MET BUV Frame/Chassis

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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Thesis Advisor:

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ABSTRACT

BUV stands for Basic Utility Vehicle. The purpose of this project is to create a low-cost reliable vehicle to transport water and people in third world countries. Every year UC has a MET BUV team that is challenged to design a vehicle. This year the team consisted of five individuals, each with there own part of the vehicle to design. This report will cover the frame/chassis part designed by Sam Campbell. IT will be broken into sections containing, background research, initial design, actual design, and fabrication. Towards the end of the semester due to the COVID-19 virus the fabrication was left unfinished. The testing was also incomplete, please see "Plan to finish" section.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The Institute for Affordable Transportation (IAT) is a not-for-profit public charity devoted to improving the lives of the world's poor by providing simple, low-cost vehicles in order to facilitate community transformation. They have created a list of technical specifications for a BUV (Basic Utility Vehicle) to be built for third world countries. This list focuses on affordability, reliability, and simplicity. The vehicle must have a payload capacity of three standard 55-gallon steel drums filled with water, plus the driver. Off-road, truck style vehicles are needed in many third world countries to transport water and other necessary resources. Most often these vehicles are made from common materials that can be found easily, such as angle iron, and sheet metal. They also have three wheels to reduce weight and cost, while increasing the handling capability. Every year, there is an endurance competition held where schools from all over the country compete to see which BUV can do the most laps around the set course.

Figure 11: Example BUV

BACKGROUND

Many production vehicles such as the one shown in Figure 2, are too expensive as well as not being easily assembled. This John Deere Gator cost around $10,000. There are many more productions BUVs that can cost up to $25,000. For our application, affordability is large factor. The goal for this project is to build the vehicle for only a few thousand dollars, and easily built, in order to make this vehicle accessibly to as many people as possible.

Figure 12: Production BUV; John Deere Gator

<u>Team:</u>
Sam Campbell: Frame/Chassis and Bed design; Team Leader
Connor Brady: Drivetrain, Engine, Transmission
Daniel Neuhaus: Controls, Brakes, Electronics, Acceleration components
Gustavo Lamas Cid: Steering and Suspension
Yuanjing Xu: Pumping and Irrigation

RESEARCH

SCOPE OF THE PROBLEM

While the BUV competition is the end goal for our designed vehicle, the real goal would be to have developed a vehicle capable of aiding developing countries. The competition serves as a test for the vehicle, with the winner being the most optimal for said country. Transportation is very important in these countries, seeing as water is not easily accessed all the time.

CURRENT STATE OF THE ART

The current market for BUV's is filled with things like the John Deere Gator pictured above. These vehicles are jammed packed with features like normal cars. The problem with these vehicles is the price. Even the lower end BUV's can cost thousands of dollars. That is the difference between the BUV we are designing. The MET BUV is affordable (<$1200) and has a more simplistic design compared to a commercial vehicle.

END USER

The end user for this vehicle will be third-world countries and anyone who requires a BUV that is inexpensive, but still reliable. The IAT has provided BUVs to many different parts of Africa, which aid in transporting water, medical care, and people though the rough terrain. They can also be used for farming applications, like harvesting crops and spreading fertilizer.

CONCLUSIONS AND SUMMARY OF RESEARCH

Based on previous years of BUV, we have decided to have a welded frame in the front, that will be connected to a Chevy S10 truck frame. These are very common trucks and the frames can be reused to make up the rear potion of our BUV. Previous years have tried a sheet metal front, but it turned out to be too heavy, as well as not ridged enough to withstand the course.

CUSTOMER FEATURES

BASIC UTILITY VEHICLE

CUSTOMER SURVEY

We are a group of five Mechanical Engineering Technology seniors at University of Cincinnati. For our senior design project, we have chosen to design and build a Basic Utility Vehicle that can be used in developing countries to help improve daily life. Please answer the following questions:

How important to you is each BUV design feature?

Please circle the appropriate answer.

	1 = low importance			**5 = high importance**	
Price	1	2	3	4	5
Ease of Assembly	1	2	3	4	5
Ease of Maintenance	1	2	3	4	5
Reliability	1	2	3	4	5
Safety	1	2	3	4	5
Cargo Capacity	1	2	3	4	5
Maneuverability	1	2	3	4	5
Off-Road Capability	1	2	3	4	5

How satisfied are you with current BUVs?

Please circle the appropriate answer.

