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ME 450 Final Report

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Team 20: Mortuary Truck

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ABSTRACT

At the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana, locally made mortuary trucks are used to transport deceased bodies from the crowded hospital rooms to morgues that are in separate buildings. Multiple bodies are usually transported during a single trip to the morgue. Currently the trucks in use are difficult to maneuver, difficult to operate, and create sanitation issues. We have designed and fabricated a new truck that is inexpensive, easy to maneuver, controls bodily fluids, conceals bodies from public view, and performs well in an indoor and outdoor environment with minimal maintenance.

EXECUTIVE SUMMARY

In the summer of 2008, Professor Sienko and a team of University of Michigan students traveled to the Komfo Anokye Teaching Hospital in Ghana. This hospital uses mortuary trucks to transport bodies from the hospital wards to an embalming area located on a different part of the hospital campus prior to transportation to the morgue located in yet another building. The trucks are required to travel inside of the hospital ward and outdoors over rough terrain. The current trucks are hard to maneuver, difficult to push across rough terrain and also leak bodily fluids that create health and sanitation concerns. Another setback the current trucks have is that the bodies are often not handled with dignity and respect. Our task is to design and fabricate an improved mortuary truck that will address these issues.

To design and fabricate such a truck, a thorough information search was conducted. The research included product benchmarking, local morgue visits, and communicating with the morgue director at KATH. From the information gathered through research, along with the obtained customer needs, and the use of a QFD diagram, a list of engineering specifications was developed. From the specifications, we determined that our truck will be at least 2.15 m long and 0.78 m wide. The truck must be able to support a load of 313.1 kg, and must be able to be maneuvered with a zero turning radius. The truck must have a cover that completely shields the bodies from view. The truck needs to be able to collect up to 23 Liters of bodily fluid. In addition, the truck should cost $600.00USD, and the required maintenance cost should be less than $4.00USD per year.

Using the specifications and several functional decomposition diagrams, the truck was decomposed into five subsystems. The five subsystems include the body concealing method, the main frame of the truck, the fluid management system, the wheels, and the brakes. Concepts were generated for each of the subsections and selected using a Pugh chart. Several concept generations and selections were performed, based on additional information and feedback that was provided. After several design modifications, we were able to come up with our final design. Our final prototype design features a one tier body tray system, with wood being the main supporting structure, and PVC piping to support the tarp cover. The body tray and fluid collecting system were made out of aluminum bars and sheet metal.

The final design of the truck is specified to be made out of aluminum and stainless steel. The estimated material cost for this design is $2000.00USD. This design will have the same function as our final prototype. One of the few factors that differ from the prototype will be geometry differences, and this is mainly due to the material changes. The final design made out of the aluminum and stainless steel will be more durable and more robust compared to our prototype due to the characteristics of the materials.

Engineering analysis was conducted to obtain parameters for the final design. Analysis performed includes static load calculations, material selecting using Cambridge Engineering Selector, risk analysis using DesignSafe software, and FMEA for purchased materials. A detailed fabrication plan was drafted. Fabrication was broken down into subsections, such as the wood structure assembly, the welding of the grill, and the fabrication of the fluid collection tray. Once each component was fabricated, we then assembled them all together into our final prototype.

Once the fabrication of the prototype was completed, we conducted validation testing. Tests that were conducted include maneuverability tests over different types of terrain, static and dynamic loading, and fluid management testing. Some recommendations we have for our design from the validation testing includes moving the fluid collection tank forward, using different methods to secure the wheels, and using kiln dried wood instead of weather treated wood. We found that our prototype meets all of our engineering specifications, but additional improvements can be made. Our prototype was showcased at the Design Expo on April 16, 2009.

Table of Contents – APPENDIX A

INTRODUCTION

In the summer of 2008, Professor Kathleen Sienko and a team of University of Michigan students traveled to the Komfo Anokye Teaching Hospital (KATH) in Kumasi, Ghana to learn about health issues and to investigate possible engineering solutions to biomedical related problems. With the insufficient human resources available at the hospital, deceased bodies are often left in their beds at the hospital ward until staff members are available to assist with further transportation. The trucks are used to first transport deceased bodies from the hospital ward to an embalming area, then the bodies are transported outside to the morgue that is in a separate building. Because of this, the trucks must be able to function both indoors and outdoors on possibly rough terrain. The mortuary trucks the hospital currently uses are not adequate, are difficult to use and create serious health and sanitation concerns. Pictures of the current truck can be found in Appendix F.

Figure 1: Current truck being used at KATH

With Professor Sienko as our team sponsor and Mr. George Fusani as our mentor, our goal for this project is to design and fabricate an improved mortuary truck at a low cost that addresses the issues of sanitation and maneuverability while making the truck aesthetically appealing and improving the handling of the deceased bodies. In the fourth quarter of 2009, the prototype of the truck will be sent to KATH for testing and evaluation.

INFORMATION SOURCES

Current Designs

We have researched and gathered information on many of the U.S patents and current products that are being sold. The truck currently used at KATH features a flat steel platform with low side guards to collect or manage bodily fluids. The steering control is simply a steel bar that protrudes from the main truck structure to act as a handle for the operator. Many of the researched alternative designs have features and qualities that could possibly be incorporated into our product design.

Currently the CSI/Jewett company produces several different models of morgue transport trucks. One model that was of special interest to us was the Model SR 1211-2 Four Tier Transport Truck [1]. This truck can transport up to four bodies at a time, while having a floor footprint of one body by stacking the bodies vertically in four different body trays. The truck is easy to maneuver with the ball bearing caster wheels. The product is very simple with a minimal number of parts and is easy to be manufactured. The company also manufactures a two-body transport model that has many of the same advantages as the other model. Pictures and additional truck specifications can be referenced in Appendix G.

The company Life Medical Supplier manufactures different mortuary and casket transport trucks and stands. The particular model, CH-100 Display Truck [2], provides a structure to transport a body tray or casket. The lack of a fastened support tray provides more flexibility for the truck and is easier to clean.

A similar truck, sold by Mortech [3], provides the same flexibility of a removable surface. This particular product has a structure made of stainless steel for robustness and resistance to corrosion. However, this specification of stainless steel results in a higher cost.

Mortech also offers a more complex transport truck that has a fixed transport surface. The 600039H model [4] provides concealed transporting of a single body. The product has a height adjustment system along with a solid surface tray that eliminates liquid coagulation. The truck is intended for heavy duty use.

The British medical equipment company Lear Barber produces a concealment transport truck for transporting a single body [5]. The structure is completely constructed of stainless steel, mounted on four rotating solid rubber maintenance-free wheels, and two of them have individual foot locks. The product contains a support structure for a cotton canopy that acts as a privacy barrier. The canopy support bars can be tilted to lift the canopy and allow removal of the body from the carrying platform. Five rollers are underneath the body tray to allow extension of the tray during transfer of the body. Pictures and truck specifications can be found in Appendix G.

The Lear Barber company also sells transport trucks that are similar to the concealment transport truck mentioned above, but lacks the cotton canopy [6]. The truck does not have the tilting support for the cotton cover and also has pneumatic wheels instead of the solid rubber wheels. The rollers, tray, main support structure, and wheel locks remain the same. This truck is slightly cheaper than the one mentioned above due to the absence of a cover system.

A special splash guard manufactured by Lear Barber [7] has a slanted plate that wraps around the perimeter of the table and includes slats that are mounted across the frame. The design is originally intended to prevent splashing during the washing process, but could possibly be applied as a bodily fluid management device during transport. A picture and product specification can be found in Appendix G.

The patent, “Tilt-top Mortuary Cot” [8], was found to provide better understanding of the tilting truck designs. The bed of this design can be collapsed and placed in a vertical position on its edge; the vertical position of the bed provides better mobility and is easier to maneuver through tighter spaces. Also, the device requires smaller storage space when stored in the vertical position.

Similar to the “Tilt-top Mortuary Cot” patent, the “All Level Truck with Swivel Casters” [9] patent can be collapsed vertically. This design provides vertical height adjustment along with angle adjustment of the body support surface.

The older patent, “Morgue Truck and Refrigeration Device” [10], we found provided us with an example of a design for a simple transport truck with a manual height adjustment crank. The body table is recessed with perimeter guards to collect any bodily fluids; a drain valve is located on the bottom of the fluid collection panel to allow proper fluid removal. The optional refrigeration system includes a full enclosure with one panel that opens at the rear of the truck to allow horizontal placement and removal of the body.

A patent filed by an inventor from New Zealand, called “Concealed Trolley” [11], provides a design for the transport of a single body. This design also includes a lift system to raise and lower the body platform. The enclosure allows the body to be inserted horizontally from one end of the truck.

The patent, “Device for Decontaminating Persons Contaminated with Hazardous Materials” [12], was analyzed to obtain design concepts for a fluid management system. This design is for a medical device of a rectangular shape that provides a surface large enough to hold a body. Under the body lays a perforated surface that allows fluids and materials to drop into a lower level. The lower level is slanted to force the material to collect in a 5 gallon bucket that can be removed for easier and safer material disposal. Side guards are on the perimeter of the platform to prevent material spillage.

Wheels

We have researched the costs and capabilities of different indoor/outdoor wheels currently on the market. The truck currently used at KATH features rubber tires mounted on steel rims that appear to be scrap parts from a small motorized vehicle. Common hardware companies such as ACE Trading [13] and Drillspot.com [14] sell shopping truck style wheels and casters for upwards of $10 to $15 dollars apiece. Larger, more robust garden truck style wheels sell for upwards of $15 dollars apiece. Our goal is to find some other possible alternative to keep the cost of the truck as low as possible.

We had the idea of using bicycle tires from abandoned or unused bikes for the truck. To get a better understanding, we researched the basic components and mechanics of a bicycle wheel from patents and a bicycle repair website [15]. From a patent, “All-terrain Welding Truck” [16], we learned that our truck would be able to better handle varying terrain if the wheels have a moderate diameter (around 0.3 m). Other features that would improve maneuverability on rough or unstable terrain are wider wheel width, rubber tires, and grooves to improve traction.

Steering

The current mortuary truck in use has poor steering abilities because all four wheels are fixed and restrict the ability to rotate the truck. We researched the advantages and disadvantages of common shopping trucks and issues in their performance. From various discussion articles on the internet such as chow.com [17] and wisegeek.com [18] we learned that the two back wheels of the shopping trucks are fixed to roll only in the forward and backward direction and the front wheels are free to rotate 360 degrees; this setup is good for forward and backward motion but not good for turning or side-to-side adjustments.

From the welding truck patent that was mentioned above and the patent titled “Care Truck and Transportation System” [19], we were able to look at possible ways to improve the steering of the mortuary truck. The welding truck design has a front axle that is steered by a handle. This allows both front wheels to be steered together while the two back wheels to be fixed. The care truck design contains six independent swivel wheels.

Additionally, we found that trucks with all four wheels free to swivel 360 degrees are often overly maneuverable and difficult to navigate around corners. Another issue with steering is the wear and tear experienced on the wheels as ball bearings, axles, and swivels begin to rust, or as pieces of truck or casters rub against the wheels.

Braking

The current truck design does not feature any braking system that allows the operator to maneuver and bring the truck to a stop or prevent the truck from rolling away. To better understand the braking system on truck wheels we researched various sources to gather more information. A patent titled “Bicycle Brake” [20] filed by the bicycle component manufacturer Shimano provides a detailed design of a conventional bicycle braking system that includes a lever which is operated by the rider. A cable connects the lever to the braking system that pulls a brake pad against the bicycle wheel’s rim. This design allows the operator to activate the brake without removing his or her hands from the handle bars.

A patent for a “Foot Actuated Wheel Brake” provides a design for a foot braking system that is intended for a standard shopping truck [21]. The brake has a foot pad that is attached to a bracket that acts as a brake pad. The brake pad assembly includes a spring that enables the pad to retract to allow free rotation of the wheel. There is one pedal to engage the brake, and one to disengage.

Suspension

We are interested in possibly having a suspension system for our truck, since the truck will be traveling across hospital floors and unpaved surfaces outside during the truck’s daily use. The current truck appears to have the wheels directly mounted to the truck frame, resulting in a rough ride on an unpaved surface. The rough outside terrain will require some shock absorption or suspension system to enable smoother and easier travel. A patent filed by GT Bikes has a design for a “Bicycle Rear Suspension System” [22]. An assembly consisting of a piston-cylinder along with a spring allows the bicycle’s rear end to move with respect to the main frame and also absorb vibrations.

The suspension patent, “Go-Truck Frame and Wheel Suspension” [23], has a design that is composed of trailing arms that allow vertical movement of the wheels while ensuring they are in an upright position. A spring coil is mounted between the frame and wheel with a spring coil wrapped around the absorption device.

A patent for a “Rough Terrain Truck” [24] gives a design for a single wheel truck that has a standard bicycle wheel. The suspension component is comprised of concentric tubes with a compression spring inserted between the tubes. The device has one of these suspension assemblies mounted on each side of the wheel. The truck is intended to carry a light load over a rough terrain, aimed at recreational hikers.

The last suspension patent we found was a “Leaf Spring Suspension” [25]. This design is composed of a leaf spring, which is several thin metal plates of various lengths stacked on top of one another, mounted between the wheel and the frame. The mounting point on the frame is composed of a linkage with a torsion spring. As the leaf spring compresses during operation, the torsion spring and linkage provide resistance and vertical travel for the desired ride quality.

Health and Sanitation Concerns

We paid special interest to health and sanitation issues specific to hospital environment. On top of that we want to further understand the health concerns that exist mainly in developing countries with regards to deceased bodies.

From the study, “Care of patients who have died” [26], used for Nursing Standards, we found that due to rough rolling of the body, significant amounts of bodily fluid are lost during the transport of the body from bed to the mortuary truck.

The Nursing Standard also provided information about religious considerations that need to be taken in to account by hospital staff when dealing with recently deceased patients. Most of these considerations do not impact our truck's design, although it is important to maintain the modesty and dignity of the recently deceased. This is an important reason to create a feature to cover the bodies from view while they are being transported on the truck.

A study published by the American Academy of Forensic Sciences [27] concluded that a body bag keeps the deceased body at a certain temperature higher than morgue refrigeration temperature. This higher temperature promotes maggot development, resulting in greater body decomposition.

The study "Infectious disease risks from dead bodies following natural disasters" [28], published by the London School of Hygiene and Tropical Medicine, compared different infections of blood borne, gastrointestinal, and respiratory types. The study concluded that the possibility of contracting gastrointestinal or respiratory infections is the same whether exposed to an infected living or deceased individual. Also, for those who handle the deceased bodies, it was discovered that the most likely type of infectious risks are those produced by blood borne viruses. The study also discovered that some of the infectious hazards for individuals who routinely handle deceased bodies include tuberculosis group A streptococcal infection, gastroenteritis, meningitis, and others. However, microorganisms involved in the decaying process are actually not pathogenic.

From a journal article titled "Medical Waste Management Practices in a Southern African Hospital" [29], we were able to better understand the waste management considerations we need to make when designing our truck. The article describes a study of hospitals in Southern Africa, and concludes that these hospitals generally lack rules, regulations, or instructions on proper waste disposal. Hazardous waste is often not separated from the hospital's domestic waste, and hospital staff are not normally educated and trained on medical waste management. Based on this information, it seems very possible that KATH does not have waste management standards that we need to follow in the design of our truck; however we plan to confirm this with a hospital representative or someone who has visited the hospital.

Interview with the St. Joseph Mercy Hospital Morgue Supervisor

Our team visited the St. Joseph Mercy Hospital morgue in Ypsilanti, Michigan on January 23rd, 2009. We met with the morgue supervisor, Mary Johnson, who provided us with valuable information regarding transporting the deceased bodies in a hospital. Currently the hospital uses two different models of mortuary trucks. Both trucks are manufactured by MOPEC. Additional information for the newer truck (model JA-500) can be referenced in Appendix G. The first and most valuable piece of information we gathered was the configuration of the wheels. Ms. Johnson emphasized to us how important it is to have all four wheels of the mortuary truck free to swivel 360 degrees. Instead of the shopping truck configuration that is designed for straight forward motion by fixing the two back wheels, the mortuary truck configuration needs to be able to slide forward and backward, side to side, and have a zero turning radius. This is because hospital rooms and hallways are often cramped, tight for space, and require more maneuvering ranges.

Body fluid management was the next important topic Ms. Johnson discussed with us. She estimated that 90% of all bodies have very little fluids leak out while being transported to the morgue. However, when asked to quantify the amount of bodily fluids to expect for a worst case scenario, she told us that she once had to use a 5 gallon bucket to collect the fluid of a body over several hours while it stayed in the morgue. Five gallons of fluid containment also agrees with quantity contained in mortuary truck titled "Device for Decontaminating Persons Contaminated with Hazardous Materials" (Pg. 5). To prevent excessive fluid leaking from the body Ms. Johnson told us that the wounds and the mouth can be plugged using gauze or other available linens. She also told us that slightly elevating the head can help prevent fluid escaping from the mouth.

Sanitary issues were also covered in our discussion. She explained to us that she cleans the mortuary trucks once a week with a spray bottle of bleach. However, the trucks she uses would never get as dirty as the truck we are designing because body bags which contain the vast majority of the fluids and prevent the truck from being exposed to the body were always used. Also, she told us that if a body was sitting out for an extended period of time, she places towels wet with bleach in the room with the body or even in the body bag to help absorb the odors.

Other miscellaneous pieces of important information include the preferred height of a mortuary truck and other physical specifications of the trucks Ms. Johnson uses today. Ms Johnson told us that the height of the truck would ideally be 1-2 inches below the height of the bed. This would help to make things easier when transitioning the body from the hospital bed to the truck, a process which can take 2-4 people and a backboard depending on the size of the body. Current trucks are designed to carry 300-400 lbs and are made with stainless steel. The stainless steel allows them to last for long periods of time without rusting or corroding.

Mr. Fusani

Mr. Fusani will act as our mentor, who will hopefully be able to help us with the questions we have, including the customer needs and the dimensions of the current trucks. Mr. Fusani will also be providing us with feedback of our design, which will help us with making improvements to our design.

Communications with Mr. Fusani

To obtain information and receive feedback from the costumer, we frequently email our mentor, Mr. George Fusani, with updates and questions to maintain an open line of communication. The following is a timeline summarizing major pieces of information that we received from him.

February 18, 2009

Mr. Fusani informed us that bodies picked up from the hospital wards are put into body bags, and the mortuary trucks are cleaned in the morning and evening with soapy disinfectants. He also mentioned that all shapes of the cover are acceptable as long as the bodies are covered from public view.

Mr. Fusani told us that the current truck is 7 ft in length and 4ft in height.

February 23, 2009

Mr. Fusani informed us that it is acceptable for the bodies to have contact with one another. With the current truck, the bodies lie on one another. In addition, he feels that it would be nice to improve the current truck design so that the bodies are separated, allowing the bodies to be treated with more dignity.

