

Project Proposal and Feasibility Study  
Team #13  
TIREd



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# **Project Proposal and Feasibility Study**

## **1. Introduction and Background**

Calvin College teaches engineering from a Christian perspective. Calvin focuses on many ethical issues that we, as engineers in industry, will be faced with on a day-to-day basis in the near future. Calvin also focuses on ways that we as engineers can use our gifts and skills of engineering to live a service-oriented life and be of help to others. As a result, there has been a slight trend toward service project-oriented senior design projects over the last few years. Though this service aspect of the project is certainly not a requirement of the course, nor a required aspect of many other engineering projects, it is an exciting option for many students to pursue.

At the time that our group was formed shortly after the fall semester began, we really had no good ideas for a project. We had a number of unrealistic brainstorming ideas, but the entire group was unable to agree on what should actually be done. Then we received an email from Professor VanderLeest about a project that had been proposed by a Calvin graduate, James Kuiper. Kuiper works as a teacher on the Zuni Native American Reservation near Taos, New Mexico, and is interested in constructing a home out of old tires. However, this type of house is very time-consuming to build because each tire must be packed with dirt by hand, which can take a rather long time. He proposed that a senior design team from Calvin design and build a tire-packing machine that would make the building process for this type of house quicker and easier. Terry Austen took a specific interest in this project, and convinced the rest of the group that it was a worthwhile project to pursue. With Terry acting as this driving force, our group decided that this was indeed what we wanted to do.

Shortly after we came to this decision, we heard rumors that another senior design group had also decided that they wanted to pursue it. This conflict led to a number of meetings between our group and the other group, and together we also contacted James Kuiper to see if he had any other potential senior design project ideas that could be spun off of the tire packer idea. By the end of the week, a second idea had come up that involved building a lift to place the packed tires on the wall as the house was built. Our group decided that we would take on this project.

The type of house that Kuiper is aspiring to build is called an “Earthship”, named by its inventor, Michael Reynolds. The concept of these “Earthships” is to use old truck tires to build a fully self-sustaining house. Earth is firmly packed into the whole tire to form a 300 lb tire brick. These are then stacked just like bricks to form the walls of the house. These houses are particularly effective in

desert areas with cool evenings and very hot days. The earth in the tires basically acts as a big “thermo-economizer” for the house. During the day, the earth and tires will soak up most of the heat from the sun, keeping it from the inside of the house; when night comes, they release the heat to the inside, therefore keeping it at a constant and comfortable temperature.

Kuiper wishes to build and live in an Earthship in order to show the Zuni natives that Earthships are a cost-effective way to inexpensively build, heat, and cool a home. Currently, the Zuni tend to rely on either wood or natural gas to heat their homes at night. Since it is a desert region, the wood supply is running thin, and natural gas prices have been rising (as they have throughout the nation). For these reasons, Earthships should be very appealing for this part of the country; unfortunately, the large time commitment and difficult labor involved with building these houses turn many people away from them. Current construction methods involve manually packing the tires with sledge hammers; this can take a person up to 45 minutes when not tired, and potentially much longer as they become fatigued over the course of the work day. Under these conditions, a typical 1200-tire house can take up to 3 years to build even with a substantial amount of help. This is not appealing to the Zuni natives. The tire packer being built by Team #4, “Solar Thermal Packing”, coupled with our lifter, could effectively reduce the 1-tire cycle time to as low as 7 or 8 minutes, and this could allow for the walls of an Earthship to be built in as little time as 3-4 weeks (optimistically). Kuiper hopes to show that one of these cost-effective and thermally efficient houses can be built in a manageable amount of time.

## **2. Project Objectives**

The basic objectives for our project can be summed up in our project scope:

We will design and build an electrically powered machine that must lift and place a 300 lb truck tire packed with earth onto the walls of an “Earthship”, which will be built up to 9 ft in height during construction.

While this statement gives the basic idea of the overall goal of our project, it can be broken down into numerous, more specific objectives. Here are the objectives we feel we must meet in order to make this project a success:

*-Must lift a 500 lb load.* A packed tire weighs somewhere around 300-400 lbs depending on size and how well it is packed. At first, we explored options of being able to lift 2 or 3 tires at once to speed up the building process, but we decided on lifting just one tire. The decision process used to

make this decision is discussed later. Our target of 500 lb is just in case a tire actually is heavier than expected.