	1 = very UNsatisfied		**5 = very satisfied**		
Price	1	2	3	4	5
Ease of Assembly	1	2	3	4	5
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Cargo Capacity	1	2	3	4	5
Maneuverability	1	2	3	4	5
Off-Road Capability	1	2	3	4	5

How much would you be willing to invest in a BUV?

$500-$1500 $1500-$2500 $2500-$3500 $3500-$4500

Figure 13: Sample survey

Weighted Importance

Table 1:

Price	13.5
Ease of Assembly	10.6
Ease of Maintenance	13.2
Reliability	14.8
Safety	13.5
Cargo Capacity	11.3
Maneuverability	10.6
Off-Road Capability	12.3

- Price (13.5%)
  a. made from common, cheap materials.
  b. <$2500
- Ease of Assembly (10.6%)
  a. Use metric bolts and tools
  b. Minimize custom parts
- Ease of maintenance (13.2%)
  a. High enough ground clearance to get under the vehicle without a jack
  b. Hand tools
- Reliability (14.8%)
  a. Stress analysis using solid works to ensure frame rigidity
  b. Will be able to turn off at least 80% of the time
- Safety (13.5%)
  a. Will have roll bar
  b. Two separate braking systems
  c. Engine shut off switch
  d. Fire extinguisher
- Cargo Capacity (11.3%)
  a. 1500lbs minimum, 2000 lbs. is the goal
- Maneuverability (10.6%)
  a. Will be able to complete the BUV competition course.
- Off-Road Capability(12.3%)
  a. Off-road tires
  b. ~12" ground clearance
  c. Suspension capable of completing the course

PRODUCT OBJECTIVES

Based on the customer features and their weighted importance, this table 2 was generated to help set some goals that would fulfill the customer features.

Table 2

Common Material	Maximize
Part Count	Minimize
Overall Weight	Minimize
Overall Size	Minimize
Ground Clearance	Maximize
Payload	Maximize
Fuel Economy	Maximize
Part Consistency	Metric
Structural Integrity	Maximize

