To: Dr. Trevas and Ulises Fuentes

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Subject: Implementation II

The SAE Mini Baja project is an international collegiate competition that requires a team of students to design and build a single-seat, all-terrain vehicle. The team will then compete with other collegiate design teams in a series of static and dynamic challenges. Northern Arizona University (NAU) possesses a team of 12 students to compete in the prestigious competition. The team is divided into four sub teams: Front End, Rear End, Frame, and Drivetrain. In the last month, the NAU competition team, Lumberjack Motorsports, has made major progress towards completing the manufacture of their vehicle. Milestones include the completion of suspension components, frame mounting configurations, and critical drivetrain components.

1 Implementation – Weeks 7-11

The following describes progress made by each sub team toward completing their system of the vehicle. Each sub team has been implementing their designs by fabricating components of their respective system, as well as assisting other sub teams in their manufacturing needs.

1.1 Manufacturing

The following section provides a brief description of the manufacturing processes implemented by the team to produce a complete final product.

1.1.1 Front End

The front-end sub team worked on manufacturing the control arms, cross bars for the upper control arms, mounting tabs and shock mounts designed to support the shock absorber. The cross bars were manufactured using 1” OD x 0.065” wall thickness 4130 Chromoly Steel tubing, which were cut to length using the chop saw in building 98C. The ends of the cross bar were subsequently coped using a drill and 1” OD hole saw bit from the machine shop in building 98C. The corresponding shock absorber and control arm mounting tabs were outsourced to Wicked Welding and Fabrication to be plasma cut. All mounting tabs were welded to the control arms and frame once they were received.

The control arms were manufactured in house by the team. A 1” OD x 0.065” 4130 Chromoly steel was used and it was cut to size, bent with the hydraulic bender and then scalloped for welding to the central uni-ball bearing. They team then fabricated chassis tube inserts on the lathe so the heim joints could be fitted into them and mounted to the mounting brackets. The team fitted and tacked the mounting avocados to every location of the front end where needed. Then once everything was tacked or welded together the front-end control arm assembly was mounted together completing the front suspension. All that remains is to bolt the shock absorbers into the mounts and the team will have fully functional front suspension.

The steering system had to be mounted on a steel plate that could hold the torsional and axial forces of the steering rack. A 1/8 in plate was used to mount the rack and instead of heim joints at the ends of the rack shaft clevis joints were manufactured in house. The clevis joints were manufactured with a 3/8 bolt that could fasten a 7/16 heim through it.

Low carbon steel was sourced from building 98C and cut to the dimensions of the rear brake rotor using the vertical bandsaw. This component was plasma cut by Wicked Welding and Fabrication due to geometry and material requirements. In addition to geometry requirements, the front brake rotors and supporting brake caliper mounts were laser cut by Vroom Engineering because the campus machine shop did not carry additional 1/8" or 3/16" thick low carbon steel required for manufacturing. The existing brake caliper mounting tabs on the aftermarket steering knuckle and the brake rotor mounting studs were cut short using an angle grinder to accommodate the brake caliper mounting bracket and brake rotor designs. This also allowed the front CV axles to be sleeved and installed to the front suspension for alignment verification.

1.1.2 Rear End

In the last month the rear end team has turned focus to assembling the parts manufactured to date. The parts being brought together include Trailing arm tubing, face plates, bearing housings, shock mounts, rear links, and ball joints. The face plates utilized the Tormach CNC machines in building 98c to create a space for the bearing to fit as well as lighten the plates. The bearing housings had to be cut using the horizontal band saw to get the length proper. The bearing housings were then put onto the manual lathe to be turned down to size and then a boring operation to get the inner diameter to proper size. The bearings could then be press fit into the housings using proper interference. The rear links were manufactured using the lathe to drill and tap to a 3/8 UNF left and right hand threaded. With all of these manufactured the assembly by welding the parts together began. The team was able to get two trailing arms built before spring break and aligned everything in preparation for shock mounts.

