required to construct a testing course layout found in previous competitions. The service roads and lots primarily used by construction services and campus maintenance vehicles located behind building 98C on Northern Arizona University will serve as the foundation for the test track. The design team will use shovels, wheelbarrows and a skid steer loader operated by a trained professional from construction services to create surface irregularities and jumps for the test track. These tools will also transport large objects that will act as obstacles for the vehicle to overcome. The MyLaps Transponder system will be ordered online and used to record the vehicle's lap times and the total laps completed before the failure of any subcomponents. This allows the design team to verify the reliability of the suspension design and make necessary changes to the geometry if required.

3.1.3 Testing Procedure 1: Schedule

The shock absorber test will be conducted on a closed course made on campus behind building 98C once the vehicle is completely assembled by late February. For assembly to be complete, the desired shock absorbers and control/trailing arms must be purchased or manufactured by late January and installed on the vehicle by early February. The test will last four hours to simulate the endurance event in the competition, which is held on April 15th.

3.2 Testing Procedure 2: Brake System Testing

3.2.1 Testing Procedure 2: Objective

The objective of this test is to assess the durability and performance of the braking system by replicating the conditions expected in a competition environment. The design team will measure the system pressure with the brake pedal actuated and the vehicle at rest, and subsequently test the braking system with the vehicle traveling at maximum speed to determine if all four wheels lock in the shortest possible stopping distance. The team will measure the stopping distance of the vehicle to determine if the engineering requirement for stopping distance is satisfied. Testing the hydraulic pressure of the braking system ensures the system is operating at maximum efficiency to lock all four wheels and provide optimal deceleration. In addition, the driver will conduct repeated cycles of hard braking to bed a layer of the pad material onto the rotor, which will improve the clamping force between the rotor and caliper [2]. The repeated compressive and thermal stresses from hard braking will also assess the endurance limit of the rotor. This test will be conducted on service roads and asphalt roadways to examine if all wheels will lock on dirt and asphalt.

3.2.2 Testing Procedure 2: Resources Required

The system pressure test required a brake force analysis to be evaluated in Excel, which provided values of expected system pressures and braking forces required to lock all wheels. In addition, this test requires a driver to fully depress the brake pedal and a Bourdon Tube gauge to be connected to the bleeder valve of the brake caliper, which can be performed when the brake system is installed onto the vehicle. The Bourdon Tube gauge kit will be ordered online or borrowed from the Experimental Methods lab equipment with permission from faculty. This leak down test will determine the total brake system pressure, allowing the design team to verify the measured pressure with the expected value from the analysis and troubleshoot the brake system for leaks. The dynamic braking test will be conducted on sections of service roads and asphalt roadways of at least 500 feet to allow the vehicle to reach maximum speed and lock all wheels on dirt and asphalt. The design team will mark the sections of road in increments of ten feet and determine the point at which the driver applies the brakes. Spotters from the front and rear end sub teams will measure the distance between where the driver applied the brakes to where the vehicle comes to rest, which will be used to conclude if the stopping distance requirement is satisfied.

3.2.3 Testing Procedure 2: Schedule

The braking system testing procedure requires a force analysis to be evaluated in Excel and finalized by late November. The brake calipers, rotors, master cylinders, brake lines and pedal are also required to be installed on the vehicle for testing. These parts will be acquired from aftermarket suppliers or manufactured in house, which will be received by early January. The initial system pressure test can be conducted when stationary and does not require the vehicle to be fully assembled, which means it can be completed during the construction of the vehicle. However, the break-in procedure for the pads and rotors and subsequent dynamic braking test requires the vehicle to be fully assembled and operational, including a full day of testing time. The design team expects to complete vehicle fabrication and assembly by late February.

3.3 Testing Procedure 3: Material Properties

3.3.1 Testing Procedure 3: Objective

The primary objective during the material properties testing is to ensure that all materials chosen for our different sub-systems will meet our engineering requirements for weight and material strength. There are many different systems that will utilize these tests, including: control/trailing arms, hubs, as well as the shocks themselves. The material for the control/trailing arms will be undergoing bending or torsion tests, this will help us conclude if the material is strong enough to withstand the rough terrain it will be driving over. This will be based on a yield strength requirement given to the team through engineering the requirements. The material test for the shocks is focused around the outer metal and making sure it can withstand a certain amount of torsion if our trailing arm does move in a unique direction and causes the mounting points to move causing a twisting motion on the shocks. Through these tests, the team will be able to conclude if the material chosen is strong enough. In addition, the weight of each component will be recorded to ensure the total vehicle weight is satisfied.

3.3.2 Testing Procedure 3: Resources Required

In order to complete the testing process for material strength there are a couple resources that will be required. First of which would be the tension test machine, on this machine the team will be able to test samples of our material and test the tensile strength to ensure it matches the given data for that material [3]. This machine can be found in many different labs through campus and will just need permission to test our materials. The other machine needed to test torsion is simply a torsion testing machine. There are many different brands that can be found online, however the team is also hoping to do this test in house at Northern Arizona University. Lastly, the design team will acquire a scale from the machine shop to weigh complete components utilizing the selected materials.

3.3.3 Testing Procedure 3: Schedule

The schedule for most of these tests are based on the timeline of manufacturing. However, the tensile test can be done on samples of our material as soon as the materials that will be used are available to the team. We will still need to conduct tensile strength tests on our control/trailing arms after all the modifications have been made. The torsion test can also be done as soon as shocks are purchased and shipped. Overall, the testing procedures will not be fully completed until the control/trailing arms are fully manufactured.

3.4 Testing Procedure 4: Maneuverability Testing

3.4.1 Testing Procedure 4: Objective

The maneuverability test is designed to assess the reliability of the steering system in situations that require swift reactions by the driver. This test also assesses the maneuverability of the vehicle when the driver is required to navigate tight corners and around stationary objects that hinder the vehicle's path. The design team will be able to adjust the front end and rear end suspension alignment for optimal cornering performance, including the steering tie rods while conducting this test. This allows the vehicle to swiftly change direction for sharp turns and maintain stability under hard cornering, ensuring success in the maneuverability event of the competition. Additionally, the vehicle will travel at low speeds with the steering at full lock to one direction, and a spotter will mark the starting and ending points when the vehicle completes a 180° turn. The corresponding radius of the path will then be measured. This allows the design team to determine the turning radius and further optimize the suspension geometry and dimensions to satisfy the engineering requirement for maneuverability. Lastly, the design teams will conduct a slalom test, where the driver will be required to swiftly maneuver the vehicle at speed between evenly spaced cones or markers. Figure 5 demonstrates a configuration of the slalom test.

Figure 5: An automobile completing a slalom test [4].

3.4.2 Testing Procedure 4: Resources Required

The front end and rear end design teams utilized an analysis of past successful competition vehicles and an Ackerman Angle analysis to determine the optimal wheelbase and ride height of the current design, including front and rear track widths**.** This allowed the design team to optimize the engineering requirements for track width, ride height and wheelbase of the vehicle to satisfy the desired turning radius. The design teams will utilize the dirt service lots located behind Building 98C to construct a course that includes a continuous set of corners that switch direction and gradually increase in radius. A tape measure will be acquired from the machine shop to measure the turning radius of the vehicle at low speeds.

3.4.3 Testing Procedure 4: Schedule

The maneuverability test requires the vehicle to be fully assembled with complete suspension geometry and a rack and pinion steering system installed. As mentioned previously, the design team aims to complete vehicle construction by late February to allow for ample testing and tuning time before the competition on April 15th.

3.5 Testing Procedure 5: Cost Analysis

3.5.1 Testing Procedure 5: Objective

The primary objective of this test is to ensure the total cost for the required materials and travel expenses do not exceed the allocated budget for the front and rear end design teams. Each sub team will use Excel to compile a list of parts that will be used to satisfy the engineering requirements based on optimal designs. This test ensures that the subsystem designs meet or exceed engineering targets while remaining within budget and inexpensive compared to previous competition teams. Lastly, the net present value of components and associated maintenance costs will be calculated to ensure a successful project.

