2009 Basic Utility Vehicle

by

DANIEL ROSS

Submitted to the
MECHANICAL ENGINEERING TECHNOLOGY DEPARTMENT
In Partial Fulfillment of the
Requirements for the
Degree of
Bachelor of Science
in
MECHANICAL ENGINEERING TECHNOLOGY

at the
OMI College of Applied Science
University of Cincinnati
May 2009

©......Daniel Ross

The author hereby grants to the Mechanical Engineering Technology Department permission to reproduce and distribute copies of this thesis document in whole or in part.

Signature of Author: ____________________________
Mechanical Engineering Technology

Certified by: ____________________________
Sanak Dave, PhD,
Thesis Advisor

Accepted by: ____________________________
Muthar Al-Ubaidi, PhD, Department Head
Mechanical Engineering Technology
2009 BUV: Steering, Brakes, and Front Suspension
By
Dan Ross


**ABSTRACT**

To this day, the world still has countries that are not fully developed. These countries, such as many of those in Africa, are considered third world countries. More developed and fortunate countries, such as the United States, have organizations that take the opportunity to help these other countries that are in need of assistance. One of these organizations is The Institute for Affordable Transportation (IAT). Since there are many different aspects of life that Africa needs help with, the IAT has a competition that has teams design and build cheap, reliable transportation.

The University Of Cincinnati College Of Applied Science has a team of Mechanical Engineering students that participated in the 2009 competition. Each team member was assigned to one of the four design areas: chassis and suspension by Scott Burke, steering and braking by Dan Ross, Drivetrain by Jeremy Augenstein, and ambulance attachment and electrical by Jason Lewis.
# TABLE OF CONTENTS

ABSTRACT ............................................................................................................................... I

TABLE OF CONTENTS .......................................................................................................... II

LIST OF FIGURES ................................................................................................................ III

LIST OF TABLES .................................................................................................................. III

INTRODUCTION .................................................................................................................... 1

  INSTITUTE OF AFFORDABLE TRANSPORTATION CHALLENGE ........................................ 1
  PROBLEM STATEMENT ...................................................................................................... 1

RESEARCH ............................................................................................................................ 2

CUSTOMER REQUIREMENTS ............................................................................................. 4

  RESULTS FROM SURVEY .................................................................................................. 4
  ENGINEERING CHARACTERISTICS .................................................................................. 4
  PRODUCT OBJECTIVES .................................................................................................... 5

DESIGN .................................................................................................................................... 5

  DESIGN ALTERNATIVES AND SELECTION .................................................................. 5
  STEERING .......................................................................................................................... 5
  BRAKES .............................................................................................................................. 5
  FRONT SUSPENSION ......................................................................................................... 9

DRAWINGS ................................................................................................................................ 9

LOADING CONDITIONS ....................................................................................................... 11

DESIGN ANALYSIS ............................................................................................................. 11

COMPONENT SELECTION ................................................................................................. 12

BILL OF MATERIALS .......................................................................................................... 12

FABRICATION AND ASSEMBLY ...................................................................................... 12

TESTING AND PROOF OF DESIGN ............................................................................. 14

PROJECT MANAGEMENT .................................................................................................. 14

  PROJECT BUDGET ............................................................................................................ 14
  PROJECT SCHEDULE ....................................................................................................... 14

BIBLIOGRAPHY .................................................................................................................. 16

APPENDIX A – COMPETITION SPECIFICATIONS ..................................................... 1

APPENDIX B - RESEARCH ............................................................................................... 1

APPENDIX C – CUSTOMER SURVEY WITH RESULTS ......................................... 1

APPENDIX D - QUALITY FUNCTION DEPLOYMENT ................................................. 1

APPENDIX E – PRODUCT OBJECTIVES ....................................................................... 1

APPENDIX F – PROOF OF DESIGN STATEMENT ....................................................... 1

APPENDIX G - STEERING DESIGN SKETCHES ........................................................... 1

APPENDIX H - WEIGHTED DECISION MATRIX FOR STEERING ......................... 1

APPENDIX I – DETAILED DRAWINGS ........................................................................ 1
APPENDIX J – NORMAL FORCES ON FRONT AND REAR WHEELS ........................................ 1
APPENDIX K – DESIGN ANALYSIS CALCULATIONS .......................................................... 1
APPENDIX L – BRAKE CALCULATIONS ............................................................................. 1
APPENDIX M – BILL OF MATERIALS .................................................................................. 1
APPENDIX N – BUDGET ....................................................................................................... 1
APPENDIX O – PROJECT SCHEDULE .................................................................................. 1

LIST OF FIGURES
Figure 1- Kubota RTV900 ........................................................................................................ 2
Figure 2- Snapper Turf Cruiser ............................................................................................... 3
Figure 3- John Deere Gator TS .............................................................................................. 3
Figure 4. Motorcycle Brake Lever with Master Cylinder ..................................................... 6
Figure 5. Wilwood Master Cylinder Concept ....................................................................... 7
Figure 6. Aftermarket Master Cylinder .............................................................................. 7
Figure 7. Vacuum Booster with Master Cylinder Sketch ..................................................... 8
Figure 8. Vacuum Booster with Master Cylinder ................................................................ 8
Figure 9. Telescoping Fork Suspension Design ..................................................................... 9
Figure 10. Steering and Suspension Assembly .................................................................... 10
Figure 11. Housed Bearing Units ...................................................................................... 10

LIST OF TABLES
Table 1 - Customer Features ............................................................................................... 4
Table 2. Tasks with Important Dates .................................................................................. 15
INTRODUCTION

INSTITUTE OF AFFORDABLE TRANSPORTATION CHALLENGE

The Institute of Affordable Transportation (IAT) holds a competition that focuses on the engineering of a basic utility vehicle (BUV), which can be used in a third-world country. To allow for creativity, the IAT changes the competition requirements annually. These requirements can focus on the many situations faced by people that live in these third-world countries. For the 2009 competition, the focus is on amputees. The following is the challenge and system description for the 2009 competition.

Challenge:

“Develop a 3-wheel vehicle to be driven by polio survivors, landmine survivors, amputees, and others that no longer have use of their legs. In addition to hand controls and affordability, design emphasis is on the steering, front suspension and a third-wheel drive (front wheel). Design vehicle based on re-using the rear axles and suspension of a small pick-up truck. Design for small scale assembly operations in Africa. Minimize factory investment at a volume of one vehicle per day. Assume every driver has an assistant that helps with loading, unloading, fueling, ingress, egress, etc.” (1).

System Description:

✓ “Front Clip” – includes front wheel, steering mechanism, front frame, driver’s seat & controls, engine, transmission, PTO

✓ Rear Clip – the rear end (i.e. the axle, suspension, wheels, brakes, etc) of a Chevy S-10, S-15, or small Toyota pickup. Excludes the sheet metal, fuel tank, muffler, bumper. Frame re-use is optional.

✓ Trailer – a small trailer with ball hitch, suspension, and 4 ft x 4 ft deck (a $200 kit from Harbor Freight or Northern Tool). All teams will use this type of trailer with the optional 12” wheels. Trailer will not be used on mogul event and mud pit event. Each team has the option to sell the trailer to IAT for $175 at the event” (1).

Specifications, design objectives, and other requirements are shown in Appendix A and can be viewed at the competition website.

PROBLEM STATEMENT

The challenge is to design the BUV for the 2009 BUV Design Competition. The design of the BUV, and all fabrication had to be complete in order to compete in the competition on Saturday, April 18, 2009. The BUV competed against other BUVs built by college students in a series of tests and events to determine the best design. As it says on the competition
website, “The Basic Utility Vehicle is a vehicle for change. Its purpose is to help meet peoples' everyday needs at the ends of the earth. More than cars, we are building people, opportunity, and freedom. BUVs will promote trade and reduce poverty at a grassroots level.” (1).

Team member responsibility is as follows:

- Scott Burke – Chassis and Suspension (Team Leader)
- Dan Ross – Steering and Braking (Safety Inspector)
- Jeremy Augenstein – Drive Train (Documentation Engineer)
- Jason Lewis – Ambulance Attachment and Electrical (Specifications Manager)

RESEARCH

Africa has regions that have high elevations that get large amounts of rain, making the ground muddy. It was shown in Appendix B that three-wheeled vehicles were recommended for this type of terrain that is typically hard to traverse. This information gave better understanding as to how the competition would be focusing on certain obstacles competitors could encounter.

Current production utility vehicles are very similar to the design of a BUV. There are wide varieties to choose from including many manufacturers. Manufacturers include John Deere, Honda, Kubota, etc.

The Kubota RTV900, Snapper Turf Cruiser, and John Deere Gator TS were three vehicles that were looked at. The Kubota RTV900, which can be seen in Figure 1, was designed to have low impact on the environment, superior ground clearance, and power steering (2).