1.1.3 Frame

Since the frame had already been CNC bent and notched, all we had to do is weld the tubes together. This was done by Tyler Trebilcock since he is our designated certified welder for the project. Most of the frame was tacked together and some parts finish welded to make sure it was sturdy while we worked on the rest of the Baja. For the miscellaneous brackets such as the fire extinguisher tabs, the rule book was consulted to ensure rules were met and then the brackets were either CNC plasma cut for precise or complex parts, or simply cut by angle grinder out of the appropriate thickness plate steel. These were then tack welded onto the frame with their counterpart components to align them according to the SolidWorks models. Some tabs (such as body panel rivet tabs) were left over from previous Baja projects.

1.1.4 Drivetrain

The Drivetrain team has used several manufacturing processes during the implementation of the team's final product. Since the completion of mounting both differentials, several subsystems have seen progress. The gearbox has a completed aluminum case built using a CNC mill machine (through NAU campus machine shop), a completed gear mesh using outsourced fabrication in the form of wire EDM cutting (through AZ Wire Specialists) and carburized heat treatment (through Phoenix Heat Treating), as well as completed mounting hardware and brackets made through use of a drill press, an angle grinder cutting wheel and stationary grinding wheel (through NAU campus machine shop). The ECVT has seen significant progress, as the on-board computer was completed using a 3D printer, soldering, drilling, and. In the case of the mounting brackets, cutting, filing, and welding (through Jacob Najmy's personal equipment and NAU campus machine shop). The CV axles are in the planned process of fitment by cutting and replacing the original main shafts with hollow tubing (1.00" OD, 0.065" WT) of identical thickness to the driveshaft.

1.2 Design Changes -Weeks 7-11

The following section provides descriptions of design changes made to systems based on physical obstacles that occurred during manufacturing processes.

1.2.1 Front End

1.2.1.1 Design Iteration 1: Change in Brake Rotor Mounts discussion

One of the primary issues for the braking system of the vehicle was manufacturing mounts for the brake rotors and calipers. Because the rear brake rotor was required to be mounted on the rear CV axle, mounting tabs had to be placed on the shoulder of the CV axle and be short enough to avoid interfering with the contact surface of the rotor. The mounting tab was designed to feature a base with the same radius as the collar of the CV axle, and a top edge with the same radius as the inner radius of the rear rotor. Four tabs are equally spaced apart on the collar and welded in place to accommodate the PCD of the rear rotor. Figure 1 displays the proposed rear rotor mounting tab design.

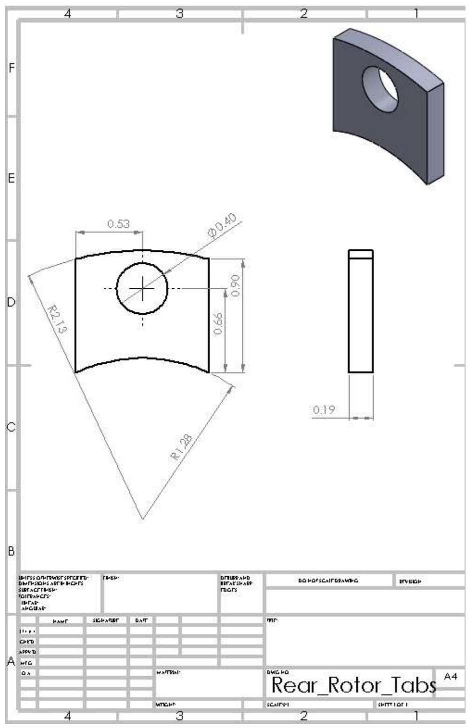

Figure 1: Rear Brake Rotor Mounting Tab Design

In addition, the front brake rotors and calipers were required be mounted to the aftermarket hubs and steering knuckles without interfering with other components as the front axles rotated. As mentioned previously, the rotor mounting studs on the front hub were cut 0.5” shorter using an angle grinder to provide sufficient space between the brake rotor and steering knuckle. The existing mounting points for the brake caliper on the steering knuckle were cut 1” shorter to provide clearance for the brake caliper mounting bracket. Figures 2 and 3 display the knuckle and hub modifications, respectively. Figure 4 represents the front brake caliper mounting bracket design.