3.5.2 Testing Procedure 5: Resources Required

As mentioned above, the design teams required Excel to compile a list of desired materials and calculate the total cost for each desired subcomponent. Both teams extensively researched cost-effective parts and materials from online suppliers that will satisfy design goals, referencing the Bill of Materials of previous competition teams from Northern Arizona University and the allocated budget to ensure the engineering requirement for cost is satisfied. If additional funding is required, the design team will contact companies for potential sponsorship opportunities, which will further decrease overall material costs and increase the team budget. Before competition, the team needs to acquire estimates for travel costs including fuel, lodging and transportation of the competition vehicle and plan contingency expenses to ensure all costs remain within the budget.

3.5.3 Testing Procedure 5: Schedule

The Bill of Materials will be finalized by the end of the Fall semester so the design teams may begin manufacturing and finalize component purchases. Travel and contingency expenses will be finalized by early March. Additional sponsors will continue to be contacted up until the day of the competition, which is April 15th.

4 Risk Analysis and Mitigation

The Baja SAE vehicle is comprised of many parts that have the potential to fail. The reasons could vary from being a manufacturing failure to failure through overloading stresses. It is vital that the potential failures are addressed, and methods are found to mitigate their effects. In order to look into all the possible failures, the sub systems that relate to both Front End and Rear End of the Baja vehicle are combined in the FMEA. The primary categorization of the subsystems are suspension, steering, brakes and wheels assembly (CV axles, hubs, and knuckles).

4.1 Critical Failures

Based on the full FMEA performed, the top ten main failure modes of the subsystems are described below. Table 5 illustrates the top ten failures while Table A1 in appendix A is the full FMEA.

Table 5 - Critical Failures

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Brake System	Brake line leak or rupture	Decreased deceleration, brake system failure	Sharp cuts on the brake lines	480	Stainless steel Brake lines to resist abrasion, expansion
Control Arms	Weld failure	Complete control arm failure, arm component separation	Lack of material at weld joint	480	Ensuring all welds are strong through testing
Steering	Deformation of teeth on pinion	Ineffective steering operation.	Over exerting torsion in a short time	480	Use durable material for rack and pinion
Brake System	Master cylinder leak	Decreased braking system pressure, pedal will not retract	manufacturer defect, improper installation	400	Integrated master cylinder
Brake System	Broken Calliper bracket	Loss of braking due to brake caliper movement	Impact/improper material selection	400	Use robust, durable metals and check routinely
Control Arms	Tube failure	Complete control arm failure	Improper tubing calculations	400	Thick enough wall on tubing
Steering	Quick release system detaches	Driver unable to control vehicle	improper installation/ mechanism failure	400	Use Ball-Lock quick release system
CV Axles	Spline failure	No power to the wheel	Improper material selection	360	Ensure power through CV axle is appropriate splines
Brake System	Brake pedal falls off	difficulty or loss of braking	improper installation/ manufacturing	360	Use a durable mount for pedal
Roll Hoop	breaks free from frame	loss of dampening, frame bottoms out on obstacles	Suspension bottoms out, object strikes roll hc	360	Use durable metal and test welds

4.1.1 Potential Critical Failure 1: Brake Line Leak or Rupture

The brake lines are very important in distributing the brake fluid from the master cylinder to the pistons. A brake line leak would possibly occur due to poor materials, contact with sharp edges or a manufacturing failure. If it occurs, the brake system will lose its pressure and the rate of deceleration will increase. The brake system will lose its effectiveness gradually. In going through dynamic events at the SAE Baja competition, the lack of braking power would affect the performance of the vehicle. In order to have excellent maneuverability, the ability to stop the vehicle as quickly as possible is vital with the regulated input by the driver on the brake pedal. The brake lines will be made using stainless steel to increase strength and prevent physical damages that can occur on the brake line.

4.1.2 Potential Critical Failure 2: Control Arm Welds

There is potential that the welds holding the control arms together could fail. This could happen if an object were to strike the control arms. This failure could also happen if an obstacle caused a large amount of stress to be placed on the welded joints. If the welds failed the control arms would fall apart and the car would not be supported. If this only happened on one control arm, the vehicle would stop functioning and come to stop. Most likely there would be minimal damage to other systems in the vehicle. However, there is a chance of loss of control of the vehicle. If the driver loses control of the vehicle, depending on the terrain of the course and speed of the vehicle, there could be severe damage to the car and possible injury to the driver. This failure can be mitigated by testing welds during the manufacturing process. Testing welds throughout manufacturing will ensure that the welder is creating quality welds in a repeatable manner. Another way the failure can be mitigated is by inspecting the control arms before each use of the vehicle. This will allow the user to see signs of potential failure, such as bends, dents, and cracks. If a sign of failure is observed than the control arms can be replaced before operation of the vehicle.

4.1.3 Potential Critical Failure 3: Steering Pinion Teeth Deformation

There is a potential that the teeth in the steering pinion could deform. The most probable cause of this failure is over exerting torsion in a short amount of time. This can occur by the driver turning the steering wheel hard while also hitting obstacles. If this failure occurs than the driver will have difficulty steering the vehicle, or if the deformation is severe enough, the driver will lose the ability to control the car. Using a strong, durable metal for the pinion and the teeth in the pinion will mitigate this failure.

4.1.4 Potential Critical Failure 4: Master Cylinder Leak

For the braking system, a critical failure that may occur is a leaking master cylinder due to manufacturer defects or improper installation. This component failure causes reduced system pressure and complete system failure if the brake fluid leaves the system, and the pedal will not return to its original position when compressed. As a result, the hydraulic pressure is unable to actuate the brake calipers to decelerate the vehicle. To mitigate this failure, an integrated master cylinder constructed from aluminum by a reputable manufacturer will be used to reduce the possibility of the brake fluid leaking from the master cylinder at fluid reservoir connections or the reservoir itself.

4.1.5 Potential Critical Failure 5: Broken Caliper Bracket

A possible failure within the braking system is a fractured brake caliper mounting bracket. This failure can be caused by large impacts or improper material selection for the bracket. If the caliper mounting bracket fails, the brake caliper will become misaligned or detach from the intended mounting point. This greatly reduce braking performance because the brake caliper is unable to efficiently apply a clamping force onto the brake rotor. To mitigate this failure, the brake caliper bracket will be constructed of a robust material to resist deformation and visually inspected for deformation or the propagation of stress cracks before each test.

4.1.6 Potential Critical Failure 6: Control Arm Tube Failure

Another possible failure is the tubing in the control arms can deform. This can happen if an object were to strike the control arms, or if an obstacle caused a large amount of stress to be placed on the control arms. If the control arms bend or shear, the suspension system can lock up, having no movement. With the arms unable to move the vehicle will experience greater stresses throughout the frame. The driver may also lose control of the car if the control arms do not move. The failure can be mitigated by performing an analysis on the control arms to ensure a proper wall thickness for the tubing is used. As the thickness of the tubing increases the chances of this failure decrease.

4.1.7 Potential Critical Failure 7: Quick Release Steering System Detaches

The ability of the driver to control the vehicle is primarily centered to the steering wheel. A major disadvantage in the competition could occur when the steering wheel is unable to transmit the physical input of the driver. The failure could occur if the steering wheel is not installed correctly and not checked if the component is locked onto the steering column. Another mode of failure would be the poor strength of that material used. In order to mitigate the possible failures on this component, the material selection needed to be consistent with the steering column. A strong material must be used to avoid material deformation. Along with this, the steering wheel must be locked on using ball locks which are very strong in holding connections and can only be disengaged with the push of an input button release.