Mr. Fusani informed us that the wards are well separated from each other and the morgue, so when more than one body is found in the ward, it is more convenient to pick up multiple bodies to transport at the same time.

With our Alpha design, Mr. Fusani made a comment regarding the lower tier of the body tray being too low, and suggested that we raise it closer to the bed height, to help with the ease of loading.

March 10, 2009

Mr. Fusani gave us a brief description of the procedure of transporting the bodies from the hospital ward to the morgue. He told us that, when death occurs in the wards, the morgue is immediately informed by the nursing staff; then the mortuary attendants go to the ward with the body bag and the truck to pick up the body. The bodies are put into the body bags on the bed before they are loaded into the truck. The truck is then transported to the embalming area. After embalming, the bodies are then loaded back into the truck and transported to the morgues. The bodies that are being transported to the new morgue are put back in the body bags, but the bodies that are being transported to the old morgue are not put in the body bags (due to the insufficient cooling system at the old morgue).

March 18, 2009

Mr. Fusani informed us that the reason he prefers the truck to be made out of stainless steel is because the material is good for preventing corrosion and very durable. This is important since the mortuary uses very corrosive chemicals and body fluids are corrosive. He also told us that with our current budget, it is reasonable to construct our new prototype design out of wood.

PROJECT REQUIREMENTS AND ENGINEERING SPECIFICATIONS

We have determined a number of requirements and specifications for our truck design. This is based on our discussions with Professor Sienko about hospital needs and problems with the current truck's design, our communications with Mr. Fusani, and on the research we conducted to determine what will make the design effective. Once the customer requirements were determined, we then established quantifiable engineering specifications for our design that will allow it to meet all project requirements. A Quality Function Deployment (QFD), which lists all requirements, specifications, and their relation to each other, can be referenced in Appendix H. A comparison of the customer requirements and our engineering specifications can be referenced in Appendix I.

Customer Needs

From talking to Professor Sienko and Ms. Johnson, and from the feedback Professor Sienko received from Mr. Fusani, we were able to come with a list of attributes for the customer needs. These attributes will be incorporated into our engineering requirements and specifications.

A list of ten attributes was provided to Mr. Fusani to rank the importance of customer needs. The attribute ranking performed by Mr. Fusani is listed in Table 1. Communications between Mr. Fusani and our team can be referenced in Appendix J. He emphasized that all of the ten attributes are important, and we should incorporate all of them into our design.

Ranking	Attributes
1	Hold at least 2 adult bodies
2	Covers bodies from view completely
3	Cast and easy to clean
4	Easy to maneuver indoors
5	Rolls smoothly over rough terrain
6	Robust
7	Easy to repair
8	Low cost
9	Collect fluids from the bodies and prevents leaking
10	Has an attractive appearance

Table 1: Customer attributes ranked by Mr. Fusani (1 being the most important and 10 being the least important)

Requirements and Specifications

Using the customer attributes ranking from Table 1, we were able to update our original QFD diagram. Table 2 shown below is our updated ranking of our engineering specifications. The updated QFD diagram can be referenced in Appendix H.

Design Parameter	Target
1. Wheel weight capacity	136 – 205 kg per wheel
2. Fluid collection capacity	23 liters
3. Number of operators	1 staff member
4. Force to brake	147 N (hand brake) 228 N (foot brake)
5. Support weight of body	313.13 Kg
6. Length of the body tray	2.15 m
7. Maintenance cost	$ 4.00 USD per year
8. Turning radius	Zero
9. Width	0.787 m
10. Frequency of maintenance	10 – 20 mins every two weeks
11. Total truck cost	$600 USD
12. Loading height of the body	0.65 m
13. Coverage of body from the view	100%

Table 2: Engineering Specifications, in order of relative importance (highest to lowest, based on QFD)

Ability to Travel Across Indoor and Outdoor Surfaces

The ability to travel across indoor and outdoor surfaces is significantly affected by the force required to move the truck. This force required is affected by the weight of the bodies and the truck's ability to roll over rough terrain. Due to the variation of body weights we will be designing for a load that is far above average (see section below). To make it easier to push our truck over rough terrain, our truck should have a suspension system to allow for smooth travel over rough terrain.

A durable wheel is also required for travel across indoor and outdoor surfaces. A durable wheel does not lose its shape, nor does it lose enough material to significantly reduce its diameter. We will use both bicycle wheels and swivel casters for indoor and outdoor use.

Other considerations include the truck's fluid collection capacity, the turning radius, keeping the wheels in good working order, force required to brake, and the number of hospital staff operating the truck.

Ability to Support and Transport Multiple Bodies
The truck must be able to support and transport at least two bodies, with the possibility of a third. As a worst-case scenario, we will assume the body weights are equal to the adult male anthropometric average weight plus two standard deviations (approximately the 97th percentile, since data is close to normally distributed). As an estimator, we used data from Nigeria from a 1998 International Journal of Obesity study [31]. According to this study, the average Nigerian male's weight is 61.3 kg with a standard deviation of 11.1 kg. Based on this, our design will support a target load of 2.5 times this 97th percentile weight of 85.3 kg. We also apply a safety factor of 1.5, which gives a total target design weight that the truck must support of 313.1 kg. We have set our lower and upper specification levels for this parameter based on two and three bodies, respectively, which gives lower and upper levels of 250.5 kg and 375.8 kg.

In addition, because of the large load the truck has to support, we will be using wheels that will be able to support loads ranging from 136 kg to 205 kg per wheel.

Other Size and Dimension Requirements
The truck must be long enough to fit the bodies completely on the surface of the truck with no body parts hanging off the edge. According to the International Journal of Obesity study mentioned in the previous section, the average Nigerian male's height is 1.684 m with a standard deviation of 0.074 m. The mortuary truck used by the St. Joseph Mercy Hospital, MOPEC JA-500, is 2.13 m long, so we have determined that our truck's target length to be 2.15 m long.

The truck should ideally be wide enough to fit the bodies completely on the surface of the truck with no body parts hanging off the edge, but must be narrow enough to fit in the aisles between hospital beds and the hallways of the hospital ward. Currently we do not have the width of the aisles between beds at the KATH, once we obtain the width of the aisles and the hallways, we will make sure that our target truck width is less than this width. The mortuary truck used by the St. Joseph Mercy Hospital, which adequately hold patients of all possible body widths according to Ms. Johnson, is 0.787 m wide. Based on this information, we have determined our truck's target width to be 0.787 m.

Collection of Bodily Fluids
We were advised by Ms. Johnson (Pg. 8) that 90% of all bodies leak minimal fluid while being transported to the morgue. However, we were also advised that a worst case scenario for containing body fluid over a span of several hours would require a 5-6 gallon (19-23 liter) container [32]. We will design our bodily fluid container to have two handles, one on either side, which can support a combined load of 37 kg (estimated mass of 23 liters of blood [33] multiplied by a safety factor of 1.5, for a total volume of 35.5 liters).

Ease of Steering Within Hospital Wards
The truck must be able to turn smoothly and with a tight turning radius. We have determined that the truck must have a zero turning radius in order to successfully navigate the hospital wards. The number hospital staff members operating the truck also affects how easy it is to steer within the hospital. We will

design our truck so that a single staff member can steer it, but ideally the truck will be operated by two or more staff members. Ease of steering is also improved by using durable wheels and by keeping the wheels in good working order.

Blocking the Bodies from View
As the bodies will be transported without a body bag through a crowded hospital filled with children and families. The target percent coverage of the body from view is 100%.

Low Cost for the Hospital
The current truck being used at the hospital costs approximately $2000USD. However, we would like the truck to be as affordable as possible. After viewing pictures of the current mortuary truck in use today, we determined a reasonable goal for the total price of the truck should be no more than $1000USD.

Ease of Loading the Body onto the Truck
From our discussions with Professor Sienko, we learned that it is difficult to load bodies onto the mortuary truck from a bed if the surface of the truck is too high. According to Ms. Johnson from the St. Joseph Mercy Hospital morgue, the ideal height of a truck surface for loading bodies is one or two inches below the height of the bed (Pg. 8). We will design our truck so that the surface where the bodies lay is at a height of 5 cm below the height of the bed. According to an article from *Nursing Economics* [34], an average hospital bed is 0.70 m high; we will design our truck so that the bodies lie on a surface 0.65 m above the ground.

Ability to Be Stopped
The truck must have braking capabilities or the ability to lock the wheels and prevent them from rolling. This will keep the truck from accidentally rolling away while loading the bodies or becoming an obstruction in the ward. This will also keep the truck from rolling away uncontrollably if there is sloping terrain outside. Force required to apply brakes will be dependent on how well the wheels are maintained, the total weight of the truck and its load, and possibly the suspension system. We will assume a fully loaded truck (255.9 kg load) when calculating braking force. According to a Washington State Department of Labor and Industries study [35], the normative power grip strength is 66 lbs. for women and 106 lbs. for men. If our truck design utilizes a hand braking system, we will design our truck to require a braking force of no more than half of the normative grip strength for females, or 33 lbs. (147 N). According to the International Journal of Obesity Study mentioned above, the average Nigerian female's weight is 56.6 kg with a standard deviation of 12.3 kg. If our truck design utilizes foot brakes or foot pedals to lock the wheels, we will design our truck to require a braking force equivalent to no more than half of this average female body weight. This equals $0.5 \times (56.6\ \text{kg}) \times (9.81\ \text{m/s}^2) = 277.6\ \text{N}$.

Minimal Maintenance
Maintenance for the truck should require no more than one person for 10 to 20 minutes every other week. The maintenance should include no more than oiling wheels or other movable joints, removing hair or other obstructions from the bearings of the wheels, and tightening fasteners on the truck. The resources and cost for maintenance should include no more than a can of lubricant such as WD-40 costing $4.00 USD per year.

CONCEPT GENERATION – FIRST ITERATION, SUB-SYTEMS

We began the concept generation process by defining the major sub-systems of the truck with the aid of the Functional Development Flow diagram. The diagram can be referenced in Appendix K. The five sub-systems include the body concealing method, the structure/layout of the truck, the fluid management, the wheels, and the brakes. Each team member brainstormed concept ideas for each sub-system. The following is a discussion of two contrasting concepts generated for each sub-system. See Appendix L for additional concepts generated.

Body Concealment Method

The current mortuary truck used in Ghana uses a grill top cover to conceal the bodies from view. We researched and brainstormed several other methods for concealing the body in case a more efficient or appropriate solution can be found. The primary goal of the cover is to completely conceal the body from view and to be easily removable for transferring the body in and out of the truck. Several concepts were generated to achieve this.

Wagon Sides

All four sides of the truck would be made from metal walls which slide on and off the truck via slots on the base of the truck just as the sides of a traditional red wagon slide on and off. The walls could be stored by hanging off the sides of the truck below the surface of the trucks bed while a body is being loaded or unloaded.

Advantages of this concept include simplicity of design and manufacturing, and the option to load or unload the body from either side of the truck. Disadvantages of this design include difficulty in achieving a water tight seal to contain fluids, the lack of a top portion to conceal view from the top, and the excessive time required to remove and store the sides every time a body is transferred.

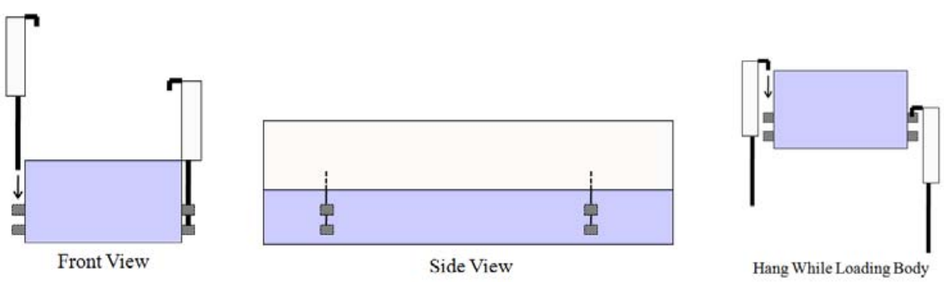


Figure 2: Wagon style walls conceal the body while on the truck and can hang from the side while transferring the body on or off the truck

Grill Top

The body would be concealed by a half cylindrical shell similar to that of a traditional grill cover. A large hinge at the bed of the truck would swing the cover back where it would rest as the body is loaded or unloaded.

The advantage of this concept is ease of use. Disadvantages of this style include the complexity involved in using a hinge, being able to only load the body from one side, and the difficulty in manufacturing a large half cylinder.

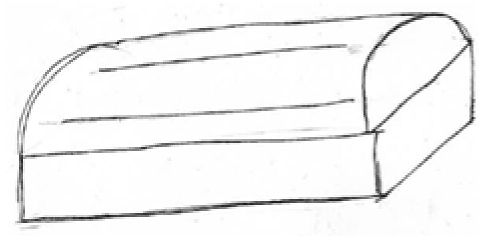


Figure 3: Grill top cover similar to one in use at KATH

Wheels

The current truck used in Ghana has four car tires that do not swivel, and this limit maneuverability. The goal of the wheel system is to come up with a design that can transport easily through both the rough terrain and the inside of the hospital ward. We brainstormed many different wheel configurations in order to attain this goal.

Six Wheel

This concept would implement two bicycle tires at the front of the truck, two swivel casters at the back of the truck, and two more removable swivel casters at the front of the truck. When used outside, the front two swivel caster would be folded up into the bottom of the truck so that they do not touch the ground. The front of the truck would be supported by the bicycle tires which would absorb the shock of the rough terrain. While being used inside, the front swivel casters would be folded back down so that they support the front of the truck. Folding the swivel caster down would also lift the bicycle wheel off of the ground so it doesn't get the floor dirty or limit the mobility of the truck.

Advantages of the six wheel design include indoor mobility and outdoor navigation of rough terrain. Disadvantages include uncertainty in reliability of the folding mechanism supporting the swivel caster, high cost of wheels, and complexity in use.

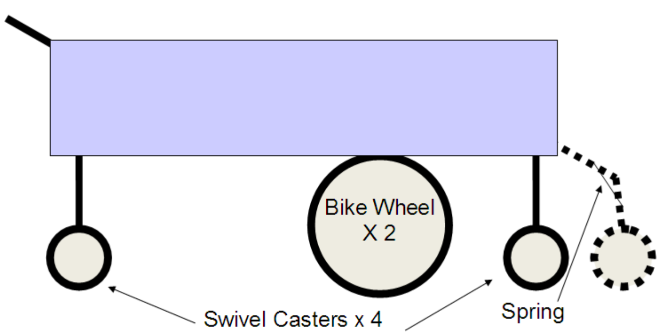


Figure 4: Folding the front swivel casters down allows for mobility indoors, folding up allows for navigation of rough terrain outdoors.

Four Wheel

This concept implements four simple but robust tires. The back tires are smaller in diameter such that they can fit below the truck and swivel 360 degrees. The front tires are larger in order to take the shock

of the rough terrain and extend off of the side of the truck because they cannot fit underneath. For braking purposes, the front tires would be fixed in the forward/backward direction. The back tires would be allowed to swivel 360 degrees to allow easy maneuvering.
Advantages of this design include simplicity, reliability, and low cost. A disadvantage includes limited mobility.

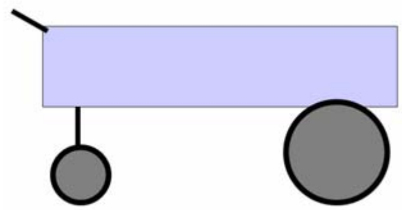


Figure 5: Four simple but robust tires, front two fixed, back two swivel

Fluid Management

The truck currently used in Ghana does not have a fluid management system; as a result the bodily fluids are left uncollected and leak from the truck. The goal of the fluid management system is to handle the fluid flow of a body so that the truck is sanitary to be used in a hospital and the body is transported and handled in a dignified manner. We researched current flow designs on the market today and brainstormed several ideas for fluid control.

Grated Holes
This concept uses a series of holes in the tray in which the bodies lies to drain fluid. After passing through the holes the fluid would flow into a collection such as a tank or trough.

Advantages of this concept include ease in manufacturing and simplicity in design. Disadvantages include difficulty in cleaning and potentially getting clogs in the holes.

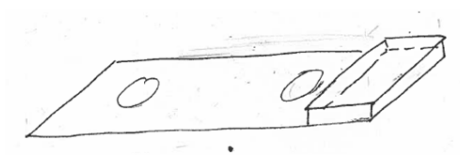


Figure 6: Fluid flows through holes in tray to collection area

Sloped Channels
This concept implements a series of channels that slope downward while keeping the body laying flat on the surface of the fluid collecting tray. The top of the channels would remain horizontal to the floor to support the body while the valleys of the channels would slope downward into a trough at the feet of the truck.

Advantages of this concept include ease of cleaning, guidance of fluid flow, and avoidance of clogs. A disadvantage includes difficulty in manufacturing.

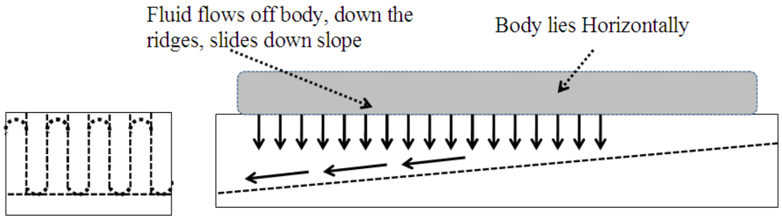


Figure 7: Bodies lay horizontally on the surface of the fluid collecting tray, valleys slope downward and direct fluid to trough.

Structure

The current truck is simply a flat base sitting on four wheels. The goal of our new structure is to support the size and weight of at least two adult bodies in a respectful and dignified manner.

Single bed
This design is similar to the current truck in that it is simply a single bed in which two bodies can fit. The sides of the truck go higher than the current truck to allow more room for the bodies.

Advantages of this design include simplicity of design and manufacturing, reliability for long term use, and low cost of materials. The major disadvantage to this design is the lack of dignity and respect shown to multiple bodies placed inside the truck at once.

Stacked trays
This design supports two bodies by implementing two trays that stack on top of one another. The bottom tray is fixed to the frame of the truck. The top tray must be removed in order to load a body into the bottom tray. Once the lower tray is occupied, the top tray is stacked on top of the lower tray. The trays would have side walls that are high enough that no additional covering system would be necessary.

The main advantage of this design includes dignity in transporting and handling of multiple bodies. Disadvantages include time consumption in taking the top tray on and off and the inconvenience in loading and unloading a body to and from the tray.

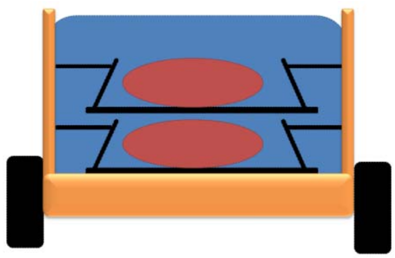


Figure 8: Stacking vertically in removable trays increases dignity, decreases ease of use

Brakes and Wheel Locks

The current truck used at KATH does not have any braking system or locks for the wheels. From rest, the truck requires a large initial force to get up to speed, and once it is up to speed, it is difficult to bring the truck to a stop due to its large mass and lack of braking system. If the truck is being operated on a downward slope, this issue is amplified. Ms. Johnson stressed the importance of having wheel locking mechanisms for loading and unloading. The goal of the brake system and wheel locks is to come up with a design that resolves this problem.