*-Must lift to a height of over 9 feet.* The walls on Earthships are built to the same heights of walls in traditional houses. This means that the top of a wall can be up to 8 or 9 feet above the ground. We must make our machine able to lift to this height, or else it will not be useful for building the most difficult part of the wall—the top. By designing the machine to lift to over 9 feet, we can be sure of the machine’s usefulness for the top row of tires even if the lift is sitting on slightly lower ground than what the wall is built on.

*-Must be semi-mobile on construction site.* Our machine will need to be moved around to different locations along the wall as the house is being built. This means it must be mobile. We are designing a simple wheel-and-axle system for the base that will allow the machine to be rolled on the ground easily. The wheels on this must be large enough that they easily can roll through the dirt surface of a typical construction site. Generally, this dirt is quite dry and reasonably flat, making for a fairly easy surface to roll an object on. The machine itself must be light enough that it actually can be pushed by hand, because we are not planning on making a motorized drive system. Also, the machine must be able to be steered in some way so that it can be rolled to where it needs to go without a struggle.

*-Need to place the tire on the wall.* Simply lifting a tire 9 feet in the air does no good unless the tire can also be placed precisely on top of the wall. This means that our machine must have a mechanism that makes placement easy. One idea for this is to have the tires be rolled out onto the top of the wall, while another idea involves a telescoping and swiveling arm that allows for precise placement of the tire.

*-Moving parts must be controlled from the ground.* To make this machine easy to operate, all moving parts involved with the lifting and placing of a tire must be controlled from the ground. An electronic control panel with joystick and/or switches that connect to motors is our preferred method for meeting this objective.

*-Cycle time of less than 90 seconds.* We need our lift to operate relatively quickly so that it actually does help to cut down the amount of time needed to build an Earthship. Our target maximum lift time is 90 seconds, meaning that placing a tire on the top of a 9-foot wall will take at most 90 seconds. This 90 seconds includes not only the lifting of the tire, but also the adjustment of whatever type of placement mechanisms we design into our machine. Obviously, if 90 seconds is the target time for placing a tire at 9 feet, placing a tire at a lower height will take a shorter amount of time.

*-Simple operation.* The people operating this machine are not going to be engineers or experienced construction equipment operators; it must therefore be easy for any average person to operate. We may need to consider the possibility that some operators might speak languages other than English. We will contact James Kuiper to ask about whether this is an issue, and then judge what must be done about it, if anything. In any case, the controls must be self-explanatory, and the actual mechanisms must operate smoothly enough that the machine and tire stay stable even if some misuse of the controls were to occur. Basically, our controls and mechanisms must be easy for anyone to figure out.

*-Compatible with “Solar Thermal Packer”.* Our proposed idea for how our machine will work with the tire packer being built by Team 13 is that our lift will sit on the ground in close proximity to the packer and be able to easily grab the packed tires directly off of the packer. It is our goal to avoid any need to roll the tires from the packer to the lift.

*-Transportable.* It is our understanding that James Kuiper actually wants to use the machine we build to help him construct his Earthship. However, if our machine is 10 feet tall or so and weighs hundreds of pounds, getting it down to New Mexico will be very difficult. For this reason, we want to design our machine so that the major components can be disassembled from each other to make for easy transportation. Ideally, the base, the truss, and the top arm will all be separate components that can be detached from each other and shipped in a U-haul moving truck or a pickup truck bed.

*-Design Norm Friendly.* Of course, any design project at Calvin College will have an emphasis on implementing several design norms into the project. Our project is not an exception. The most evident norm in our project would be **stewardship**. This is evidenced by the fact that we are putting some of the millions of waste rubber tires to a practical and non-detrimental use. Also, by helping to construct these houses, we are decreasing the depletion of natural resources such as wood and natural gas, while at the same time lowering the cost of living for the Zuni natives. Another design norm evident in our project is **caring**. By accomplishing our goals we will be caring for the Zuni natives by reducing their cost of living with no tangible benefits to ourselves (well, other than hopefully receiving credit for ENGR 339 and 340 and getting our college degrees). Also, we will be producing this product we will be providing a way to aid the construction of their houses at virtually no cost to them. Another design norm evident in our project is that of **integrity**. In order to model integrity, we feel that we need to produce a quality product. Not only to show that we are capable and ready to produce quality products now and in the future, but also to show that we have an active interest in how our product will benefit the users practically and aesthetically. Modeling integrity also means that we will conduct ourselves in a professional manner in all aspects of the project,

especially in the area of communication and acknowledgements. Finally, the last design norm evident in our project is **transparency**. Our design will be easy to use and set up, and will require very little training to use effectively. We are building a machine in a significantly different culture from that in which it will be used, so consideration of how it will blend into that situation is also very important. Our product will be electrically controlled, so it is imperative that our controls and control board are easy to use and understand.