4.1.8 Potential Critical Failure 8: CV Axles Spline Failure

The CV axles are the component which drives the power from the differentials to the wheel. The connection of the CV axle to the wheel is vital for continuous movement. A major effect could be caused when the spline connection fails. The purpose of the splines is to lock the CV axle with the wheels so that they move with same torque output coming out of the differential. If this locking mechanism fails, the torque distribution will be disrupted and power in the motion of the car will drop. Possibilities of the splines to fail are higher when the material strength is lower than expected or poor manufacturing. This form of failure can be rectified by ensuring that the material and the dimensions on the splines can take the stress and torsion exerted on the entire CV axle.

4.1.9 Potential Critical Failure 9: Brake Pedal Shears off

Another possible failure for the braking subsystem is the brake pedal shearing off of its mount. If the brake pedal breaks off, then the driver will have difficulty or be unable to use the brakes. This can cause loss of control of the vehicle. Loss of control of the vehicle can cause further damage to the vehicle and possibly the driver. This failure can be mitigated by using a strong, durable metal in the mount of the brake pedal.

4.1.10 Potential Critical Failure 10: Roll Hoop Breaks Free from Frame

In the suspension subsystem, a potential critical failure is the roll hoop breaking free from the frame. The roll hoop is where the shocks are mounted to the frame. If the roll hoop breaks from the frame the shocks will no longer function. Without the shocks functioning, the car will no longer be supported and will bottom out on obstacles. The vehicle may also experience higher stresses throughout its control arms and the frame creating a higher risk for other failures. This failure can be mitigated by ensuring the welds used to hold the roll hoops to the frame are strong and the metal used in the roll hoops is also strong and durable. This can be done by performing an analysis on the roll hoops and testing the welds during manufacturing.

4.2 Risks and Trade-offs Analysis

These critical failures are all important to mitigate, as all of them will cause negative effects on the overall performance of the vehicle. All of the critical failures can be mitigated together. Most of the failures can be mitigated by increasing the thickness of the part or by using a stronger material. While these mitigations do not make it more difficult to mitigate another failure, they do negatively impact the performance of the car. One of the engineering requirements for our vehicle is to be lightweight. By increasing part thickness or using stronger materials the weight of our vehicle increases. Due to this dilemma of needing strong reliable parts and a lightweight vehicle, analysis of the parts are performed to ensure the team uses a strong enough material so the car will not fail, while also not over designing the vehicle and keeping its weight as light as possible.

The weight to performance ratio is a major concern with regard to the competition. The ability to build the components with necessary strength and reasonable weight allowed the sub teams to select a material with high tensile and yield strength. Hence, the most chosen material is 4130 chromoly. 4130 chromoly is expensive when compared to other materials. In order to reach our needed weight to performance ratio, the cost of the chromoly is a price the team is willing to make.

5 DESIGN SELECTED – First Semester

In this section, the final design of front and rear end will be detailed. The calculations behind this design will be explained and the prototypes of each subsystem will be visualized. The final CAD of each design is picture with different views to clarify all of the components within them. The process of how the team will implement each of their subsystems into physical parts is also outlined.

5.1 *Front End Design Description*

5.1.1 Lotus Calculations

The front end team began the design by using Lotus Suspension Geometry software to analyze the front suspension under different dynamic conditions. The software was able to give the team camber and toe angle changes when the system undergoes a bump. For maximum maneuverability and stability, a bump should add around -1 degrees wheel camber on shock compression and around -3 to -5 degrees negative wheel camber on shock expansion, as seen in Figure 6. Ideally for the toe angle, a bump should cause no more than positive 2 degrees and no less than 0 degrees, as seen in Figure 7. From this analysis, the team approved the geometry and mounting locations for the front components.

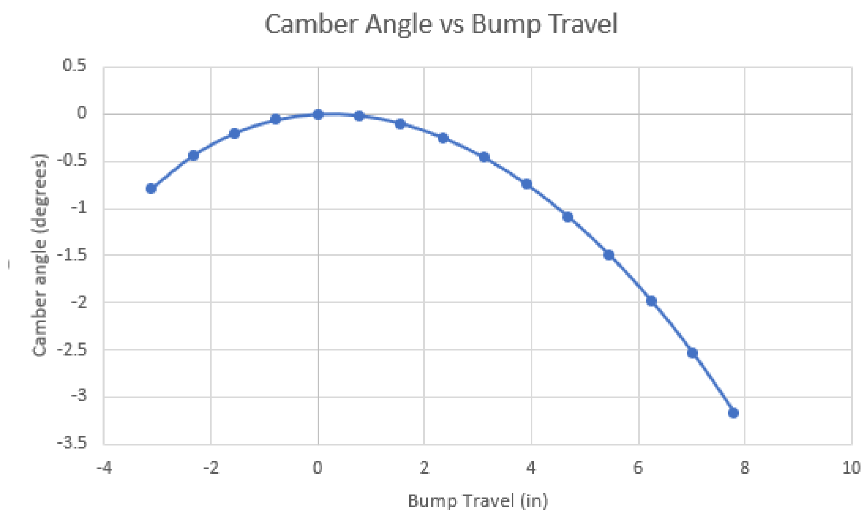

Figure 6: Front End Camber Angle vs. Bump Travel

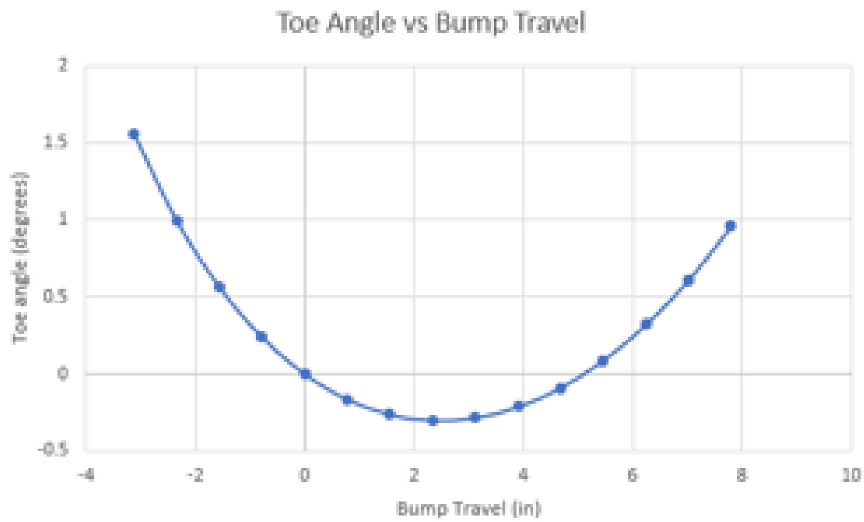

Figure 7: Front End Toe Angle vs. Bump Travel

5.1.2 Front End Prototype

After the front-end suspension angles were approved, a SOLIDWORKS model was created with all the matching geometry. A low-cost prototype was created to roughly display the teams design. As seen in Figure 8, the front-end prototype is 1:4 scale composed of wood dowels, metal eyelets and a model car spring. An overall layout of the design was beneficial to the team, to visualize the design and make alterations if necessary.

Figure 8: Front End Prototype

The prototype revealed to the team that since the shock will be mounted to the upper control arm to avoid the CV axles, the upper shock mounting location was drastically raised. So high that it exceeded the height of the nose section of the frame. Without a proper mounting location for the shock, the shock travel and performance would be greatly affected. This problem was solved by getting with the frame team and redesigning the front nose section of the frame to accommodate for the taller shock mount. The final solution, as seen in Figure 9, is an added tube to the frame above the nose to give the shock an upper mounting location.