![Figure 1- Kubota RTV900](image)
The Snapper Turf Cruiser was designed to operate on soft, uneven ground and be easy to operate (3).

![Figure 2- Snapper Turf Cruiser](image)

Lastly, the John Deere Gator TS 4X2 is the most widely known and used utility vehicle. It can carry a load up to 500 pounds and still have minimal impact on the ground (4).

![Figure 3- John Deere Gator TS](image)

Jason Bird owns a Kawasaki Mule 600 2WD and a John Deere Gator HPX 2WD. The knowledge obtained from this interview was that the vehicles that Jason owns are 2WD and do not work well enough to cross through creeks and muddy terrain (5).

This research showed us that we needed to design our BUV to meet the same requirements someone would want out of an existing utility vehicle currently on the market.
CUSTOMER REQUIREMENTS

RESULTS FROM SURVEY

The survey was passed out to about forty people with related interests in utility vehicles. Of the thirteen features, five were found to have high importance:

<table>
<thead>
<tr>
<th>Customer Features</th>
<th>Level of Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Maneuverability</td>
<td>4.3/5</td>
</tr>
<tr>
<td>✓ Reliability</td>
<td>4.3/5</td>
</tr>
<tr>
<td>✓ Safety</td>
<td>4.2/5</td>
</tr>
<tr>
<td>✓ Ease of Operation</td>
<td>4.0/5</td>
</tr>
<tr>
<td>✓ Durability</td>
<td>4.0/5</td>
</tr>
<tr>
<td>✓ Low Cost</td>
<td>3.7/5</td>
</tr>
<tr>
<td>✓ Resistance to the Elements</td>
<td>3.4/5</td>
</tr>
<tr>
<td>✓ Accessibility for Drivers With Special Needs</td>
<td>3.3/5</td>
</tr>
<tr>
<td>✓ Ease of Repair</td>
<td>3.2/5</td>
</tr>
<tr>
<td>✓ Ease of Assembly</td>
<td>3.0/5</td>
</tr>
<tr>
<td>✓ Environmental Impact</td>
<td>2.9/5</td>
</tr>
<tr>
<td>✓ Quiet Operation</td>
<td>2.7/5</td>
</tr>
<tr>
<td>✓ Ability to Cross Water</td>
<td>2.3/5</td>
</tr>
</tbody>
</table>

The top five features from Table 1 became the top five customer requirements for the BUV. The remaining features came back as having medium importance. The survey results are formulated in Appendix C – Customer Survey with Results.

ENGINEERING CHARACTERISTICS

Below are the top three engineering characteristics that are important and need to be focused on for the design of the BUV. The complete QFD can be found in Appendix D.

✓ Braking Distance to Stop from Maximum Speed
✓ Number of Parts
✓ Driver Seat Position

These three characteristics are important for designing the Braking and Steering of the BUV. The steering mechanism needs to be easy to assemble, which means it should have a low number of parts. Also, depending on where the Driver Seat Position coincides with the design of the steering mechanism.
PRODUCT OBJECTIVES

Objectives for this product were created from the QFD and the specifications from the IAT. The following lists the Product Objectives for the IAT Competition:

List of Product Objectives for IAT Competition
✓ The BUV must use the existing truck brakes with hydraulic activation
✓ The BUV must use the existing truck emergency brake operable from driver’s seat

DESIGN

The engineering characteristics and product objectives allowed for the design concepts of the vehicle to be developed. A proof of design statement was made as an agreement of the requirements that the Steering, Brakes, and Front Suspension must meet to make the designs successful. The proof of design statement can be found in Appendix F. Three design concepts for the Steering, three design concepts for the Brakes, and Front Suspension are created to meet these requirements. All these design concepts are discussed below.

DESIGN ALTERNATIVES AND SELECTION

STEERING

Three different designs were chosen to be looked at for the steering of the vehicle. These three designs were the Tri-Fork, Dual Fork, and Mono-fork. Hand sketches of these three designs can be seen in Appendix G.

After taking the results from the customer survey and the QFD, a weighted decision matrix was created to aid in the selection in the best design for the steering. Most important factors considered were low cost, ease of operation, maneuverability, and durability. To come up with the top design, the ranking for the three designs was multiplied by the relative weight of each factor. Once this was done the top design came out to be the Mono-fork design, which will satisfy all the requirements of who ever uses the BUV. The weighted decision matrix can be seen in Appendix H.

BRAKES

The IAT Competition Specifications require the vehicle to be operated by amputees, i.e. people with no legs. This requires that the brakes be hand activated. This means the design has to supply enough force to stop the vehicle by means of hand activated. Several designs were researched as possibilities. This resulted in three different designs for activating the brakes.

1. Brake Lever with Master Cylinder
This design would use a motorcycle brake lever with a master cylinder built in. Figure 4 shows how this type of part looks.

![Motorcycle Brake Lever with Master Cylinder](image)

This design is simple and easy to operate. However, motorcycle brake levers do not produce the desired force to stop a vehicle of the size of the BUV.

2. Master Cylinder

The next design incorporated an aftermarket Wilwood master cylinder rigged to a fabricated lever that reached up to the handlebars. The fabricated lever would create a mechanical advantage using a lever ratio of 5:1. Figure 5 shows an initial sketch of this concept and Figure 6 shows the aftermarket Wilwood master cylinder.
This design was slightly more complicated and requires more parts. The master cylinder was used a lot in previous year’s BUVs. To get the best lever ratio the assembly would have to be located at the front of the vehicle. This risks the system getting caught up in branches that the vehicle could possibly drive through.

3. Vacuum Booster with Master Cylinder

The last design used a vacuum booster with a master cylinder rigged to a fabricated lever system. The fabricated lever system is actuated by means of a bicycle lever pulling a cable attached to the lever system. Figure 7 shows an initial sketch of this concept and Figure 8 shows the vacuum booster with master cylinder that will be used.
This design has some time required for assembly. The vacuum booster with master cylinder comes straight out of the vehicle that the rear clip was taken from too. This eliminates extra cost and makes the part readily available. The vacuum booster creates extra output force which aids in the braking of the vehicle.

With the amount of extra force gained from using the vacuum booster when only using hand activation, that design was chosen. The other designs would not create the required force needed to stop the vehicle.
**FRONT SUSPENSION**

Since the vehicle has to have a mono-fork design, a suspension with a minimum travel of 2.5” is required. After preliminary research, the best design for the front suspension was going to have to be a telescoping fork design. This design involves a tube sliding in another tube with a spring inside of it. This type of suspension allows for the desired suspension travel needed and is easy to assemble. Telescoping forks can be found on the majority of motorcycle front ends. Figure 9 shows a basic schematic of this concept.

![Telescoping Fork Suspension Design](image)

**DRAWDINGS**

After selecting the final design, the overall assemblies could be drawn up into SolidWorks design software. Below is a drawing of the front end of the vehicle and the area with the housed bearing units. Individual component drawings can be viewed in Appendix I.
Figure 10. Steering and Suspension Assembly

Figure 11. Housed Bearing Units
LOADING CONDITIONS

The front end of the vehicle will see two types of loading conditions. Most of the front end will see repeat loading, while the front spindle, spindle mount, and fork bar will see impact loading. The spring that is being used for the suspension will reduce the force seen on the rest of the steering assembly. A worst case scenario of going down a 20° slope at 20 miles per hour while braking with a full load was used to analyze the front end of the vehicle. By doing this, the maximum amount of weight transferred to the front of the vehicle can be seen. It was assumed that the BUV will weigh approximately 2,500 pounds fully loaded meaning that the front suspension will see close to 800 pounds. Then an additional 300 pounds when braking down a 20° slope.

DESIGN ANALYSIS

After determining the loading conditions, design analysis of the front end of the vehicle was done with a design factor determined. Initially, forces were computed for traveling down a 20° slope while braking, which came out to be 1,118 pound-force pushing against the front wheel and 1,231 pound-force on the rear wheel. Then, an 824 pound-force pushing against the front wheel and a 1,676 pound-force pushing against the rear wheel was found from calculating the forces on the vehicle braking on level ground. The free-body diagrams and calculations can be seen in Appendix J.

Bending moments and stresses on the front end were then calculated using the 1,118 pound-force found in the force calculations. The bending moments and stresses were found for critical components by working up the front end from where the tire contacts the ground. This was started at the spindle mount, then the fork bar, fork tube, and ending at the bottom steer brace. These calculations can be seen in Appendix K.