QUALITY FUNCTION DEPLOYMENT

See Appendix A for Full-sized HoQ

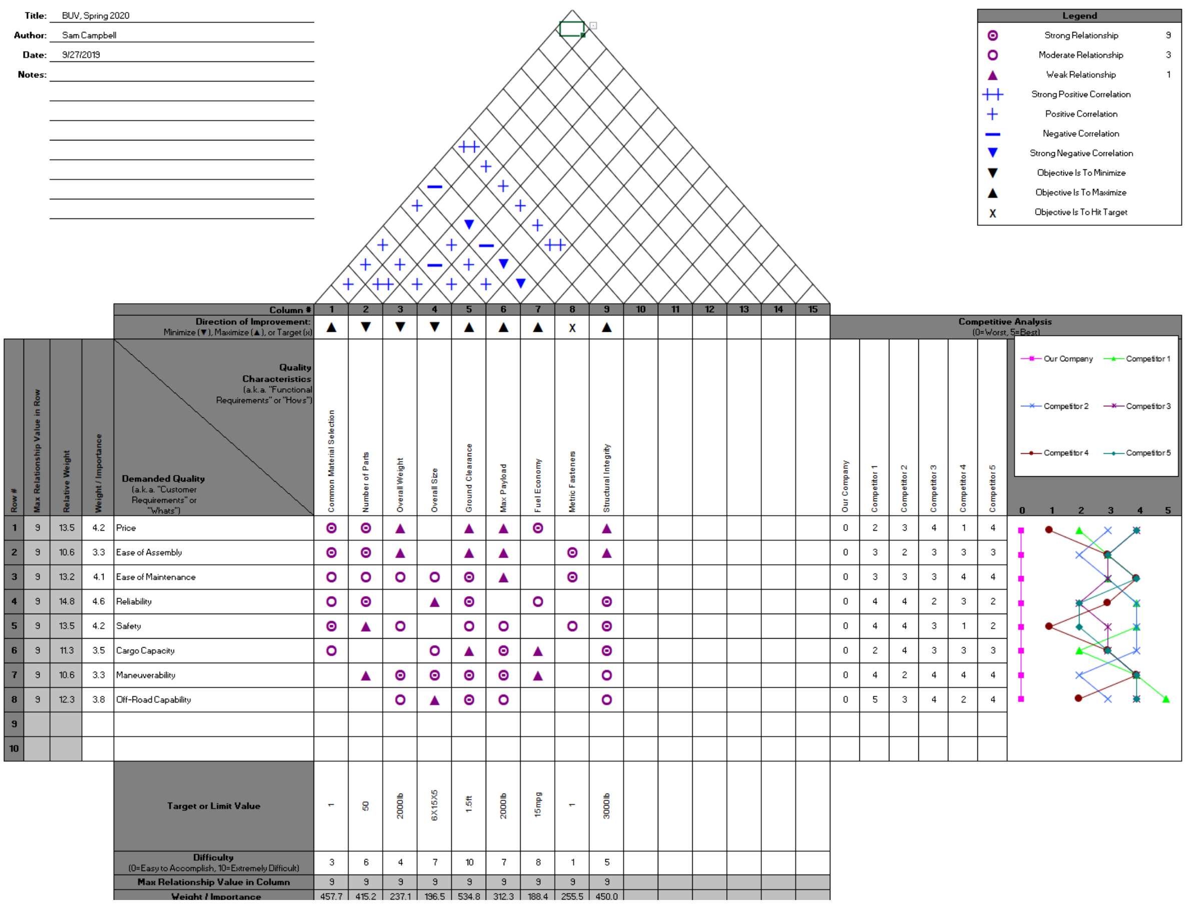


Figure 14: House of Quality

DESIGN

Concepts

As stated above, many productions vehicles that exist are expensive, and have complex designs. They often have four wheels, seating for 2-4 people and a small cargo space in the back. Top speed is usually between 20-60mph depending on the model. They also have front and rear suspension, as well as 4WD.

In previous years, student designed BUVs where made of a variety of materials, such as sheet metal, angle iron, and Electrical conduit EMT/INC. The 2010 design used 14-gauge sheet metal welded together, and then fixed to a S10 Chassis. This design required a great deal of welding and fabrication, which takes more time. However, this does increase the rigidity, and act a a skid plate to protect the vital components which prove to be vauable in the endurance competition.

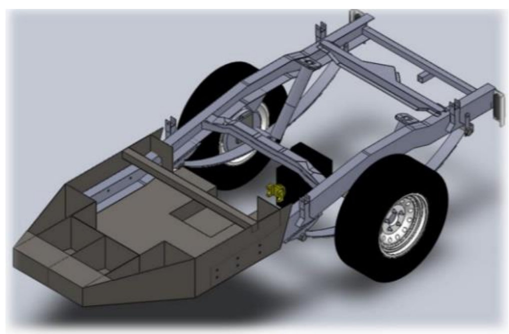


Figure 15: 2010 BUV Frame

The design from 2011 was like 2010, but instead of using a welded sheet metal design, they used a bolted one. This allowed the components to be put on and removed easily, while still maintaining some rigidity. This design also allows the front wheel to be under the frame more, increasing handling capabilities. This design was much simpler than 2010, but that lead to failure during the competition. The weight of the vehicle caused the transmission pan to deform, disabling the vehicle.

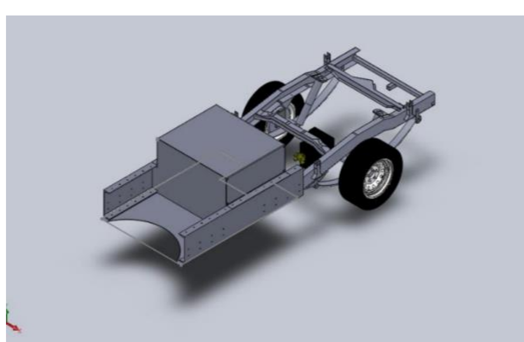


Figure 16: 2011 BUV Frame

In 2013, the frame was constructed from steel angle iron in a "V" shape. The triangle shape allows for reduced material and weight but does not sacrifice strength. This design did require significant welding since the frame is all one piece. This design proved very effective as UC placed 3rd in the competition that year. The drivetrain was completely protected, and even after the competition, had no mud on it. One improvement that could be made would use a truss design to allow for the cuts to be 90°. This would make the material for the vehicle easier to manufacture.

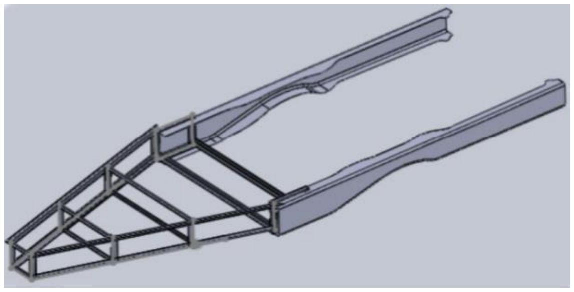


Figure 17: 2013 BUV Frame

In 2017, the IAT suggestion to use a truss design was used and a Warren Truss design was made. This frame is like 2013, but has more material holding it together. This leads to increased rigidity, but also adds weight. This frame design is by far the strongest one found. The equilateral triangles that connect the top and bottom allow a uniform design without large stress points. This BUV failed in the competition due to low ground clearance, which was caused by the excessive weight of the vehicle.