Bicycle braking system
The bicycle braking system gradually slows the truck down by brake pads held by a set of calipers and actuated via a cable and hand lever system.

Advantages of this system include that it would slow down the truck when desired and that we could buy the system instead of having to manufacture it. One of the disadvantages of this system is the swiveling of the braking wheels, as the cable system prevents over 360 degree rotations due to the attached cable. Also, the wheels cannot be locked in place without the operator applying constant force to the hand lever.

Figure 9: Bicycle brake pads that will be part of the braking system

Locking Device
The outrigger and the door stop style locks help provide stability to the truck during loading and unloading of the body, stationary transport as in an elevator, and during maintenance. Both devices involve a rubber or other high friction flat pad that is pressed against the floor to prevent motion of the truck. The outrigger system would keep the pad against the floor due to the overhead mass of the extending bracket or arm. The arm would be hinged to allow the operator to return the device to its position of the floor. The door stop system would include a helical spring that applies constant pressure.

Advantages of this design includes that it is easy to use and easy to manufacture. Disadvantages of this design include the easy wear and tear of the rubber pad, and that it would not be useful for slowing down the truck at any speed and would need to be activated and used once the truck is at rest.

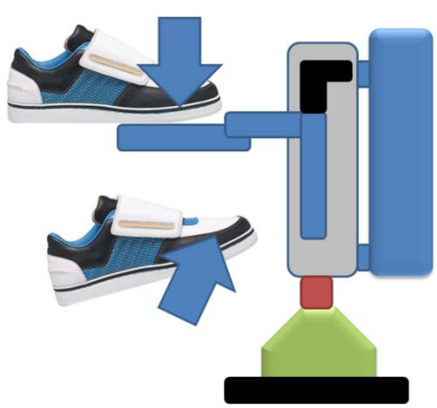


Figure 10: Retractable high friction pad with engage/disengage foot pedal

CONCEPT SELECTION – FIRST ITERATION, SUB-SYSTEMS

To establish a final design for each sub-system the team went through the concepts one-by-one, and discussed how well each concept meets our engineering specifications, how feasible it would be to implement, and its advantages and disadvantages. Each team member then voted yes, no, or maybe to each design. At the conclusion of voting, we compiled each yes and maybe into a smaller list and decided on one final design for each sub-system. A Pugh chart was developed to aid us in analyzing the advantages and disadvantages of each concept. The Pugh chart can be referenced in Appendix M. Classification Trees were also created for each sub-system to help us breakdown and analyze each component. The classification trees are referenced in Appendix N.

Body Concealing Method

We selected the grill top cover because of its ease of use, and because it is currently being used in Ghana. This concept is ranked the highest in the body concealing category of our Pugh chart. On our Pugh chart, the other concepts had more positive marks than the grill top cover but at the same time they also had more negative marks. The wagon style and swinging style sides were attractive because of their simplicity and ability to expose the entire surface of the bed such that the body can be transferred from either side. However, these designs did not allow for water tight fluid management, would be time consuming to use, and did not have the ability to cover the exposed top portion of the truck.

Wheels

We selected the four wheel design because of its simplicity, reliability, and low cost. This concept ranked the highest in the wheels category of our Pugh chart. The high mobility and outdoor navigation of rough terrain were attractive features of the six wheel designs, but the uncertainty in reliability of the folding mechanisms, high cost in wheels, and complexity in use outweighed its advantages.

Fluid Management

We selected the sloped channel design because of its ease of cleaning and avoidance of clogs in fluid flow. The grated holes design had the advantages of being easy to manufacture and simplicity in design, but it would be difficult to clean and could easily clog preventing fluid flow.

Structure

We selected the single bed design because of its simplicity in design and manufacturing, reliability for long term use, and low cost of materials. The dignity and respect shown to the bodies in the stacked tray design was an attractive advantage, but the time consumed in stacking the trays along with the inconvenience of loading and unloading a body from a deep walled tray outweighed the advantages.

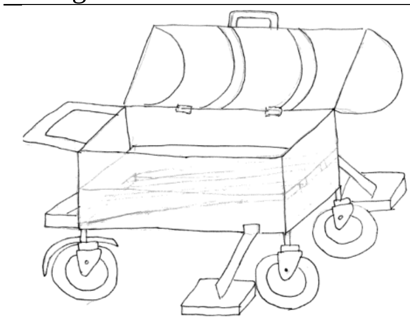
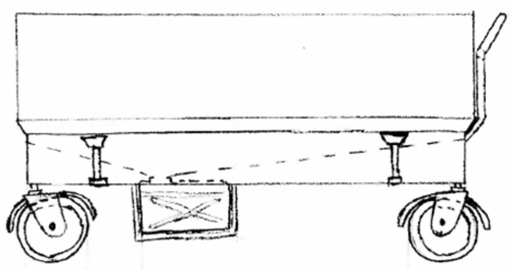
Brakes and Wheel Locks

The bicycle brakes and outrigger/door stop wheel lock systems serve different purposes in controlling the speed and stability of the truck at all times. Thus, we determined that both systems should be incorporated in the final design to ensure proper speed control and a locking feature.

CONCEPT GENERATION – SECOND AND THIRD ITERATIONS

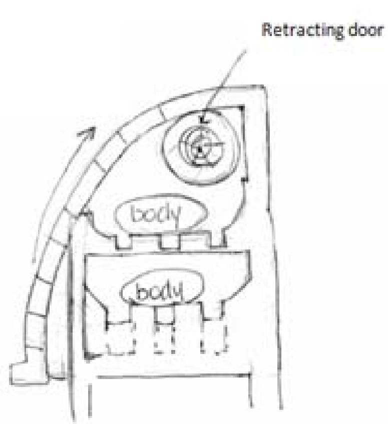
Once the final design for each sub-system was selected, each team member drafted his or her own version of the assembled truck. We then discussed each design as a group, focusing on issues such as manufacturability, functionality, and satisfying customer priorities. The following table discusses two of the concepts generated. Images of the remaining concepts can be found in Appendix O. A complete summary of the concept generation and selection process can be found in Appendix P.

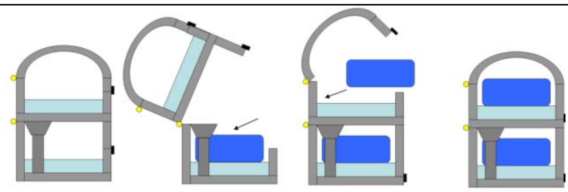
Concept Generation – Second Iteration

Design Sketch	Design Features	Design Flaws
	The body lies flat on a series of channels which allow the fluids to flow down to a drain at the foot of the truck. The bed of the truck lies 4-6 inches below the walls of the truck to ensure fluids do not splash or flow out when the top is not sealed shut. Outriggers extend diagonally from the truck via a ball and socket joint at the base of the truck and act as brakes while bodies are transferred to and from the truck.	Limited space to collect fluid at the foot of the truck due to the placement of the wheels and incontinences of the large outriggers in a crowded hospital.
	The body lies flat on a series of channels which allow the fluid to flow to a drain at the center of the truck. Positioning the drain at the center of the truck allows more room for the fluid collection tank to fit in the center of the truck where the wheels will not get in the way.	Limited space for fluid collection.

New information gathered: Mr. Fusani likes the current grill top cover for body concealing. For the structure of our cart, he was particularly interested in the CSI/Jewett Four Tier Transport Cart (Appendix G). He likes the idea that the bodies are separated by the tiers, but would like to have a cover concealing the body. In addition, we learned that that the truck needs to have a device to slow down the truck and control its speed, especially during outside use.

Concept Generation – Third Iteration, Subsystems

Design Sketch	Design Features	Design Flaws
	Uses two fixed beds, one above the other, which are accessed by a sliding door. The sliding door rolls up and around its self at the top of the truck, exposing both beds.	Difficulty in transferring bodies on the lower bed which is blocked on the sides by the supports for the upper bed, difficulty in manufacturing the sliding door, difficulty in cleaning due to the complexity of the sliding parts, and having to view the body on the lower bed when the door is up and loading a second body on

		the upper bed.
	Two large hinges to separate the two storage beds. The first body is loaded by opening the bottom hatch and tilting the top of the truck back to gain access to the lower bed. The second body is then loaded by opening the top hatch and tilting the grill-style lid back to gain access to the upper bed. Both beds have a drainage system which channels fluid through troughs to a storage container at the bottom of the truck.	Reliability of a hinge system and the weight of the top tier and cover being too heavy. Upper and lower trays must be independently water tight. Cart may tip over when top tray is lifted up due to shifted center of gravity

Outcome: It was determined that the hinged compartment design best suited the requirements of the customer. It is easy to use, it provides respect and dignity to the body during transport, and the ability to access only one body at a time without viewing the second body made it more favorable than the other prospective designs.

Table 3: Summary of Second and Third Concept Generation Iterations

ALPHA DESIGN

Design Description

Once the third concept generation and selection process was completed, we started to develop our alpha design. The Alpha design was first drawn by hand, then as a group we determined the dimensions of each component. Once the dimensions of each component were determined, we drafted a three-dimensional design using Unigraphics 4.0 CAD software.

The alpha design consists of a standard frame supported by 4 bicycle type wheels with two that fully swivel. The two wheels that are stationary include a braking system similar to a bicycle caliper-style brake with a brake hand lever mounted on the truck's handle bars. The bicycle wheels will be mounted by the traditional annular sleeve and stub to enable part interchangeability. The bicycle wheels will have standard fenders to prevent the wheels from propelling debris and objects toward the truck structure. A vertical outrigger will be mounted onto the truck near the swivel casters to provide stability to the truck during loading and unloading of the bodies.

The truck has a capacity of holding at least two bodies by having two parallel body trays stacked vertically. The bottom tray will be fixed and both trays will slope along their length toward one end. The second tray will be hinged to allow the operator to flip up the upper tray to gain access to the bottom tray. Each tray will have a horizontal slot at one end to allow fluids to drain into a trough and finally into a vertical drain pipe that will continue on to the fluid container.

The removable fluid container will be placed on a flat platform below the lower tray. Straps tied to vertical posts will enable the operator to tightly secure the upright fluid container. Our current design can hold two 6 gallons gas tanks; this will provide more fluid collection.

The cover will be shaped like a grill top and hinged as well for access to the upper and lower trays. Possible additions to the upper cover are linear dampers as seen on automotive trunk lids to ensure smoother closing and prevent the cover from suddenly closing during an opening motion. A latch that connects the upper tray to the cover will enable the operator to lift both the cover and upper tray in one motion.

Engineering Drawings

Our alpha design was drafted with UG 4.0. Some of the screenshots of our CAD drawings are illustrated below.

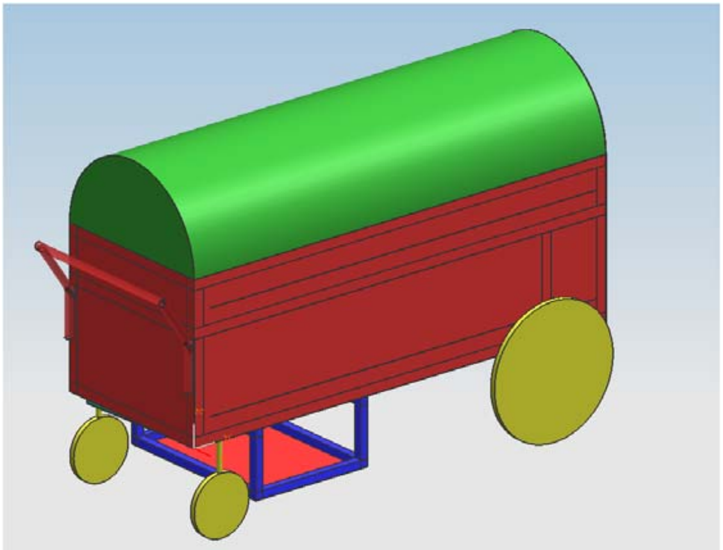


Figure 11: Full truck view colored by component

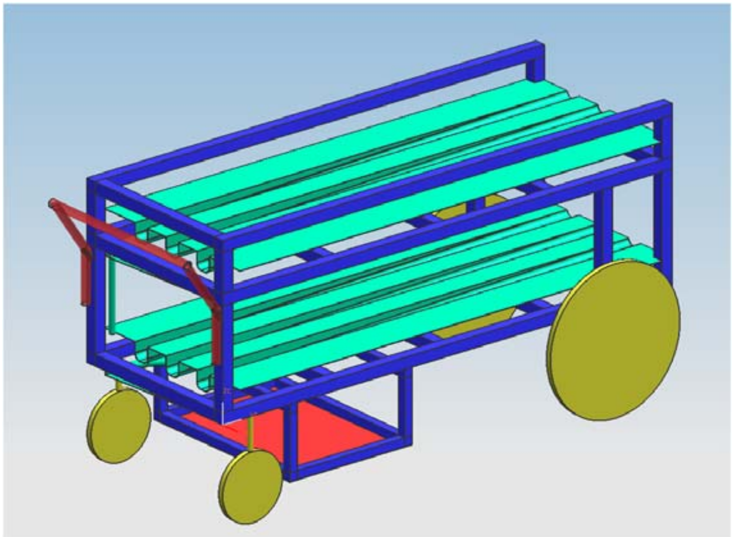


Figure 12: Major structure of our truck design

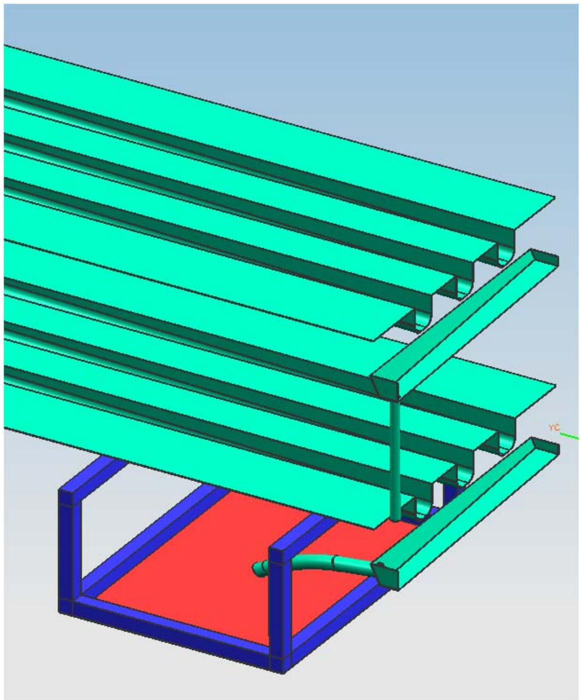
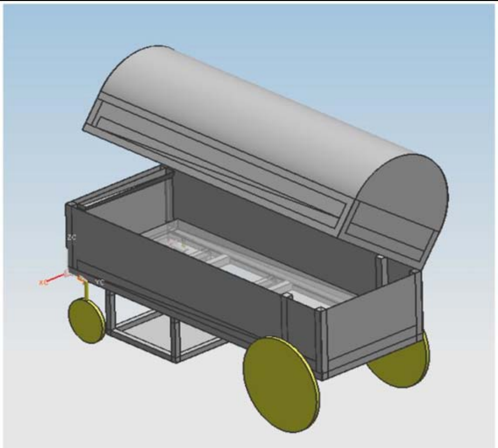


Figure 13: Fluid management system, including body tray ridges, troughs, pipes, and fluid collection container holder

DESIGN EVOLUTION

From our alpha design, we went through several more design changes before we came up with our final design. The following table discusses the reasons for changes in our design. For the full description of the design evolution, reference Appendix R.

Alpha Design

Design Sketch	Design Features	Design Flaws
	Tiered body trays allow two bodies to be carried separately, while each body is placed in an independent fluid collection tray. Upper tray hinged to provide access to lower tray. Hemispherical cover carried over from current truck.	The round cover shape requires a more elaborate support frame that conforms to the rounded surfaces. Multiple body trays increased required material and manufacturing time by including more welds and joints. The multi-tray design adds complexity by requiring separate trays to be independently "water tight", even when the upper tray is being lifted during loading of the body. Low loading height. The hinges

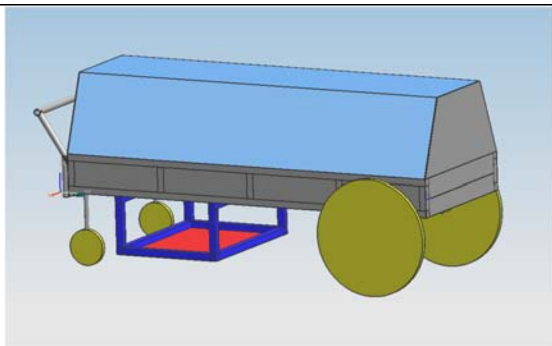
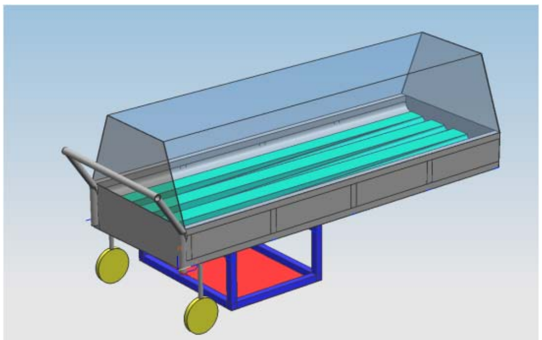
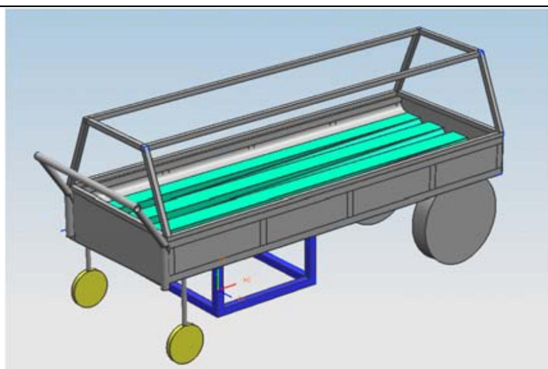
		would need to be extremely robust and durable to handle the weight of the cover and upper tray
	A single tray that has the capacity for multiple bodies. Grated horizontal surface and lower slanted collection tray. Trapezoidal shaped cover instead of hemispherical.	Grated surface involved high complex joining of sheet metals, bar stocks, and grated sheet metals. Cleaning concerns with large number of small holes in grated surface.
	Fluid collection system changed to a fiberglass tray and front tires located directly under the truck. The new design for the fluid collection system involved forming the sloped channels out of a piece of foam and covering it with fiber glass.	Total width of the cart beyond engineering specifications. Cut out area in the body tray to allow the wheels to extend up through the truck. Wheels rise 8" above the body tray, making loading and unloading of bodies from the tray difficult. Fiberglass manufacturing process is complicated and introduces high level of variability.
	20" wheels and PVC pipe and tarp cover in trapezoidal shape. The 20" wheels also have bonus feature of coming equipped with a shock system to help absorb shock in the legs and wheels of the truck.	Trapezoidal shaped cover features complex angles that do not provide any extra features. Tarp may have shorter lifespan and absorb odors. Bicycle wheels support large amount of expected loads.