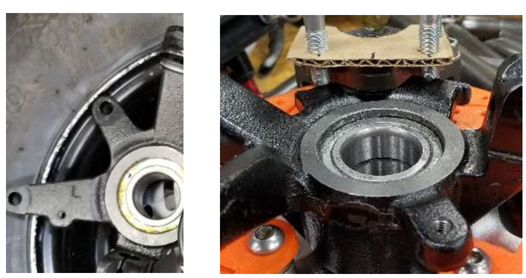

Figure 2: Brake Caliper Mounting Points - Original (left) vs Shortened (right)

Figure 3: Front Hub Assembly on CV Axle

Figure 4: Front Brake Caliper Mounting Bracket (Prototype)

1.2.2 Rear End

1.2.2.1 Design Iteration 1: Change in [subsystem/component] discussion

At the end of week before spring break the team assembled the parts of the trailing arm they had in place. At this point the team was able to visualize where the shocks would best align to not bind during use. The original plan of mounting was not able to be used as the shocks were too long, thus we moved it to more align. The plan for creating shock mounts can be seen in Figure 5, where the mounting points are circled. The original design was to have the mounts further up the trailing arm. The shocks were too short as well as the tire was rubbing on the shock mount. The old trailing arm can be seen attached to a previous year's frame in Figure 6.

Figure 5: Rear end shock mount locations

Figure 6: Old rear end shock mount

1.2.3 Frame

1.2.3.1 Design Iteration 1: Change in frame width discussion

In the process of welding the frame tubes together, there was a miscommunication on the width of the roll hoop being welded to the roll hoop lateral member. We accidentally welded it 1 inch wider overall. This caused very minor problems in other areas, but the CAD had to be updated to reflect the changes in order to model further mounting brackets that depended on this change. This change can be seen in Figure 7

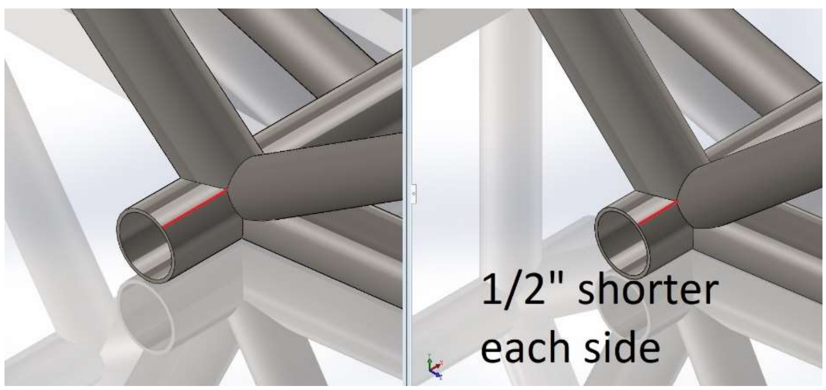

Figure 7: CAD Model Differences

1.2.3.2 Design Iteration 2: Change in seat discussion

Once we started getting the cockpit are dialed in, we realized that the drive shaft under the seat was in fact hitting the seat. We checked the rule book on the height requirements with a driver in the seat. It in fact could not move up any further due to this restriction. Since the seat was molded off a school chair, the bottom was a simple shallow bowl shape. To make the small clearance we needed we cut out an oval shape along the drive shaft length. A thin sheet of aluminum was then bent to match the oval cut out and curved around the drive shaft. The seat was then taken to Nova Kinetics where we patched the hole with carbon fiber in the form of the bent plate. The logic behind this was that it would be just enough to clear the driveshaft and the seat might conform to a butt shape a little better. This ended up working perfectly for our needs. The before and during patching photos can be seen in Figure 8.

Figure 8: Seat Differences

1.2.4 Drivetrain

1.2.4.1 Design Iteration 1: Change in ECVT Shaft discussion

The engine output shaft connects to the first subsystem of drivetrain, which is the electric continuously variable transmission (ECVT). The ECVT has a custom sleeve that slides over the engine shaft that helps transmit torque to the sheaves. This is one of the most critical components in the drivetrain subsystem. After the design was finalized the team was ready to begin manufacturing. After discussion with the NAU shop employees the design was too complex for them to design. It required an effort of work they did not want to contribute. This led to further discussions of where to have the shaft manufactured. After talking with a local shop about manufacturing, the technician requested a redesign.

