2009 Basic Utility Vehicle

by

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2009 Basic Utility Vehicle

Chassis

Scott Burke
6/5/2009
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**ABSTRACT**

Vehicles are needed for use in third world countries to help farmers with day to day activities. There is a lack of low cost vehicles available for farmers and the working poor. New designs are necessary to increase the availability of low cost vehicles to people around the world. This paper covers the determination of product features the picking of most important features, concept selection, design, analysis and fabrication. A best concept was selected and the chassis was designed. The chassis was also analyzed to compute the max stresses on the structure. All parts passed with an acceptable factor of safety. Styling cues from this chassis design may be used by BUV factories in the future.
INTRODUCTION

BUV is an acronym for Basic Utility Vehicle. The BUV concept comes from ideas set forth by the Institute for Affordable Transportation. The IAT is a non-profit public charity devoted to developing high-quality, low-cost transportation for the working poor in developing countries. IAT is based in Indianapolis, Indiana, USA and funded by individuals, foundations, churches, and international corporations.

The BUV is a group project was broken up into four parts. This report focuses on the chassis and suspension portion of the project. The project is broken down as follows:

- Scott Burke – Chassis and Suspension
- Jeremy Augenstein – Drive Train
- Jason Lewis – Electrical and Body
- Dan Ross – Front End and Braking

The need for a BUV comes about because there is a lack of low-cost transportation for the working poor in rural developing countries in Africa and other parts of the world. The BUV must be designed for the environment it will be used in. As you can see in the figure, 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 regions. (1)

Vehicles must be able to navigate over surfaces of sand, dirt and water. The vehicle must be able to go off-road. The terrain can at many times be rough with rocks, trees, mud holes and sand. The vehicle must be able to cross streams without a problem. The drive train, motor and transmission must be protected from rocks, logs, sand and water.

In addition to being designed to operate in rough terrain the BUV was judged on guidelines set forth by the IAT. This year the BUV must also use all hand controls. It is supposed to be able to be operated by someone who no longer has the use of their lower body.
The BUV was judged at competition on the following Design Objectives:

- Minimize total cost of ownership
- Utilize off-the-shelf components where possible
- Minimize the number of part numbers
- Require only two people to assemble BUV
- Utilize a simple, durable, low maintenance design
- Minimize the center of gravity
- Minimize the number of tools needed to work on BUV
- Minimize machining, welding and fixtures required to assemble
- Emphasize safety

The BUV will also be judged on the following Performance Requirements:

- Capable of climbing 15 degree slope with a 1200 lb load in cargo bed
- Able to cross 15 in of water
- Brakes will lock in an emergency stop with full load
- Safely transport 14 ft log

Figure 2 Competition vehicle in hill climb
Figure 3 Competition vehicle in mud crossing

Based on the design specifications set forth by the IAT, the utility vehicle will start with the rear half of an S-10 pickup truck. The chassis will be built to add on to the existing rear clip, brakes, and rear end. The stock leaf spring suspension will be used in the rear and a rubber torsion type with a mono fork design will be used in the front.

BUV vehicles from previous competitions were studied to determine what features were necessary for a good design. It was found that most vehicles had been designed with large cargo areas. The cargo bed is typically two thirds of the entire vehicle length. BUV’s were also designed with few pinch points. Areas were someone could get a body part smashed were covered. The vehicles were equipped with roll over protection in the form of a roll bar. Lighting was also included either on the front of the vehicle or on top of the roll bar. (2) The complete competition specifications can be found in Appendix A.
Current utility vehicles on the market were also studied. These vehicles were similarly designed as the BUV. It was found that they had minimal impact on the environment. They do not tear up the land they travel on. They were found to be easy to operate. It was also found that they were good on soft and uneven ground. The vehicles had sufficient ground clearance, and most had a tow option.

An interview was conducted with Jason Bird. Mr. Bird has owned two different utility vehicles. When asked “what were the most important features when making a buying decision?” His response was “price and looks.” He was also asked “what he did not like on the utility vehicles he had owned?” His reply was “not being able to get over rough terrain and cargo area was too small.” The compiled research can be found in Appendix 6.