The brake system was the next design for which calculations were done. The crucial calculation needed was the required force to stop at a worst case distance of 55 feet while fully loaded on a 20° slope. This was done by first finding the total energy of the vehicle which can be done by adding the kinetic and potential energy of the BUV. Taking the total energy and dividing it by the stopping distance, a braking force of 1,461 pound-force was found. The vacuum booster, also, has its own set of calculations that found that amount of output force the booster produced when activated (6). To accomplish this, first, the pressure differential acting on the diaphragm within the booster had to be calculated. Then, the area of the diaphragm was found and, since the vacuum booster is a dual-diaphragm booster, the area was multiplied by two. Lastly, to find the output force, both the diaphragm area and pressure differential had to be multiplied together to result in 929 pound-force. All brake calculations can be seen in Appendix L.
COMPONENT SELECTION

In order for the steer tube to turn smoothly, roller bearings needed to be used. Special y-bearing flanged units from SKF were selected because they are excellent for axial and radial loading. Choosing these types of bearings was based off how ball bearings are used in the head tube on bicycles.

Since the Yanmar diesel engine does not create enough vacuum that is required by the manufacturers for the vacuum booster, a vacuum pump had to be used. The vacuum pump was purchased from Grainger and had a maximum vacuum capacity of 22.5 in.Hg. This was more than enough to create the desired vacuum within the booster.

With one of the requirements being that everything has to be hand operated, a component that gives a mechanical advantage was needed to be used in the braking system. This component was a vacuum booster. A vacuum booster reduces that amount of energy needed to active the brakes in a car. The vacuum booster being used is out of a 1987 Chevy S-10, which is the same vehicle that the rear clip was taken from. This made the booster more easily available.

BILL OF MATERIALS

A bill of materials allowed for the ability to keep track of purchased parts and total cost for Steering, Brakes, and Front Suspension. A copy of a most recent Bill of Materials can be seen in Appendix M.

FABRICATION AND ASSEMBLY

Since there are three designs to this report, the fabrication and assembly will be discussed for each design individually. All fabrication was done at Xtek Incorporated, our main sponsor, and assembly was done in the lab at the College of Applied Science.

STEERING

Fabrication

The top and bottom steer braces came from 4” x 2” x 1/4” rectangular tubing. The top steer brace was cut to 21 1/4” long and the bottom steer brace was cut to 17 1/4” long using a horizontal band saw. The holes for the all-thread were drilled using a 1 1/8” drill bit on a milling machine. The holes for the steer tube were drilled using a 1 5/8” drill bit on a vertical drill press. The holes for the bearing were drilled using a 2 1/4” hole saw bit on the vertical drill press. The steer tube came from a 1 1/2” O.D. bar that was cut to length by the horizontal band saw. A piece of 3/16” steel left over from the fabrication of the chassis was used for the handlebar mounting plate.
Assembly

Using a MIG welder, the steer tube was welded to one side of the bottom steer brace. The bottom and top steer braces were tightened together using the 1” all-thread. This also allowed for proper pressure against the bearing units. The handlebar mounting plate was then centered and welded to the top of the steer tube.

BRAKES

Fabrication

All parts fabricated for the brake system were used from the left over 3/16” steel used for the chassis. All parts were cut using a CNC plasma cutter.

Assembly

All parts were welded to the inside of the chassis using a MIG welder. The lever was assembled using brass bushings and hex bolts. The power booster was mounted to the plate that had matching bolt hole pattern using nuts and lock washers.

FRONT SUSPENSION

Fabrication

The fork tube came from a 4” x 1/4” thick wall square tube, which was cut to the length of 18” long using a horizontal band saw. The fork bar came from a 3 1/4” square bar that was cut to the length of 23” long. The spindle mount came from a 3” square bar that was cut to length of 5 5/8” long using a horizontal band saw. A 1 3/4” hole that was 1 5/8” deep was drilled using a 1 3/4” oversize drill bit on a drill press. The nylon bushing plates were cut to size using a band saw.

Assembly

The nylon bushing plates were attached to the inside of one end of the fork tube using a high strength epoxy. The fork tube was welded to the top and bottom steer braces using a MIG welder. The spindle mount was also welded to one end of the fork bar. The spindle was then welded into the spindle mount into a position that would center the front wheel with the center of the steer tube. The coil over spring was put into the fork tube and then the fork bar was inserted into the fork tube. To keep the fork bar from coming completely out of the fork tube, tabs for a camaro shock were welded to the face of each part.
TESTING AND PROOF OF DESIGN

Most of the testing was done during the IAT competition. All of the designs were tested fully throughout the competition. The steering, from an engineering stand point, did not fail. However, the turning radius ended up creating some a few problems for the agility and modal courses. This was not something that could be fixed right away, so the driver had to take this into consideration while driving the vehicle. To improve the turning ability of the vehicle, the rake and led would need to be changed.

The brakes had initially worked after assembly. However, for unknown reasons the brakes had stopped working during the competition. Attempts to repair the brake system were made, but nothing seemed to fix the brakes. One improvement that could be made would have a brake lever with a longer lever arm.

The front suspension saw a lot of forces at the competition. During the obstacle course, the vehicle had to drive over a log. However, it instead pushed the log right out of the way. The front suspension turned out to be the best design at the competition. It had won Most Innovative Design from the IAT. The only set back was the weight of the overall assembly. Instead of using solid material for the fork bar, another tube could have been used.

For the proof of the design, seven standards were set. Of these seven standards, five were accomplished. These five were as follows:
- The vehicle will stop on dry hard pavement from 20 mph in a distance of 55 ft or less.
- The vehicle will have a steering mechanism.
- All controls for the vehicle will be hand operated.
- The vehicle will have a turning radius of 15 ft or less.
- The vehicle’s rear brakes will use a hydraulically activated hand brake.

PROJECT MANAGEMENT

PROJECT BUDGET

While developing the product, a budget was made and can be seen in Appendix N. The proposed total cost for the Steering, Brakes, and Front Suspension was $1,105. The updated combined total cost is $952.92. This updated cost may change due to many different factors that could come up.

PROJECT SCHEDULE

The schedule needs to also include responsibilities of the individual and the group. The key dates for the BUV are as follows:
Table 2. Tasks with Important Dates

<table>
<thead>
<tr>
<th>Activity</th>
<th>Proposed</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proof of Design Agreement</td>
<td>11/17/08-1/5/09</td>
<td>11/17/08-1/5/09</td>
</tr>
<tr>
<td>Concept Sketches &amp; Selection</td>
<td>1/5/09-1/25/09</td>
<td>1/5/09-1/25/09</td>
</tr>
<tr>
<td>BUV: Design Tasks</td>
<td>1/26/09-2/12/09</td>
<td>1/26/09-2/16/09</td>
</tr>
<tr>
<td>BUV: Design Freeze</td>
<td>2/12/2009</td>
<td>2/18/2009</td>
</tr>
<tr>
<td>BUV: Ordering Parts</td>
<td>2/16/09-3/1/09</td>
<td>2/16/09-4/10/09</td>
</tr>
<tr>
<td>BUV: Fabrications</td>
<td>3/02/09-3/15/09</td>
<td>2/16/09-4/10/09</td>
</tr>
<tr>
<td>BUV: Preliminary Test</td>
<td>3/30/09-4/08/09</td>
<td>4/13/09-4/15/09</td>
</tr>
<tr>
<td>IAT Competition Report</td>
<td>3/30/09-4/19/09</td>
<td>4/17/09</td>
</tr>
<tr>
<td>BUV: Final Testing</td>
<td>4/13/09-4/22/09</td>
<td>4/15/09-4/16/09</td>
</tr>
<tr>
<td>Senior Design II - Final Report</td>
<td>5/18/09-6/4/09</td>
<td>06/05/2009</td>
</tr>
</tbody>
</table>

A fully detailed schedule can be found in Appendix O.
BIBLIOGRAPHY
APPENDIX A – COMPETITION SPECIFICATIONS

Capstone Design Project - International

BUV Overcomer - for Amputees

Basic Utility Vehicle (BUV) for Developing Countries

Keywords: Africa / Bio-Diesel / Hybrid Drive / SX3 / Hand Controls / Long Loads / Trailer / Re-use

Institute for Affordable Transportation

Challenge: Develop a 3-wheel vehicle to be driven by polio survivors, landmine survivors, amputees, and others that no longer have use of their legs. In addition to hand controls and affordability, design emphasis is on the steering, front suspension and a third-wheel drive (front wheel). Design vehicle based on re-using the rear axles and suspension of a small pick-up truck. Design for small scale assembly operations in Africa. Minimize factory investment at a volume of one vehicle per day. Assume every driver has an assistant that helps with loading, unloading, fueling, ingress, egress, etc.

System Description:
Front Unit – includes front wheel, steering mechanism, front frame, driver’s seat & controls, engine, transmission, PTO

Rear Clip – the rear end (i.e. the axle, suspension, wheels, brakes, etc) of a Chevy S-10, S-15, or small Toyota pickup. Excludes the sheet metal, fuel tank, muffler, bumper. Frame-re-use is optional.