Table 4: Summary of design evolution after the Alpha Design

Final Prototype Design

The final design changes involved changing the material of the frame from aluminum to wood, replacing the fiberglass fluid channel system with a grill and tray system, converting the trapezoidal cover to a rectangular cover, moving the bicycle wheel and brake system to the middle of the cart, and adding a second pair of casters. Explanations for these design changes are discussed below, and the final design is discussed in the following section.

Due to budgetary restrictions, we realized we needed to restrict our design to only using aluminum where body fluids will touch the truck. We determined that all other support aspects of the frame and legs can be made from wood. The wood is also weather treated to prevent degradation due to exposure to liquid.

After further researching and considering the high cost of fiberglass, the difficulties and unknowns in manufacturing and engineering analysis, and the lack of resources in Ghana to repair or replace the fiberglass, we decided to abandon the idea and pursue the grate or grill system further.

When we realized how low the cart sits to the ground, we decided that there is no need to have a trapezoidal cover for the sake of the operator being able to see around the cover. The top of the cover will be low enough for any operator to see over, therefore we decided to maximize the volume under the cover and make the frame rectangular. Another advantage of this design change is simplicity in purchasing and fabricating the PVC fittings. It is simpler to work with 90 degree corners instead of 45 degree corners when constructing a frame out of PVC.

While researching the weight capacity specifications for the 20” bicycle tires, we were only able to obtain the maximum weight tested for the entire bike. The manufacturing specification for the bicycle is up to160 lb. Due to the complexity, and the large amount of unknowns with the 20” wheels we have decided to modify our design. To make sure that we have wheels that will be able to support our truck structure and the weight of the bodies, we decided to replace the front bicycle wheels with strong 12” swivel casters and to move the bicycle tires to the middle of the truck.

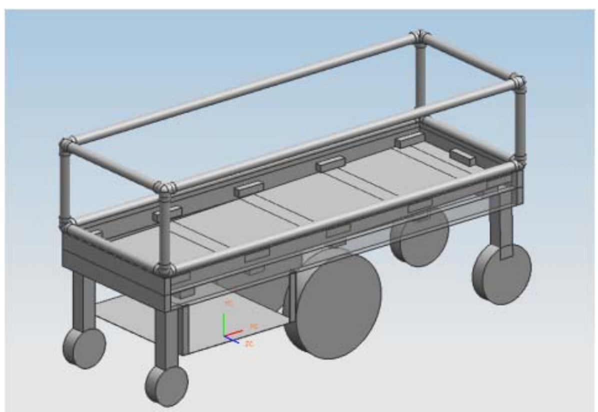


Figure 14: CAD drawing of our prototype design

PROTOTYPE DESCRIPTION

Our final prototype design is a truck made from a wooden frame containing an aluminum fluid collection system and body tray, PVC piping that supports the tarp cover, four swiveling casters (two of which have locking capabilities), two bicycle wheels, and a fluid drain and storage system. A full bill of materials used in our prototype can be referenced in Appendix B. Modifications made to our prototype design since Design Review Three can be referenced in Appendix C.

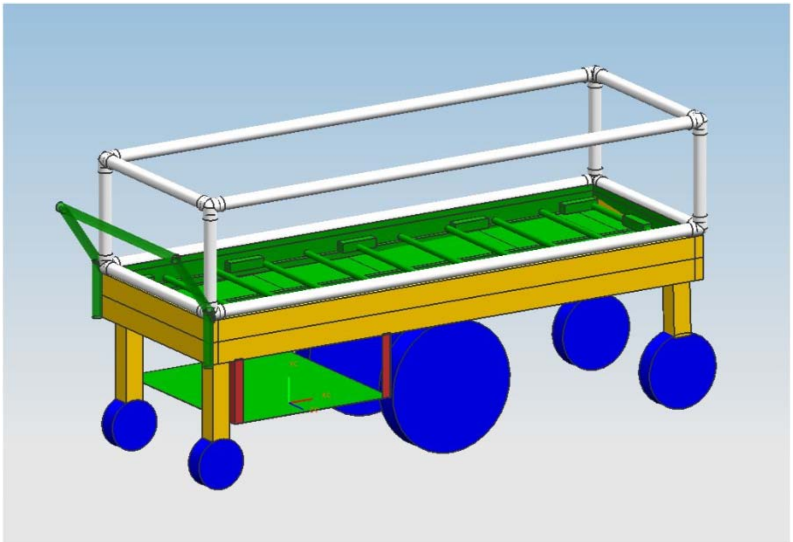


Figure 15: CAD drawing of our final prototype design

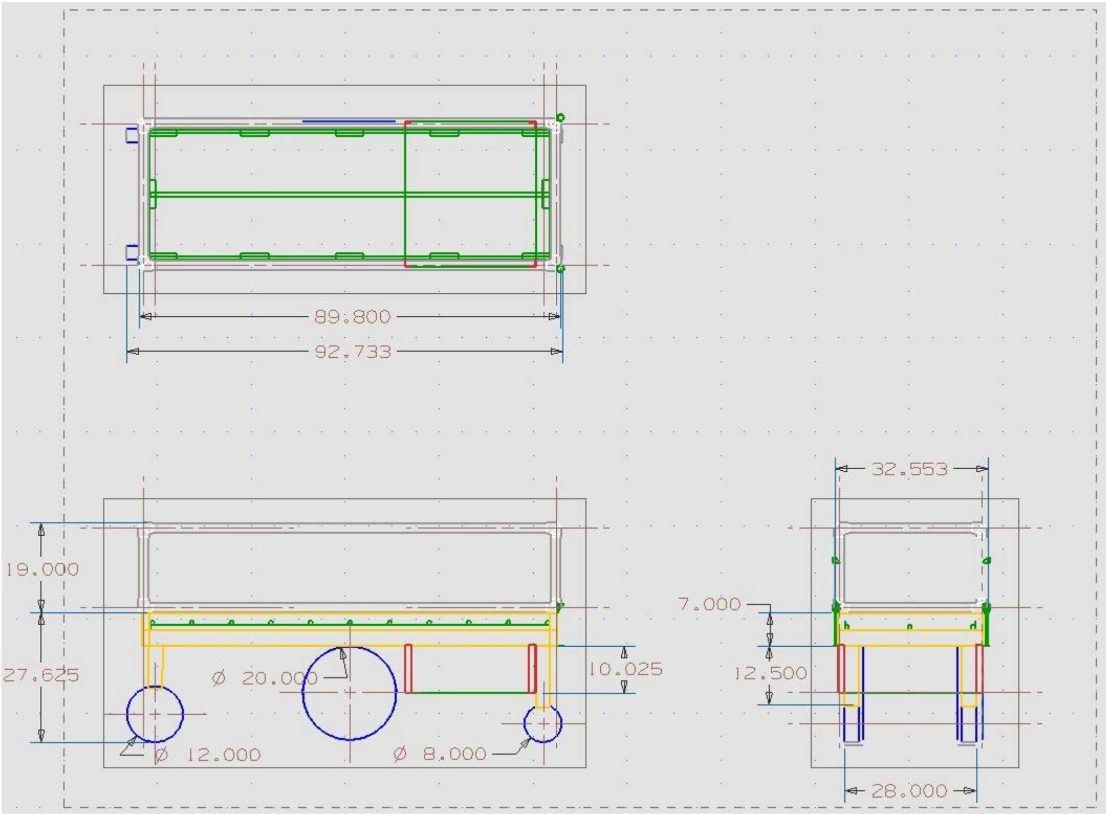


Figure 16: Dimensions of our final prototype design

In Figure 15, components that are in green are aluminum, components that are in yellow are wood, components in red are stainless steel, components in white are PVC, and components in blue are purchased parts.

Frame

The main support for the body surface is a frame consisting of wood studs with rectangular cross sections. The wood frame provides support and mounting points for the fluid collection tray and grill.

The upper frame consists of wood boards that are stacked vertically on their short sides. Two boards are allocated for each side, resulting in eight boards total for the sides of the upper frame. Short reinforcement boards span across the joint between the two boards for each side, shown in Figure 17. Other boards run across the width of the cart to provide extra frame rigidity. The studs remain straight with no curves or angular bends in a single component. The legs of the cart are wood posts with square cross sections mounted on the inside surface of the cart at the corners. The legs serve the function of supporting the cart and also help hold the sides together to provide cart rigidity.

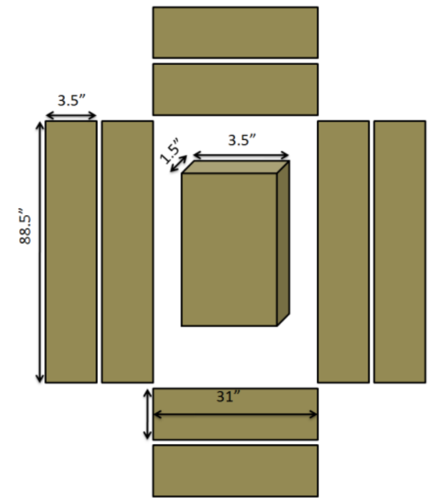


Figure 17: Wood boards and dimensions for upper frame structure

Fluid System

The fluid system for the final design is made from aluminum and restricts the flow of fluid only to the aluminum portions of the truck so fluids do not reach the wood. The body rests on top of a grill which is supported by aluminum bars which are bolted to the inside of the cart. Fluid flows from the body, onto a fluid collection tray, though drain tubing and into a fluid collection container.

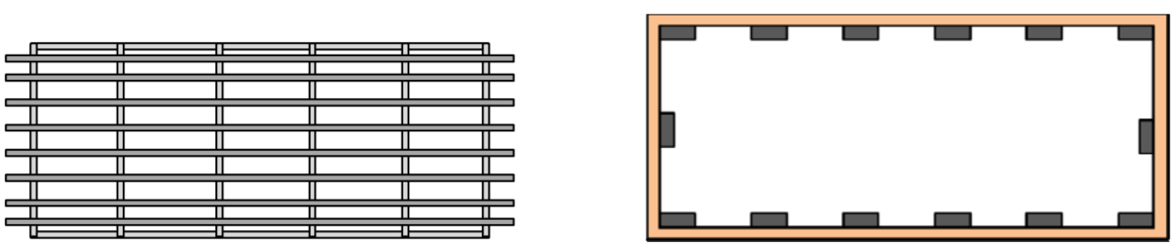


Figure 18: Body rests on grill, grill rests on bars bolted to the inside of the frame

The grill is made from aluminum cylindrical rods and thin aluminum slats all welded together. It rests on top of the aluminum bars which are bolted to the inside of the frame as seen in Figure 18. The grill is free to be removed without being attached or detached each time. This greatly aids in the daily cleaning and maintenance of the truck. With the weight of one or more bodies on the cart the grill will not slide around much, however, if it does slide it will only slide ½ inch in either direction before it hits the inside of the wooden frame in which it is contained.

The fluid collection tray is made from sheets of aluminum together. Its walls are bolted in between the frame of the truck and the bars that support the grill, as shown in Figure 19. Washers are used with the bolts to ensure the loads from the bolts are distributed over a larger area of the frame and thus preventing cracking in the wood. The tray extends below the grill to collect the fluid dripping from the body above on the grill. The tray is sloped as seen in Figure 20 to allow the fluid to flow down into a drain and collection bin. All connecting joints and points of contact with other metals are sealed with silicone sealant to prevent fluid from entering the cracks and corroding the aluminum.

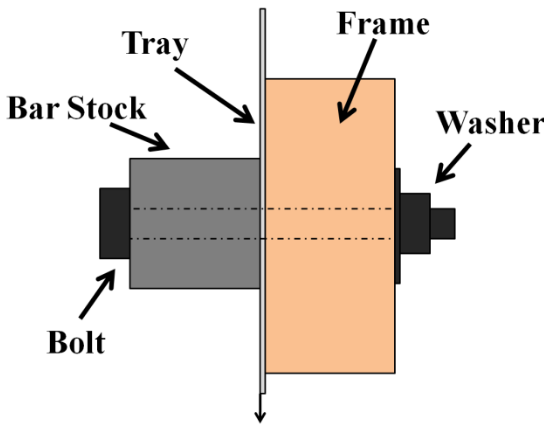


Figure 19: Fluid tray walls bolted between frame and support bar for grill

Figure 20: Fluid tray is sloped to allow fluid to flow into drain

The drain is made from a rubber hose and runs from the hole in the fluid collection tray to the fluid collection container stored under the frame of the truck. The hose is connected to the tray using a fitting similar to the one shown in Figure 21. The fitting is permanently and rigidly connected to the tray. The drain hose is connected to the fitting but will also be easily removable. The drain piping does not rigidly connect to the fluid collection container as shown in Figure 22.

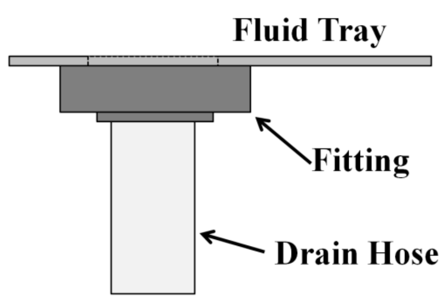


Figure 21: Fluid flows from tray into drain hose attached by fitting

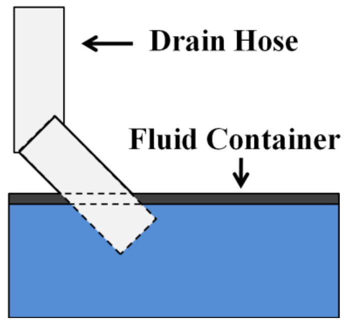


Figure 22: Drain hose fits loosely into top of fluid container

For the fluid collection container, a six gallon gasoline canister with the opening on the top is used. It is supported by steel brackets suspended down from the frame of the cart. The container is held in place using a simple fabric strap, as shown in Figure 23 below.

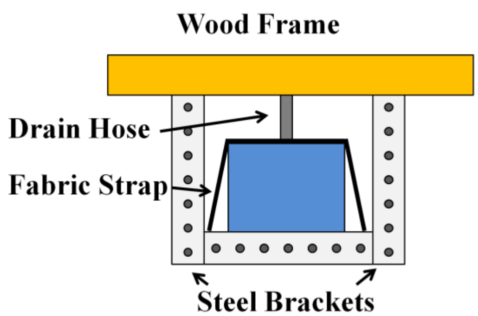


Figure 23: Fluid container is supported by steel brackets and suspended from frame

Wheels

The cart includes six wheels which consist of two 8” pneumatic swivel casters with locks located at the back of the truck and two 12” swivel casters located at the front of the truck. In the middle of the truck, we have two 20” bicycle wheels with a braking system that will be mounted to the wooden structure.

Figure 24: 8” pneumatic caster wheels and bicycle wheel

Cover

The cover is made from PVC piping support covered by a tarp. The PVC piping is attached to each other using fittings. The cover is hinged on one length side of the cart to allow the cover to open like a traditional grill cover. The tarp is pulled tight around all sides to avoid unappealing slack or droops. The tarp is held tight using rope or bungee cord hooked to the PVC piping as seen in Figure 25 below.

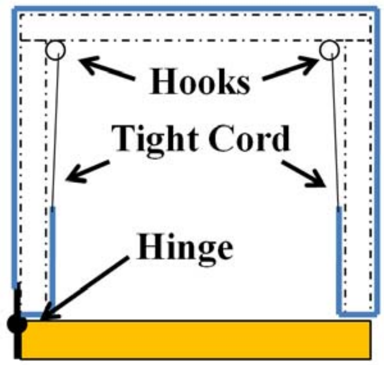


Figure 25: Tarp is wrapped around the PVC frame

FINAL DESIGN

Due to budgetary constraint, our prototype was manufactured out of a variety of materials, including aluminum, wood, and PVC pipes. Ideally, we would manufacture our truck design out of stainless steel and aluminum. The overall truck structure will be the same as our prototype, and the functionally of the truck will remain the same. In addition to the material changes, another area in which the final design differs from the prototype is the general geometry. Components like the bicycle wheels, the swivel casters, and the fluid collection tank will still be used for the final design.