The redesigned shaft was designed for ease of manufacturing. This included a shorter shaft that allowed for bearings to be pressed in right next to each other. This still allowed the shaft to keep the contact points required for proper support but also allows for in house manufacturing. Figure 9 is the old shaft, which required complex manufacturing. Figure 10 is the new simple shaft, which still allows for support through bearings next to each other, while allowing for simple manufacturing.

Figure 9: Old Complex Shaft Design

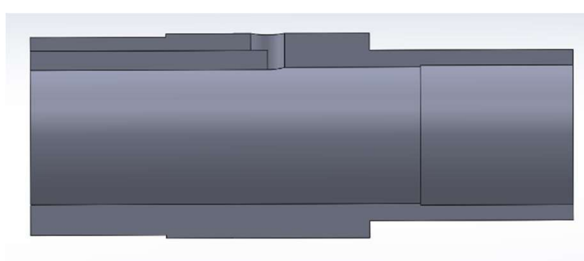

Figure 10: New Simple Shaft Design

2 Standards, Codes, and Regulations

The following section provides the standards that the team followed in their design and fabrication of the Baja in a table format.

2.1 Standards applied to project

For this project, we made sure to follow any standards set forth by the competition rule book along with any standards that applied to the parts being designed. This includes ASTM, ASME, ANSI, AGMA, AWS, ABMA, IEEE, NSPE, and SAE standards. Some standards did not apply directly to the design and manufacturing but to the project, such as using IEEE formatting in documentation.

Table 1: Applicable Standards, Codes, and Regulations

Standard Number or Code	Title of Standard	How it applied to Project
ASTM – 8620 and T6-6061	American Society for Testing and Materials	Physical properties for gear reducer materials. Used for AGMA equations and SolidWorks FEA
ASME-Y14.5-5M-2004	Dimensioning and Tolerancing (American Society of Mechanical Engineers)	Helped in identifying proper press fitting tolerances for gear reducer bearing housings
ANSI/AGMA 2001-D04 & 2101-D04	American Gear Manufacturers Association	AGMA standard gear equations used to analyze gears that were going to be used in the rear spur gear reducer
ANSI H35.2-2017	Aluminum Mill Products	Helps in wall thickness determination for aluminum gear casing
AWS D1.4/D1.4M:2018	American Welding Society Structural Welding Code	All frame welding is performed in house and includes welding of 4130 steel and 6061 aluminum
ABMA 9:2015	American Bearing Manufacturers Association	Load ratings and fatigue life for deep groove ball bearing used in gear reducer
IEEE	Institute of Electrical and Electronics Engineers	All citations are in IEEE format
NSPE – II-1	Rules of Practice	This rule ensures our designs and manufacturing processes were holding the safety of the public paramount.
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 provides relevant information for any fittings in the braking system, shocks, and/or steering system
SAE J1703	Motor vehicle brake fluid	This standard is relevant for the braking system, as it requires brake fluid to operate

SAE 1739	Potential failure mode and effects analysis in design, in manufacturing and assembly processes, and for machinery	This standard provides useful information for FMEA's conducted by the team

3 Risk Analysis and Mitigation

The sub teams focused their respective designs to target potential failures identified through FMEA analysis. To ensure full mitigation of potential risks, sub teams often worked in collaboration, or simply mitigated risk by natural progression of individual designs.

3.1 Potential Failures Identified Fall Semester

The following section exhibits the potential failures most likely to occur in both the Front & Rear End and the Frame & Drivetrain systems. The ten most likely failures were selected based on RPN values. For a full list of potential failures, see Appendix 4.

3.1.1 Front & Rear End

Based on the full FMEA performed and provided in the appendix, the top ten main failure modes of the front and rear end subsystems are described below. Table 2 illustrates the top ten failures from the FMEA performed.

Table 2: List of Front End and Rear End 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 ho	360	Use durable metal and test welds

The design changes did not affect the FMEA performed on the subsystems.

3.1.2 Frame & Drivetrain

The following table represents the top ten most likely failures anticipated to occur during the operation of the frame and drivetrain systems.