MARKET STUDY

Surveys were completed by engineers, factory workers, salesmen and technicians. These surveys were used to determine what would make a good BUV. A total of thirty five surveys were filled out, and the results were tabulated.

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

Those surveyed were asked to rate on a scale form one to five how important each feature was when choosing a Basic Utility Vehicle. The ratings were 5 being the highest and 1 being the lowest. Table 1 gives the average rating achieved by each feature given in the survey. Maneuverability, reliability, and safety ranked among the top three. The ability to cross water came in last.
Those surveyed were also asked how satisfied they were with utility vehicles they had owned. Only seven individuals surveyed had never owned a utility vehicle. The table outlines these average ratings of the satisfaction. The surveys showed that the safety of the vehicles was sufficient while the ease of repair, the sound level, and the ability to cross water needed to be improved.

<table>
<thead>
<tr>
<th>CUSTOMER FEATURE</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>3.9</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>3.7</td>
</tr>
<tr>
<td>Reliability</td>
<td>3.4</td>
</tr>
<tr>
<td>Durability</td>
<td>3.3</td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>3.2</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>3.0</td>
</tr>
<tr>
<td>Resistance to the Elements</td>
<td>2.9</td>
</tr>
<tr>
<td>Ease of Repair</td>
<td>2.8</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>2.8</td>
</tr>
<tr>
<td>Quiet Operation</td>
<td>2.8</td>
</tr>
<tr>
<td>Ability to Cross Water</td>
<td>2.7</td>
</tr>
<tr>
<td>Accessibility for Drivers With Specials Needs</td>
<td>2.5</td>
</tr>
</tbody>
</table>

A third question asked how much someone would be willing to spend on a utility vehicle. The range was given to people taking the survey and the number of people for each interval is shown in Table 3. The majority went with the $1000-$1500 range. Only four people were willing to spend $2000-$2500. A complete survey with results can be found in Appendix B.

**PRODUCT OBJECTIVES**

Once the data was analyzed a list of product objectives was created. 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 the IAT competition. 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.
Safety:
- Safety guards covering pinch points and moving parts.
- Easy to access kill switch, tow hooks, fire extinguisher, and “anti-roll” role protection.
- Padding, seat belts.

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

Ease of Operation:
- Use a simple lever throttle (as seen on ATVs).
- Include handle bar type steering system.
- Maintain a ground clearance of more than 10.5”.

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

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

Low Cost:
- Vehicle will cost below $4750.

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

Durability:
- The frame will be able to withstand a torque load of 2250 lbs
- All parts will be design for impact loading, a safety factor of 12.

Quiet Operation:
- The vehicle will adhere to OSHA standards for driver.

Ability to Cross Water:
- The vehicle will have an intake that is above 25”.
  The vehicle will have at least 3 shields to protect the engine from water.
Based on the information obtained from the surveys and the customer importance and customer satisfaction, compared with planned improvements, a QFD was created. The table shows the engineering characteristics and their relative weight in percentage from highest to lowest. A complete QFD can be found in Appendix C.

Table 4 Engineering characteristic and customer importance

<table>
<thead>
<tr>
<th>ENGINEERING CHARACTERISTIC</th>
<th>RELATIVE WEIGHT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility for Drivers with Special Needs</td>
<td>11</td>
</tr>
<tr>
<td>Low Cost</td>
<td>10</td>
</tr>
<tr>
<td>Safety</td>
<td>9</td>
</tr>
<tr>
<td>Ease of Operation</td>
<td>9</td>
</tr>
<tr>
<td>Ease of Repair</td>
<td>8</td>
</tr>
<tr>
<td>Durability</td>
<td>8</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>8</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>7</td>
</tr>
<tr>
<td>Reliability</td>
<td>7</td>
</tr>
<tr>
<td>Resistance to the Elements</td>
<td>6</td>
</tr>
<tr>
<td>Ability to Cross Water</td>
<td>6</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>5</td>
</tr>
<tr>
<td>Quiet Operation</td>
<td>5</td>
</tr>
</tbody>
</table>

**DESIGN AND ANALYSIS**

In order to come up with a good design three separate concepts were created and evaluated. Each concept differed slightly with them all sticking the requirements.