Figure 18: 2017 BUV Frame

In 2018, the BUV team went with a square designed frame, allowing for easier assembly and materials that had flat ends. It requires significantly less material than the previous year and was easier to weld together. Despite being less material, this frames load capacity was calculated to be structurally sound and could carry the required load. This BUV also failed to compete because it was rushed and through testing could not be done.

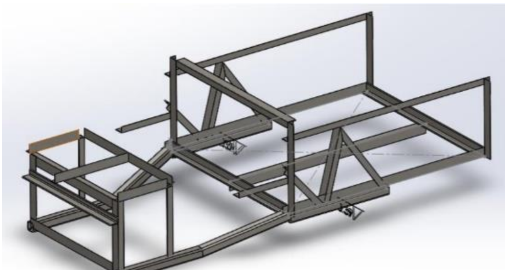


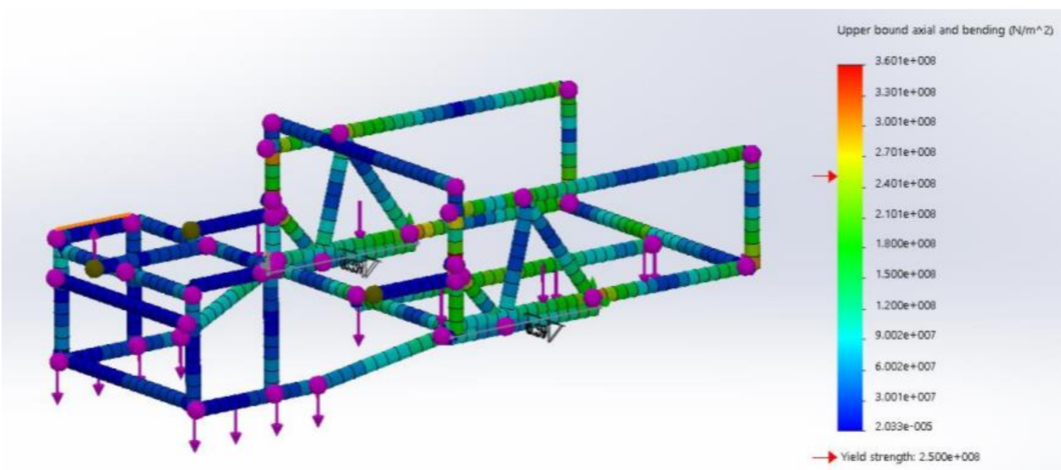
Figure 19: 2018 Frame

Criteria	Weight %	Concept 1 (2011)	Weight %	Concept 2 (2013)	Weight %	Concept 3 (2010)	Weight %
Ease of Assembly	20	4	0.8	3	0.6	2	0.4
Durability	40	1	0.4	5	2	4	1.6
Ease of Maintenance	20	4	0.8	2	0.4	3	0.6
Cost	10	2	0.2	2	0.2	2	0.2
Frame Weight	10	3	0.3	1	0.1	2	0.2
	100		2.5		3.3		3

Concept 2 is the best design because of its durability. Sheet metal is simply not strong enough to use over angle iron, and although no welding would be a huge plus, using bolts cannot replace the strength of welding. For Spring 2020 BUV we will use a truss design similar to 2013 but minimize number of angled welds to ease manufacturing.

Loading Conditions

We have been given the 2018 frame to use as a starting point. Shown below is there stress analysis and frame calculations.



$$+\Sigma moments\ of\ fixed\ points = (-333\ lbf * 24\ in) + (-333\ lbf * 24\ in) + (-200 lbf * 83 in) + (-200 lbf * 63 in) + (1000\ lbf * 100\ in) = 54{,}816\ lb * in$$

$$+\Sigma moments\ of\ a\ single\ fixed\ point = \frac{54{,}816 lb * in}{2} = 27{,}408\ lb * in$$

$$\sigma_{\max of\ a\ fixed\ point} = \frac{M_c}{I} = \frac{27.41 kLb * in * 1 in}{1.24 in^4} = 22.1\ ksi$$

Figure 20: 2018 Frame Calculations

Based on this information, we have determined that the modifications that we planned to complete would not jeopardize the structural load bearing capability of the existing frame.