Table 3: Frame & Drivetrain - Top Ten Critical Failures

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls	Detection (D)	RPN
Frame contain and protect driver while holding together all other subcomponents together	Fatigue failure	broken members leading to unfunctional parts of the frame or entire Baja	8	repeated high stress situation	7	Over design the frame	9	504
ECVT modulates and transmits power from the engine to the gear reducer	stepper motor overheating	ECVT would be stuck in gear	7	improper cooling	7	ensure proper cooling is designed	7	343
	electrical shortage	ECVT would be stuck in gear	6	improper soldering	6	use quality soldering techniques	9	324

	bearings overheat	bearings get stiff and cause high losses and potential jamming	7	improper lubrication	7	properly lube the bearings	7	343
Gear Reducer transfers power from ECVT to the front and rear differentials	Case Puncture	oil leaks and contamination of the gears causing overheating and grinding	8	rock hitting case	8	design protection around case	8	512
	overheat	gears loose proper temper and cause extra friction and potentially snap teeth	8	wrong or no oil	5	use correct oil	10	400
Differentials takes power from the gear reducer and splits it between the left and right tires	front case puncture	oil leaks and contamination of the gears causing overheating and grinding leading to loss of power in the front	8	rock hitting case	6	design protection around case	7	336
	rear case puncture	oil leaks and contamination of the gears causing overheating and grinding leading to loss of power in the rear	8	rock hitting case	7	design protection around case	7	392
	rear case dent	potentially leaks from seal and contacts internal parts leading to lockup in rear wheels	7	rock hitting case	6	design protection around case	8	336
	overheat	gears loose proper temper and cause extra friction and potentially snap teeth	8	wrong or no oil	5	use correct oil	10	400

No new potential failures were recorded in the frame and drivetrain systems.

3.2 Risk Mitigation

The following section provides short descriptions of design solutions to potential failures for each major system of the vehicle. Obviously, design solutions focus on the most likely failure scenarios, as seen in Section 3.1. For a full list of potential failures, refer to Appendix 4.

3.2.1 Front End

The Front End conducted several FEA analyses to determine the optimal geometry and material for suspension, steering, and brake components as well as mounting tabs for all subsystems. These analyses proved beneficial in the material selection and component design process, as the primary objective was to mitigate component failure due to stress. Due to the proper FEA analysis from the front-end team, the nose section of the Baja vehicle will perform well in the dynamic competitions.

Rear End

Rear End has implemented many design changes based on the risks and potential failures involved. One early design change the team focused on was reducing parts and eliminating the need for a knuckle. After running FEA on our trailing arm and testing the prototype, it was proven the design was certainly strong enough. We were worried about potential shocks not working correctly which was compensated for in the design for the brackets. The main concern was focused around the connecting ball joint from the trailing arm to the frame so the team made sure to use a thick enough material to be sure it can withstand the forces needed.

3.2.2 Frame

Since the frame only had one major potential failure mode it was not too difficult to mitigate that risk. This failure mode was fatigue failure. In the FMEA the RPN score was high since this failure would most likely be catastrophic, fatiguing happens all the time, and it is difficult to detect before failure. But that does not mean it is hard to mitigate. By leaning towards thicker and stronger materials when these decisions were made, this greatly reduced the risk of this kind of failure. One example of this is using chromoly steel instead of mild steel. This however made the frame more expensive. When components were made thicker, this also made the frame heavier than it otherwise would have been. While also reducing this risk we also helped mitigate many of our other failure modes. Many of them were variations of different impacts which are helped by stronger and thicker materials.

3.2.3 Drivetrain

The Drivetrain team designed their system to mitigate the failures listed in Table 3 largely through collaboration with the Frame team. Many of the identified potential failures can be avoided using body paneling, as the primary function of paneling is to prevent penetration from external sources. The benefit of the paneling's function is that the risk of puncture to the gearbox and differentials is nearly nonexistent. Likewise, overheating in the gearbox and differentials are easily avoided through use of specified gear oils. For the differentials, SAE grade 80w-90 gear oil is the manufacturer suggested usable oil for the hardened steel gear mesh and is the industry standard for heavy duty gear mesh applications. For the custom-designed gearbox, a similarly weighted gear oil is used (75w-80), chosen for its lighter weight in cold conditions. The modification will allow for the gearbox to actuate easier during startup by providing less strain on the ECVT transmission system. Unfortunately, by using lighter weight oil in the gearbox, more strain can potentially occur in the differentials under cold conditions. The ECVT system itself is designed to mitigate overheating by incorporating more fans than originally included. More fans will provide increased airflow through the computing system to cool components by convection cooling at the cost of increased weight due to additional components. Electrical shortages in the system are mitigated by soldering techniques verified through multiple team members collaborating on both the soldering process and the testing of individual connections.