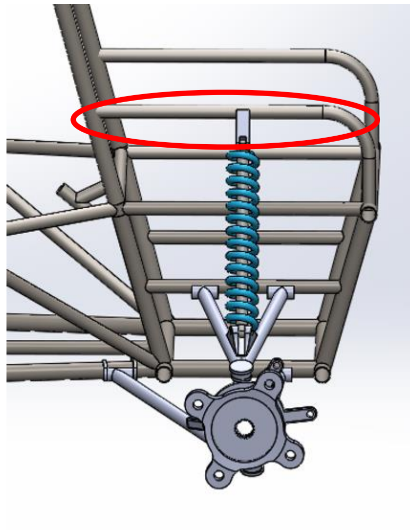

Figure 9: New Nose Section of the Frame

5.2 Rear End Design Description

5.2.1 Lotus Calculations

The rear end team started the design by using Lotus Suspension Geometry to gain the mounting locations for a trailing arm suspension setup. The Lotus Suspension program was able to provide camber angles and toe angles at different extensions of the suspension. This was the first stage of back of the envelope calculations to get an approximation for mounting locations. Figure 10 and 11 show the angles previously mentioned. The target values for toe angle at zero inches of travel is ideally ± 1 degree.

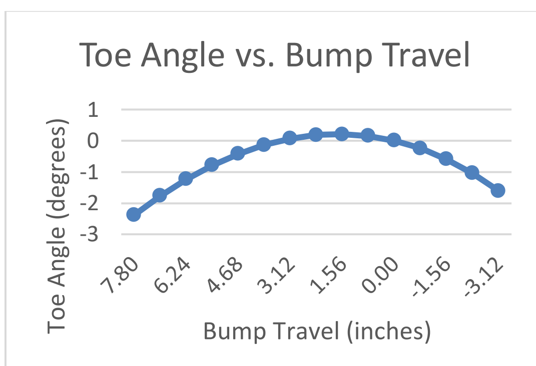

Figure 10: Rear End Toe Angle vs Bump Travel

Where a camber angle is best at a zero-camber angle to maximize the wheel contact with the ground.

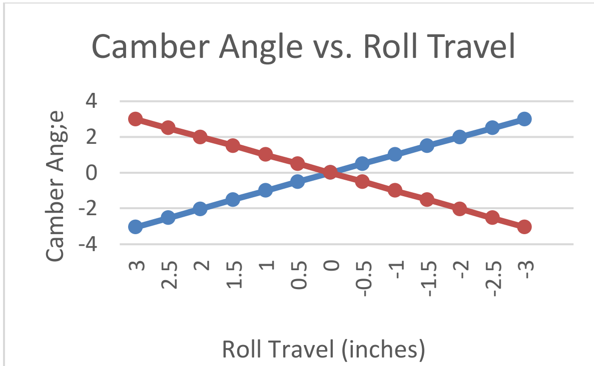

Figure 11: Rear End Camber Angle vs Roll

5.2.2 Rear End Prototype

Once the ideal camber and toe angles were met solid models were created in SOLIDWORKS and an assembly to test spacing of the design. The next step was to create a model to visualize the manufacturing process. The material being used is costly, so a prototype was constructed out of an alternative material.

When the rear end team conducted a prototype of the trailing arm, positives and negatives to the design were found. As seen in Figure 12, is a 1:1 scale prototype constructed of wood. The first successful find was ease of assembly of the plates, which will be located near the rear of the vehicle. Those were able to be aligned and brad nailed on for the prototype, for the final model the plates will be welded to the tubing. The second positive was the mounting tabs for the ball joints, this part of the design will also be welded onto the existing plates. With the prototype there are no holes drilled to mount the ball joints, this did due to the difficulty of drilling after the part has been attached. In the future assemblies the holes shall be predrilled and aligned before welding.

Figure 12: Rear End Prototype

The one portion of the design that was changed due to the prototype was the hinge connection which mounts directly behind the firewall of the vehicle seen on the right side of Figure 12. The reasoning behind this change is the lack of misalignment in the rear end. If there is a lack of misalignment the suspension geometry would be too constrained to fully cycle or even become fully fixed in extreme cases. The design change will be to add a misalignment ball joint instead of the hinge connection. Along with the new ball joint, an additional member will be added to the frame to allow the training arms connection to be perpendicular to the frame attachment. This can be seen in Figure 13 along with the new ball joint connection.

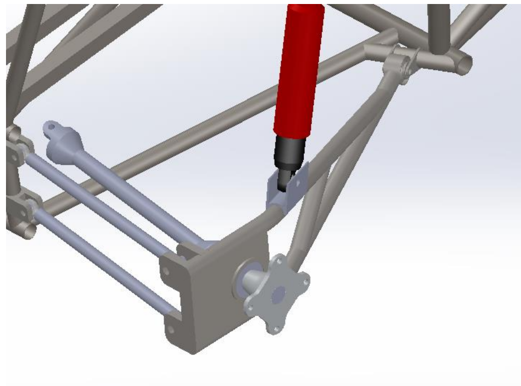

Figure 13: New Ball Joint Connection

5.3 Front End Implementation Plan

As mentioned in section 5.1, the front end team constructed a front suspension prototype and had to add another frame member above the nose section of the frame to give room for the upper shock mount. Next, the team will begin to build the front end and purchase off the shelf parts for the knuckle, ball joints, hub and shocks. The only part being fabricated in house is the control arms, as seen in Figure 14

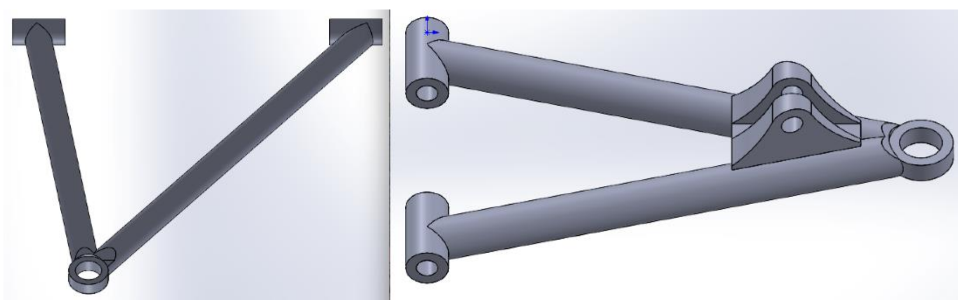

Figure 14: Top and Bottom Front End Control Arms

The current material selected for the trailing arm is 4130 Chromoly with a 1" OD and 0.049" wall thickness. To make both sides of the suspension control arms, the team will use two six-foot sections of steel tubing and to make two sets the total cost will be $145.84 for material. When the length are cut and the end notched for the ball joint connection, the pivot point mounts on the frame end will be cut from the same material. These lateral mounts, as well as, the ball joint connection eye will be welded in place setting the appropriate angles between the tubes. The last step in completing the control arms, the team will weld a 1/4" steel plate on top of the upper control arm for the lower shock mount assembly to be fitted. Lastly, the team will CNC an arched shock mount to be welded to the mounting plate. The team will utilize water jetted frame mounting tabs for the front suspension control arms, as seen in Figure 15. These mounting tabs will be welded to the frame so that the control arm lateral mounts can be fixed to them via bolt.

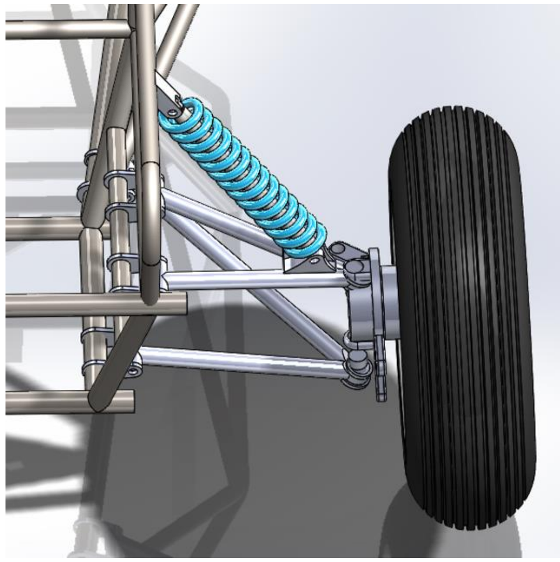

Figure 15: Front Suspension Full Assembly

The rest of the front suspension components will be purchased and fitted with bolts and nuts to the rest of the assembly. This front-end design was built in a way so that the drivetrain components, the front differential and the CV axles would not be hindered from operating. For the front shocks, King off road shocks were selected costing $948.10 before tax and before the dealer discount that the team was fortunate to gain. As seen in Figure 16, the front-end suspension assembly is visualized.