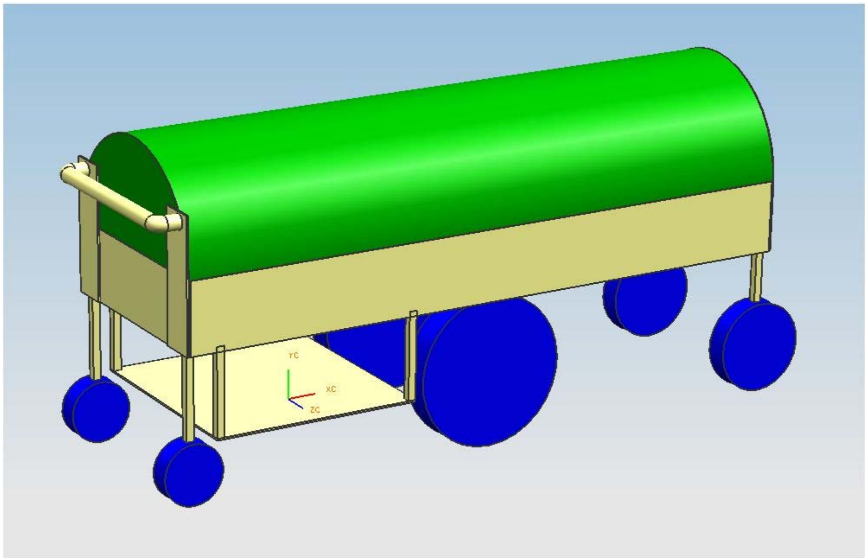


Figure 26: Our final design

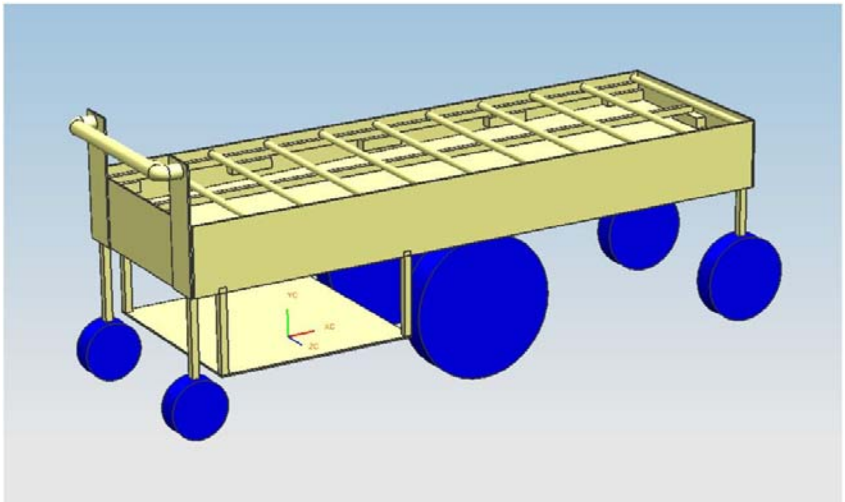


Figure 27: Our final design without the cover

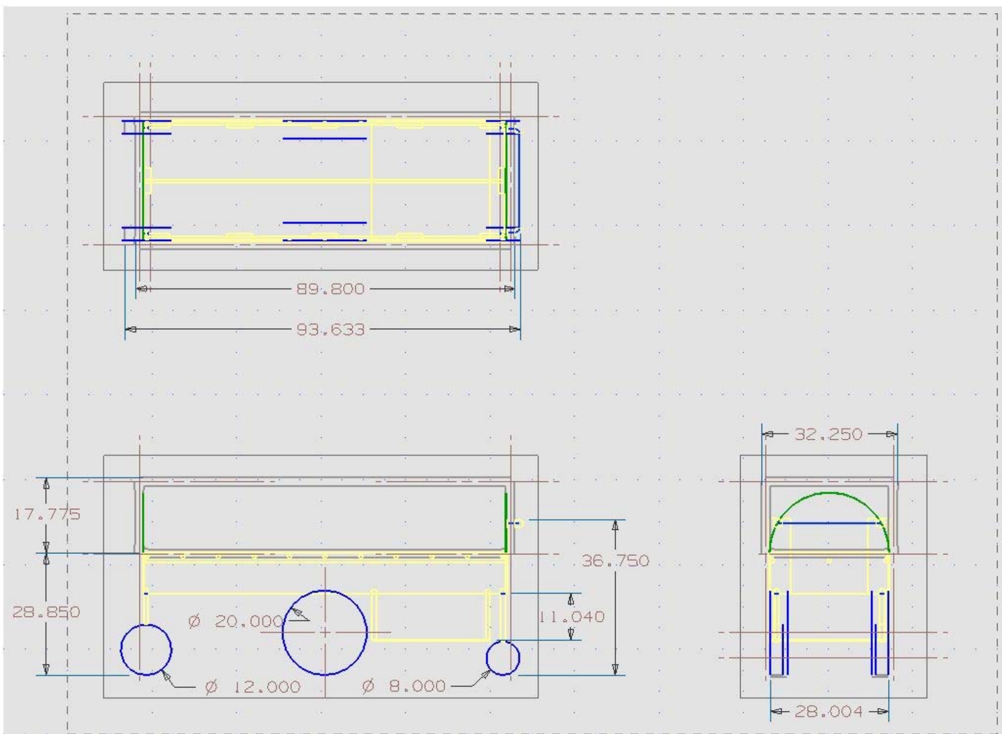


Figure 28: Final design dimensions

In Figures 26 and 27, components that are in green are aluminum, components that are in ivory are stainless steel, and components in blue are purchased parts.

For the final design, the lower half of the truck is made out of stainless steel. This includes the truck structure, the fluid collection tray, the grill, and the legs that are secured to the wheels. The upper half of the truck, the cover, will be manufactured out of aluminum, since it is lighter than the stainless steel. Stainless steel and aluminum are chosen due to their robustness, strength, and ability to withstand corrosive chemicals.

The shape of the truck frame and cover in the final design differ from the prototype design. Since we will not be using two-by-fours for the frame, we will be replacing them with sheet metal made out of stainless steel. This will allow for a narrower truck body which will make it easier to fit through doors. The use of stainless steel metal will eliminate the use of brackets and bolts on the frame since the parts will be welded together. We will be making the cover out of aluminum sheet metal, and since we will not be using PVC pipes and fittings, there will be even more room for the bodies to lay in the truck.

An estimate of our final design is $2000 USD, which is broken down in a bill of materials in Appendix S. This design will be more robust, and will have a longer life span compared to our prototype. We will not be conducting additional engineering analysis on our final design, since aluminum and stainless steel are stronger than the materials that were used for our prototype. Validation testing that will need to be done with the final design includes the water seal test, the ergonomics test, and the maneuverability test.

MATERIAL SELECTION – FUNCTIONAL PERFORMANCE

Truck Frame

We chose spruce as our truck frame material for a number of reasons. Because spruce is the most common wood used to make two-by-fours in the United States, we decided to use this in our prototype design. Lumber made of pine wood is available in much of Africa (including Ghana), and has properties that are very similar to spruce. We have concluded that if we use two-by-fours and four-by-fours for the truck frame, spruce will be able to withstand worst-case scenario stresses that will result from truck's use. This lumber will also be available at a price that is significantly less than any metal or composite materials we considered.

It is necessary to coat the wood to make it waterproof and resistant to decay. The wood used for our prototype will be primed and painted to ensure sufficient protection. These coatings increase the cost of the frame, but not beyond our budget constraints.

If we had no budget constraint, we would choose stainless steel as our prototype truck frame material because of its strength, resistance to corrosion and other deterioration, and its attractive appearance. This is the material we selected for our final design. Our customer would also prefer stainless steel if possible. We are unable to use this material for our prototype, however, because its cost is very high. We also chose not to use standard steel, which would cost significantly less, because we are concerned about corrosion and deterioration from water, bleach, and bodily fluids. Also, standard steel would still cost more than wood.

Fluid Tray

We chose wrought aluminum 6061 alloy (T4 and T6511 temper) to be used for the body tray. This material's properties are very similar to the aluminum alloys in our top choices and it meets the criteria. This material was decided on because we were able to obtain it locally for a good price.

If we had no budget constraint, we would choose stainless steel as our prototype fluid tray material for the same reasons we would chose it for the truck frame. This is the material we selected for our final design. Stainless steel is even more resistant to corrosion than aluminum, so our truck's life would be increased using stainless steel.

MATERIAL SELECTION – ENVIRONMENTAL PERFORMANCE

To analyze the environmental impact of the materials we selected for functional performance, we used SimaPro software. We compared total emissions that result from the production of our materials, as well as the magnitude of environmental impact in various damage categories. Our analysis was completed based on the mass of each material required for our prototype, which are 31.24 kg of spruce wood and 24.81 kg of aluminum alloy. A full analysis of our material selection process and findings can be referenced in Appendix D.

According to our analysis, the majority of the environmental impact from the use of these materials comes from the resources required for the aluminum. Production of the aluminum also has a slight adverse environmental impact on human health and ecosystem quality. The production of the spruce wood that our prototype requires has a small adverse effect on ecosystem quality, but has negligible effects on human health and resources.

In general, the aluminum alloy required for our prototype has a greater environmental impact than the spruce wood required. This was expected, because spruce wood is a natural material, whereas aluminum alloys are man-made. The environmental impact of spruce wood may be underestimated by SimaPro, however, because the spruce wood we used for our prototype was treated to be resistant to rotting and insects. The chemicals used for this treatment have an environmental impact that is most likely not taken into account by SimaPro.

SAFETY REPORT

A full safety analysis of the final design of the mortuary truck was done to ensure that there are no major risks in the manufacturing or operation of the truck. The major purchased components for the project will be the casters and bicycle wheels, which were analyzed through Failure Modes and Effects Analyses. To highlight areas of possible risk, DesignSafe software was used to analyze risks with the current cart. The team has planned the manufacturing and assembly procedures to ensure that the fabrication process will be safe for all those involved. Risks were assessed for each sub-process. Once assembly is complete, validation will begin to verify the cart's static and dynamic load capacities, ergonomic qualities related to pushing and loading, maneuverability, and water tightness of fluid system. The full safety report can be referenced in Appendix E.

ENGINEERING DESIGN PARAMETER ANALYSIS

Once our final design and materials were selected, a detailed engineering analysis was conducted using our previous engineering fundamentals analysis (Appendix S) as a reference. We conducted analysis on the components of the truck that have the largest risk of failure. Analysis performed included buckling of the supporting legs, bending of the cylindrical rods for the grill, and the stress on the bolts that will be used for the prototype. Additional analysis such as failure modes and effects analysis (FMEA) and design risks were also conducted. A summary of the material properties used for our analysis can be referenced in Appendix T. Equations for the analysis come from Dowling's *Mechanical Behavior of Materials* [37].

Buckling

The four cart legs will be subjected to loads from the upper structure and bodies, as shown in Figure 29, and must not buckle under these operating conditions. The maximum force that can be supported by a column before buckling is given by the equation

$$F = \frac{\pi^2 EI}{(Kl)^2}$$

The Young's Modulus (E) of Spruce wood is 13 GPa and the assumption is made that common woods will share a similar modulus of elasticity. The maximum mass expected for the cart legs will be 350 kg for all four legs, or 87.5 kg per leg. This mass results in a force of 858 N per leg. The truck legs will have a square cross section where the base and height lengths are equal. The moment of inertia (I) for a solid rectangular cross section is provided by

$$I_x = I_y = \frac{bh^3}{12}$$

Both moments of inertia are equal due to the square cross section, where the base length equals the height. The constant K is equal to 0.5 because the legs will be fixed at both ends. The final design specifies minimum leg lengths of 40 cm. The critical force equation for a post with cross section lengths of 3" (.0762 m) will yield a critical force of 9×10^6 N, which greatly exceeds our maximum expected loads for a single cart leg.

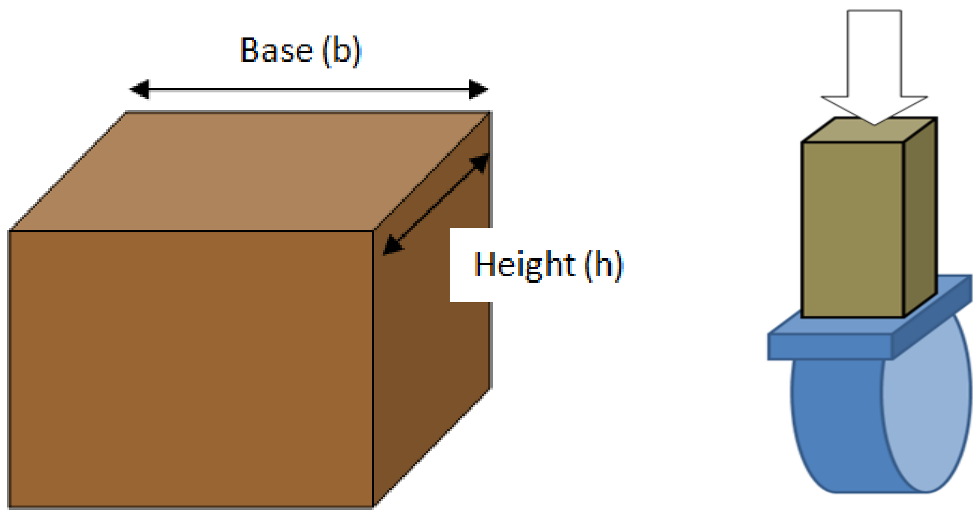


Figure 29: Diagram of loading on cart leg and attached caster wheel

Bending

To design the grill of the fluid collection system we needed to know how much weight can be put on each supporting bar before it yields. First, a 6061 cylindrical aluminum rod was specified with a length of 28", radius of 5/16", and yield strength of 100 MPa. The yield strength was then used as the maximum stress by the equation

$$\sigma_{MAX} = \frac{M_{MAX} * (r)}{I}$$

, where M_{max} is the maximum moment on the bar, r is the radius of the rod's cross section (m) and I is the moment of inertia (m^4).

The moment of inertia for an object with a circular cross section is

$$I = \left(\frac{1}{4}\right)\pi r^4$$

After determining the maximum moment, the resulting value was used in the sum of moments about the end of a bar, given by

$$\Sigma M = 0 = \left(\frac{Wa}{2}\right)\left(\frac{L}{2}\right) - \left(\frac{Wa}{2}\right) * \frac{\frac{a}{2}}{2} - M$$

, where W is the weight (N) distributed along the bar, a is the length (m) that the load is distributed along, and L is the length of the entire bar (m), as seen in Figure 30.

We then calculated the maximum distributed load over a length of 22" of the bar which would cause the rod to yield. We determined that the maximum distributed load that one bar can handle before yielding is 2667 N (600 lb). This is well above our target worst case scenario with a safety factor of 1.5 which is 556 N (125 lb) loaded on one bar.

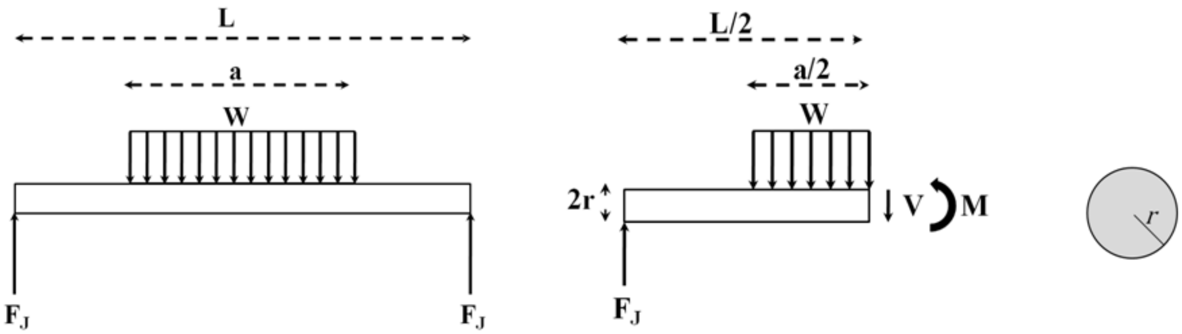


Figure 30: Bending analysis of distributed load over aluminum rod yield occurs at 146 lb

Bolt Shear

The bolts that hold together the structural members of our truck frame undergo shear stress on multiple planes. This shear stress occurs at each plane (perpendicular to the length of the bolt) where the bolt enters or exits a structural member. A representative diagram of a bolt through a structural member can be seen in Figure 31.

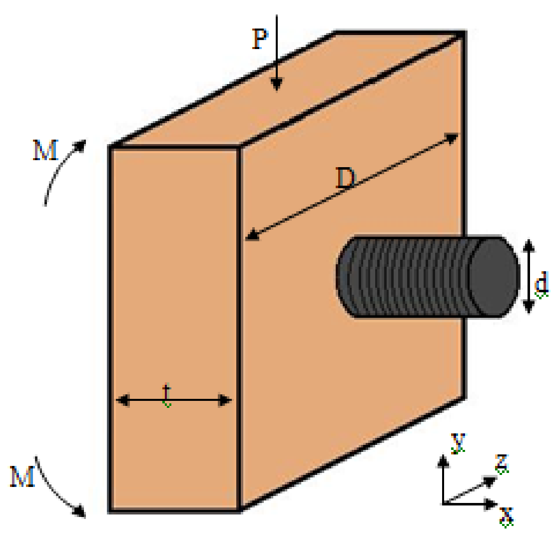


Figure 31: Diagram of a bolt through a structural member

Shear stress on a bolt holding together two or more axially loaded structural members is given by

$$\tau = \frac{P}{A_c}$$

, where τ is the shear stress (Pa) on the bolt in the plane described above, P is the axial load (N) on the structural member, and A_c is the cross-sectional area (m^2) of the bolt. The bolt's cross sectional area is equal to $\pi(d/2)^2$, where d is the bolt diameter (m).

The total mass of the bodies and the truck that the frame must support is 350 kg, with a safety factor of 1.5. If we assume that the weight of this mass all ends up on a single joint with a single bolt, which is highly unlikely but would give a conservative estimate of stress on the bolt, then P would equal 3432 N. If a stainless steel bolt is used, and we assume a yield strength of 690 MPa (which would be the maximum allowable shear stress, and which is the lowest value for stainless steels), then the bolt must have a diameter of at least 2.5 mm, or 0.099 inches.

Stress Concentration Around Bolts

For a structural bar with axial loading or a bending moment, the axial stress will be concentrated the most around the bolts where cross-sectional area is at a minimum. That is to say, axial stress will have a higher magnitude at this location.

For the setup in Figure 31, maximum axial stress for axial loading is given by

$$\sigma_{force} = \frac{P}{A} = \frac{P}{(D-d)t}$$

, where σ_{force} is the nominal axial stress (Pa), P is the axial load on the bar (N), A is the minimum cross-sectional area of the bar (m^2), and D, d, and t are distances (m) indicated in Figure 31. This maximum stress occurs on the plane perpendicular to the axial length of the bar and even with the centers of the holes.

For the setup in Figure 31, maximum axial stress for a bending moment is given by

$$\sigma_{moment} = \frac{Mc}{A} = \frac{6M}{(D-d)t^2}$$

, where σ_{moment} is the nominal axial stress (Pa), M is the bending moment on the bar about the x axis (N-m), c is the distance in the z direction from the neutral bending axis, and D, d, and t are distances indicated in Figure 31.

The bending moment at the site of the bolt hole can be large on the horizontal structural members, but is very small on the vertical structural members. On the horizontal two-by-four that runs the length of the truck, the maximum bending moment would occur when a point load is applied at the midpoint of the beam. Since bending moment is given by the equation

$$M = Pr = P\frac{L}{2}$$

, where M is the bending moment (N-m) on the joint, P is the vertical load (N) on the beam, r is the distance (m) from the load's point of application to the joint, and L is the distance between the joints on either end of the beam, as seen in Figure 32.

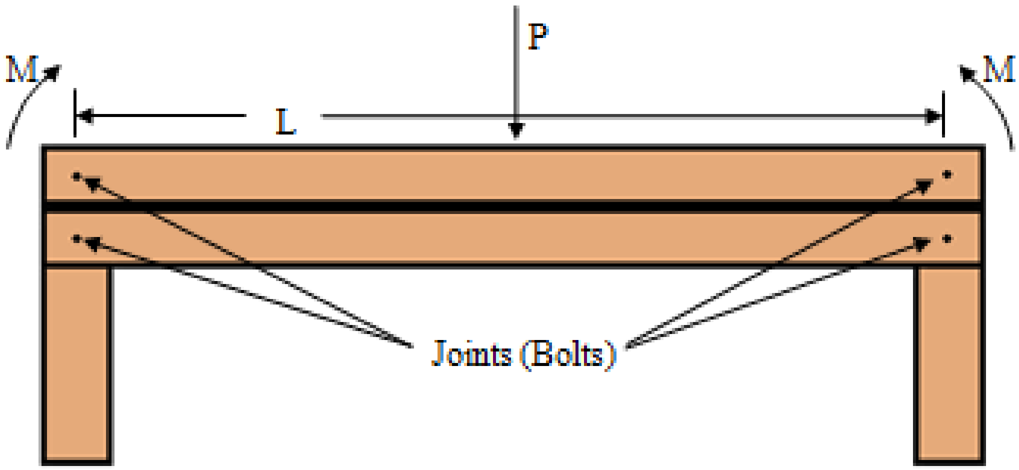


Figure 32: Diagram of loading on the truck frame

The total mass of the bodies and the truck that the frame must support is 350 kg, with a safety factor of 1.5. If we assume that the weight of this mass all ends up on a single wooden two-by-four structural member, which is highly unlikely but would give a conservative estimate of stress on the bolt, then P would equal 3432 N. This load will be in the vertical direction.