4 Appendix

4.1 Front & Rear End Full FMEA

Table 4.1: Front & Rear End FMEA

1	2019-2020 Baja Vehicle		Will Preston, Jesse Summers, Jacob Grudynski, Michael Edirmannasinghe, Jacob Ruiz, Aaron King, and Lucas Cramer				Page No 1 of 1			
2	Front and Rear End						FMEA Number 1			
3	CV Axles, Brakes, Suspension, and Steering						11/16/2019			
4	Component Name									
5	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
6	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
7	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
8	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
9	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
10	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
11	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
12	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
13	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
14	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
15	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
16	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
17	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
18	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
19	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
20	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
21	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
22	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
23	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
24	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
25	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
26	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
27	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
28	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
29	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
30	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
31	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
32	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
33	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
34	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
35	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
36	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
37	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
38	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.
39	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
40	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
41	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
42	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
43	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
44	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
45	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

4.2 Frame & Drivetrain Full FMEA

Table 4.2: Frame & Drivetrain FMEA

Lumberjack Motorsports Baja Vehicle		Frame and Drivetrain Mini-Team				Page No 1 of 1			
Baja Vehicle						FMEA Number 2			
Frame and Drivetrain						Date: 11/14/2019			
Frame, ECVT, Gear Reducer, Differentials									
Part # and Functions	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Severity (S)**	**Potential Causes and Mechanisms of Failure**	**Occurrence (O)**	**Current Design Controls**	**Detection (D)**	**RPN**	**Recommended Action**
Frame contain and protect driver while holding together all other subcomponents together	Weld Failure	Members will become detached and frame will warp under normal loading. If any severe impact occurs, the frame will be severely damaged and endanger the driver or lead to	9	High Stress Concentration	6	Design to distribute loads evenly, strong materials and welds	5	270	Design to distribute stresses

		accident.							
				Poor Welding	2	Quality control in the fabrication process, using a highly skilled welder	3	54	use a qualified welder
	Font End Impact	Nose could have bent member or completely collapse	7	Ramming into another vehicle	5	Avoid hitting another vehicle	3	105	Use a qualified driver
	Side Impact	SIMs bend	6	Rolling onto side	3	Drive carefully	4	72	Use a qualified driver
	Rear Impact	Rear cage bends or collapses	7	Another vehicle rear ends the Baja	5	don't slam on brakes while another vehicle is close behind	3	105	Use a qualified driver
	Roll Over	Bend in FBMs or RHO members	7	Taking a ramp incorrectly	5	power through any ramps, or take them slow	2	70	Use a qualified driver
				taking a turn to fast	7	slow down before curves	2	98	Use a qualified driver
	Torsion from Suspension	permanent deformation in the twist of the frame	4	The entire Baja balancing on two wheels	6	Design for the entire weight on two wheels	6	144	Stiffen the frame
	Frame Buckles in Hard Landing	Entire Baja is immobile and unable to function at all	10	Hard landing	1	Design for a heavy load and large FOS	1	10	nothing
	Bottom Impact from Rocks	Bent USMs	4	landing on a tall rock	7	Design frame to withstand this situation	7	196	nothing
	Fatigue failure	broken members leading to unfunctional parts of the frame or entire Baja	8	repeated high stress situation	7	Over design the frame	9	504	use quality materials
	Driveshaft Fails	no power to the front or potential lock up of the front	6	High torque on the driveshaft	2	use a stronger shaft than needed	4	48	perform testing on drive shaft
ECVT modulates and transmits power from the engine to the gear reducer	stepper motor overheating	ECVT would be stuck in gear	7	improper cooling	7	ensure proper cooling is designed	7	343	perform endurance type testing
	belt	power not	6	incorrect	3	align	6	108	nothing