*Concept 1 - CNC Plasma Cut Plate Steel*

As you can see in figure 4 parts are cut from steel plate by CNC Plasma machine. Design will include tabs and slots for self locating of parts. Pieces are stitch-welded together. There will be little to no need for jigs.

![Figure 5 Design Concept #1](image-url)
Concept 2 - Mandrel Bent Steel Round Tube

Figure 5 shows steel round tube being used. The tube would be bent with tubing bender. The tube would need to be notched and jugs will be required. Welding must be all the way around tube.

Figure 6 Concept #2

Concept 3 - 2”x4” Steel C-Channel

Figure 6 is of the C-Channel design. Mild steel would be wet-saw cut, and welded together. Jigs will be necessary for fabrication. Welding will be minimal.

Figure 7 Concept #3

The concepts were evaluated to determine the best design. The highest weighted criteria from the QFD were used.

- Material Cost –This will affect the budget on the entire project. It will also affect selling price, and profit.
- Safety-Important on any project. This should be number one however it came in a close second to price
- Durability-The BUV must be able to withstand the torture the competition will put the vehicle through.
- Ease of Assembly-How well the kit will go together is a major part of the evaluation process.
Table 6 shows the features, their relative weights, and the scores of the three designs.

Table 5-Decision Matrix

<table>
<thead>
<tr>
<th>Feature</th>
<th>Weight (%)</th>
<th>Plate Steel</th>
<th>C-Channel</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Cost</td>
<td>11</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Safety</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Durability</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Ease of Assembly</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>4.64</td>
<td>4.46</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The design with the highest score was concept #1. For it’s easy to assemble design

**DESIGN**

The design of the chassis was set up to be a kit as set forth by the IAT. A good kit would be one that could be fabricated affordably, and require little need for special equipment to assemble.

The entire chassis has been designed as a hollow box that connects to the factory rear clip of a Chevrolet S-10 pickup. The dimensions of the frame gave a point from which to start the design. The chassis rests on the top edge of the S-10 frame. The opening in the chassis is set up so it will rest against the outside of the frame rails. Holes will be drilled in the frame to bolt the chassis to the frame. The chassis and rear clip can be seen in figure 7.
The construction is based on a tab and a slot on mating process. This construction allows for the kit to be assembled quickly without the need for costly fixtures. Pieces that lay in a horizontal plane have slots and pieces arranged vertically have tabs. An exploded view of the engine compartment can be seen in figure 8.

A way was needed to gain access to the motor, transmission, battery, and master cylinder. The portion in the back of the chassis doubles as a seat mount and the engine compartment sides. The top piece has slots in it to give the rear seat adjustment for the rider. The front seat was designed in the same fashion. The holes in the engine compartment sides were designed based on what they were shielding. The holes in the rear part of the engine compartment sides were placed with only 0.8” gap to shield the drive belt and the chain connecting the transmission to the intermediate shaft.
When needed, parts would have a cut out in which to drop a nut. The nuts are welded to give a stationary anchor for the bolts. Figure 10 give a good look at this.

**ANALYSIS**

The vehicle was analyzed using a worst case scenario. The forces would be analyzed under breaking on a 20 degree slope with a full load. The reactions were analyzed where the total combined stresses would be the most. It was determined that the highest combined stresses would be seen where the neck meets the main chassis. The section was analyzed and the bending stress and the axial stress were combined to get a resultant of 1,841 PSI. This put the factor of safety at 19.5.

The main chassis was also analyzed where the height changed. The front portion of the chassis is 5.5” tall. The rear portion of the chassis is 10.5”. The frame connects the chassis and rests on the top edge of the frame. On the front part of the frame it was determined that the max stresses at this point would be 888 PSI. This put the factor of safety at 40.5. At the rear of the frame the max combined stressed 657 PSI. This put the factor of safety at 54.7. These calculations do not take into account all the material that has been removed from the chassis top and bottom. This material was removed to lighten up the chassis and bring the overdesign amount down. The calculations can be found in Appendix F.
MATERIAL SELECTION

The material selection for the chassis was based on yield strength and the cost. After analysis was completed it was found that the 3/16” steel would be strong enough. The hot rolled plain carbon steel has yield strength of 36,000 PSI.

The 3/16” steel would be used throughout the chassis and front end section. The only other material necessary would be 16 gauge sheet metal. The sheet metal would be used for the skid plate on the front of the chassis.