Specifications – Driveable Chassis:

<table>
<thead>
<tr>
<th>Cost Targets:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front suspension/steering $125; weld/paint/fab frame $420; underdeck storage $27; Front-wheel drive Granny gear (fwd/rev) $155; brake actuation/mstr-cyl $61, assembly labor $48</td>
</tr>
</tbody>
</table>

Engine / Fuel:
10 hp Yanmar diesel motor, fuel is bio-diesel B100 at the event (change fuel lines, seals, etc)

Transmission:
Not specified. Tuff Torq transmission K115 available at minimal cost. No automotive transmissions

Hybrid FWD:
Provide a powered front wheel. Forward and reverse at 1 mph with 1200 lbs load on flat dry ground.

Front Suspension:
Rubber: torsion type or aircraft bungee type. Mono-fork style. Min 2.5” wheel travel.

Noise Level:
Within OSHA standards for driver. Exhaust routed under the vehicle.

Front Seats:
Motorcycle seating arrangement for two people. The driver’s assistant is the cargo handler / guard. No side by side seating. Not designed for amputee

Payload:
1200 lbs (includes driver). Do not count the cargo bed as part of the payload.

300 lbs of sand at event.

Top Speed:
20 mph unloaded on grass (governed)

Hand Controls:
Mount throttle and brake actuator on steering mechanism. No foot throttle or foot brake (you can use foot brake as a redundant brake... a backup to the hand operated brake).

Rear Brakes:
Use existing truck brakes with hydraulic activation (Not foot or leg activated)

Parking Brake:
Use existing truck emergency brake operable from driver’s seat. Activation method not specified

Ground Clearance:
> 10.5” except at differential, leaf springs, or lower shock mounts

PTO Pulley:
Power items on board or off-board vehicle. Disengage driveline when using PTO.

Storage:
Provide at least 2 cubic feet of easy-access, water resistant storage on the cargo deck.

Appearance:
University name (or abbrev.) on all 4 sides in 4” letters. Colorful hand prints on the tailgate.

Tow Package:
Class I Hitch or similar, standard 4 wire connector, wiring, chains, etc.

Seal Protection:
Required for the motorcycle seating area only (driver and drivers assistant)

Safety Equipment A:

Without these items, points will be deducted. But you can still be in the driving events:

- Horn, passenger handles/ropes, 1 headlight, 2 tail-lights, 2 brake lights, 2 light reflectors per side, fender, grab handles for rescue, appropriate engine noise shielding, on-board tool kit ($50 of critical tools) rounded edges, padding (no sharp burrs), seat belts. Includes 3 boards (6’L x 2”x10”) stored under deck for crossing gulleys/ditches, and rescuing vehicles which are stuck (a leverage device).

Safety Equipment B:

Without these items, you will not be allowed to drive in the competition: easy-to-access kill switch, tow hooks (front mounted lower than 30” high), on-board fire extinguisher, appropriate shielding from moving parts, “anti-roll” protection (shoulder height roll-bar helps stop vehicle rotation at 1/4 roll and helps shield driver from cargo), all lug nuts installed on wheels.

Appendix A1
Design Objectives:
- Minimize total lifetime cost of ownership
- Utilize off-the-shelf components where possible
- Minimize the number of part numbers, and the part count to simplify purchasing, logistics, service, etc.
- Require only 2 people to assemble BUV. Use DFA methods
- Utilize simple, durable, low maintenance design
- Minimize center of gravity to increase stability
- Minimize number of common tools required to repair vehicle
- Minimize machining, welding, and fixtures for African assembly to reduce investment/skill required
- Emphasize safety in all aspects of design.

Performance Requirements:
- Emphasize reliability and ease of service
- Capable of climbing 15 degree slope with a 1200 lb load in cargo bed (and no trailer).
- Fording Ability: 15 inches of water
- Brakes will lock during an emergency stop on grass full load
- Safely transport 14 ft long timber, pole, or log

Note: Items in blue on page ! Highlight some of the changes in this spec from the previous year spec.

Fyi... there was one aircraft bungee front suspension and one rubber torsion front suspension in the 2008 competition.

BUVs donated to IAT at the competition will be sent if safe & intact to humanitarian organizations in developing countries.

Other Data that Judges will collect
(which is related to the performance and objectives)
- Number of “off-the-shelf” parts not including fasteners
- Number of fabricated or custom parts
- Number of fasteners used.
- Total Number of Parts
- % of fabricated parts to Total Number of Parts
- The number of different part numbers (i.e. 4 screws of the same type count as 1 part number)
- Number of Special Tools or fixtures used in fabrication or assembly
- Area of cargo bed (inside dimensions)
- Distance from level ground to bottom of engine (inches)
- Estimated man-hours of assembly time front steering unit
- Total Cost of FWD
- Inches of weld on prototype
- Ability to power other devices
- Frame Weight (weighed or calculated)
- Total weight of vehicle
- Corrosion Prevention Methods used
- Tool Kit to travel with BUV
- Estimate Production Cost (fully assembled)
- Noise level (decibels). Measured at drivers head (R and L side) at full throttle on grass. Drive-by measured at 10 ft.

Guidelines for Trailering with your BUV. Address carrying long loads (spanning BUV and trailer).

Casing Information:
Engine: use $1200 for diesel engine & $500 for KT135 tranny
Truck rear clip - use $150 (no matter the actual cost)
Other purchased parts - use 50% of retail price. For fabricated parts & painting, use industry quotes based on orders of 25 units/month
Volume for sourcing parts: 300 BUVs/yr (about 1 BUV/day)
Use $1/hour labor rate. Use new equipment rental pricing.

Engineering Report
Follow your class requirements. Additionally, IAT wants a costed Bill of Material (BOM) with part number, source, weight info and a cost breakdown by system (powertrain, frame, front steering, cargo bed, etc.) in the report. Include cost and weight subtotals by system. Also include a summary of the assembly process, equipment required & cost, assembly time, and micro-factory costs. Determine labor content per unit, equipment investment required, factory layout for 4000 sq ft, and staffing for a 1 unit per day micro-factory. Predict which three parts are most likely to fail first.

Common Errors to Avoid:
Heavy and over-designed vehicles: a good target is 950 lbs to perform well at the competition
Inappropriate/ Gearing: ensure that you have at least a 60:1 reduction in your powertrain in low gear
Inappropriate Tires: car tires or tires over 30” in dia. usually do not perform well in the competition. Use aggressive tread.
Appropriate Shielding & Guards: Protect operator, passenger, and bystanders (rescuers) from driveline & pinch points.
Also, design against mud, sand, water intrusion. If necessary, use debris guards to protect vehicle.
Weak driveshaft and u-joints (be ready for high torque loads)
A high center of gravity… please design a LOW C of G

Trailer: http://www.harborfreight.com/cgi-bin/dst televised?itemnumber=96152 You can save freight by getting it from the retail store. Also, you can sign up for their flyers and get a 15% off coupon. IAT bought one for $187 in Aug 2008. The following trailer is also acceptable http://www.harborfreight.com/cgi-bin/dst televised?itemnumber=2075 Similar trailers are also available at www.northernind.com

Contact: will.austin@drivebuv.org 317.213.1088

Appendix A2
The Basic Utility Vehicle is being designed for use in developing countries. Such countries can be found in the Continents of Africa and South America. These continents have very unique conditions that we are not familiar with.

The climate of Africa ranges from tropical to subarctic on its highest peaks. Its northern half is primarily desert or arid, while its central and southern areas contain both savanna plains and very dense jungle (rainforest) regions. In between, there is a convergence where vegetation patterns such as Sahel, and steppe dominate.

The climate of South America has a lot of the same conditions. South America is also home to the world's highest waterfall, Angel Falls in Venezuela, the largest river (by volume), the Amazon River, the longest mountain range, the Andes (whose highest mountain is Aconcagua at 6,962 m (22,841 ft)), the second-driest desert after the McMurdo Dry Valleys of Antarctica, the Atacama Desert, the largest rainforest, the Amazon Rainforest, the highest capital city, La Paz, Bolivia, the highest commercially navigable lake in the world, Lake Titicaca, and the world's southernmost town, Puerto Toro, Chile.