### **3. Environmental Discussion**

When we first proposed our project to our professors, they raised an important question: Are tires safe when they are decomposing, or do they let off harmful gases? It was important for us to have an answer to this question because we did not want to aid in building homes that would be harmful to their occupants. As we researched tire decomposition, we came into contact with James Lee of the EPA, who gave us a few websites to look at. One of the sites said that the “EPA does not consider scrap tires a hazardous waste.”<sup>1</sup> This was good news to us since it was from an unbiased source that had no vested interest in our project. We had also read some other pieces about this issue from people who had actually built and/or lived in Earthships, but we had to consider these sources to be somewhat biased simply because of their connections to Earthships.

Even though we were feeling comfortable about the safety of the decomposing tires, we still wondered why tires would cause the problems they cause in landfills but not in houses. This question has a fairly simple answer: the tire’s shape. Since a tire has a lip inside of it, gases can be trapped inside the tire. The decomposing garbage in landfills creates a substantial amount of methane that comes up out of the ground. When a tire is put in a landfill, this methane gas gets trapped inside the tire. Methane has a lower density than air and thus causes the tire to “float” to the top of the landfill and ruin the design of the landfill. This gives people a general misconception that old tires themselves are actually dangerous. This concern is misguided, because the methane gas is not produced by the tire. Since the houses we will be helping to build are not built on landfills or with other decomposing garbage items that would give off methane or other gases, we need not worry about this problem. The only problem that exists with using tires for houses is the fire hazard. Burning tires are very dangerous. However, the tires will be firmly surrounded with packed earth that will strongly inhibit their ability to burn, and burning is also a hazard associated with conventional wood homes. We do not consider fire hazard an issue worth scrapping the entire project over.

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<sup>1</sup> <http://www.epa.gov/epaoswer/non-hw/muncpl/tires/fires.htm>

#### 4. Initial Design Alternatives

To come up with design alternatives, we broke our machine down into what we saw as the major components: base, lift mechanism, placement mechanism, and stability system. We then brainstormed alternatives for each of these components.

##### Base

The base must give the machine proper stability and decent mobility. Here are our preliminary base ideas:

*-BBQ Grill Base:* The “BBQ” base idea makes use of the design of a typical outdoor gas grill design (Figure 4.1). The base of a grill usually has two wheels at one end and two feet at the other end. This design allows the grill to be mobile when necessary, but also stable and stationary when it is in use. The BBQ base for the tire lifter would use this same concept, but simply on a larger scale. It would consist of two wheels at one end and two feet at the other end. The wheels would need to be large enough in diameter and width to easily roll over dirt, and the feet would need to have



Figure 4.1: BBQ Base

some kind of traction system on the bottom that digs into the ground to hold the lift stationary while it is in use.

A potential downside of the BBQ base is that our lift will be large (10 or 11 feet tall) and potentially heavy. The BBQ base would require considerable lifting strength from the people trying to move the machine since the feet would actually have to be come

off the ground. Furthermore, lifting one end off the ground could cause the machine to tip over.

*-Four Wheel Base:* The Four Wheel base idea is simply a rectangular shaped base with a wheel at each corner. This design eliminates the need to lift and tip the machine to move it like in the BBQ base idea. However, to allow for easy mobility, two of the wheels would need to be swiveling wheels so that the lift could turn like a car. Furthermore, the wheels would need some sort of locking device on them to prevent the lift from rolling while in use.

*-Tripod Base:* The Tripod base idea is to have a base made of three legs that angle down from a central point in a triangular pattern, similar to the design used for a microphone stand (Figure 4.2). The Tripod base would again need to have wheels at the bottom of the base for mobility. A downside to the Tripod design is that it might be more difficult to integrate with the other components for the lifting and placing mechanisms. However, this design might force us to keep the rest of our design simple because of this restriction. Furthermore, the Tripod has the advantage of its inherent stability on slightly uneven ground—it will always have all three legs touching the ground.