Only a small number of bolts would be required for the chassis design. The engine compartment is removable to gain access to the motor, transmission, master cylinder and battery. A total number of 8 fasteners would be required.

The front end uses the same bolts as well. It requires a total of 12 fasteners.

FABRICATION

All of the parts were designed to be easy to fabricate. The 3-D models from Solid Works were saved in .dxf format. This .dxf format was is what is used to create tool paths in most torch and water jet CAD applications. The parts were nested onto the material. This was necessary to make sure you got the most parts with the least amount of waste. The Torch Mate automated plasma table was used to cut out the parts. The tool cuts the parts out quickly while maintain good accuracy.

The parts were cut out using the services of one of our sponsors Tuff Shop. They use a Torch Mate automated plasma table to cut parts. This tool cuts the parts out quickly while maintain good accuracy. Their plasma table included a water table which made the cutting a lot faster and reduced the amount of smoke released during the process. First the 4’x8’ sheet was loaded onto the table then two touches were made with torch to make sure the piece was in alignment which you can see in the figure 13.

Figure 14 squaring the workpiece on the table
With all the parts requiring a lot of cuts the run time was well over an hour. The plasma torch uses an arc of electricity as well as compressed air to blow through the metal. As you can see in the figure 14 the process creates a big arc and it is best to wear dark vision protection when around. Once the machine had ran the entire program the pieces were off loaded onto the pallet.

The sides of the chassis as well as the front end needed to have bends in them. The parts were created in Solid Works using the sheet metal features built in. Notches were put in where the bends were. The bend locations were designated by the solid works files. Test bends were needed to create the proper angles. The final bends were made in the parts using a hydraulic press brake similar to the one pictured in figure 16.
ASSEMBLY

The chassis was assembled at one of our sponsors Big Papa’s Car Audio. The parts were placed on a level surface and the process began. First the nuts that were to be used as faster points were welded into place. The top plate was then placed upside down on the surface and the two sides were clipped in place. A hammer and some maneuvering of the pieces were required to get pieces square. Once the pieces were ready the chassis was stitch welded at the corners and welded on top of the tabs as well. The remaining pieces were clipped into place and welded in. The engine compartment was removable and welded together separately.

Once the chassis was assembled it was not difficult to attach it to the rear clip. Figure 17 shows the rear clip and chassis section attached. Areas that would be difficult to reach latter were spray painted before the pieces were bolted together. The chassis was squared up on the rear clip and the holes were marked and drilled in the sides of the frame rails. Six - 3/8” bolts, washers and lock washers were used to attach.

The engine compartment was easily removable and provided shielding adequate air flow to the motor. Slots were designed into the front and rear seat mounts to provide for adjustment. The seat belts were welded into place. The chassis was coated with an automotive grade rust prevention system which gave the BUV a nice finish.
Inside the chassis were all of the essential components. The engine was mounted using urethane bushing and the 3/8” fasteners. The transmission tucked nicely in the cutouts provided. The master cylinder, brake pump, intermediate shaft and lever mechanism for brakes all resided inside the chassis as well.

The final product assembled was very strong as was referred to by many onlookers as a tank. It was also thought to be the biggest BUV yet. This was attributed to the requirement of two seats for the competition. The total weight of the entire vehicle was not able to be tested. The IAT says 1250lbs is a good target. The total weight of the 2009 BUV was estimated to be 2000lbs. Material properties were used in design and Solid Works gave approximate mass quantities but it did no include motor, transmission, and wheel and tire mass.
BUDGET

In order to meet the specifications set forth by the IAT the total cost of the BUV must not exceed $4750. The projected budget is $4573. Price comparison among vendors must be utilized as to not exceed the amount set forth by the IAT.

Table 7 Projected Chassis budget and actual chassis budget.