We must include some special features in order for our Basic Utility Vehicle to be helpful operating in these conditions. The terrain can at many times be rough with rocks, trees, mud and sand. We must protect our drive train of our BUV. The motor and transmission must be protected. The bottom frame rails of the chassis will do most of the work. However we will need to include a skid plate to protecting against smaller things from protruding in to the smaller voids of the undercarriage. Electricity is sometimes non-existent in some portions of these countries. We must include lighting that will be guide the BUV in even the darkest conditions. Also without electricity we need to provide a way we can use the power of the motor to drive auxiliary devices. With the mountainous regions and sharp elevation changes more than just two-wheel drive will be need. Three-wheel drive will help in sand, mud or climbing over just about anything. The vehicle must be able to cross streams without a problem.
## Previous BUV Competition Vehicles

<table>
<thead>
<tr>
<th>Wooden Cargo Bed</th>
<th>Converts easily</th>
</tr>
</thead>
<tbody>
<tr>
<td>No bracing visible</td>
<td>Few Pinch Points</td>
</tr>
<tr>
<td>Length is about 2/3 of car</td>
<td>Weight concern</td>
</tr>
<tr>
<td>Hinged Sidewalls</td>
<td>No seats</td>
</tr>
<tr>
<td>Sidewalls about 2 ft. tall</td>
<td>Roll Bar Bent Tubing</td>
</tr>
<tr>
<td>Headlights on front grill</td>
<td></td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Wooden Cargo Bed</th>
<th>Few Pinch Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removable sidewalls</td>
<td>No seats</td>
</tr>
<tr>
<td>Headlights attached to roll bar</td>
<td>Long time to convert</td>
</tr>
<tr>
<td>Bracing is visible to exterior</td>
<td>Weight Concern</td>
</tr>
<tr>
<td></td>
<td>Welded square tubing for roll bar</td>
</tr>
</tbody>
</table>

---


---

Appendix B2
Utility Vehicles

Model 6021 X2

- Aluminum Sidewalls
- All three sides fold down
- Sidewalls approx. 1.5 ft.
- Headlights on grill

- Easily converts
- Few Pinch Points
- No Seats
- Major weight concern

The Carryall 6 has outstanding cargo capacity with a vehicle-rated capacity of 1500 lbs. Available in gas or electric models, these vehicles can be equipped with flatbed, cargo box or stake-side kit for multiple applications.

- Aluminum walls
- Tailgate folds down
- Sidewalls approx. 1.5 ft. tall
- Headlights on front grill

- Easily converts
- Few Pinch Points
- No seats
- Weight concern

http://www.cruisecarinc.com/gallery-utility-vehicles.htm
9/26/08 Cruise Car, Inc. – Model 6021 X2

9/26/08 Club Car Utility Vehicle – Carryall 6

Appendix B3
# All-Terrain/Utility Vehicles

So versatile you won’t be far from it. Farm, field, yard and forest — owning a Turf Cruiser or Trail Cruiser is like having a hired hand. Rugged dependability with comfortable operator compartment where you can stretch out and enjoy the view. Quick-view gauges and convenient controls for easy direction changes and maneuvering.

- Easy to Operate
- Power Steering
- Tow option
- Good ground clearance
- Good on soft uneven ground
- Powered

Reliable and Durable with a single cylinder, 4-cycle Kawasaki gasoline engine. Cargo box is made from 16-gauge steel and hauls up to 500 lbs. Gator can tow up to 900 lb on level terrain. Has a low center of gravity which enhances the stability and handling.

- Minimal ground impaction
- Rated weight typical
- Tow option
- Good ground clearance
- Good on soft uneven ground
- Powered
All-Terrain/Utility Vehicles Cont.

Features a powerful 3-cylinder Kubota Diesel Engine that allows for navigating rough, rugged terrain. Also features the exclusive Kubota Variable Hydro Transmission (VHT) which allows for quick acceleration, optimum traction on any terrain and for a smoother ride. Frame made of high-intensity, lightweight metal

Interview from Owner of Two Utility Vehicles

INTERVIEW CONDUCTED 9/26/2008

Jason Bird – A carpenter who has owned both a Kawasaki Mule 600 2WD and a John Deer Gator HPX 2WD

Interviewer: Scott Burke
Interviewee: Jason Bird: Harveylopez513@hotmail.com

Scott: What is the number one factor affecting your purchasing decision when buying a utility vehicle?
Jason: Price.
Scott: What is the second most important factor that affects your purchase?
Jason: Looks.
Scott: What is your biggest complaint about the past utility vehicles you have owned?
Jason: Problems getting over rough terrain. The 2WD just didn’t cut it.
Scott: What is your second biggest complaint about the past utility vehicles you have owned?
Jason: The cargo area was too small to haul.
Scott: What other things do you look for when shopping for a utility vehicle?
Jason: Power, top speed, ride quality and lighting.
Scott: What kind of features will be included in the next utility vehicle you purchase?
Jason: 4WD, bigger bed or trailer, better lights and unique color.
Scott: What specific obstacles might your utility vehicle face?
Jason: Creeks, mud pits, fallen trees, rocks, and sand.
APPENDIX C – CUSTOMER SURVEY WITH RESULTS

We are a group of seniors at the University of Cincinnati studying Mechanical Engineering Technology. Our Senior Design Project is a Basic Utility Vehicle (BUV) that is to be used for amputees in third world countries such as Africa as a means of transportation. Please take a few minutes to answer the following questions:

1. **How important is each feature to you for the design of a Basic Utility and All-Terrain Vehicle?**

   Please circle the appropriate answer! 1 – Low Importance  5- High Importance

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>N/A</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>4</td>
<td>(12)</td>
<td>3</td>
<td>8</td>
<td></td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>Accessibility for Drivers</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>3.3</td>
</tr>
<tr>
<td>With Specials Needs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>4</td>
<td></td>
<td>13</td>
<td>7</td>
<td></td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>Ease of Repair</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>3.2</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>2</td>
<td>11</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>Low Cost</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td>Resistance to the Elements</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>5</td>
<td></td>
<td>3.4</td>
</tr>
<tr>
<td>Durability</td>
<td>2</td>
<td>19</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>2</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>Reliability</td>
<td>2</td>
<td>13</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>3</td>
<td>12</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>2.9</td>
</tr>
<tr>
<td>Ability to Cross Water</td>
<td>6</td>
<td>12</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>Quiet Operation</td>
<td>4</td>
<td>16</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>2.7</td>
</tr>
</tbody>
</table>
2. How satisfied are you with the current Basic Utility and All-Terrain Vehicles?

<table>
<thead>
<tr>
<th><strong>Please circle the appropriate answer! 1 – Very Unsatisfied  5- Very Satisfied</strong></th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td>1  2 (1)  3 (5)  4 (12)  5 (14)  N/A (3)  3.9</td>
</tr>
<tr>
<td><strong>Accessibility for Drivers With Specials Needs</strong></td>
<td>1(6)  2(5)  3 (12)  4 (5)  5 (3)  N/A (4)  2.5</td>
</tr>
<tr>
<td><strong>Ease of Operation</strong></td>
<td>1  2(3)  3 (4)  4 (16)  5 (6)  N/A (6)  3.2</td>
</tr>
<tr>
<td><strong>Ease of Repair</strong></td>
<td>1(2)  2(3)  3(11)  4 (9)  5 (4)  N/A (6)  2.8</td>
</tr>
<tr>
<td><strong>Ease of Assembly</strong></td>
<td>1(2)  2(6)  3(12)  4(6)  5(5)  N/A (4)  2.8</td>
</tr>
<tr>
<td><strong>Low Cost</strong></td>
<td>1(8)  2(5)  3(9)  4(8)  5(2)  N/A (3)  2.5</td>
</tr>
<tr>
<td><strong>Resistance to the Elements</strong></td>
<td>1(3)  2(4)  3(10)  4(13)  5(2)  N/A (3)  2.9</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>1  2(3)  3 (13)  4 (11)  5(5)  N/A (3)  3.3</td>
</tr>
<tr>
<td><strong>Maneuverability</strong></td>
<td>1  2(1)  3(5)  4 (17)  5 (9)  N/A (3)  3.7</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>1  2  3(14)  4(13)  5(5)  N/A (3)  3.4</td>
</tr>
<tr>
<td><strong>Environmental Impact</strong></td>
<td>1(1)  2(6)  3(15)  4(8)  5(3)  N/A (2)  3.0</td>
</tr>
<tr>
<td><strong>Ability to Cross Water</strong></td>
<td>1(3)  2(4)  3(8)  4(5)  5(8)  N/A (7)  2.7</td>
</tr>
<tr>
<td><strong>Quiet Operation</strong></td>
<td>1(2)  2(2)  3(12)  4(10)  5(3)  N/A (6)  2.8</td>
</tr>
</tbody>
</table>

3. How much would you be willing to pay for this product?

- $ 500 - $ 1000 (8)
- $ 1,000 – $ 1,500 (17)
- $ 1,500 - $ 2,000 (6)
- $2,000 – $ 2,500 (4)

We would like to thank you for your time in filling out our survey!
## APPENDIX D - QUALITY FUNCTION DEPLOYMENT

<table>
<thead>
<tr>
<th></th>
<th>Traction Force</th>
<th>Acceleration</th>
<th>Weight of BUV</th>
<th>Low Center of Gravity</th>
<th>Noise Level</th>
<th>Braking Distance to stop from maximum</th>
<th>Steering Ability</th>
<th>Ride Comfort</th>
<th>Traction on Different Surfaces</th>
<th>Assembly Time</th>
<th>Number of Parts</th>
<th>Driver seat position</th>
<th>Ability to Haul Weight</th>
<th>Customer Importance</th>
<th>Current Satisfaction</th>
<th>Planned</th>
<th>Improvement ratio</th>
<th>Modified Importance</th>
<th>Relative weight</th>
<th>Relative weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessibility for Drivers with Special Needs</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Repair</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Cost</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance to the Elements</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maneuverability</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to Cross Water</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quiet Operation</td>
<td>3</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abs. importance</td>
<td>0.44</td>
<td>0.55</td>
<td>0.39</td>
<td>0.37</td>
<td>0.45</td>
<td>0.92</td>
<td>0.00</td>
<td>0.37</td>
<td>0.55</td>
<td>0.24</td>
<td>1.16</td>
<td>1.03</td>
<td>0.25</td>
<td>45.3</td>
<td>57.8</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rel. importance</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX E – PRODUCT OBJECTIVES

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on the Basic Utility Vehicle’s ability to meet competition design standards and on the list of objectives that will most likely result in a win at said competition.