Material Selection

The frame is made of A36 Steel angels. The two sizes that we will use are 1/8” thick and 3/16” thick. Both sizes have yield strength of 36000 psi and have been shown to work in SW. Attached is a screen shot from Mcmaster-Carr for both the sizes. Since we are reusing the 2018 frame, the new material needed will be the same kind of steel.

Low-Carbon Steel 90° Angles

Outside		Inside		Corner Shape					
Ht.	Wd.	Ht.	Wd.	Outside	Inside		1 ft. Lg.	3 ft. Lg.	6 ft. Lg.
1/8" Wall Thick.									
1/2"	1/2"	3/8"	3/8"	Round	Round	9017K124	$3.01	$6.94	$11.57
3/4"	3/4"	5/8"	5/8"	Square	Round	9017K424	3.98	7.46	12.43
1"	1"	7/8"	7/8"	Square	Round	9017K444	4.79	8.99	14.98
1 1/4"	1 1/4"	1 1/8"	1 1/8"	Square	Round	9017K474	4.91	9.21	15.35
1 1/2"	1 1/2"	1 3/8"	1 3/8"	Square	Round	9017K484	5.42	10.17	16.95
1 3/4"	1 3/4"	1 5/8"	1 5/8"	Round	Round	9017K13	5.83	13.46	22.43
2"	1 1/2"	1 7/8"	1 3/8"	Round	Round	9017K11	5.43	12.52	20.87
2"	2"	1 7/8"	1 7/8"	Square	Round	9017K494	5.67	13.09	21.81
3/16" Wall Thick.									
1"	1"	13/16"	13/16"	Round	Round	9017K144	4.90	9.19	15.32
1 1/4"	1 1/4"	1 1/16"	1 1/16"	Round	Round	9017K15	4.86	11.21	18.69
1 1/2"	1 1/2"	1 5/16"	1 5/16"	Square	Round	9017K594	6.46	12.12	20.20
1 3/4"	1 3/4"	1 9/16"	1 9/16"	Round	Round	9017K164	6.15	14.19	23.65
2"	1 1/2"	1 13/16"	1 5/16"	Round	Round	9017K17	5.84	13.48	22.47
2"	2"	1 13/16"	1 13/16"	Round	Round	9017K184	6.00	13.84	23.06
2 1/2"	2 1/2"	2 5/16"	2 5/16"	Round	Round	9017K224	7.62	17.59	29.31
3"	2"	2 13/16"	1 13/16"	Square	Square	9017K3	7.10	16.38	27.30
3"	3"	2 13/16"	2 13/16"	Round	Round	9017K244	8.92	19.89	34.29

Figure 21: A36 Steel Pricing

PROJECT MANAGEMENT

Budget, Proposed/Actual

Initial budget: $1,500 (per competition guidelines)

Table 3

Part	Cost
Frame	400
Braking	150
Suspension	175
Power Train	200
Irrigation	200
Steering	200
Controls	100
Miscellaneous	400
Total	1825

Actual spending for the frame: $50. Since we were able to reuse the 2018 frame, the only material I needed to purchase was around <20ft of new angle iron steel. As far as the overall of the vehicle, it is unknown due to the school shutting down before all of the parts were purchased. My estimation on overall price if we were to make it from complete scratch would be <$1500.

Schedule, Proposed /Actual

Table 4: Initial Schedule

Milestone	Estimated Date
Design Agreement	10/4/2019
1st Submodel Iteration	10/18/2019
Development Sharing	10/25/2019
2nd Model Iteration	11/1/2019
BOM	11/8/2019
System Integration/ Complete CAD Mod	11/15/2019
Fabrication	1/17/2020
Testing 1	3/2/2020
Modifications 1	3/4/2020

Table 5: Actual Schedule

Milestone	Actual Date
Frame is brought to Shop	1/20/2020
Fabrication Begins	1/20/2020
Extra Material Purchased	1/27/2020
Fabrication Continues	2/3/2020

Frame Fabrication is Complete	3/16/2020

FABRICATION AND PLAN TO FINISH

Figure 22: 2018 Frame Initial Starting Point

This was the first time I saw the 2018 frame in person. I went to David Conrad's farm to inspect it and then he brought it to the shop for my team.