Figure 4.2: Mic Stand Tripod

*-Pickup Truck:* A briefly considered possibility for the base of the machine was to actually build machine to fit into the back of a pickup truck. This idea originally came when we were still brainstorming about how we could design the tire packing machine that we originally thought we were going to build. While a truck would make for good mobility around the construction site, a number of concerns also were identified with this idea. First, someone would need to donate their pickup truck to be used for the machine. This would make the truck basically useless for doing anything else. The availability of a truck that could be used for this is uncertain. Furthermore, we have concerns about what kind of truck our machine could fit into. We would need to know if the truck was a compact, a midsize, or a full-size, because each of these has different bed dimensions that we would need to consider in the design. With so much uncertainty about the type and availability of a truck, we decided that a free-standing design would be better.

### **Lift Mechanism**

The lift mechanism is responsible for using an electric motor to lift the tire(s) up off the ground. Here are our preliminary lift ideas:

*-Winch-Powered Crane:* This mechanism would consist of a winch and a truss. The winch would be mounted in the bottom of the truss, and the steel cable would run up through the truss through a system of pulleys. The cable would hang freely from the end of the truss and be attached to a device that holds the tire(s). Initially, we had considered building our own winch out of a motor, gears, shaft, and steel cable. However, after analyzing this classic issue of “make vs. buy”, we saw that it would be much more feasible economically to simply buy the winch instead of finding all the

necessary parts on our own. Furthermore, the reliability of a tested and manufactured winch is likely better than that of something we could put together ourselves.

*-Winch-Powered Forklift:* This mechanism would be similar to the crane design, except that the cable would not be free hanging at the end of the truss. Instead, the mechanism that holds the tire(s) would be secured in a vertical track that stabilizes its motion as the steel cable pulls it up. In this way, it is similar to a forklift in that the motion is restrained by use of a track rather than being free hanging.

*-Dump Truck Hydraulic Lift:* This mechanism would consist of a large hydraulic cylinder that would push a large horizontal beam up into a vertical position as it extended; it would operate similarly to how a dump truck hydraulic system pushes one end of the dump bed high into the air



Picture from [www.fostertrailers.com](http://www.fostertrailers.com)

Figure 4.3: Dump Truck Hydraulics

(Figure 4.3). This system would involve a cylinder, a pump, hydraulic fluid, fluid lines, fluid valves, a fluid reservoir, and a hydraulic control system to control the valves and pump; in other words, it could potentially be very expensive.

*-Vertical Hydraulic Cylinder Platform:* This mechanism would consist of a compound hydraulic cylinder (Figure 4.4) that extends vertically to push a lift platform high into the air.

The cylinder would need to be huge, however, for it to reach the necessary height of 9 or 10 feet. Furthermore, it would be difficult to make this design reach all the way down to the ground because the cylinder would still be in the way even if it were collapsed all the way down to its resting position. As with the dump truck design, the cost could potentially be very high.

Picture from [www.ahpower.com](http://www.ahpower.com)



Figure 4.4: Telescoping Hydraulic Cylinder

### **Placement Mechanisms**

Once the tire is lifted in the air, the machine must also be able to place it where it needs to go on top of the wall. Here are our preliminary placement ideas:

*-Tilting Tire Tray:* This placement mechanism would work best with the forklift style lift system, and would consist of a tray which the tires could be rolled into vertically and then tipped over onto the top of the wall once they were lifted. This device would look like an uneven channel tray—a cross section of this device is shown holding a tire in Figure 4.5 at the left. This tray would be

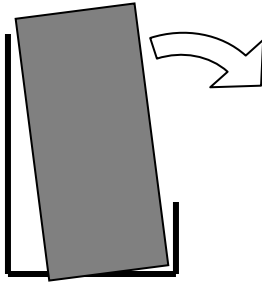


Figure 4.5: Tilting Tire Tray Cross Section

mounted into the track system of the lift, and when it reached the proper height, it would be able to tilt forward (in the direction of the shown arrow) to drop the tire onto the wall.

*-Tire Hook:* This placement mechanism would work best with a crane style lift system, and would basically consist of four L shaped brackets coming from the winch cable. The four brackets would then be put under the edges of the tire. This method could be simplified and improved by having a tire packer that was designed to allow the lifting brackets to be placed under the edge of the tire. Once the brackets were manually positioned on the tire, the winch would then begin to lift the tire. The weight of the tire would put tension on the cables going from the brackets to the winch cable. This tension causes the lifting brackets to be pulled in tight against the tire.