**Safety:**
1.) Safety guards covering pinch points and moving parts.
2.) Easy to access kill switch, tow hooks, fire extinguisher, and “anti-roll” role protection.
3.) Horn, passenger handles, 1 headlight, 2 tail lights, 2 brake lights, 2 light reflectors per side, fenders, grab handles for rescue, engine noise shielding, tool kit, rounded edges, padding, seat belts.

**Accessibility for Drivers with Special Needs:**
1.) The vehicle will have the ability to be operated by a person having no legs.
2.) There will be at least 2 of the following: driver handles, passenger handles, and rescue handles.

**Ease of Operation:**
1.) The BUV will have a simple lever throttle (as seen on ATVs).
2.) The BUV will have a handle bar type steering system.
3.) The BUV will have a ground clearance of more than 10.5”.

**Ease of Repair:**
1.) Only 3 types of bolts will be used.
2.) Shields will un-bolt for easy access to guarded parts.

**Ease of Assembly:**
1.) Only basic tools will be needed (ex. no cutting).
2.) Assembly manual will be provided.

**Low Cost:**
1.) Vehicle will cost below $4750.

**Resistance to the Elements:**
1.) The vehicle will have skid plates protecting the engine compartment, transmission, the front differential, and rear differential.
2.) Snorkel for intake will be 25 in. above the ground.

**Durability:**
1.) The frame will be able to withstand a torque load of 2250 lbs.
**Quiet Operation:**
1.) The vehicle will adhere to OSHA standards for driver.

**Ability to Cross Water:**
1.) The vehicle will have an intake that is above 25”.
2.) The vehicle will have at least 3 shields to protect the engine from water.
APPENDIX F – PROOF OF DESIGN STATEMENT

The proof of design statement is documented as a contract agreement of the features that the engineer will design the end product to include. The proof of design statement for the brakes and steering of the basic utility vehicle was extracted from the specifications and performance requirements listed by IAT. For the basic utility vehicle to be successful, it must at least meet the specifications set forth by IAT, and thus must at least meet the specifications described in the proof of design statement for the brakes and steering, which are as follows:

✔ The vehicle’s rear brakes will use a hydraulically activated hand brake.
✔ The vehicle’s parking brake will use existing cable operated emergency brake operable from driver’s seat.
✔ The vehicle’s brake(s) will lock during emergency stop on grass with full load.
✔ The vehicle will have a steering mechanism.
✔ All controls for the vehicle will be hand operated.
✔ The vehicle will stop on dry hard pavement from 20 mph in a distance of 55 ft or less.
✔ The vehicle will have a turning radius of 15 ft or less.
APPENDIX G - STEERING DESIGN SKETCHES

Tri-fork

Dual Fork
Mono-fork
## APPENDIX H - WEIGHTED DECISION MATRIX FOR STEERING

<table>
<thead>
<tr>
<th>Relative Weight</th>
<th>Low Cost</th>
<th>Ease of Operation</th>
<th>Maneuverability</th>
<th>Durability</th>
<th>Final Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Relative Scale</td>
<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Tri-fork</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>1.03</td>
</tr>
<tr>
<td>Dual Fork</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>1.57</td>
</tr>
<tr>
<td>Mono-fork</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>2.00</td>
</tr>
<tr>
<td>6 is the best</td>
<td>1 is the worst</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix H1
## Appendix I – Detailed Drawings

### Table of Parts

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Part Number</th>
<th>Description</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29240000</td>
<td>Ball Bearing Housed Unit</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>29241000</td>
<td>Steering Link</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>29242000</td>
<td>Steering Brace (Bottom)</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>29243000</td>
<td>Steering Brace (Top)</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>29262000</td>
<td>Steering Handle Bar</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>29264000</td>
<td>Thrust Washer Bearing</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>29265000</td>
<td>Zinc Plated Steel Threaded Rod 1/4&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thread x 1/4&quot; Long</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>29266000</td>
<td>Zinc Yellow Plated Flat Barage Lock</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Washer 1/2&quot; Grip 5/8&quot; ID, 1-19/32&quot; OD,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-13/32&quot; min Thr.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>29267000</td>
<td>Zinc &amp; Yellow Plated Grounded Steel</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hex Nut T/2&quot; Threaded Size 1-1/2&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Width, 85/64&quot; Height</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>29268000</td>
<td>Front Suspension Hub</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>29269000</td>
<td>Front Suspension Spindle</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>29270000</td>
<td>Steering Handle Bar/Mounting Plate</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>29271000</td>
<td>Vibration Damper Clamping Vane</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zinc Plated 1/2&quot; x 20&quot; Thd. for 1-1/8&quot; OD &amp; 3/4&quot; Pipe</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>29272000</td>
<td>Front Suspension Fork Tube</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>29273000</td>
<td>Front Suspension Fork Tube</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>29274000</td>
<td>Minimum Steel Vane, Screw Eye</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring 1/8&quot; Hole, 5/8&quot; Red, 1/2&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length, 33/4&quot; Wise</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>29275000</td>
<td>Front Suspension Fork Bar</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>29276000</td>
<td>Front Suspension spindle Mount</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>29277000</td>
<td>Front Suspension Coulsel</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>29278000</td>
<td>Front Suspension Tie</td>
<td>1</td>
</tr>
</tbody>
</table>

### Diagram of Steering & Front Suspension Asy

[Diagram of Steering & Front Suspension Asy]

Appendix II
Appendix I11
APPENDIX J – NORMAL FORCES ON FRONT AND REAR WHEELS

✓ Worst case scenario: free-body diagram of BUV traveling down 20° slope while braking

\[ F_{CGx'} = \sin(20^\circ) \times 2500 \text{ lb} = 855 \text{ lb} \]
\[ F_{CGy'} = \cos(20^\circ) \times 2500 \text{ lb} = 2349 \text{ lb} \]

\[ \Sigma M_{CG} = 0 = -5.7F_{Ay'} + 2.8F_{By'} + 2F_{Brake} \]
\[ \Sigma F_{y'} = 0 = F_{Ay'} - F_{CGy'} + F_{By'} \]

2 Equations, 2 Unknowns, Solve for \( F_{By'} \) and \( F_{Ay'} \)
\[ F_{By'} = 1231 \text{ lbf} \]
\[ F_{Ay'} = 1118 \text{ lbf} \]
Static loading on level ground while braking

\[ \Sigma F_y = 0 = F_{Ay} + F_{By} - F_{CGy} \]
\[ \Sigma M_A = 0 = 8.5F_{By} - 5.7F_{CGy} \]

2 Equations, 2 Unknowns, Solve for \( F_{Ay} \) and \( F_{By} \)

\( F_{Ay} = 824 \text{ lbf} \)
\( F_{By} = 1676 \text{ lbf} \)
Spindle Mount Calculations

\[ M = 1118 \text{ lbf} \times 10.375'' = 11599 \text{ lb - in} \]

\[ \sigma = \frac{Mc}{I} = \frac{(11599 \text{ lb - in})(1.5'')}{6.75 \text{ in}^4} = 2578 \text{ psi} \]

ASTM A36 – Yield Strength =36 ksi
Design Factor – 12 (Impact Loading)
Design \[ \sigma_d = \frac{36 \text{ ksi}}{12} = 3000 \text{ psi} > 2578 \text{ psi} \]
✓ Fork Bar Calculations

\[ M = 10.25'' \times 1118 \text{ lbf} = 11404 \text{ lb } \cdot \text{ in} \]

\[ \sigma = \frac{Mc}{I} = \frac{(11404 \text{ lb } \cdot \text{ in})(1.6'')}{9.3 \text{ in}^4} = 1962 \text{ psi} \]

\[ \sigma = \frac{P}{A} = \frac{-1118 \text{ lbf}}{10.6 \text{ in}^2} = 105 \text{ psi} \]