<table>
<thead>
<tr>
<th>Projected Chassis Budget</th>
<th>Actual Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4’x8’ Sheet of 1/4” Hot Rolled Plain Carbon Steel $200</td>
<td>3 – 4’x8’ Sheets of 3/16”Hot Rolled Plain Carbon Steel $350</td>
</tr>
<tr>
<td>1-4’x8’ Sheet of 1/8” Hot Rolled Plain Carbon Steel $150</td>
<td>16” -1.5” Steel Tube, 1 ½” OD, 1/8” Wall $85</td>
</tr>
<tr>
<td>CNC plasma cutting $200</td>
<td>CNC plasma cutting $350</td>
</tr>
<tr>
<td>Paint and undercoat $30</td>
<td>Paint and undercoat $30</td>
</tr>
<tr>
<td>Hex Cap Screw, Grade 8, 3/8-16 x 1,Package 50 $12.21</td>
<td>Hex Nut, Full, 3/8-16, Package 100 $8.73</td>
</tr>
<tr>
<td>Split Lock Washer, 0.385ID, Package 100 $1.45</td>
<td>Flat Washer, 0.385” ID, Package 100 $2.98</td>
</tr>
<tr>
<td>Total = $580</td>
<td>Total = $840.37</td>
</tr>
</tbody>
</table>

The projected vehicle budget for the entire project can be found in Appendix D.

TESTING AND RESULTS

There was not time for a lot of testing. Initial test on the BUV were conducted at CAS the week of the competition. The first test was done in the parking lot of CAS to verify that the drive train gearing would be sufficient to compete in competition. The BUV ended up traveling very well. Some modification had to be made to the chassis to allow clearance for the chain. A few more drives around the CAS parking lot playing with the wet brake and differential lock on the transmission ensured everything would work.

The IAT completion involved many events to test the competitor’s vehicles. The IAT does a good job of making any weak points fail with their events. Many competitor vehicles brake during the competition. The 2009 BUV competed in all events and had no chassis failures.
**JUDGES DRIVE**

Right of the bat the BUV was tested by a judge on a small course. The vehicle was driven over small ramps and navigated through turns through mud and over a couple logs. The vehicle got praise for its speed and criticism for the difficulty to turn.

**ENDURANCE TEST**

The endurance test was designed to make sure the vehicles would not fail. Many competitors had failure in this event. The IAT recommended that the BUV not compete in this event the first day because of our choice of tires and the mud on the course. The event was completed the next morning with chains on the tires. One bolt vibrated loose and caused the BUV to lose the reverse lever.

**ACCELERATION TEST**

The event was basically a drag race between all of the BUVs at the competition. The first race the team almost came in last because the transmission slipped out of the forward gear twice. The event was the better of two runs and on the second run the BUV came in first place.

**AGILITY COURSE**

The agility course required the vehicles to navigate through cones and around bushes and make 180 degree turns. The first run the BUV ran into a tree that was there because the turn was not taken wide enough. But on the second run corrections were made and this course was complete quickly and with only hitting the last two cones of the slalom section.

**OBSTACLE COURSE**

The obstacle course was not what was expected. It did a really good job of testing the BUVs to their max. It began with BUV rolling over logs and other pieces of wood. Then the BUV had to climb and descend a hill and go into a mud pit that had bricks thrown into it. After going over a couple of more hills the BUV had to make a u-turn around a barrel. The final stretch consisted of going through a sand pit and into some ruts. Then the BUV had to make a left turn down a hill, through a mud pit, over a shipping palette, into another mud pit, and then a right turn through the finish line. On the first run our BUV ran the course in 2 minutes and 9 seconds. The nearest collegiate competitor ran the course in 3 minutes and 9 seconds. This by far proves that our BUV was the fastest vehicle at the competition. The second run however presented problems. In the beginning of the run a log hit one of the side storage boxes and knocked it off the bed. The box wedged up in front of the tire and the vehicle got stuck. While trying to get the BUV unstuck the people were pushing and pulling on the sides of the cargo bed and ripped off the sides. The vehicle was then free and went to complete the second run.
**Mogul Course**

The mogul course consisted of large mounds of dirt about 3 feet high those BUVs had to navigate over. The BUVs and need good ground clearance and a well articulating suspension. Many competitors had to back up in the course to make it through. The BUV was not able to make it over the mogul field due to low traction at the start and low ground clearance.

**Mud Pit**

The mud pit consisted of a course marked off in and out of water and mud about 10in deep. Mud was always a concern because most competitors ran mud tires. The BUV was running chains on snow tires and had traction problems. The BUV then went through a relatively hard mud put and then back on dry land. After a turn the course led back through a longer dapper portion of mud and water in which the BUV splashed through and ended up getting stuck.