*-Swivel System:* Allowing the truss to swivel will allow for easier placement of the tire by giving the machine more adjustability. How the swivel would actually work depends on what ideas are chosen for the final designs of the truss and lift mechanisms. Two possible ideas are a turntable at the bottom of the truss that allows the entire truss to swivel over the base, or a joint at the top of the truss that allows a top beam to swivel. Either of these designs could be done using either a simple lubricated shaft or a more complicated shaft-and-bearing system. Bearings would allow for easier motion, but they also add cost and can be very sensitive to the dusty working conditions found at Earthship construction sites. We would need to make sure the bearings were housed inside of something to keep the dust and dirt out.

*-Telescoping Arm:* Designing a telescoping arm into the top of the lift would allow for greater precision in the placement of the tire. If both a telescoping arm and swivel system can be designed into the machine, these two mechanisms will allow for outstanding adjustability for precision tire placement; furthermore, they will allow for many tires to be placed on the wall before it is necessary to move the machine to a different spot. There are a number of ways a telescoping arm could be designed. A large hydraulic arm would be ideal, but would also be very costly. A four-bar linkage with one end mounted in a horizontal track would be possible. A rack-and-pinion device attached directly to the beam would be easy to motorize, but would introduce some tricky design problems with the swivel and lift mechanisms as far as mounting the arm is concerned. No matter what the idea for the telescoping arm, the balance of the machine becomes a major concern when the arm is at full extension; a counterweight hanging opposite of the telescoping arm would likely be a necessary part of the design.

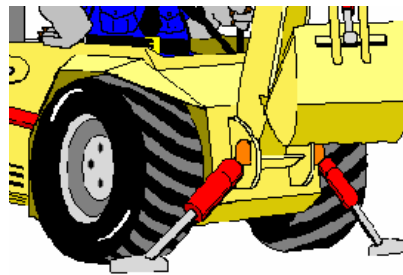
## Stability Systems

Our lift will need to have some sort of stability system to keep it from tipping while it is lifting and placing tires. It will be lifting 300+ lb tires up to 9 feet air, and then possibly moving them laterally once they are up that high. For this reason, it is very important that the center of mass of the lift is still within the base when the tire is up in the air. Here are our ideas to help keep our machine stable:

-*Backhoe Support Arms:* Backhoes have stabilizing arms that swing down and lock in place on the ground to help maintain stability while digging or carrying heavy loads (Figure 4.6). A similar system could work for our BBQ base or 4-wheel designs. Such a system would essentially expand the footprint of the base so that the center of mass could still be within the base while a tire is being placed up on a wall.

-*Counterweight:* A counterweight could be used to keep the machine balanced while it is lifting a tire. If the machine lifts the tires up along the wall, a counterweight could stick off the rear of the lift away from the wall to keep the center of mass within the base footprint.

-*Wheel Locks:* Locking the wheels in place will be an important way to keep the machine stable while it is operating. A simple hand-operated clamping mechanism can probably be used on one front wheel and one rear wheel to keep the machine from rolling.



Picture from  
[www.iupps.com](http://www.iupps.com)

Figure 4.6: Backhoe Support Arms

After these initial design alternatives had been brainstormed, each was considered for its practicality, usefulness, and cost to determine which ideas could be quickly ruled out. This was done so that we could avoid wasting time doing further research and design on ideas that would ultimately lead nowhere. Here is a summary of the alternatives that we ruled out:

-*Hydraulics:* After doing some initial research into hydraulic systems, we determined that the cost of such systems is far out of the reach of the budget we are working with—there are simply too many necessary components of a system for us to afford. While hydraulics would be extremely useful for this machine, they are simply not practical from a cost standpoint.

-*BBQ Grill Base:* Since our machine will be built out of steel, and since steel is rather heavy, it is not practical to expect that one end of the machine could be lifted up by people and moved in the way that this type of base would require. Thus, the BBQ Grill Base design is not practical.

*-Tripod Base:* We want our base to have a fairly large footprint, and a tripod base simply doesn't allow for this. While the tripod design could be nice for strength and balance, it leaves potential for balance problems if we add a swiveling arm—if the load were to swivel to a point between two of the legs, the machine could become unbalanced. While this balance issue could be overcome through the use of backhoe-style support arms, these arms would not help with balance when the machine is being rolled around the construction site. Having a machine that could potentially become unstable while people are pushing it is not a risk we are willing to take just for the sake of using less steel and having a simpler design.