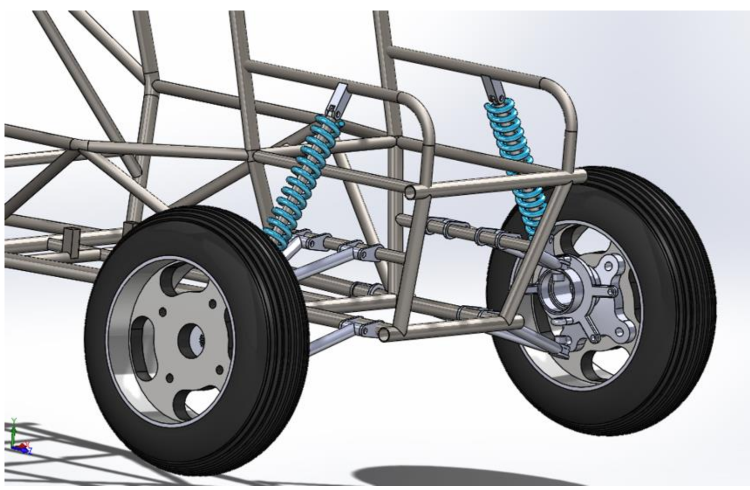

Figure 16: Front End Assembly

Figure 17 illustrates the front suspension exploded view for more detailed visualizations.

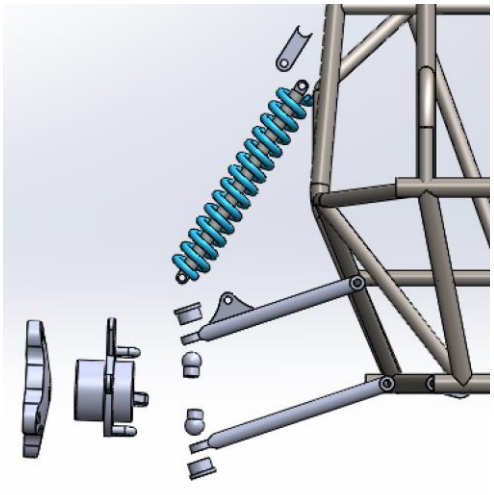

Figure 17: Front Suspension Exploded View

The last step of the front-end team's design was developing a final cost of the front suspension assembly. Currently, the total design will cost $3,479.03 without using any existing parts in the machine shop or using any business sponsorships. The breakdown can be further visualized in Figure 18 and a full part itemization can be found in Appendix B.

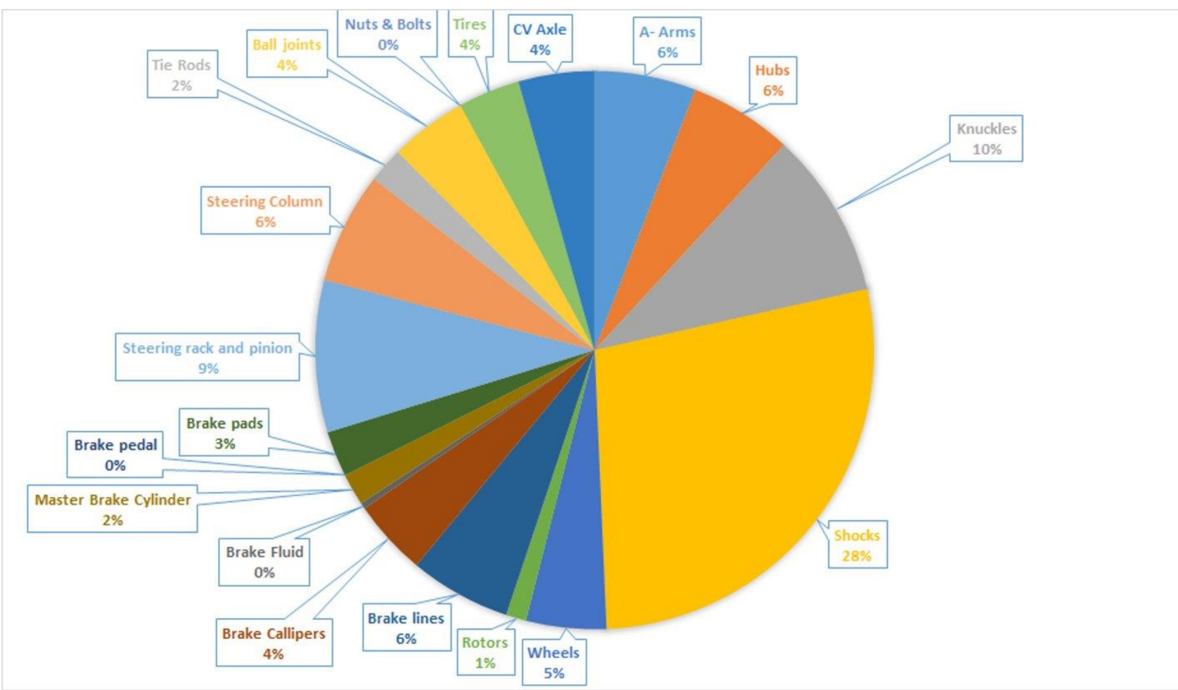

Figure 18: Front End Cost

The schedule in which front end is planning for is to have the front end control arms built by the beginning of February. Then once all the other components get delivered, the team will assemble the entirety of the front suspension assembly. The goal is to be complete with the front end suspension by late March.

5.4 Rear End Implementation Plan

As mentioned in section 5.2, the rear end team first constructed a prototype and altered the design to accommodate some negatives to the design. The next step will be to have the entire design fabricated or purchase the parts that are available off the shelf. The major component being fabricated by the rear end is the trailing arm tubing. As seen in Figure 19 is the trailing arm tubing that is to be bent and coped.

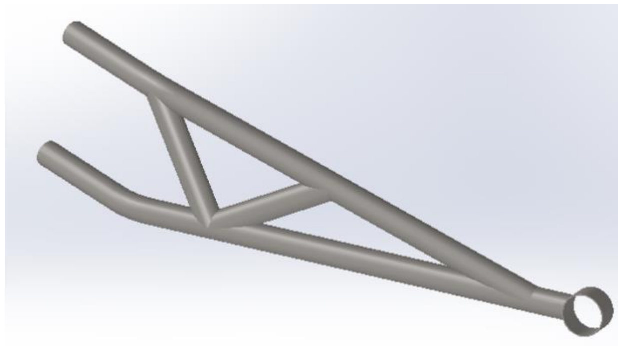

Figure 19: Trailing Arm Tubing

The current material selected for the trailing arm is 4130 Chromoly with a 1” OD and 0.049” wall thickness. To make a pair of trailing arms the team will utilize two six-foot sections of steel tubing and to make two sets the total cost will be $145.84 for material. The next parts to be fabricated in house are the rear lateral links. These will simply be turned down to their final outer diameter and have steel tube ends welded on to accept the threaded rod ends. To connect the misalignment ball joint to the tubing on the rear various mounting tabs will be utilized. Some of the tabs will be mounted onto the frame before assembly and will not be allowed to be shifted. The rest of the tabs will not wrap around the tubing and can be added after the frame has been completely welded together. For a visualization of the tabs see Figure 19.