The following chart outlines the scoring percentage and scores of all competitors. As you can see the 2009 BUV team did well in many events and ended up with a 4th place finish.

Table 8 IAT scoring sheet
PRODUCT MANAGEMENT

This senior design project was a joint effort by all members of the group. Every Wednesday at 3:00 P.M. the group and senior advisor, Janak Dave, would meet to discuss the work completed in the previous week and plans for the upcoming week. In the end it is up to the students to step up to the plate and make things happen. Depending on their particular skills, some students may have to do more work than others in their area of expertise.

SCHEDULE

The following is a table of the proposed and actual schedule. The IAT was slow in updating their website for the competition. Most of the information came the week before the competition. When the project began the event coordinator was contacted about the dates of the competition. An exact date was not given and from the info gathered from the coordinator the event was thought to be one week later than it really was. This caused the project to be rushed at the end.

<table>
<thead>
<tr>
<th>Event</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>
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<tr>
<td>BUV: Ordering Parts</td>
<td>2/16/09 - 3/1/09</td>
<td>2/16/09-4/18/09</td>
</tr>
<tr>
<td>BUV: Fabrications</td>
<td>3/2/09 -3/15/09</td>
<td>3/10/09-4/18/09</td>
</tr>
<tr>
<td>BUV: Preliminary Test</td>
<td>3/30/09 - 4/8/09</td>
<td>4/3/09</td>
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<tr>
<td>IAT Competition Report</td>
<td>3/30/09 - 4/19/09</td>
<td>4/19/09</td>
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</table>
RECOMMENDATIONS AND CONCLUSIONS

To any students completing the BUV project I recommend the following. Make sure you start as early as possible. The project is big but reasonable to complete. The project requires the dedication of all team members to be successful. I also recommend doing a lot of calculations. Sometimes a thinner piece of metal will work. Make sure you design for enough ground clearance taking into account a loaded suspension. Make sure with the higher ground clearance that you still design for a low center of gravity.

The 2009 Basic Utility Vehicle was a success. We took 4th place and won an award for most innovative design for the telescopic front suspension. The vehicle had no major failures and drove in and out of Tech Expo.

Without the effort of all members it is hard to complete in the time allotted. Some skill with fabrication and design is needed by all members in order for all the parts to work together. As long as every member completes their part the University of Cincinnati’s BUV team will continue to be successful in IAT competition.
BIBLIOGRAPHY


**APPENDIX A- RESEARCH**

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>
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<tr>
<td>No bracing visible</td>
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<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>

http://www.niu.edu/PubAffairs/RELEASES/2007/may/BUV.shtml
Previous BUV Competition Vehicles Cont.

- Wooden Cargo Bed
- Removable sidewalls
- Headlights attached to roll bar
- Bracing is visible to exterior

- Few Pinch Points
- No seats
- Long time to convert
- Weight Concern
- Welded square tubing for roll bar

Calvin College BUV
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
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

http://www.kubota.com/F/products/rtv900/index.cfm
9/29/08 Kubota RTV900, kubota.com

- Minimal impact on environment
- Power Steering
- Tow option
- Good ground clearance
- Good on soft uneven ground
- Powered
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 B – 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

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</table>
2. How satisfied are you with the current Basic Utility and All-Terrain Vehicles?

Please circle the appropriate answer! 1 – Very Unsatisfied 5- Very Satisfied

<table>
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<tr>
<th>Feature</th>
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</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 C - QUALITY FUNCTION DEPLOYMENT

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<th>Accessibility for Drivers with Special Needs</th>
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Appendix C1
# APPENDIX D- PRELIMINARY BUDGET

## 2009 BUV Competition Team Budget

### Engine and Drive train
- Motor (10 HP Yanmar diesel motor) $1200
- Transmission (Tuff Torq KT135) $500
- Front wheel drive granny gear $125

### Materials
- 4’x8’ Sheet of 1/4” cold rolled steel $200
- 4’x8’ Sheet of 1/8” cold rolled steel $150
- 2x4’s $20
- 3/4” Plywood $38
- Truck Rear Clip $150