Figure 23: Frame is in Shop

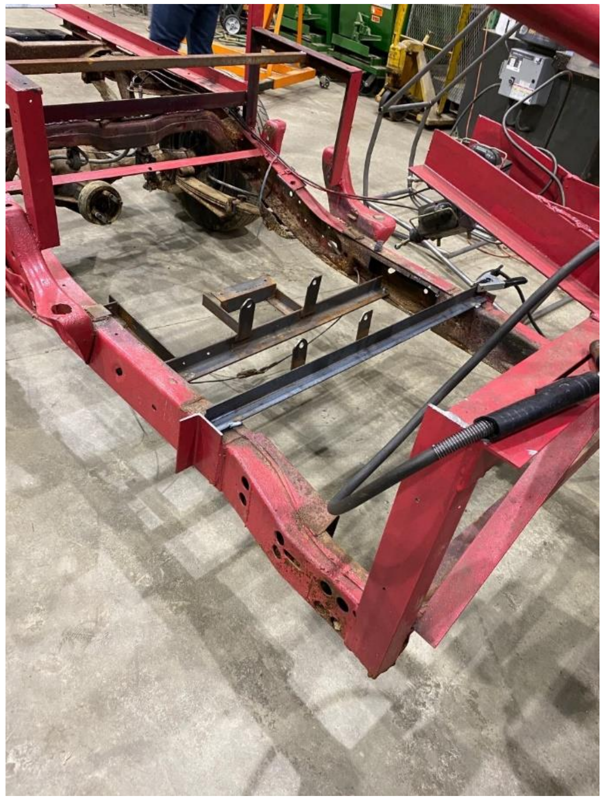


Figure 24: Frame is gutted

As seen above, the frame motor housing was cut off, and the drivetrain was removed in order to continue with the frame modifications. The motor and transmission mounts were bolted to the inside of the existing S10 frame, and a frame support was welded on the top.

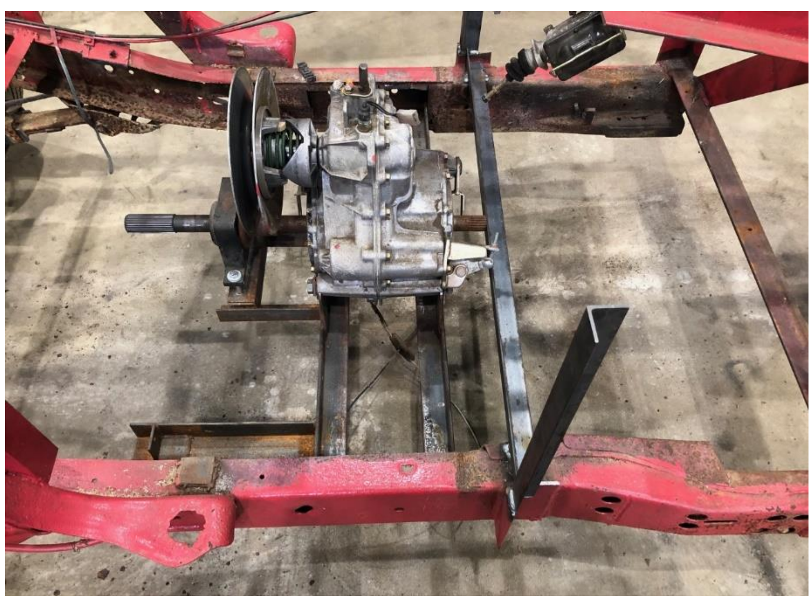


Figure 25: Transmission and Seat Supports

Seen in figure 15 above, the engine and transmission will now be housed under the seat. The vertical support posts were welded on to the S10 to support the front of the seat.

Figure 26: Seat Mounting

The seat supports were held on with hood pins. This allowed the entire seat to be removed very quickly in order to access the engine.

Figure 27: Final Picture

This was the final picture taken before the school shut down. The frame and drive train were complete. The irrigation system was around 80% complete and the steering/controls were incomplete due to COVID-19.

SUSTAINABILITY AND MATERIAL USAGE

I did end up with extra material that was unused, so the only thing I would do differently is measure more carefully. I believe our design could have been successful in complete a obstacle course and I am most proud of the seat design. To future teams: Finding a S10 truck frame is by far the most important part of this project. I would highly recommend meeting with David Conrad ASAP as his knowledge and resources are extremely valuable to this project.