The rest of the rear end parts will be purchased. The design has been built around parts that the drivetrain team has decided to go with. This is primarily the constant velocity (CV) axle which connects to the hub from a Yamaha Grizzly 350. To utilize the CV axle and hub there is a press fit bearing in the trailing arm to allow the CV axle to move freely. The last portion of the rear end is the shocks, for these the team has a few options to consider and will decided based on final funding. Currently the shocks have been selected to use King off road shocks and cost $948.10 before tax and the dealer discount that the team was fortunate to gain. To further understand the components of the rear end, seen in Figure 20, a top exploded view of the final CAD assembly is pictured.

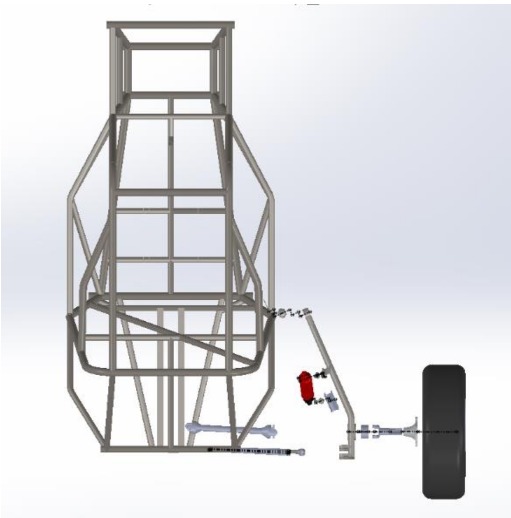

Figure 20: Exploded View (Top)

As seen in both Figures 20 and 21 is the rear end exploded to view all components. Within each connection joint there is a ball joint with different misalignment allowance. The wheel is connected to the hub which attaches directly to the CV axle. This connection will ride in a carrier bearing that is press fit into the trailing arm. The four main components that make up the rear end is the CV axle, rear lateral links, trailing arm, and shocks.

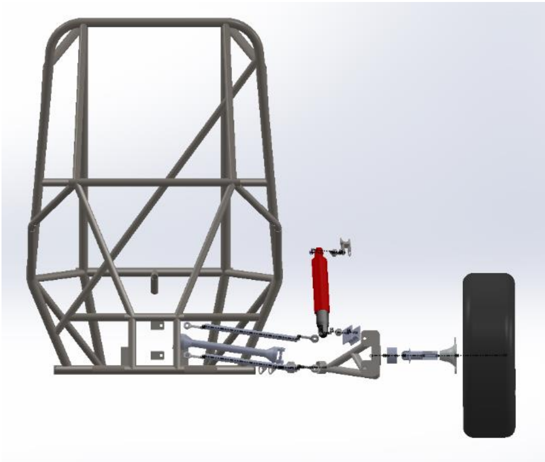

Figure 21: Exploded View (Rear)

The final portion of the team's design was evaluating the cost of all material. Currently the rear end design will cost $2628.87 without the aid of using any existing parts in the shop or any sponsorships. This cost includes creating two sets of trailing arms and all the connections for each of those. The team will only purchase one set of shocks due to the high costs and the limited budget. To see the breakdown of where money is allocated for each part of the rear end see Appendix C. For a simplified percentage of each portion see Figure 22.

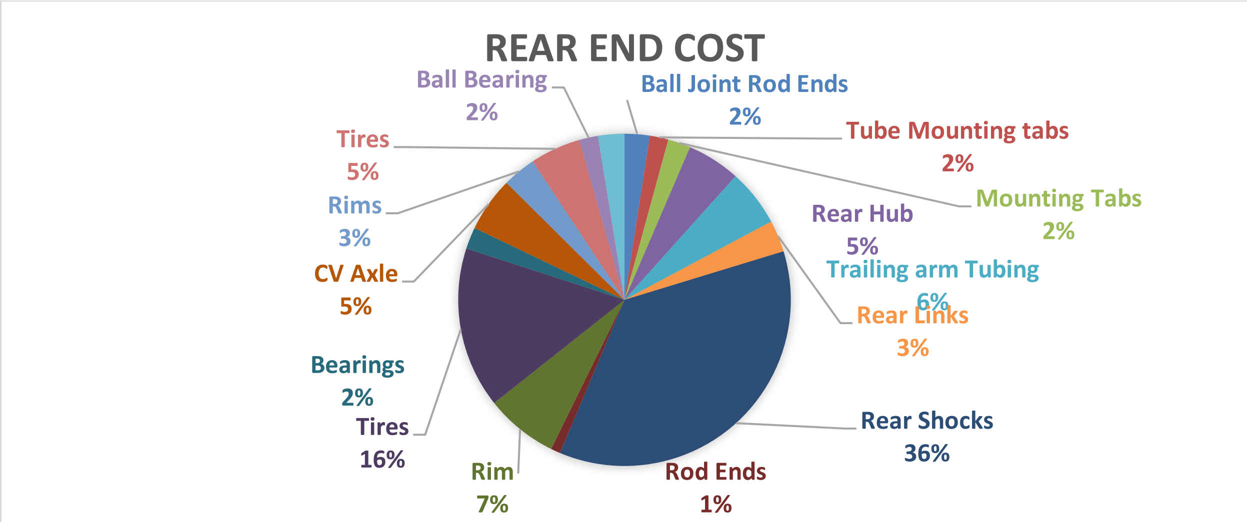

Figure 22: Rear End Cost

The plan to implement the rear end starts with getting the tubing bent and coped. This shall be done before January 1st to stay on schedule. The next step will be to get the plates and bearing on the trailing arm all linked together. This shall not take more than a few days to complete both sets. The next step is to mount all parts to the frame, which time will be allocated for. The goal is to have all parts fabricated by the end of February at the latest to be prepared for competition in April.

6 CONCLUSION

Through the hard work and diligent efforts put forth by both Front and Rear End teams, this semester has concluded in a fully functional design. In order to successfully meet the competition requirements both front and rear end created designs that would be an efficient suspension system given our four-wheel drive train. Both teams did an immense amount of research for every sub-system involved within our designs. The front end designed a system that utilized control arms so that none of the other sub-systems would be colliding during testing/driving. The rear end utilized a design made up of a trailing arm with two-lateral links. Through the analysis done by the team, it was concluded that this system was best suited for our purpose. After both teams have finalized their designs, it was confirmed that these designs would work with the full system for the entire Baja. This final design now includes every sub-team's final design and just needs to be manufactured.