### **Control System**

A final part of our initial design alternatives involves determining which components can realistically be electronically controlled. We considered a lot of options as to what systems could electronically control the motors that will be used in our design mechanism. The following possibilities were considered:

*-Joystick controllers:* Joystick controllers use potentiometric, inductive or photoelectric sensing systems, and/or switches to translate joystick motion into an output signal. There is usually a distinction made between joystick controllers used in heavy-duty industrial applications, precision applications or game applications. An industrial joystick controller is often used in demanding environmental conditions and heavy-duty industrial applications such as forklifts, cranes, agricultural machinery, hoist devices, vehicle steering, excavators, and municipal or military vehicles; this is a plus, because our machine fits within these categories. One advantage of Joystick controllers is that the response of the system to the joystick is immediate—it is either on or off. The disadvantage of using the Joystick controller is that it is inefficient when dealing with a variable speed system.

*-Pulse Width Modulator (PWM Variable-speed Controllers):* A pulse width modulator (PWM) is a device that may be used as an efficient DC motor speed controller. The circuit shown in the Appendix D is a general purpose device that can control DC devices which draw up to a few amps of current. From our discussion with James Kuiper, we know that our source of power is going to be an AC source, most likely from a generator. With this in mind, a rectifier circuit will be needed to regulate the current levels. A PWM circuit works by making a square wave with a variable on-to-off ratio, where the average on time may be varied from 0 to 100 percent. In this manner, a variable amount of power is transferred to the load. The main advantage of a PWM circuit over a resistive power controller is the efficiency: at a 50% level, the PWM will use about 50% of full power, almost all of which is transferred to the load. One additional advantage of pulse width modulation is that the pulses reach the full supply voltage and produce more torque in a motor by being able to overcome

the internal motor resistances more easily. The main disadvantages of PWM circuits are the added complexity and the possibility of generating radio frequency interference (RFI). RFI may be minimized by locating the controller near the load, using short leads, and in some cases, using additional filtering on the power supply leads.

*-Programmable Logic Controllers (PLCs):* A Programmable Logic Controller is a device used to automate monitoring and control of industrial plants and machines that are similar to our tire lift. They contain multiple inputs and outputs that use transistors and other circuitry to simulate switches and relays to control equipment. For PLCs, a specific code of logic program has to be written for the PLC to work in the desired way. They are programmable through software interfaced via standard computer interfaces, proprietary languages, and network options. The I/O channel specifications of PLCs include the total number of points, number of inputs and outputs, ability to expand, and maximum number of channels. The number of points is the sum of the inputs and the outputs. PLCs may be specified by any possible combination of these values.

## 5. Preliminary Design Decision

After the number of our initial physical design alternatives was reduced, we were essentially left with eight different designs consisting of combinations of the following alternatives:

- 2-tire lift or 1-tire lift (at this point, this decision had still not been made)
- Swivel or no swivel
- Crane or track

A decision matrix was used to determine the best of these eight designs (Table 5.1):

Table 5.1: Design Decision Matrix

|                     | <i>Usefulness</i> | <i>Cost</i> | <i>Safety/stability</i> | <i>Durability</i> | <i>Mobility</i> | <i>Size</i> | <i>Ease of Build</i> | <i>Sex Appeal</i> | <i>Shalom</i> | <i>Total</i> |
|---------------------|-------------------|-------------|-------------------------|-------------------|-----------------|-------------|----------------------|-------------------|---------------|--------------|
| <i>Weight:</i>      | 28                | 17          | 16                      | 11                | 10              | 8           | 7                    | 1                 | 2             | 100          |
| Swivel 2 tire crane | 20                | 9           | 9                       | 7                 | 5               | 5           | 2                    | 1                 | 1             | 59           |
| Swivel 2 tire track | 17                | 8           | 11                      | 6                 | 5               | 5           | 2                    | 1                 | 0             | 55           |
| Fixed 2 tire crane  | 11                | 15          | 12                      | 10                | 7               | 7           | 5                    | 1                 | 0             | 68           |
| Fixed 2 tire track  | 3                 | 15          | 13                      | 9                 | 7               | 7           | 5                    | 1                 | 0             | 60           |
| Swivel 1 tire crane | 24                | 13          | 13                      | 9                 | 9               | 7           | 4                    | 1                 | 2             | 82           |
| Swivel 1 tire track | 7                 | 12          | 14                      | 7                 | 9               | 7           | 4                    | 1                 | 0             | 61           |
| Fixed 1 tire crane  | 8                 | 17          | 14                      | 11                | 10              | 8           | 6                    | 1                 | 0             | 75           |
| Fixed 1 tire track  | 3                 | 17          | 15                      | 10                | 10              | 8           | 7                    | 1                 | 0             | 71           |