We cannot assume that any of the load is transferred directly to the lower horizontal beam (two-by-four) in the diagram. The worst case bending moment would be the scenario indicated in Figure 32 where all 3432 N load is applied to a single point. Also assume that bolt holes are 0.5 inches (0.0127 m) in diameter. Using the stress equations above, this gives a total stress of 6.95 MPa. This is significantly less than the yield stress of spruce wood, which is 35.0 MPa.

On the vertical wood 4x4 supports, the worst case scenario would still be the entire load P (3432 N) acting vertically on a single support. We will assume 0.5 inch (0.0127 m) bolt holes and will neglect the moment on the support since it is very small, coming from the force used to accelerate the cart. Using the stress equation given above, $\sigma_{force} = P/A$, where A is the minimum cross sectional area around the bolt hole, the maximum stress on the vertical wood four-by-four support is 327 Pa. This is significantly less than the compressive stress of spruce wood, which is 34.4 MPa.

Figure 33 shows a view of a bolt going through a wood two-by-four structural member, the sheet metal lining of the body tray, and one of the aluminum bars that support the body tray rack.

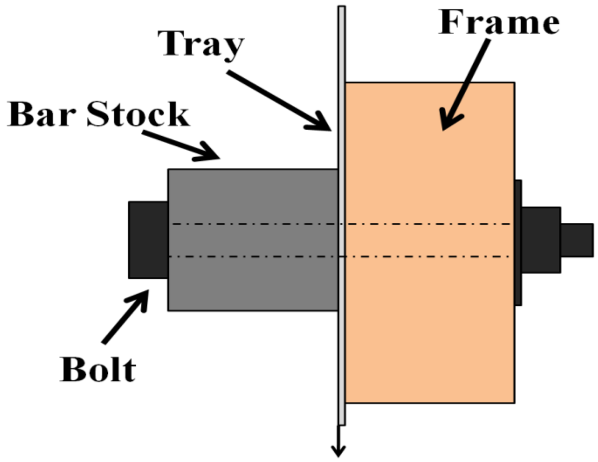


Figure 33: Diagram of a bolt through three truck components

For the aluminum bars that support the body tray, stress concentration can be analyzed similar to the wood two-by-four analysis. The moment on the bars will be negligible because of their short length and because weight will be fairly evenly distributed across the bar. The bars have 0.75 inch (0.0191 m) square cross-sections and are 6 inches (0.152 m) long. Using the stress equation given above, $\sigma_{force} = P/A$, and assuming a worst-case load P of 3432 N and two 0.25 inch (6.4 mm) diameter bolt holes, the maximum stress on the aluminum bar will be 1.42 MPa. This is significantly less than the yield stress of Aluminum 6061 (T6 temper), which is 193 MPa.

To determine whether bolts will tear through the thin aluminum sheets that make up the fluid collection tray, a tear out analysis was conducted. If a bolt were to tear out, the aluminum sheet would fail along the shear planes indicated by dotted lines in Figure 34.

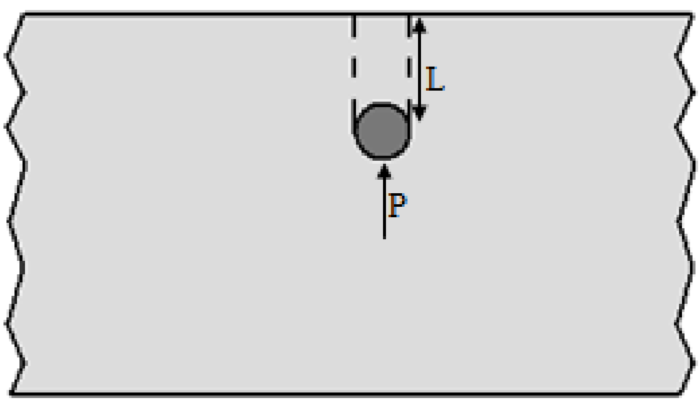


Figure 34: Diagram indicating shear planes for tear out analysis

In Figure 34, P is the reaction force on the aluminum from the bolt, which is equal to the weight of the tray divided by the number of bolts supporting the tray. For our design, this force is equal to 95.33 N. L is the length of the shear planes that the bolts would tear out from if P is large enough, which is 2.75 inches (69.85 mm). The aluminum sheets have a thickness t of 0.025 inches (0.635 mm). This gives a total cross sectional area of the shear planes $A_c = 2Lt = 8.871 \times 10^{-5}$ m^2. Using the shear stress equation, we find that shear stress on the shear planes is equal to 1.07 MPa, which is far below the yield stress of the aluminum (193 MPa).

Dynamic Loading

If a body is thrown onto the cart there is an impulse as the body hits the truck. The average force on the truck during this impulse will be higher than the static loads described above. To determine this average force we considered a situation where a 125 kg (275 lb) body is dropped a distance of 0.5 meters onto the truck. Given the flexibility of the cart we assumed the time it takes for the body to come to rest after being dropped is 0.25 seconds. We first determined the velocity of the body upon hitting the truck using the equation

$$\frac{1}{2}mv^2 = mgh$$

Where m is the mass of the person, v is its velocity just as it is hitting the truck, g is the gravitational constant, and h is the height of the drop. The velocity of the person was determined to be 3.13 m/sec. We then used the following equation below to determine the average force incurred during the impulse.

$$F_{av} = (mv_2 - mv_1)/\Delta t$$

Where F_{av} is the average force incurred during the impulse, v_1 is the velocity of the person just before it hits the truck, v_2 is the final velocity (in this case it =0), and Δt is the time it takes for the body to come to rest after it hits the truck. This average force was determined to be 1566 N. This force is the same amount of force a 160 kg person lying statically on the truck produces. As the truck is designed to support 313 kg statically, we can conclude the truck is capable of handling a dynamic load as long as the truck is not already fully loaded.

Tipping Force

Tipping of the truck is not a large concern for our engineering analysis. The frame of the truck does not extend over the truck's wheel base more than 2.6 inches on any side, so under static loading conditions, the truck will not tip unless a load is centered on the very edge of the truck. There is also a very low risk of tipping under dynamic conditions because the truck will not be pushed very fast at all, especially while turning. The fact that the truck's center of rotation is within it's wheelbase further reduces the risk of tipping.

Additional Analysis

Failure Modes and Effects Analysis

Analysis for the three main components we will be purchasing for our truck was conducted using FMEA. The failure analysis summary is listed in Table 5 below. For the full analysis, reference Appendix U.

Component	Highest risk priority number	Other major risks
Casters	Cracked Wheel	Other major risks: Wheel bearing stuck, brakes stuck, yield or fracture in metal
Bicycle Wheels	Broken structure (e.g. hub, rim, spokes, fork)	Flat tire
Bicycle Brakes	Snapped cable	Loss of cable tension, calipers jammed

Table 5: Summary of the FMEA

Design Risk Analysis
To evaluate the risks associated with our truck design, we used DesignSafe software to analyze the risks and determine possible solutions to reduce those risks. A summary of the risks we considered is listed in Table 6. For the full analysis, reference Appendix V.

Category	Possible risks
Mechanical	Unexpected start, fatigue, machine instability, impact
Ergonomic / Human Factors	Posture, lifting / bending / twisting, excessive weight
Environmental / Industrial hygiene	wastewater contamination, corrosion
Chemical	Skin exposed to toxic chemicals, irritant chemicals
Biological / Health	Blood borne diseases, unsanitary conditions, hazardous biological waste

Table 6: Summary of the DesignSafe analysis

FABRICATION PLAN

Fabrication of the prototype involves simple hand tools such as wrenches, screw drivers, c-clamps, drills, metal files, and hand saws. The only advanced manufacturing process involved is the cutting and welding of aluminum. These processes required the use of an electric circular saw and a sheet metal cutting station. All fasteners are involve wood screws, lag screws, bolts, washers, and/or metal brackets. The following is a detailed description of the fabrication process.

Frame
The frame is constructed from boards of treated wood. 14 pieces of wood are required for assembly and are listed according to dimensions in table XX. The following is the manufacturing plan for building and assembling the frame.

Dimensions	Quantity
1.5" x 3.5" x 88.5"	4
1.5" x 3.5" x 29"	6
1.5" x 3.5" x 8"	2
1.5" x 3.5" x 6"	2
1.5" X 2.5" X 5.5"	8
3.5" X 3.5" X 7.25"	2
3.5" X 3.5" X 10"	2

Table 7: Dimensions of wood for construction of frame

Step 1 Before the boards of wood are assembled, ¼" holes are dilled are drilled along the length of two of the 88.5" boards and two of the 31" boards. The holes are drilled in the center of the board at the locations shown in Figure 35.

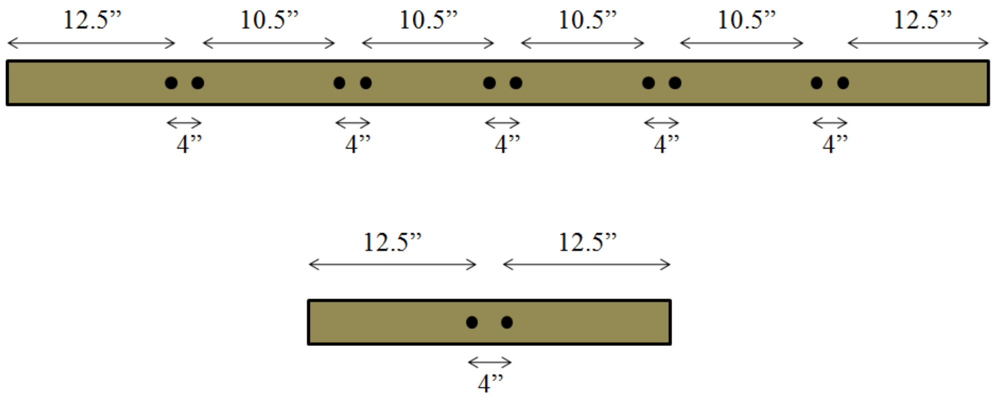


Figure 35: Locations of ¼" holes drilled in frame

Step 2 The frame construction begins by bolting two of the 88.5" long boards to two of the 29" boards to create a rectangular box. The boards are held together by two, 90 degree inner brackets as shown in Figure 36. Each bracket is held in place by four 3/16" x 2" bolts.

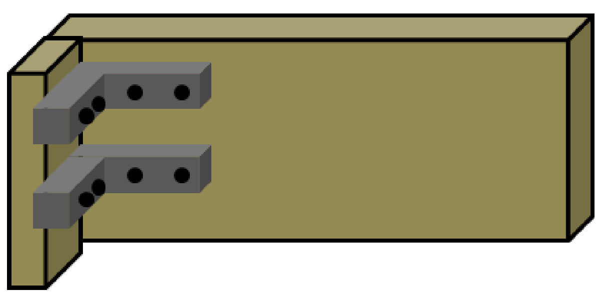


Figure 36: Wood joints held together by two, inner, 90 degree brackets

Step 3 Two of these boxes are created and strapped together using 6" aluminum straps as seen in Figure 37. The top box is the one with the ¼" holes drilled created in Step 1. Two 1.5" x 3.5" x 6" and two 1.5" x 3.5" x 8" boards are attached to the bottom corners of one end of the frame using 4 6" aluminum straps per corner. The aluminum straps are held in place by four ¼" x 2" bolts.

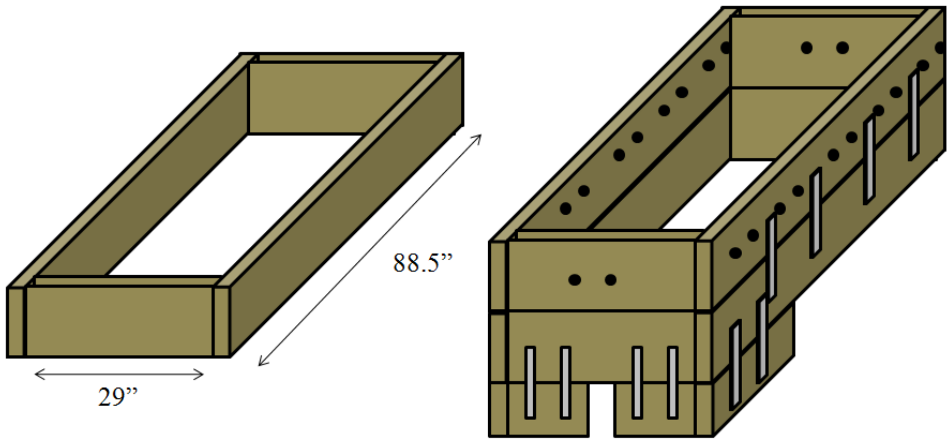


Figure 37: Two wooden frames and four corner boards strapped together

Fluid Collection System

The fluid collection system consists of a grill supported on a rim of rectangular bar stock over a fluid collection tray. These components are made from aluminum and are assembled in such a way as to completely isolate the body fluid to the system and not touch any portion of the wood frame. The fluid collection system also consists of a drain system which includes a hose which runs from the fluid collection tray to a fluid collecting container. The following is the manufacturing plan for building and assembling these components.

Step 1 - Tray The fluid collection tray is made from sheet aluminum which is .635 mm (0.025 in) thick. The tray is formed from three sheets, A, B, and C shown in Figure 38 – Figure 40. The sheets are bent along the dotted line such that the large flat portion of each piece would rest flush with the ground and the small flap pieces on the sides would bend upward 90 degrees and perpendicular to the ground. A 2” hole is made in sheet C to be used for fluid draining.

Sheet A is sealed to sheet B insuring that A overlaps B by 2.5 cm (1 in). Sheet B is sealed to sheet C insuring that B overlaps C by 2.5 cm (1 in). This overlap is to prevent large quantities of liquid from leaking between the seams. The seal is created from silicone sealant intended for application to aluminum.