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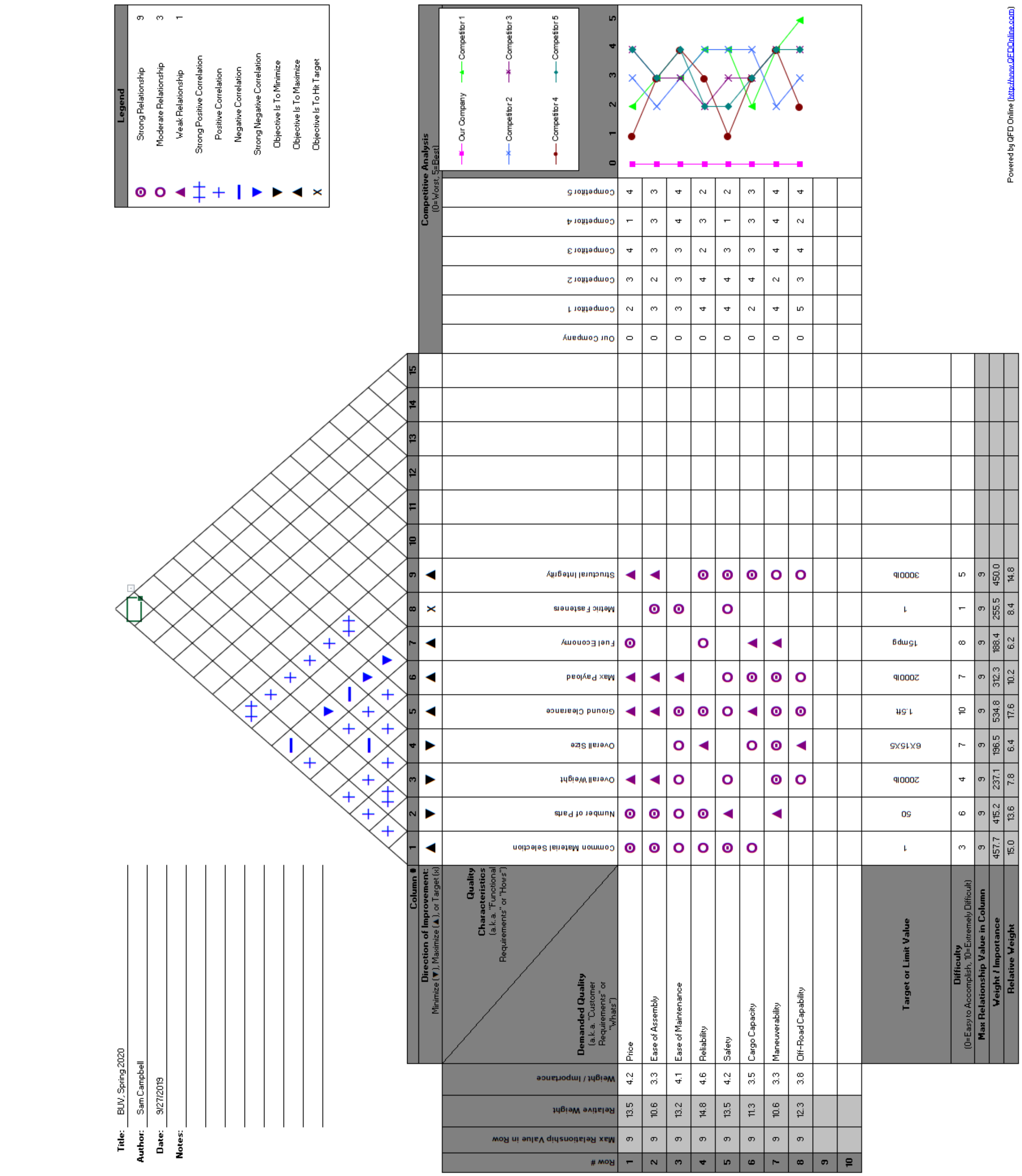
APPENDIX A – HOUSE OF QUALITY



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Common Material Selection	Number of Parts	Overall Weight	Overall Size	Ground Clearance	Max Payload	Fuel Economy	Metric Fasteners	Structural Integrity	10	11	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▼	▼	▲	▲	▲	x	▲												
1	9	13.5	4.2	Price	◎	◎	▲		▲	▲	◎		▲							0	2	3	4	1	4
2	9	10.6	3.3	Ease of Assembly	◎	◎	▲		▲	▲		◎	▲							0	3	2	3	3	3
3	9	13.2	4.1	Ease of Maintenance	○	○	○	○	◎	▲		◎								0	3	3	3	4	4
4	9	14.8	4.6	Reliability	○	◎		▲	◎		○		◎							0	4	4	2	3	2
5	9	13.5	4.2	Safety	◎	▲	○		○	○		○	◎							0	4	4	3	1	2
6	9	11.3	3.5	Cargo Capacity	○			○	▲	◎	▲		◎							0	2	4	3	3	3
7	9	10.6	3.3	Maneuverability		▲	◎	◎	◎	◎	▲		○							0	4	2	4	4	4
8	9	12.3	3.8	Off-Road Capability			○	▲	◎	○			○							0	5	3	4	2	4
9																									
10																									