ASTM A36 – Yield Strength = 36 ksi
Design Factor – 12 (Impact Loading)
Design \( \sigma_d = \frac{36 \text{ ksi}}{12} = 3000 \text{ psi} > 2067 \text{ psi} \)
✓ Fork Tube Calculations

~ Distance from center of tire to center of Fork Tube is same from Fork Bar, thus,
Fork Tube sees same Bending Moment.

\[ \sigma = \frac{Mc}{I} = \frac{11404 \text{ lb} \cdot \text{in} \cdot (2'')}{8.2 \text{ in}^4} = 2781 \text{ psi} \]

\[ \sigma = \frac{P}{A} = \frac{-1118 \text{ lbf}}{3.7 \text{ in}^2} = 302 \text{ psi} \]

ASTM A36 – Yield Strength = 36 ksi
Design Factor – 12 (Impact Loading)
Design \( \sigma_d = \frac{36 \text{ ksi}}{12} = 3000 \text{ psi} > 3083 \text{ psi} \)

✓ Steer Brace – Bottom Calculations

\[ M = 1118 \text{ lbf} \cdot 8.2'' = 9168 \text{ lb} \cdot \text{in} \]

\[ \sigma = \frac{Mc}{I} = \frac{9168 \text{ lb} \cdot \text{in} \cdot (1'')}{1.5 \text{ in}^4} = 6112 \text{ psi} \]

ASTM A36 – Yield Strength = 36 ksi
Design Factor – 4 (Repeated Loading)
Design \( \sigma_d = \frac{36 \text{ ksi}}{4} = 9000 \text{ psi} > 6112 \text{ psi} \)
APPENDIX L – BRAKE CALCULATIONS

BRAKE CALCULATIONS
✓ Worst case assumption is that the vehicle will be fully loaded at 2500 lbs driving down a 20° slope.
✓ Actuation force will be applied by the two stock rear hydraulic brakes off a 1987 Chevy S-10.
✓ Braking figured for dry, hard surfaces (i.e. concrete/blacktop).
✓ Calculations solved for a stopping distance of 55 feet.

Total Energy Needed to Dissipate
Total Energy = Kinetic Energy (KE) + Potential Energy (PE)
\[
\text{Total Energy} = \frac{1}{2}mv^2 + mgh = \frac{1}{2} \left( \frac{2500 \text{ lbs}}{32.2 \text{ ft} / \text{s}^2} \right) (29.3 \text{ ft} / \text{s})^2 + (2500 \text{ lbs})(55 \text{ ft}) \sin(20°)
\]
Total Energy = 33,326 ft-lbs + 47,028 ft-lbs = **80,354 ft-lbs**

Force Required Stopping in 55 ft
\[
F_{\text{Brake}} = \frac{\text{Total Energy}}{\text{Stopping Distance}} = \frac{80,354 \text{ ft-lbs}}{55 \text{ ft}} = 1,461 \text{ lbf}
\]

Deceleration
\[
D_x = \frac{\text{Force}}{\text{Mass}} = \frac{1,461 \text{ lbf}}{78 \text{ slug}} = 19 \text{ ft/s}^2
\]

VACUUM BOOSTER CALCULATIONS
✓ Atmospheric pressure = 14.7 psi (30 in.Hg)
✓ Vacuum pump vacuum (Max) = 11 psi (22 in.Hg)
✓ Manufacturers maximum required vacuum at booster = 7.4 psi (15 in.Hg)
✓ Diameter of Diaphragm = 9''
✓ Booster has dual-diaphragm or tandem-diaphragm

Pressure Differential Acting on Diaphragm
14.7 psi – 7.4 psi = 7.3 psi

Area of Diaphragm
\[
A = \pi r^2 = \pi (4.5 \text{ in})^2 = 63.6 \text{ in}^2 \times 2 = 127 \text{ in}^2
\]

Brake Application Force
7.3 psi * 127 in² = **929 lbf**
# APPENDIX M – BILL OF MATERIALS

## Bill of Materials

### Steering, Brakes, & Front Suspension

<table>
<thead>
<tr>
<th>MANUFACTURED PARTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part#</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Steer Tube</td>
</tr>
<tr>
<td>Top Steer Brace</td>
</tr>
<tr>
<td>Bottom Steer Brace</td>
</tr>
<tr>
<td>Handlebar Mounting Plate</td>
</tr>
<tr>
<td>Gusset</td>
</tr>
</tbody>
</table>

**Estimated Total Cost** $48.84

<table>
<thead>
<tr>
<th>Brake Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part#</td>
</tr>
<tr>
<td>Booster Activating Lever</td>
</tr>
<tr>
<td>Booster Mounting Plate</td>
</tr>
<tr>
<td>Booster Activating Lever Mounting Plate</td>
</tr>
</tbody>
</table>

**Estimated Total Cost** $3.60

Appendix M1
### Front Suspension Assembly

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
<th>Manufacturer/Supplier</th>
<th>Qty.</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fork Tube</td>
<td>Square Tube – ASTM A-500 Grade B – 4” x 4” x 1/4” Thick Wall x 18” Long</td>
<td>Ackerman Steel</td>
<td>1</td>
<td>$19.80</td>
</tr>
<tr>
<td>Fork Bar</td>
<td>Square Bar – Grade ASTM A-36 – 3 1/4” x 3 1/4” x 23” Long</td>
<td>Ackerman Steel</td>
<td>1</td>
<td>$143.90</td>
</tr>
<tr>
<td>Fork Tube Bushing</td>
<td>Plate – Nylon – 2 7/8” x 8” x 1/8” Thick</td>
<td>Queen City Polymers</td>
<td>4</td>
<td>$26.00</td>
</tr>
<tr>
<td>Spindle Mount</td>
<td>Square Bar – Grade ASTM A-36 – 3” x 3” x 5 5/8” Long</td>
<td>Ackerman Steel</td>
<td>1</td>
<td>$23.58</td>
</tr>
</tbody>
</table>

**Estimated Total Cost**: $213.28

---

### Bill of Materials

#### Steering, Braking, & Front Suspension

**PURCHASED PARTS**

<table>
<thead>
<tr>
<th>Part#</th>
<th>Part Description</th>
<th>Manufacturer Part #</th>
<th>Manufacturer/Supplier</th>
<th>Qty.</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steering Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throttle</td>
<td>BZ30992</td>
<td>Bladez/Extreme Scooters</td>
<td>1</td>
<td>$14.99</td>
</tr>
<tr>
<td></td>
<td>16” Ape Hanger Handlebars</td>
<td>50-222</td>
<td>Kustom Emporium</td>
<td>1</td>
<td>$43.90</td>
</tr>
<tr>
<td></td>
<td>Ball Bearing Flanged Unit</td>
<td>FY 1. 1/2 TF</td>
<td>SKF Industries/Kaman</td>
<td>2</td>
<td>$77.77</td>
</tr>
<tr>
<td></td>
<td>SAE841 Thrust Washer Bearing, 2-1/16&quot; ID x 4&quot; OD x 1/4&quot; Thick</td>
<td>TT4002</td>
<td>Bunting Bearing Corp/Kaman</td>
<td>2</td>
<td>$5.11</td>
</tr>
<tr>
<td>Item</td>
<td>Part Number</td>
<td>Supplier</td>
<td>Quantity</td>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------------</td>
<td>-------------------</td>
<td>----------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Vibration-Damping Clamping U-Bolt Znc-Pltd Stl, 1/4&quot;-20 Thrd, for 1-1/16&quot; OD, 3/4&quot; Pipe</td>
<td>3176T320</td>
<td>McMaster-Carr</td>
<td>2</td>
<td>$12.10</td>
<td></td>
</tr>
<tr>
<td>Zinc-Plated Steel Threaded Rod 1&quot;-8 Thread, 3' Length</td>
<td>98841A038</td>
<td>McMaster-Carr</td>
<td>1</td>
<td>$19.35</td>
<td></td>
</tr>
<tr>
<td>Zinc &amp; Yellow Plated Grade 8 Steel Hex Nut 1&quot;-8 Thread Size, 1-1/2&quot; Width, 55/64&quot; Height</td>
<td>94895A038</td>
<td>McMaster-Carr</td>
<td>8</td>
<td>$9.28</td>
<td></td>
</tr>
<tr>
<td>Zinc Yellow Pltd Stl Hvy Dty Spring Lck Washer 1&quot; Screw Sz, 1.024&quot; ID, 1.656&quot; OD, .250&quot; min Thk</td>
<td>91104A049</td>
<td>McMaster-Carr</td>
<td>4</td>
<td>$3.20</td>
<td></td>
</tr>
</tbody>
</table>