7 REFERENCES

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8 APPENDICES

8.1 Appendix A: Full FMEA

Table A1: Full FMEA

2019-2020 Baja Vehicle		Will Preston, Jesse Summers, Jacob Grudynski, Michael Edirmannasinghe, Jacob Ruiz, Aaron King, and Lucas Cramer				Page No 1 of 1			
Front and Rear End						FMEA Number 1			
CV Axles, Brakes, Suspension, and Steering						11/16/2019			
Component Name									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
CV Axles	Binding joint	Tire locks up	8	Lack of dense material provided at the joint	4	Visual checks before and during use	2	64	Use durable and heavy duty boots to seal the binding joints
CV Axles	Spline failure	No power to the wheel	10	Improper material selection	6	Visual checks and Stress tests	6	360	Ensure power through CV axle is appropriate splines
CV Axles	Hub deformation	Imbalanced wheel mount	8	Improper dimensions/ material selection	4	Test to failure	8	256	Stress and Strain Analysis done on Hub with factor of Safety
CV Axles	Twisted axle	Risk of breaking and damaging other parts	6	Too much power	2	Material and tubingTest	10	120	Diameter of axle must withstand power output
CV Axles	Torn Boot	Dirt, Dust, and debri can enter other parts of the CV axle	4	Object Strikes Boot	4	Visual checks before and during use	10	160	Check CV axle boots before each use and replace if necessary
CV Axles	Damaged Joint	less power to the wheels, wears and tears until joint breaks	6	Dirt entered joint	2	Test to failure	6	72	Listen for clicking noises in turns, have boots on axles
CV Axles	Broken Joint	No power to the wheel, possible damage to other parts of the car	10	Dirt entered joint	2	Visual test before use	6	120	Listen for clicking noises in turns, have boots on axles
Knuckles	cracked knuckle	loss in manuverability	6	bottomed out suspension	4	Visual test before use	8	192	Use a durable metal to make the knuckles out of
Hub	siezed bearing	loss of power to the wheel	10	manufacturer defect, not maintained under extended use	2	Visual test before and during use	10	200	Follow manufacture instructions on how often to replace
Hub	loose bearing	loss in manuverability and power	6	improper installation/ manufacturing	4	Visual test before use	6	144	Be aware and check that bearing is tight during manufacturing and instalation
Brake System	Master cylinder leak	Decreased braking system pressure, pedal will not retract	10	manufacturer defect, improper installation	4	Visual test before and during use	10	400	Integrated master cylinder
Brake System	Seized Caliper piston	Vehicle pulls to one direction during braking/ partial system failure	8	Rust corrodes piston	4	Visual test before use	8	256	Brake Bias system to redirect braking force to either axle
Brake System	Brake line leak or rupture	Decreased deceleration, brake system failure	10	Sharp cuts on the brake lines	6	Visual test during use	8	480	Stainless steel Brake lines to resist abrasion, expansion
Brake System	Brake fluid boils	Reduced brake system pressure	6	Unaccountability on heat dissipatio	6	Listen for bubbling/ heat test	8	288	DOT 4 Brake fluid, higher fluid boiling point
Brake System	Brake rotor thermal deformation	Vibrations in steering system feedback, decreased braking efficiency	6	Unaccountability on heat dissipatio	6	Visual test before use	8	288	Ventilated or cross drilled and slotted rotors to improve heat dissipation
Brake System	Brake pedal falls off	difficulty or loss of braking	10	improper installation/ manufacturing	6	Visual and physical test before use	6	360	Use a durable mount for pedal
Brake System	Brake pedal deforms or shears	partial or total loss of braking ability	10	Improper material selection	4	Visual and physical test before use	6	240	Use material with high modulus of elasticity, redesign cross section of pedal
Brake System	Brake pad deterioration	decreased braking efficiency	6	Improper material selection	8	Visual test before use	6	288	Use high performance pad friction material such as ceramic compound, change pad design
Brake System	Broken Calliper bracket	Loss of braking due to brake caliper movement	10	Impact/improper material selection	4	Visual test before use	10	400	Use robust, durable metals and check routinely
Brake System	Brake rotor misalignment	Unequal wear on brake pads	6	improper installation	6	Visual test before use	4	144	Correct runout by turning rotors on lathe
Control Arms	Ball joint seize	Suspension dampening loss, separation from wheel knuckle/hub	6	Improper material selection	4	Visual test before use	6	144	Big enough ball joint for weight of vehicle
Control Arms	Weld failure	Complete control arm failure, arm component separation	10	Lack of material at weld joint	6	Visual test before use/ test untill fail	8	480	Ensuring all welds are strong through testing
Control Arms	Tube failure	Complete control arm failure	10	Improper tubing calculations	4	Visual test before use/ test untill fail	10	400	Thick enough wall on tubing
Control Arms	mounting tab deformation	control arm locked in place	10	bottom out suspension	4	Visual test before use/ test untill fail	6	240	use durable metal and check routinely
Control Arms	rear lateral link breaks	loss of manuverability	6	bottom out suspension	4	Visual test before use/ test untill fail	6	144	use durable metal and check routinely
Control Arms	rear lateral link siezes	control arm locked in place	8	bent link from impact on link	2	Visual test before use/ test untill fail	8	128	use durable metal and check routinely
Shocks	Binding mount	Reduced shock mobility	6	Improper calculation of torsion tolerance	2	Visual test before use	6	72	Mounting geometry correct for movement of shock
Shocks	Blown shock	Decreased damping ability, soft or stiff ride quality	6	Poor quality seals in shock	6	Visual test before use	6	216	Purchase capable shock for our vehicle weight
Roll Hoop	breaks free from frame	loss of dampening, frame bottoms out on obstacles	10	Suspension bottoms out, object strikes roll hoop	6	Visual test before use	6	360	Use durable metal and test welds
Shocks	binding shocks	control arm locked in place	10	bent shock cylinder, from object impact on shock	2	Visual and physical test before use	6	120	Use shocks that can easily be replaced
Steering	Deformation of teeth on pinion	Ineffective steering operation.	10	Over exerting torsion in a short time	6	Visual and physical test before use	8	480	Use durable material for rack and pinion
Steering	Steering column failure	Detachment of the driver to control the vehicle	6	Improper material selection	4	Visual test before use	10	240	Stress analysis performed on Steering Column
Steering	External interfrence in rack and pinion	Jammed steering system	10	dirt of rock in teeth of pinion	4	Visual and physical test before use	8	320	Sealed rack and pinion set up.
Steering	Tie rod bending	Steering alignment will be off	10	Struck by an object	4	Visual test before use	6	240	Stress analysis conducted prior to mounting
Steering	Steering wheel breaks off	loss of steering	10	used too much force in steering	4	Visual test before use	8	320	Use metal steering wheel
Steering	Loss of hydraulic fluid due to leak	more effort required to steer vehicle, increased vibrations	6	Debris/impact fractures casing	6	Visual test before use	8	288	Use durable casing with strong welds
Steering	bent steering column	difficulty steering	6	object strikes steering column	2	Visual test before use	10	120	use a durable material for column, guard column within frame
Steering	Quick release system detaches	Driver unable to control vehicle	10	improper installation/ mechanism failure	4	Visual test before use	10	400	Use Ball-Lock quick release system
Tires	Flat tire	loss of manuverability	4	Drove over sharp object, improper inflation	8	Visual checks during use and check tire pressure before use	2	64	Check routinely, use reliable tires
Tires	Tire blowout	Severe loss of manuverability	8	Drove over sharp object, improper inflation	4	Visual checks during use and check tire pressure before use	4	128	Check routinely, use reliable tires