### Towing
- Trailer $200
- Class 1 hitch with ball mount $135

### Body
- Trailer fenders (3 Steel fenders) $150

### Safety
- Fire Extinguisher $35
- Reflectors $20

### Braking
- Brake shoes $20
- Brake drums $45
- Emergency brake cable $25

### Wheels
- 3-15x7 American Racing Polished Baja $375

### Tires
- 3-15” Agricultural tires $375

### Electrical
- Headlight $125
- Taillight/brake lights $80
- Wiring $20

### Hand controls
- Brake lever with master cylinder $125
- Throttle $50

### Fabrication
- CNC plasma cutting $200

### Seating
- 2 Tractor seats $200

### Miscellaneous
- Paint and undercoat $30
- Nuts, bolts, and wire ties $35
- Sales tax, and shipping + $125

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### APPENDIX E- PROJECT SCHEDULE

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### Contact Breakdown
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- Research: 30
- Customer Features: 30
- Survey: 7
- QFD: 14
- Product Objectives: 21
- Appendices: 28
- Draft: 11
- Report: 18
- Proof of Design Agreement: 25
- Concept Sketches & Selection: 25
- Chassis & Suspension: 2
- Long Term Parts Ordered: 9
- Design Freeze: 2
- Oral Presentation: 5
- Design Report: 10
- Assembly: 27
- ASME Conference Presentation: 28
- Preliminary Test: 8
- Competition Report: 17
- Final Testing: 22
- BUV Competition: 27
- CAS Tech Expo: 7
- Final Oral Presentation: 25
- Final Report Due: 4

Appendix E1
APPENDIX F - CALCULATIONS

Front of the chassis where it is 5.5” tall

\[ I_{\text{front of chassis}} = \frac{Bh^3}{12} - \frac{Bh^3}{12} = \frac{41.75 \times 5.5^3}{12} - \frac{41.375 \times 5.125^3}{12} = 114 \text{ in}^3 \]

Cross Section Area_{\text{front of chassis}} = 2(41.75 \times 0.1875) + 2(5.125 \times 0.1875) = 17.56 \text{ in}^3

\[ M = F_y \times d = 1050 \times 33 = 34,650 \text{ in} - \text{lbs} \]

\[ \sigma_{\text{bending}} = \frac{Mc}{I} = \frac{34,650 \times 2.75}{114} = 866.25 \text{ PSI} \]

\[ \sigma_{\text{axial}} = \frac{P}{A} = \frac{382}{17.56} = 21.75 \text{ PSI} \]

\[ \sigma_{\text{max}} = \sigma_{\text{axial}} + \sigma_{\text{bending}} = 866.25 + 21.75 = 888 \text{ PSI} \]

Factor of Safety = \( \frac{36,000}{888} = 40.5 \)

Rear of the chassis where it is 10.5” tall

\[ I_{\text{rear of chassis}} = \frac{Bh^3}{12} - \frac{Bh^3}{12} = \frac{41.75 \times 10.5^3}{12} - \frac{41.375 \times 10.125^3}{12} = 448 \text{ in}^3 \]

Area_{\text{front of chassis}} = 2(41.75 \times 0.1875) + 2(10.125 \times 0.1875) = 19.4 \text{ in}^3

\[ M = F_y \times d = 1050 \times 49 = 51,450 \text{ in} - \text{lbs} \]

\[ \sigma_{\text{bending}} = \frac{Mc}{I} = \frac{51,450 \times 5.25}{448} = 638 \text{ PSI} \]

\[ \sigma_{\text{axial}} = \frac{P}{A} = \frac{382}{19.4} = 19.7 \]

\[ \sigma_{\text{max}} = \sigma_{\text{axial}} + \sigma_{\text{bending}} = 638 + 19.7 = 657.7 \text{ PSI} \]

Factor of Safety = \( \frac{36,000}{657.7} = 54.7 \)
At the neck

\[ I_{neck} = \frac{Bh^3}{12} - \frac{Bh^3}{12} = \frac{8x2.3^3}{12} - \frac{7.5x1.8^3}{12} = 4.46 \text{ in}^3 \]