**Estimated Total Cost** $355.24

### Brake Assembly

<table>
<thead>
<tr>
<th>Item</th>
<th>Part Number</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake Lever</td>
<td>HTKLMT3.0</td>
<td>Bontrager/Trek Bicycle Store</td>
<td>1</td>
<td>Freebie</td>
</tr>
<tr>
<td>Power Brake Booster w/Master Cylinder</td>
<td>50-1268</td>
<td>Cardone/U-Pull &amp; Pay</td>
<td>1</td>
<td>$43.94</td>
</tr>
<tr>
<td>Compressor/Vacuum Pump</td>
<td>22D1180-251-1002</td>
<td>Gast Manufacturing Inc./Grainger</td>
<td>1</td>
<td>$218.75</td>
</tr>
<tr>
<td>SAE 841 Bronze Sleeve Bearing for 5/16&quot; Shaft Diameter, 7/16&quot; OD, 1/2&quot; Length</td>
<td>6391K163</td>
<td>McMaster-Carr</td>
<td>1</td>
<td>$0.59</td>
</tr>
<tr>
<td>Silicon Bronze Flat Washer, 1/2&quot; ID, 1-1/8&quot;</td>
<td>93490A032</td>
<td>McMaster-Carr</td>
<td>1</td>
<td>$0.92</td>
</tr>
</tbody>
</table>

Appendix M3
<table>
<thead>
<tr>
<th>Item Description</th>
<th>Code</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD, .052&quot;-.072&quot; Thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAE 841 Sleeve Bearing, 1/4&quot; ID x 3/8&quot; OD x 5/8&quot; Thick</td>
<td>6391K133</td>
<td>McMaster-Carr</td>
<td>1</td>
<td>$0.82</td>
</tr>
<tr>
<td>SAE 841 Thrust Washer Bearing, 3/8&quot; ID x 3/4&quot; OD x 1/8&quot; Thick</td>
<td>EW061202</td>
<td>Bunting Bearing Corp/Kaman</td>
<td>2</td>
<td>$1.44</td>
</tr>
<tr>
<td><strong>Estimated Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$266.46</td>
</tr>
<tr>
<td><strong>Front Suspension Assembly</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front Hub</td>
<td>545</td>
<td>Tractor Supply Company</td>
<td>1</td>
<td>$39.99</td>
</tr>
<tr>
<td>Front Spindle</td>
<td>350</td>
<td>Tractor Supply Company</td>
<td>1</td>
<td>$24.99</td>
</tr>
<tr>
<td>Coil-Over Spring</td>
<td>800-250-080</td>
<td>APC</td>
<td>1</td>
<td>Freebie</td>
</tr>
<tr>
<td><strong>Estimated Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$64.98</td>
</tr>
<tr>
<td><strong>Assembly Cost Totals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MANUFACTURED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$48.84</td>
</tr>
<tr>
<td>Brake Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$3.60</td>
</tr>
<tr>
<td>Front Suspension Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$213.80</td>
</tr>
<tr>
<td><strong>Estimated Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$266.24</td>
</tr>
<tr>
<td><strong>PURCHASED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$355.24</td>
</tr>
<tr>
<td>Brake Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$266.46</td>
</tr>
<tr>
<td>Front Suspension Assembly</td>
<td></td>
<td></td>
<td></td>
<td>$64.98</td>
</tr>
<tr>
<td><strong>Estimated Total Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$686.68</td>
</tr>
<tr>
<td><strong>Estimated Total Overall Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td>$952.92</td>
</tr>
</tbody>
</table>
## APPENDIX N – BUDGET

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Proposed Cost</th>
<th>Prototype Cost</th>
<th>IAT Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Train Assembly</td>
<td>$1,975.00</td>
<td>$227.55</td>
<td>$2,083.28</td>
</tr>
<tr>
<td>Chassis Assembly</td>
<td>$1,148.00</td>
<td>$350.00</td>
<td>$175.00</td>
</tr>
<tr>
<td>Rear End Assembly</td>
<td></td>
<td>$208.00</td>
<td>$254.00</td>
</tr>
<tr>
<td>Steering Assembly</td>
<td></td>
<td>$242.23</td>
<td>$121.12</td>
</tr>
<tr>
<td>Brake Assembly</td>
<td>$1,105.00</td>
<td>$53.47</td>
<td>$26.74</td>
</tr>
<tr>
<td>Front Suspension</td>
<td></td>
<td>$522.04</td>
<td>$261.02</td>
</tr>
<tr>
<td>Accessories</td>
<td>$615.00</td>
<td>$1,312.50</td>
<td>$666.25</td>
</tr>
<tr>
<td>Labor</td>
<td>Free</td>
<td>Free</td>
<td>$46.00</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$4,843.00</strong></td>
<td><strong>$2,915.79</strong></td>
<td><strong>$3,633.41</strong></td>
</tr>
</tbody>
</table>
# APPENDIX P – 2009 BUV COMPETITION RESULTS

## BUV COMPETITION JUDGE'S SCORING

<table>
<thead>
<tr>
<th>EVENT</th>
<th>MAIN CLASS</th>
<th>Open Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. WRITTEN REPORT</td>
<td>2.50 3.00 4.75 3.25 4.00 4.75 3.50 4.00 2.50 3.58</td>
<td>2.50 3.00 3.25 4.00 4.75 3.00</td>
</tr>
<tr>
<td>2. B.O.M. &amp; COST</td>
<td>3.25 3.00 5.00 3.75 5.00 5.00 2.50 4.75 3.00 3.92</td>
<td>3.25 3.00 5.00 4.00 8.00 8.58</td>
</tr>
<tr>
<td>3. DESIGN OBJECTIVES</td>
<td>8.00 7.50 9.00 9.00 8.50 8.00 9.50 9.75 4.00 8.58</td>
<td>8.00 7.50 9.00 8.50 4.00 3.50</td>
</tr>
<tr>
<td>4. SPECIFICATIONS MET</td>
<td>4.00 4.00 3.00 5.00 3.00 5.00 4.00 3.00 2.00 3.00</td>
<td>4.00 4.00 3.00 2.00 2.00 3.00 4.00 3.00</td>
</tr>
<tr>
<td>5. JUDGES DRIVE</td>
<td>12.00 12.00 17.00 13.00 9.00 16.00 15.00 15.00 5.00 14.00</td>
<td>12.00 12.00 17.00 13.00 9.00 16.00 15.00 15.00 5.00 14.00</td>
</tr>
<tr>
<td>6. ENDURANCE</td>
<td>3.00 1.00 8.00 3.50 4.00 5.00 1.00 7.00 4.50 4.36</td>
<td>3.00 1.00 8.00 3.50 4.00 5.00 1.00 7.00 4.50 4.36</td>
</tr>
<tr>
<td>7. ACCELERATION</td>
<td>3.00 3.00 2.00 2.00 4.00 1.00 2.00 4.00 2.00 2.56</td>
<td>3.00 3.00 2.00 2.00 4.00 1.00 2.00 4.00 2.00 2.56</td>
</tr>
<tr>
<td>8. AGILITY</td>
<td>3.00 4.00 3.00 2.00 2.00 1.00 4.00 4.00 2.00 2.78</td>
<td>3.00 4.00 3.00 2.00 2.00 1.00 4.00 4.00 2.00 2.78</td>
</tr>
<tr>
<td>9. MUD PIT</td>
<td>2.00 5.00 10.00 6.00 9.00 9.00 10.00 6.00 7.13</td>
<td>2.00 5.00 10.00 6.00 9.00 9.00 10.00 6.00 7.13</td>
</tr>
<tr>
<td>11. OBSTACLE</td>
<td>4.00 4.00 7.00 6.00 5.00 5.00 6.00 10.00 6.00 5.89</td>
<td>4.00 4.00 7.00 6.00 5.00 5.00 6.00 10.00 6.00 5.89</td>
</tr>
<tr>
<td>12. MOGUL</td>
<td>1.00 3.00 6.67 6.67 3.00 6.00 9.33 10.00 9.33 6.11</td>
<td>1.00 3.00 6.67 6.67 3.00 6.00 9.33 10.00 9.33 6.11</td>
</tr>
<tr>
<td>Bonus FWD (up to 5%)</td>
<td>3.50 2.00 2.50 1.00 #DIV/0!</td>
<td>3.50 2.00 2.50 1.00 #DIV/0!</td>
</tr>
<tr>
<td><strong>TOTAL SCORE</strong></td>
<td>50.75 20.48 53.58 72.25 71.82 0.00 58.17 70.58 17.00 78.50 7.50 11.00 66.50 60.90 44.22</td>
<td>50.75 20.48 53.58 72.25 71.82 0.00 58.17 70.58 17.00 78.50 7.50 11.00 66.50 60.90 44.22</td>
</tr>
<tr>
<td><strong>RANKING</strong></td>
<td>6 7 5 1 2 9 4 3 8 1 4 5 2 3</td>
<td>6 7 5 1 2 9 4 3 8 1 4 5 2 3</td>
</tr>
</tbody>
</table>