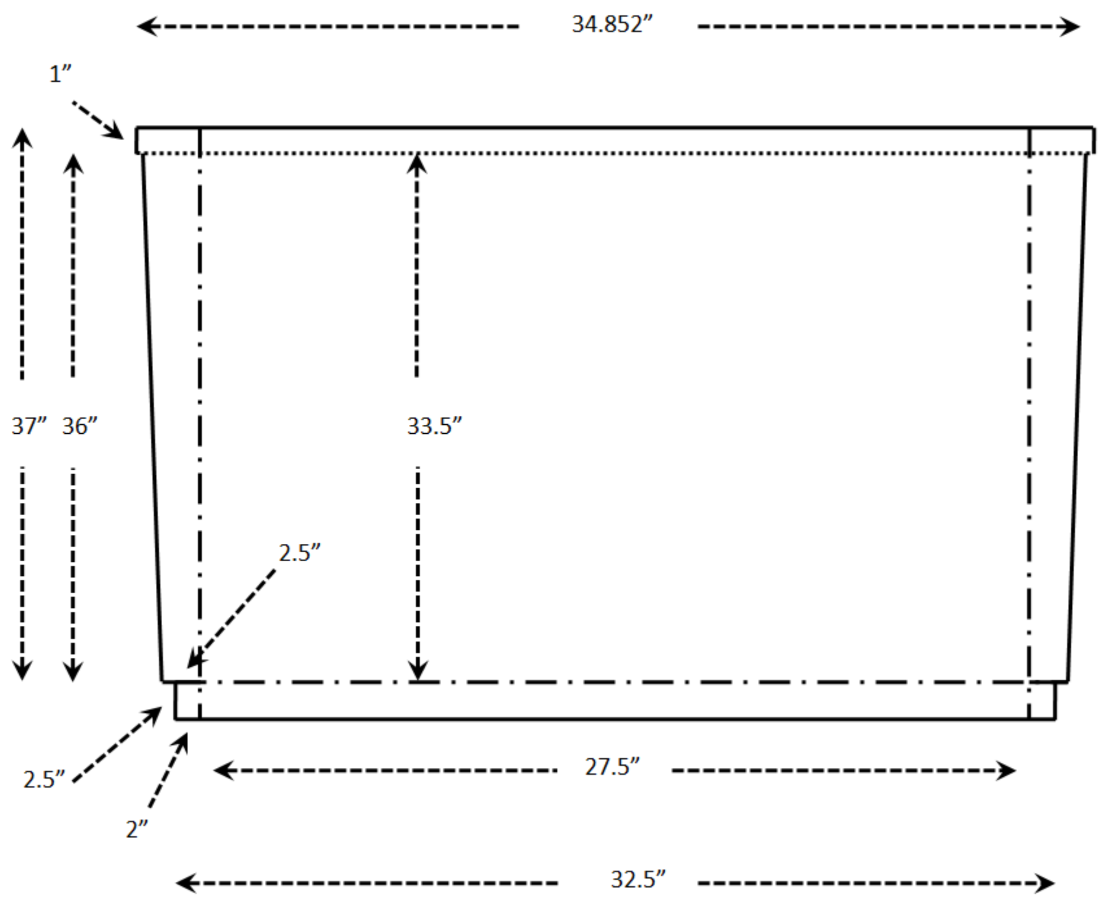


Figure 38: Dimensions of sheet A

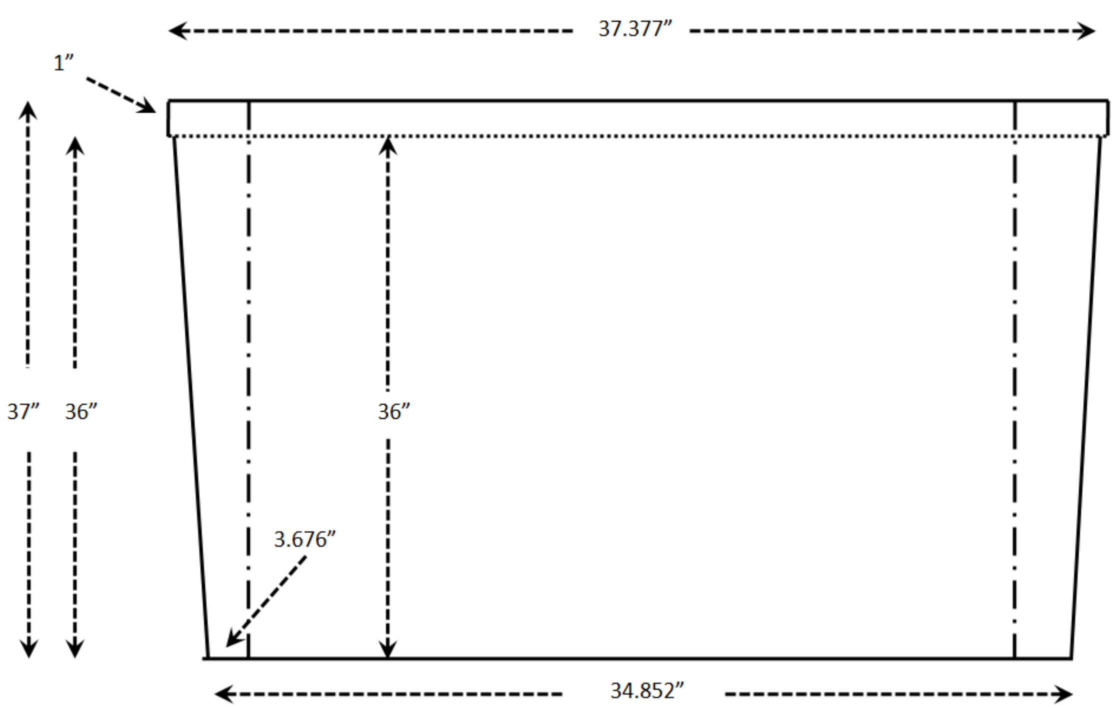


Figure 39: Dimensions of sheet B

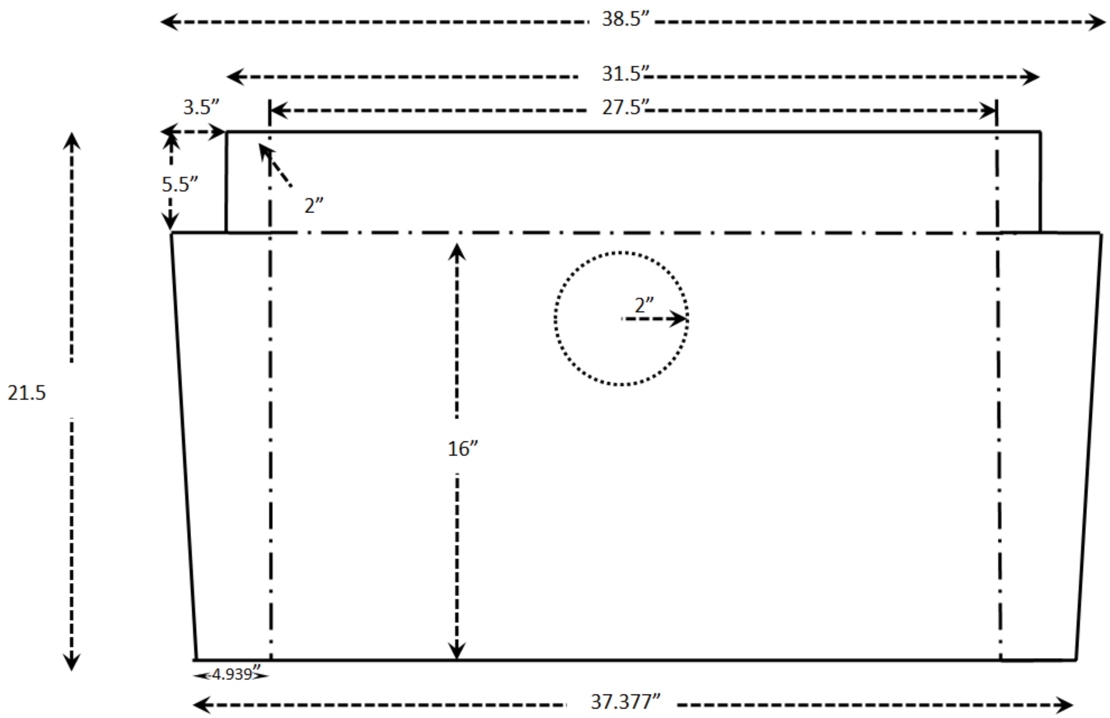


Figure 40: Dimensions of sheet C

Figure 41: Assembled fluid tray

Step 2 - Outer Rim 12 pieces of solid aluminum bar stock with dimensions of ¾” x ¾” x 5” are used to create the outer rim. Two ¼” holes centered on the bar and ½” in from each side are drilled in each bar as shown in Figure 42.

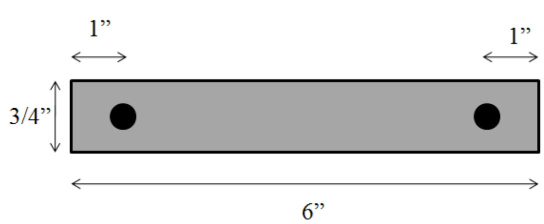


Figure 42: Aluminum bar used for outer rim

Once the fluid tray is assembled, it is placed in between the bar stock and the wood frame and bolted to the frame as shown in Figure 43. A washer will be used with a ¼” x 4” bolt to insure that the load from the bolt is distributed over a larger area of the wood to prevent cracks. All connecting joints and points of contact with other metals will be sealed with silicone sealant to prevent fluid from entering the cracks and corroding the aluminum.

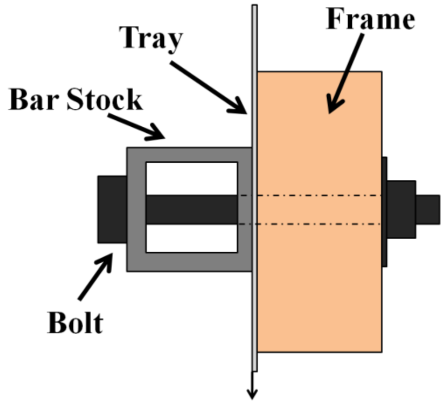


Figure 43: Fluid tray is bolted between the outer rim and wooden frame

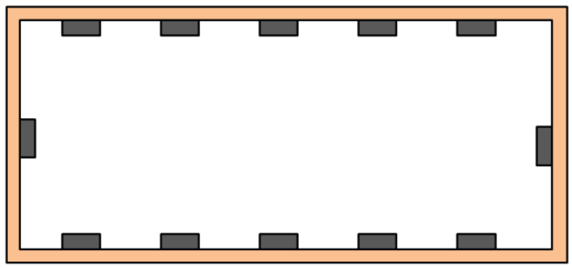


Figure 44: 12 pieces of aluminum bar stock make the outer rim

Step 3- Grill The grill is made from six, solid, aluminum, cylindrical beams and 2 hollow, rectangular, aluminum bars. The cylindrical beams are 30” long and have a ¾” diameter. The rectangular beams are 84” long and have side dimensions of ¾”. The beams are welded together to create a grill as shown in Figure 45.

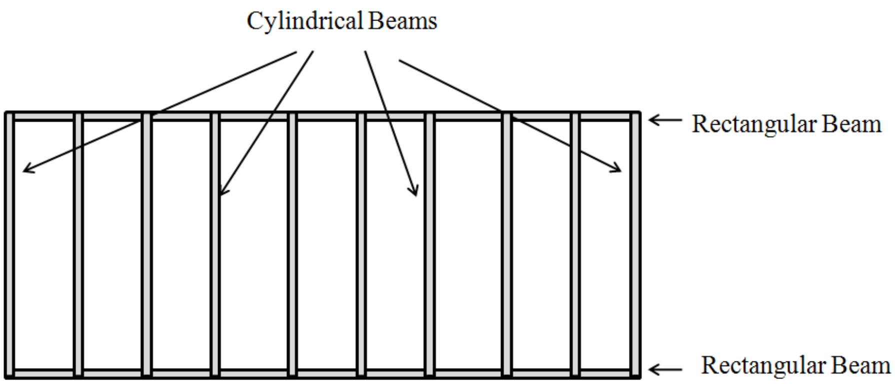


Figure 45: Rectangular beams run length of grill, cylindrical run width

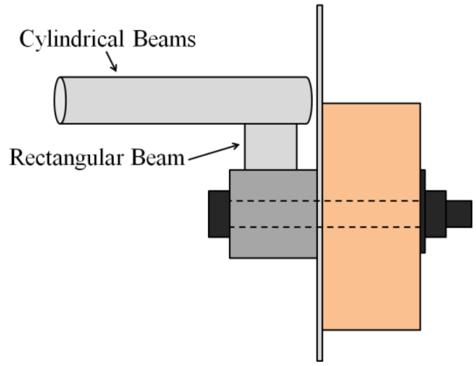


Figure 46: Assembled portion of fluid collection system

Step 4 - Drain The drain is made from a standard shower drain fitting similar to the one pictured in Figure 47. It fitted and glued to the hole in the fluid collection tray. A 3" long PVC pipe with a 4" diameter is attached to the bottom of the drain. Attached to the PVC pipe is a 4:1 PVC diameter adapter. Attached to the adapter is a 1" pipe threaded hose adapter similar to the one seen in Figure 48.

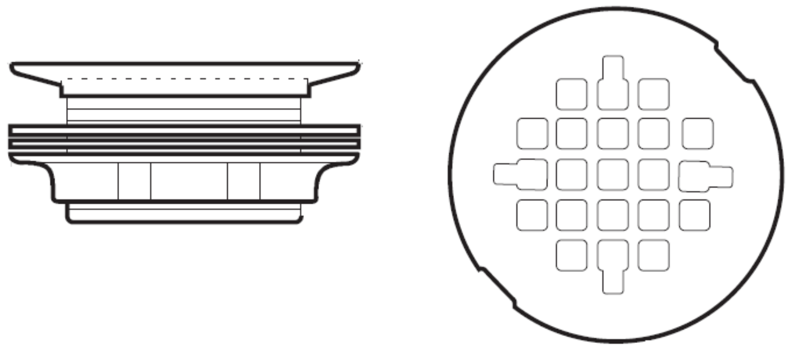


Figure 47: Drain used at the interface between fluid tray and container

Figure 48: 1" threaded hose adapter connects hose to fluid tray drain

Step 5 – Container and Support The hose described above rests inside the fluid container. The fluid container is a 6.5 gallon gasoline tank which has dimensions 21.5"×13.75"×10" and is pictured in Figure 49

Figure 49: Fluid hose runs into 6.5 gallon fluid tank.

The support structure for the fluid container hangs off of the bottom cart and is pictured in Figure 50. It is made from 8 steel brackets, four of which are 14" long, two are 28" long, and the other two are 48" long. The brackets are fastened to each other using ¼" x 1" bolts. A 48" x 28" piece of plywood is bolted using the same bolts across the bottom of the structure.

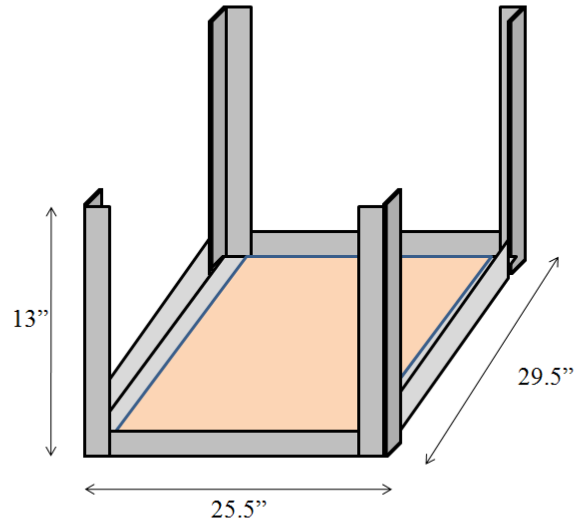


Figure 50: Support for fluid container made from steel brackets and plywood.

Cover

The cover is made from PVC piping covered by a tarp. The PVC is cut to the dimensions shown in Figures 51 – 53 and fit together using standard 90 degree joints. Sides A and B are the two width ends of the cover and sides C and D are the two length ends of the cover. The four sides come together to form a box. The cover is hinged on side D to allow the cover to open like a traditional grill cover. The hinge is attached to the PVC by 3/16" x 2" bolts and is attached to the wooden frame using three ¼" x 1" woodscrews. The tarp is pulled tight around all sides to avoid unappealing slack or droops. The tarp is held tight using bungee cords hooked to the PVC piping.

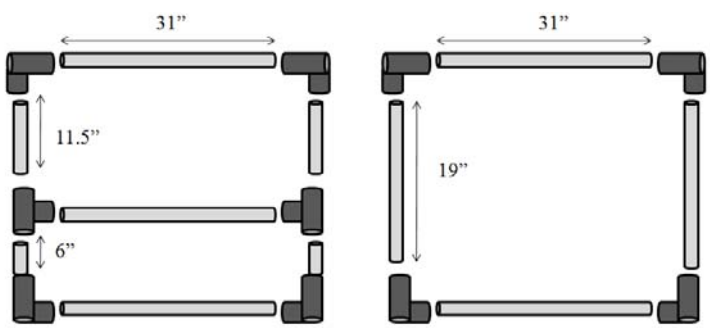


Figure 51: Dimensions of sides A and B

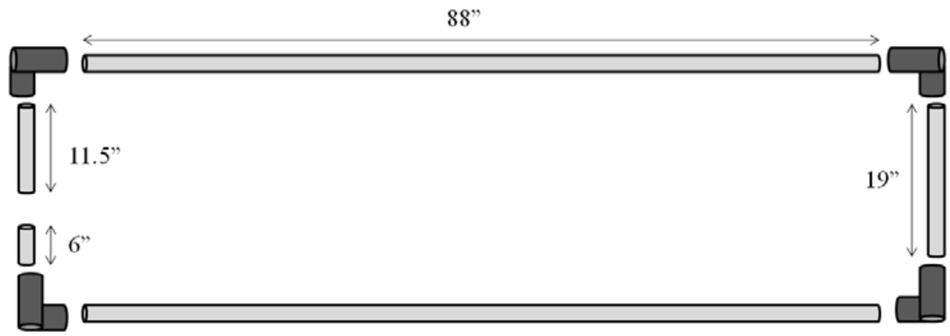


Figure 52: Dimensions of side C

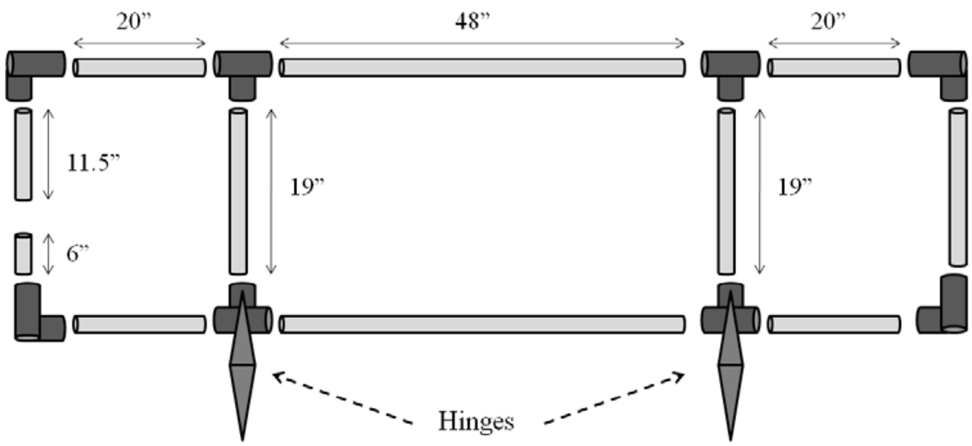


Figure 53: Dimensions of side D

Wheels
The wheels are composed of two 8” diameter pneumatic casters with a foot lock, two 12” diameter pneumatic casters, and two 20” bicycle tires. The following is the manufacturing plan for attaching the wheels to the frame.

Step 1 – Casters The legs which are attached to the casters are made from the 3.5” x 3.5 x 7.25” and the 3.5” x 3.5” x 10” pieces of wood. Using four 5/16” x 3” lag bolts, two 1.5” x 2.5” x 5.5” pieces of wood are attached to each leg as shown in Figure 54 to act as an adapter so the casters can be attached to the leg. Pre-drilling the holes with a .2975” bit is required. The casters are mounted to the wood adapters with four 5/16” x 3” lag bolts as shown in Figure 55.

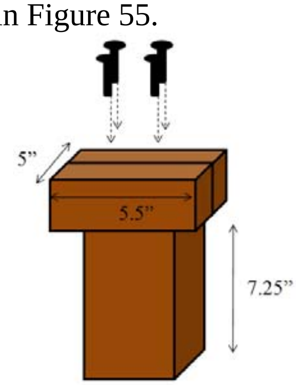


Figure 54: Lag bolts hold adapter wood to bottom of wheel leg

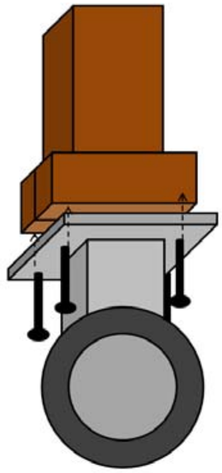


Figure 55: Lag bolts attach caster to adapter wood at the bottom of the leg

Once all four legs have been assembled in this manner, four ¼” x 4” wood screws are used to attach each leg to inside of the frame. The front (12”) casters are mounted such that the top of the leg extends 4” past the bottom edge of the frame as shown in Figure 56. The rear, 8” casters are mounted such that the top of the leg extends 6 inches past the bottom edge of the frame also shown in Figure 56.

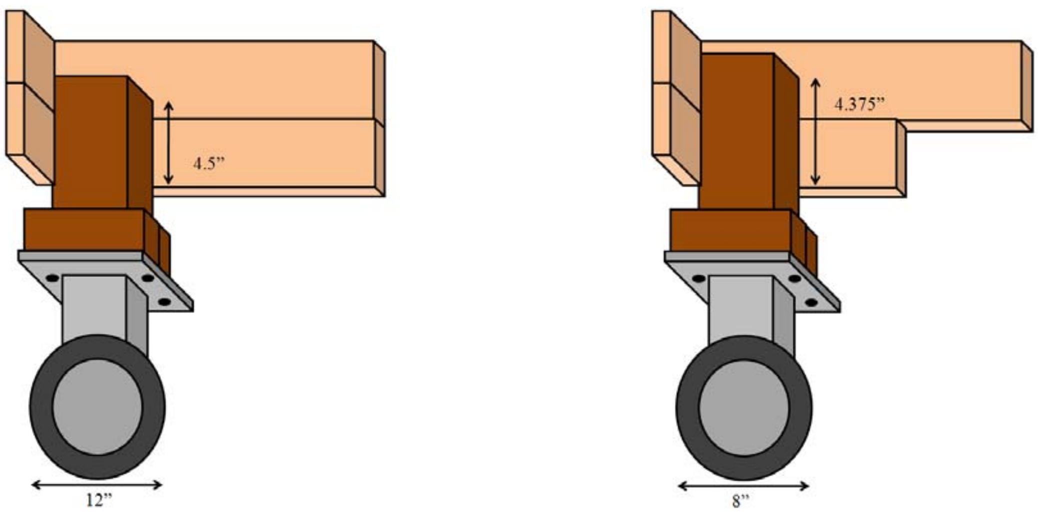


Figure 56: Positions of legs relative to the bottom edge of the frame

Step 2 – Bicycle wheels The bicycle wheels are attached via a 1.3” x 3.5” x 29” piece of wood running the width of the truck. Attached to the wood is the fork used to hold a bicycle wheel in place for a standard bicycle shown in Figure 57. Each fork is attached using three 3/16” x 4” bolts.