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value	1	50	2000lb	6X15X5	1.5ft	2000lb	15mpg	1	3000lb						
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	6	4	7	10	7	8	1	5						
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9						
Weight / Importance	457.7	415.2	237.1	196.5	534.8	312.3	188.4	255.5	450.0						
Relative Weight	15.0	13.6	7.8	6.4	17.6	10.2	6.2	8.4	14.8						

APPENDIX B – COMPETITION SPECIFICATIONS

BUV Farm Tanker & Transporter
2020 Design Specifications:

Engine	Use up to 11 horsepower unmodified engine. An auxiliary fuel tank may be added.
Exhaust	Stock muffler, which may be relocated, with additional heat shields as needed.
Gauges	An engine temperature indicator located in view of the driver.
Fuel	Retail pump fuel and oil with provisions to prevent spilling fuel on a hot engine.
Transmission	It is builder's choice, to meet event conditions, but should have reverse** and should have at least two forward speeds** not counting any variable drive features.
Power Takeoff	The ability to power auxiliary equipment** at approximately 1000 rpm.
Electrical	A 12 volt 35 amp or larger automotive alternator and an automotive battery are required**.
Cargo Bed	The bed must hold two, but may hold three 55 gallon standard steel drums**. The drums must be located on their sides with features to verify they are full. The drums must be located as low as possible in the bed. The drums must not be stacked in any manner. The front of the cargo bed must have a 16 inch minimum high bulkhead between the driver and the cargo. The other sides of the bed must be a minimum of 8 inches high. Drums should be easily removable for cargo**and not have any holes that would leak water.
Roll Bar	A minimum height of 36 inches above the surface the driver will sit upon. The roll bar must be completely padded above the seat height. It must have a cross member that covers the ends of the vertical structures, and adequate bracing to prevent the roll bar from collapsing.
Driver Safety	A helmet is required for each person aboard the vehicle. Seat belts are at the option of the team and the team advisor.
Safety Items	To participate in the event, you must have the following safety items: 1. An engine shutoff device marked with a nine-inch red streamer located within reach of the driver. 2. A ***dead man*** throttle with the spring located directly on the throttle linkage of the engine and not on the throttle control devices of vehicle. A ***dead man*** to neutral directional control valve is required on hydraulic powered vehicles. 3. Guarding from all moving parts and Padding of all sharp or dangerous areas. 4. Automotive horn, a fire extinguisher with a rating of 5 B-C or higher, and a high visibility safety flag above the vehicle.
Brake System	A redundant brake system** that will prevent total brake failure if a brake line is severed anywhere on the vehicle. The brakes must be located at the wheels and not on the drive-line. A front wheel brake is not required on three wheeled vehicles. The parking brake is not considered the redundancy that is required. Hydraulic drives may use reverse for redundancy.
Parking Brake	A parking brake capable of overcoming the engine power. It may be on the drive-line.
Tires	Agricultural tread, or aggressive tire chains are required. Chains must remain with the vehicle.
Towing	Each vehicle must have a 20 foot looped-end tow strap. No hooks allowed. There must be an attachment point at the front of the vehicle for towing. The trailer ball will be the rear attachment point for towing.
Trailer Hitch	A 1-7/8 inch trailer ball must be mounted at a height of 15 inches above the ground when the vehicle is unloaded.
Speed	Maximum of 20 MPH.
Load	Maximum of 165 gallons of water, weighting roughly 1376 pounds.
Water Pump	Ability to fill 55-gallon drums from within 15 feet of a pond. All pumping equipment and hoses must be carried on the vehicle during the event. Pump driven form PTO device only.
Name Plate	The school name and team number displayed in 4-inch font on all sides of the vehicle.

**** See Tech Inspection Sheet for deductions if this feature is missing**

July 21, 2019

APPENDIX C - CUSTOMER SURVEY

BASIC UTILITY VEHICLE

CUSTOMER SURVEY

We are a group of five Mechanical Engineering Technology seniors at University of Cincinnati. For our senior design project, we have chosen to design and build a Basic Utility Vehicle that can be used in developing countries to help improve daily life. Please answer the following questions:

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Cargo Capacity	1	2	3	4	5
Maneuverability	1	2	3	4	5
Off-Road Capability	1	2	3	4	5

How much would you be willing to invest in a BUV?

$500-$1500 $1500-$2500 $2500-$3500 $3500-$4500