	wear failure	transferred between ECVT and secondary		pulley alignment		pulleys			
	output shaft bends	further damage to gear reducer and high fatigue to secondary parts	8	high moment on shaft	1	properly mount drivetrain components	8	64	nothing
	input shaft bends	fatigue to ECVT parts	8	high moment on shaft	1	properly mount drivetrain components	8	64	nothing
	electrical shortage	ECVT would be stuck in gear	6	improper soldering	6	use quality soldering techniques	9	324	test connections
	programming malfunction	ECVT would be stuck in gear	5	improper testing	5	test run many times in many scenarios	8	200	nothing
	actuation belt tear	ECVT and primary would be out of sync	7	high stress on belt	6	design for proper tension on belt	6	252	ensure specs are met
	secondary helix bends	Secondary would not properly grab the belt	7	high forces on secondary	3	properly install the cvt system	8	168	nothing
	secondary spring fails	Secondary would not grab the belt at all	7	spring over compresses	2	use correct spring	7	98	nothing
	bearings overheat	bearings get stiff and cause high losses and potential jamming	7	improper lubrication	7	properly lube the bearings	7	343	perform destructive testing on bearings
Gear Reducer transfers power from ECVT to the front and rear differentials	Case Puncture	oil leaks and contamination of the gears causing overheating and grinding	8	rock hitting case	8	design protection around case	8	512	ensure case is strong
	gasket leak	oil leaks and gears overheat	5	poor sealing procedure	6	use correct parts and installation procedure	3	90	pressure test
	mounting bolts shear	gear box dismounts and potentially breaks other parts	7	high forces on the case	1	design strong enough bolts	7	49	nothing
	overheat	gears loose proper temper and cause extra friction and potentially snap teeth	8	wrong or no oil	5	use correct oil	10	400	temperature testing
	case impact	Case dents and potentially leaks	7	rock hitting case	7	design protection	6	294	ensure case is strong

		from seal and contacts internal parts leading to lockup				around case			
	oil contamination	grinding gears	6	improper seal and handling	3	properly seal and fill the oil	8	144	consider an oil filter system
	pressure relief valve contamination	relief valve doesn't operate properly	4	improper handling and covering	4	use debris shields	9	144	nothing
	pressure valve overflow	valve won't properly release pressure	2	overfilling oil	5	use proper amount of oil	6	60	nothing
	bending failure in gears	additional friction in gears and potential to break teeth	8	high forces through reducer	2	design strong gears	7	112	nothing
	compressive failure in bearings	bearing seizes up	7	high forces on bearings	2	use strong bearings	8	112	nothing
Differentials takes power from the gear reducer and splits it between the left and right tires	front case puncture	oil leaks and contamination of the gears causing overheating and grinding leading to loss of power in the front	8	rock hitting case	6	design protection around case	7	336	use quality body paneling
	rear case puncture	oil leaks and contamination of the gears causing overheating and grinding leading to loss of power in the rear	8	rock hitting case	7	design protection around case	7	392	Protection
	front case dent	potentially leaks from seal and contacts internal parts leading to lockup in front wheels	7	rock hitting case	5	design protection around case	8	280	use quality body paneling
	rear case dent	potentially leaks from seal and contacts internal parts leading to lockup in rear wheels	7	rock hitting case	6	design protection around case	8	336	design stronger case
	front case gasket leak	loss of oil and overheating of gears	5	poor sealing procedure	5	use correct parts and installation procedure	3	75	nothing
	rear case gasket leak	loss of oil and overheating of gears	5	poor sealing procedure	5	use correct parts and installation procedure	3	75	nothing
	front	differential	7	high forces on	1	design	8	56	nothing

	mounts shear	dismounts and potentially breaks other parts in the nose		case		strong enough mounts			
	rear mounts shear	differential dismounts and falls out of Baja	7	high forces on case	1	design strong enough mounts	8	56	nothing
	oil contami nation	gear grinding	7	improper seal and handling	5	properly seal and fill the oil	8	144	consider an oil filter system
	overheat	gears loose proper temper and cause extra friction and potentially snap teeth	8	wrong or no oil	5	use correct oil	10	400	temperature testing