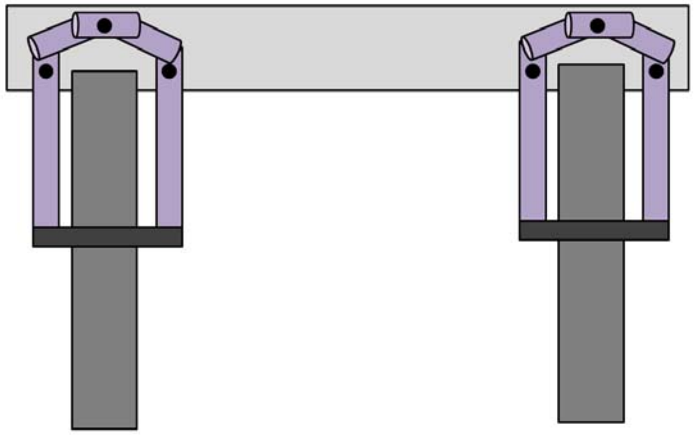


Figure 57: Bicycle wheels attached to aluminum sheet on wood cross member

VALIDATION TESTING

Validation began once the truck was fully assembled. We conducted testing for water tightness of the fluid system, static loading, ergonomic qualities, ease of cleaning, and maneuverability.

Static Loading

The truck's load capacity was verified by adding loads on to the grill. We loaded 500 lbs onto the grill, which is equal to 72% of our engineering specification requirement. This test checked for any visible issues with the structure during loading, including excessive bending, cracking, or other movement. The test was repeated three times with the load placed in different areas of the grill.

Figure 58: Dynamic loading

Results. From the static load testing, we were able to load the truck up to 500 lb.

Dynamic Loading

Testing was done to ensure the truck's ability to handle impulses and dramatic changes in loading. A team member of 140 lbs. stood on top of the grill, made a one foot high jump in the air, and then landed on the grill to create a dynamic load. This dynamic load is to recreate loads from bodies being thrown onto the grill surface during normal operation. The test was to check for any visible damage or structural issues in the truck's frame and other components during loading.

Results. The grill and supporting structures showed no damage, movement, or structural issues during loading.

Indoor Testing

Indoor Maneuverability

Maneuverability was tested by having four different operators pushing the truck around the first and second floors of the G.G. Brown Building at the University of Michigan. The test involved pushing the truck through the hallway while avid people and objects on the ground. This test is done to ensure that our truck is easy to maneuver and control. This test also allowed us to evaluate how the casters and wheels operate indoor.

Figure 59: Indoor maneuverability testing

Results. From the indoor maneuverability testing, we found that with the two bicycle wheels guiding the movement of the truck, the truck is easy to maneuver.

Turning Ability

Turning ability of the truck was tested by having five different operators pushing the truck around corners and testing the turning radius. This test was done to ensure that the specification of a zero turning radius is met.

Figure 60a-b: Turning capability testing

Results. From the turning test, we found that our truck does have a zero turning radius, and pivots about a point between the two bicycle wheels.

Fluid Management

Water tightness

Water tightness was validated by flooding the body tray with water. This replicates the fluids leaving the body during transport. The main purpose of the test was to check for leaks of the fluid tray. The test was conducted while the truck was both stationary and in motion. This was to ensure that truck movement and vibrations do not jeopardize the fluid system’s effectiveness.

Figure 61a-b: Water tightness testing

Results. From the water tightness testing, we found that the fluid tray is watertight and that fluid does not leak.

Fluid Drainage System

Fluid drainage system was tested by pouring water down the fluid tray. We observed the flow of the water, and how easy it was for the water to flow the drain, down the tubing into the collecting tank. This test was done to ensure that our fluid drainage system will work and that the flow of fluid is guided into the collecting tank.

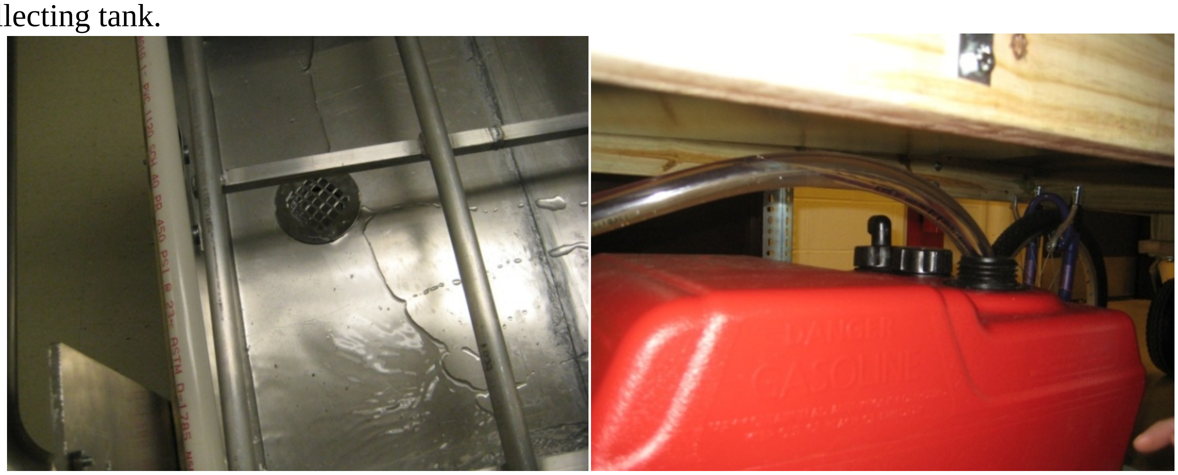


Figure 62a-b: Fluid going into the drain, through the tubing and into the container

Results. From the fluid drainage testing, we found that the fluid does flow through the drain through the pipe and into the tank; however, water below the drain does not flow, and forms a puddle at the end of the tray.

Tank Exchange

Tank exchange was tested by having flowing water going down the drainage system while removing the tube from one tank and putting it back into another tank. We observed the flow of the water, and test to see whether or not water leak out of the tubing during the tank exchange. This test was done to ensure the ability of fluid tank exchange.

Figure 63a-c: Switching the tank

Results. From the tank exchange test, we found that with our current design we could exchange the tank without leakage, however the procedure would be easier if the container is moved forward allowing for longer tubing.

Outdoor Testing

Pushing Uphill and Downhill

To test how easy it is to push the truck uphill and downhill, the truck was pushed outside in front of the FXB building. The truck was pushed downhill and then pushed uphill. This test was done to ensure that the truck is easy to control.

Figure 64: Pushing of the truck downhill

Figure 65: Pushing of the truck uphill

Results. From the uphill and downhill test, we found that the truck is capable of going uphill and downhill. However when going downhill, it would make speed control a lot easier if the braking system of the bicycle wheels were attached.

Traveling through Different Terrain

To test the ability of the truck to travel across rough terrain, the truck was pushed through different types of surfaces outdoor, such as grass, cement, and mulch. The truck was also pushed over curbs. This test was done to ensure that the wheels are capable of travelling over these types of terrain.

Figure 66: Pushing of the truck over a curb

Figure 67: Pushing of the truck through cement

Figure 68: Pushing of the truck over mulch

Figure 69: Pushing of the truck over grass

Results. Results. We found that occasionally when pushing the truck over uneven terrain, the truck turns unintentionally when not all of the wheels are touching the ground. We also found that because the wheels are not tightly secured to the truck frame due to the warping of the wood, the back caster wheels have a hard time staying in line when pushing through rough terrain.

Wheel Lock Capabilities

To test the wheel locking capabilities, we locked the wheels on various surfaces indoors and outdoors. The truck was tested on a flat surface and an angled surface. This test was done to ensure that the wheels can lock the truck.

Figure 70: Truck staying stationary on a slope

Results. From the lock capability testing, we found that the 8” swivel casters with locks can lock the wheels and keep the truck stationary even when the truck is on a sloped surface.

Coverage from View

To ensure that the body is covered 100% from view, we had people lay in the truck and close the cover to see whether or not body could be viewed from outside.

Figure 71: Testing of the coverage of the tarp

Results. From the coverage test, we found that our tarp cover is sufficient, and prevent view of the body from outside.

Ergonomic Testing

The truck was pushed indoor and outdoor by four different operators. Each operator had the opportunity to push the truck for 15 minutes. The operators had to push the truck through different types of terrain, evaluating how easy it is to push the truck, and how comfortable it is to push the truck. The operator will note any discomfort during operation. This test will allow us to obtain information on the ergonomic design of our truck.

Figure 72: Ergonomic testing of the truck

Results. From the ergonomic testing, we found that the handle height of the truck allows for operator with height ranging from 5’6” to 6” to push the truck easy and comfortably with no discomfort.

Future Testing

Because of the limited resources we have available to us and the limited amount of time we have, there are some testing we would like to conduct but are unable to do so. Additional testing we suggest to conduct in the future includes fast aging test and humidity/temperature test.

We suggest putting the truck into a fast aging chamber to simulate the effects of aging of six months, one year, five years, and 10 years. Once the fast aging is completed, the tests listed above could be re-run. This will help determine or at least give an estimate of the lifespan of the truck.

For the humidity/temperature combination testing, we suggest putting the truck into a humidity chamber, and testing in relative humidity ranging from 0% to 100% with different combinations of temperature, alternating between high and low temperatures. Once the testing is completed, the tests listed above could once again be re-run. This test will be useful to see how the temperature and humidity will affect the strength of the truck.

DISCUSSION

Some of the things we could have done differently during manufacturing include purchasing wood that is kiln dried, instead of weather treated. One of the greatest challenges we dealt with during fabrication was the warping of the wood. The warping of the wood caused our team to have to modify our design. Modifications made can be referenced in Appendix C.

Our design is easy to maneuver, easy to turn with a zero turning radius, and it can withstand a large load and has a fluid drainage system that does not leak. While the truck is in motion, the truck is stable and does not rock.

Some weaknesses to our prototype design include the angling of the bicycle wheels inwards and outwards while turning in high speed, the difficulty of switching the tank, the pooling of the water at the end of the fluid tray, the excess amount of the brackets, bolts, and nuts used, and the difficulty to secure or remove the tarp.

Future improvements that can be made to our design include using T-nuts to eliminate the use of nuts so the bolts will be flushed against the wood, using kiln dried wood so wood warping will not be a problem and fewer brackets are needed, and to improve the design of the tarp cover, so it is easy to use and remove. Also by shifting the fluid container forward, there will be most space for additional tubing which will make the tank exchange easier. In addition, if wheel forks are not chrome coated, a metal bar can be welded onto the top of the fork, and this will make securing the wheel set to the main structure easier and more reliable.

RECOMMENDATIONS

Some recommendations we have for our final design include modifying the drainage system, redesign the tarp cover, and wheels attachments.

For the drainage system, we recommend to move the fluid container forward so longer tubing can be used. Also we recommend lowering the drain so that there will not be pool of water collecting at the bottom of the fluid tray.

For the cover, we recommend redesigning the whole cover. We do not recommend using PVC and a tarp cover since that it is hard to secure and remove, and that it is also not very aesthetically appealing.

For the wheel attachment, we recommend attaching the bicycle wheels with a welded bar instead of directly drilling holes on the fork and for the swivel casters, we recommend finding a way to attach them without cracking the wood, and finding a better way to secure the four-by-fours to the main frame, so that they do not wobble when traveling through rough terrain.

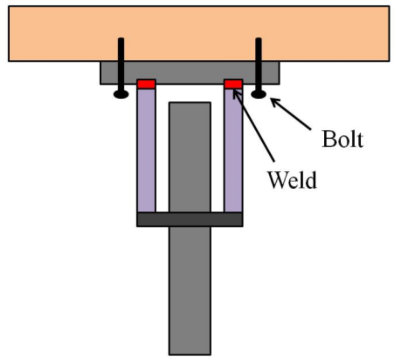


Figure 73: Recommended way to attach the bicycle wheels

CONCLUSIONS

Our task is to design a new mortuary truck for the Komfo Anyoke Teaching Hospital in Kumasi, Ghana. Major requirements of our truck design include the ability to carry at least two bodies, a cover to keep the bodies from view, the ease of cleaning, the ease of transportation over different surfaces or terrain, and a low construction cost.

Through dialogue with hospital staff, morgue visits, and literature research of the current products and patents, we were able to generate a set of engineering specifications. Once the main customer requirements were captured, we began to identify engineering fundamentals that will possibly impact our design.

The concept generation began by performing a functional decomposition analysis on the truck. We broke the truck down into sub-systems to better understand their functionality and the requirements that need to be met. The truck consists of five major sub-systems which include the body concealing method, the main frame of the truck, the fluid management system, the wheels, and the brakes. Each team member created multiple concepts for each sub-system. Using discussion, voting, classification trees, and the aid of a Pugh chart, we went through three iterations of design generations and selections. Between the second and third concept generation we received feedback from Professor Sienko and Mr. Fusani that helped modify our designs. Once the third concept selection was completed, we designed and drafted our alpha design.

The alpha design is a structure supported by two large fixed bicycle wheels along with two small swiveling caster wheels. The design features two trays that stack vertically, with the upper tray hinged to allow lower tray access. Other features include a dome shaped cover, bicycle wheel brakes, two fluid collection trays, and two collection containers. During the concept generation and decision process, tools such as team brainstorming, functional decomposition, classification trees, and feedback enabled us to evaluate the concepts and perform modifications to the original designs to produce a refined alpha design.

With the development of our alpha design, we recognized some design problems. To deal with those design issues, we went through several other concept generation and redesign of the truck. After several design modifications, we were able to come up with our final design. Our final prototype design features a one tier body tray system, with wood being the main supporting structure, and PVC piping to support the tarp cover. The body tray and fluid collecting system were made out of aluminum bars and sheet metal.

The final design of the truck is specified to be made out of aluminum and stainless steel. The estimated material cost for this design is approximately $2000 USD. This design will have the same function as our final prototype. One of the few factors that differ from the prototype will be geometry differences and this is mainly due to the material changes. The final design made out of the aluminum and stainless steel will be more durable and more robust compare to our prototype due to the characteristics of the materials.

Engineering analysis was conducted to obtain parameters for the final design. Analysis performed includes, static load calculations, material selecting using the Cambridge Engineering Selector, risk analysis using DesignSafe software, and FMEA for purchased materials. A detailed fabrication plan was drafted. Fabrication was broken down into subsections, such as the wood structure assembly, the welding of the grill, and the fabrication of the fluid collecting tray. Once each component was fabricated, we then assembled them all together into our final prototype.

Once the fabrication of the prototype was completed, we conducted validation testing. Tests that were conducted include maneuverability tests over different types of terrain, static and dynamic loading, fluid management testing. Some recommendations we have for our design from the validation testing include moving the fluid collection tank forward, using different methods to secure the wheels, and using kiln dried wood instead of weather treated wood. We found that our prototype meets all our engineering specifications, but additional improvements can be made.

BIOGRAPHIES

Mr. Todd Bueschen
Undergraduate Student
B.S. E Mechanical Engineering at The University of Michigan, Ann Arbor, December 2009.

Todd was born in New Brunswick, New Jersey and grew up in Montgomery, New Jersey. He resides in Ann Arbor, Michigan while attending school. His primary interests in mechanical engineering lie in the fields of energy and thermal sciences. As an intern with ThermoAnalytics, Inc., a consulting company in Novi, Michigan, he performed computational fluid dynamics and computational heat transfer simulations for a number of clients including architecture firms and major auto manufacturers. As a co-op for GE Energy, he worked on monitoring heavy-duty gas turbines from a systems engineering perspective. From this co-op, he also gained valuable insight about the manufacturing of these turbines. After completing his undergraduate degree, Todd plans on pursuing a Masters degree in Mechanical Engineering, and then a career in the energy industry. In his spare time, Todd enjoys playing volleyball, cooking, and running.

Mr. Robert Cudini
Undergraduate Student
B.S. E Mechanical Engineering at The University of Michigan, Ann Arbor, May 2009.

Robert was born in Detroit, Michigan and grew up in Grosse Pointe Farms, Michigan; currently he resides in Ann Arbor, Michigan during the fall and winter. He has focused his engineering degree on Manufacturing Systems, discovering his fascination for this subject while working at General Motors in Warren, MI. During his two internships at GM, Robert worked as a manufacturing engineer in the Body-In-White Manufacturing group, assigned to manufacturing development teams for the next generation global mid-size sedans. These assignments gave him the chance to visit assembly plants, product development departments, design studios, and manufacturing laboratories. Once his undergraduate degree is completed, Robert will begin his Master’s degree in Manufacturing Engineering. After completion of graduate school, Robert plans to pursue a career in automotive manufacturing as an engineer assigned to programs for an automotive OEM.

Ms. Wei-Tung (Cindy) Wang
Undergraduate Student
B.S. E Mechanical Engineering at The University of Michigan, Ann Arbor, December 2009.

Cindy was born in Taiwan, and grew up in Windsor, Ontario; currently she resides in Ann Arbor, Michigan. Her motivations in the area of mechanical engineering heightened after discovering that she was greatly interested in working as an R&D engineer on medical devices. During her work at Ethicon Endo-Surgery, Inc., Cindy worked on several minimal invasive surgery devices, mainly with the vacuum assisted breast biopsy device, Mammotome. Following the completion of her undergraduate studies, Cindy looks forward to pursuing a Masters degree in Mechanical Engineering at the University of Michigan. After graduation, she is motivated by obtaining a career in the health care field, particularly in the medical devices industry including work as a research and development engineer. In her spare time, Cindy enjoys reading, doing Pilates and baking.

Mr. Max Wineland
Undergraduate Student
B.S. E Mechanical Engineering at The University of Michigan, Ann Arbor, April 2009.

Max was born in Dearborn and grew up in Chelsea, Michigan. He comes from a family of Mechanical Engineers and has always been interested in building things and understanding how things work. Max spent the summer of 2007 working for a start-up biomedical company called Cameron Health as a Mechanical Engineer Intern. The company is located in Southern California and is developing a new implantable heart defibrillator. Max worked primarily in the manufacturing areas of the development process. After graduation, Max will enter the Marine Corps where he is interested in pursuing a wide variety of jobs ranging from Infantry, to intelligence, to combat engineer. In his spare time, Max enjoys working with his church, relaxing with friends, and running.

ACKNOWLEDGMENT

Dr. Cynthia Brincat; Mr. Bob Coury; Mr. Marv Cressey; Mr. George Fusani; Mr. Kofi Gyan; Mr. Dan Johnson; Ms. Mary Johnson; Professor Kathleen Sienko; The Students of University of Michigan ME450 Global Health Design: Africa Section.

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