8.2 *Appendix B: Front End Bill of Materials*

Bill of Materials - Front End							
Part #	**Part Name**	**Qty**	**Functions**	**Material**	**Estimated Unit Cost**	**Estimated Total Cost**	**Links**
1	A- Arms	4	Suspension System	4130 Chromoly Tubing	50.00	200.00	Manufactured in house
2	Hubs	2	Mount wheels and brake rotor to vehicle	Aluminium	102.00	204.00	https://www.polarispartshouse.com/oemparts/a/pol/5c38140f87a866171473b29a/suspension-front-carrier
3	Knuckles	2	Mounting A-Arms and steering	Steel	164.00	328.00	https://www.polarispartshouse.com/oemparts/a/pol/5c38140f87a866171473b29a/suspension-front-carrier
4	Shocks	2	Dampen impacts		474.05	948.10	https://www.summitracing.com/parts/kss-20001-111?seid=srese1&gclid=CjwKCAjwxOvsBRAjEiwAuY7L8h0YbcTliDPkO50dnYWvXvqRKZLkY-cs8R_nVpVYrPOJ3mz0H124HhoC66EQAvD_BwE
5	Wheels	2	Translate vehicle	Steel	78.97	157.94	https://www.bbwheelsonline.com/remington-utv-buckshot-atv-wheels-rims-satin-black-12x7-4x110-0mm-offset-BS1270430SB/
6	Brake Rotors	2	Decrease wheel rotation	Steel	20.00	40.00	Manufactured in house
7	Brake lines	2	Distribute brake fluid to system		100.00	200.00	http://lsracing.com/honda-trx250r-atc250r-stainless-steel-front-brake-lines-universal.372.2.atv-utv-racing
8	Brake Caliper	2	Apply clamping force to brake rotor	Aluminium	69.99	69.99	https://www.ebay.com/itm/WILWOOD-GP200-Billet-Caliper-Black-P-N-120-12178-/254407811513?_trksid=p2349526.m4383.l4275.c2#viTabs_0
9	Brake Fluid	2	Provide hydraulic Pressure		2.99	5.98	https://www.oreillyauto.com/detail/b/o-reilly-chemicals-4521/chemicals---fluids-16461/maintenance-chemicals-16867/brakes-25134/brake-fluid-17733/371c20e7cfcc/o-reilly-12-ounce-dot-3-brake-fluid/72126/4600007?pos=5
10	Master Cylinder	2	Hold and displace brake fluid	Aluminium	58.10	116.2	https://www.jegs.com/i/Wilwood/950/260-2636/10002/-1
11	Brake pedal	1	Actuate braking system	Steel	131.39	131.39	d=711-117182-37290-0&mkcid=2&itemid=380372659231&targetid=475515323741&device=c&mkt
12	Brake pad (Set of 2)	2	Apply friction to brake rotor	Ceramic	44.39	88.78	https://www.jegs.com/i/Wilwood/950/150-12270K/10002/-1
13	Steering rack and pinion	1	Change direction of vehicle	Aluminium	299.95	299.95	https://www.superatv.com/polaris-rzr-xp-1000-rackboss-heavy-duty-rack-and-pinion-
14	Steering Column	1	Allow driver to control steering	Aluminium	220.00	220.00	https://www.summitracing.com/parts/pfn-cl01ah?seid=srese1&gclid=CjwKCAjwxOvsBRAjEiwAuY7L8v6QdkR2pdO-O9pfQJx-DW1stWYKLrUmiXYVdBCH5O-GlqQOKGz2cRoCESMQAvD_BwE
15	Tie Rods	2	Mount steering rack to knuckle	Aluminium	34.95	69.90	Buggy/dp/B003LJ0Y8U/ref=asc_df_B003LJ0Y8U/?tag=hyprod-20&linkCode=df0&hvadid=331942329025&hvpos=1o1&hvnetw=g&hvrand=2
16	Ball joints	8	Mount control arms to knuckle	4130 Chromoly	18.99	151.92	https://www.summitracing.com/parts/qdb-41-3558?seid=srese1&gclid=CjwKCAjwxOvsBRAjEiwAuY7L8uelqf4WXsz-wo3YFhFPPZtoJirNRqBsOTRonVwGu3kZaoBDuQRJNhoCQgkQAvD_BwE
17	Nuts & Bolts	20	Attachments and mounting	Steel	0.00	0.00	Copper State Nut and Bolt
18	Tires (Set of 2)	1	Provide traction	Rubber	96.98	96.98	https://www.ebay.com/p/8008100633?iid=252718706130&chn=ps&norover=1&mkevt=1&mkrid=711-117182-37290-
19	CV Axle	2	Transfer rotation from front differential to wheels	4130 Chromoly Tubing	74.95	149.9	https://www.superatv.com/polaris-rzr-s-800-axles-adr-brand?gclid=Cj0KCQjw9fntBRCGARIsAGjFq5Fa23bk0EkqWfcREwHQ2iIkpaOX
Total Cost Estimate:					**3479.03**		

8.3 *Appendix C: Rear End Bill of Materials*

Bill of Materials									
Baja Rear End									
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost**	**Total Cost**	**Link to Cost estimate**
6960T6	Ball Joint Rod Ends	6	Super-Swivel Ball Joint Rod Ends	Attach rear links to trailing arm	Black-Oxide Alloy Steel	3/8" - 24 thread Super-Swivel Ball Joint Rod End	$10.68	$64.08	https://www.mcmaster.com/6960t6-6960T61
1388K452	Tube Mounting tabs	1	Steel Sheet	Mointing tabs for trailing arms	Low Carbon Steel	6" x 12" x 1/8"	$47.53	$47.53	https://www.mcmaster.com/1388k452
6547K37	Mounting Tabs	1	Steel Bar Stock	Mounting tabs for rear links	12L14 Carbon Steel	1 1/2" x 1 1/2" x 12"	$57.94	$57.94	https://www.mcmaster.com/6547k37
5KM-25311-10-00	Rear Hub	2	2010 Yamaha 350 Grizzly IRS hub	Connects CV axel to wheel	Reinforced Aluminum	7" x 7" x 7"	$68.25	$136.50	https://www.partzilla.com/product/yamaha/5KM-25311-10-00?gclid=EAIaIQobChMIpfqpqPnR5QIVYhh9Ch1MLQYiEAQYASABEgKgUvD_BwE
89955K646	Trailing arm Tubing	4	Steel Tubing	Makes up members of rear trailing arms	4130 Alloy Steel	1" x 0.049" x 6'	$ 36.46	$145.84	https://www.mcmaster.com/89955k359
1615T72	Rear Links	2	Aluminum Rod	Links rear to Traiing arms	6061 aluminum	1" x 6'	$ 40.63	$81.26	https://www.mcmaster.com/1615t72-1615T29
20001-118A	Rear Shocks	2	King Shocks UTV Performance Series Coilover Shocks	Reduces forces taken by suspension	Aluminum	12.5" to 19"	#####	$948.10	https://www.summitracing.com/parts/kss-20001-111
60645K14	Rod Ends	6	3/8" Ball Joint Rod Ends	Links rear to Traiing arms	Zinc-Plated carbon Steel	3/8" - 24 Thread Super-Swivel Ball Joint Rod End	$ 4.07	$24.42	https://www.mcmaster.com/60645k14-60645K142
1520263-463	Rim	2	Rim, Flat Black	Links tire to hub	Cast Aluminum	Fits 25x8 - 12	$ 92.80	$185.60	https://www.partzilla.com/product/polaris/1520263-463?ref=d5473e3fd0ef85e6063d67b2d931889e5ebdedca
5413060	Tires	2	Rear Tire	Contact between ground and the vehicle	Rubber	25 x 8 - 12	#####	$411.98	https://www.partzilla.com/product/polaris/5413060?ref=d5473e3fd0ef85e6063d67b2d931889e5ebdedca
DAC30550032-2RS	Bearings	2	Bearings	between cv and trailing arm	Steel	30x55x32 sealed	$27.77	$55.54	https://www.amazon.com/DAC30550032-2RS-Wheel-Bearing-30x55x32-Sealed/dp/B01MQT91WN
YFM450FGW	CV Axle	2	Cv axle	Power to wheels	unknown	unknown	$ 69.99	$139.98	https://www.eastlakeaxle.com/mm5/merchant.mvc?Screen=PROD&Product_Code=Yamaha-350-GRIZZLY-IRS-Rear-Left-4x4-2010
D12R511	Rims	2	Connect hub to tire	Support Vehicle	Aluminum	12 x 7 rim size	$42.63	$85.26	https://www.amazon.com/ITP-Delta-Steel-Wheel-Position/dp/B000WJL65W?ref_=fsclp_pl_dp_2
SunF A041	Tires	2	Tires	Support Vehicle	Rubber	24x8-12	$ 64.99	$129.98	https://www.amazon.com/SunF-A041-Trail-Tire-25x10-12/dp/B01MS86QPY?th=1
NA	Nuts and Bolts	0	Nuts and bolts for connecting members	Connects Members	steel	Misc.	$ -	$0.00	Copper State Nut and Bolt
YPB12T	Ball Bearing	2	For misalignment at the joint	Connects memebers	440C Stainless	1.5625" x 1.28"	$ 23.88	$47.76	https://www.qa1.net/rod-ends-and-related/spherical-bearings/ypb-t-high-misalignment-stainless-steel-series
YPB7T	Ball Bearing	4	For shock misalignment	Connects Shocks	440C Stainless	0.8775" x 1"	$ 16.78	$67.10	
Total Cost Estimate:								$2,628.87	