Cross Sectional Area\(_{neck} = 2(8 \times 0.1875) + 2(1.925 \times 0.1875) = 3.72 \text{ in}^3 \]

\[ M = F_y \times d = 472 \times 12.9 = 6088 \text{ in} - \text{lbs} \]

\[ \sigma_{bending} = \frac{Mc}{I} = \frac{6088 \times 1.15}{4.46} = 1569 \text{ PSI} \]

\[ \sigma_{axial} = \frac{P}{A} = \frac{1013}{3.72} = 272 \text{ PSI} \]

\[ \sigma_{max} = \sigma_{axial} + \sigma_{bending} = 1569 + 272 = 1841 \text{ PSI} \]

Factor of Safety = \[ \frac{36,000}{1841} = 19.5 \]
APPENDIX G - COMPETITION SPECIFICATIONS

Capstone Design Project - International

BUV Overcomer - for Amputees

Basic Utility Vehicle (BUV) for Developing Countries

Keywords: Africa / Bio-Diesel / Hybrid Drive / 3x3 / Hand Controls / Long Loads / Trailer / Re-use

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

Cost Targets:
- Front suspension/steering $125; weld/paint/fab frame $420; underdeck storage $27, Front-wheel drive granularity gear (fwd/rev) $155, brake actuation/mstr-cly $61, assembly labor $48
- 10 hp Yanmar diesel motor, fuel is bio-diesel B100 at the event (change fuel lines, seals, etc)

Engine / Fuel:
- Transmission:
- Hybrid FWD:
- (bonus items)

Front Suspension:
- Noise Level:
- Front Seats:
- Motorcycle seating arrangement for two people. The driver's assistant is the cargo handler / guard. No side by side seating. Note: this seating is for IAT purposes and is NOT designed for amputee

Payload:
- Trailer Load:
- 300 lbs of sand at event

Top Speed:
- 28 mph unloaded on grass (governed)

Hand Controls:
- Mount throttle and brake activator 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:
- 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.

Sun 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, brake lights, two light reflectors per side, fenders, grab handles for rescue, appropriate engine noise shielding, on-board tool kit ($50 of critical tools) rounded edges, padding (no sharp burrs), seat belts. Include 3 boards (6' 1 x 2' x 10") 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 (for/fit 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 1/2 roll and helps shield driver from cargo), all lug nuts installed on wheels.

Photo is for reference only. BUV and trailer not to scale.

Trailer - a small trailer with bull 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.

Appendix G1
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:
- Capable of climbing 15 degree slope with a 1200 lb load in cargo bed (and no trailer).
- Fording Ability: 15 inches of water
- Brake(s) will lock during emergency stop on grass full load
- Safely transport 14 ft long lumber, pole, or log

Note: Items in blue on page 1 highlight some of the changes in this space from the previous year space.

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 40 ft.
- Guidelines for Trailering with your BUV. Address carrying long loads (spinning BUV and trailer).

Costing 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 BUV's/yr (about 1 BUV/ day)
Use $1/hour labor rate. Use new equipment retail pricing.

Engineering Report
Follow your class requirements. Additionally, IAT wants a detailed 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 1000 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 driveshift and u-joints (be ready for high torque loads)
A high center of gravity...please design a LOW C of G

Trailer: [link to trailer information]
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. [link to trailer information] Similar trailers are also available from [link to trailer provider]

Contact: will.austin@drivebu.org 317.213.1088

Appendix G2
2009 BUV: Chassis and Suspension
Scott Burke

Proof of Design Statement
The purpose of this document is to determine whether the students design portion of the 2009 BUV has been fulfilled. This proof of design statement will deal with the chassis and suspension portion of the project. Some of the requirements have been set forth by the IAT while others come from safe and durable design criteria. In order for the design to be considered acceptable it must fulfill the specifications set forth below.

- The BUV will have at least 10.5” of ground clearance
- The BUV will be able to hold 1200lbs including the driver
- The BUV will have a class I hitch
- The BUV will have tow hooks mounted forward and aft mounted lower than 30”
- The BUV will have appropriate shielding form moving parts
- The BUV will have anti roll protection in the form of shoulder height roll bars
- The BUV will be designed with a separate frame that will connect to the rear clip

_______________________
Scott Burke

_______________________
Dr. Dave