The following section describes how each category was judged:

### Usefulness

The most important aspect of our design is how useful it is. If the design we come up with cannot successfully place tires on the wall in a time-saving manor, our project is a failure. For this reason, usefulness is the heaviest weighted aspect of our decision matrix.

Initially we thought that the more tires we could lift at once, the more useful the lift would be, because it would be able to do the necessary work faster. However, after our experience of packing a tire and experiencing firsthand how heavy and awkward they can be, we determined that the machine's ability to place a tire exactly where it is needed was more important than its ability to lift multiple tires quickly. With the multiple-tire lift designs, the precision placement of a tire would be much more difficult to achieve. Our ideas for placing multiple tires involved either tipping the tires out of a tray and onto the wall or rolling the tires out of a track onto the wall. Neither of these designs could really work to place the tire with precision. To tip the tires out of the tray directly onto the wall, the curvature of the tray would have match that of the wall perfectly to allow the tires to be placed right; however, the curvature of the wall is different in different locations of the house, so this could not be done. Rolling the tires out of a track would be very difficult and potentially dangerous; a packed tire is very difficult to roll on flat ground, let alone in a track 9 feet in the air or on top of a wall of tires.

The two ideas for the actual lift were a crane lift with a free hanging cable or a forklift style lift that operates on a fixed track. Since the placement of the tire was so important to the usefulness, the crane was determined to be better because it would have greater adjustability. The forklift style would require the entire lift to be placed exactly in the right spot along the wall in order to place the tire well, but this would make the operation difficult.

The final decision was whether or not the lift should be allowed to swivel. Allowing the machine to swivel makes it much more useful, because it allows it to pick up the tires in one place and then swivel around to put them on the wall. With this idea, the tire packer can be placed about 7 or 8 feet behind the machine, and the wall can be 7 or 8 feet in front of the machine; the machine can then grab a tire off the packer and place it on the wall without moving the machine or rolling the tire. Furthermore, the swivel allows for much more adjustability in placing the tire, especially when combined with the telescoping motion of the top arm of the machine.

We have mentioned a lot about being able to place the tire with precision, but have yet to discuss just how precise the placement must be. The machine must be able to drop the tire exactly where it needs to go in order to build the wall evenly and sturdily. Currently, the tires are stacked up by hand when they are empty, and then packed with sledge hammers while they are on the wall. The workers simply must eyeball where the tire is to go based on where the existing tires already are, and then the workers pack them. Pounding the tires with sledge hammers as they are packed likely moves them slightly away from their original position. The point of all this is that there is no set tolerance that says exactly where the tires must be placed. The wall becomes stable enough through just eyeballing the tire placement and then securing it with rebar. By allowing our machine to have swivel, vertical (lifting), and horizontal (telescoping) ranges of motion, it will be very easy to place the tire in exactly the right spot on the wall as directed by the people supervising the placement of the tires; with the crane design, the fact that the tire is free hanging on a cable will also allow for hand guided adjustments as the tire is lowered onto the wall. The eyeballing technique still will be used as it was before, but the tire being placed will already be packed, and it will be placed by machine rather than hand.

### **Cost**

Cost was determined to be the next most important aspect of our design. Our budget is small at around \$500, and we must design something that we can actually afford to build with this amount. The bigger and more ambitious our design is, the more expensive the materials will be. However, after talking to Dave Ryskamp about availability of steel, we hope to obtain a considerable amount of the necessary steel at no or little cost. For this reason, the cost considerations will change less with the size of the design than we had originally thought.

Designing a swivel mechanism into the machine will mean that we need some sort of bearing and/or shaft system that allows for easy rotation. This could add a considerable amount of cost to the project.

To lift two tires rather than one, a larger winch would be needed, and this would certainly cost more than a smaller winch. We would also potentially need more steel for a stronger truss, potentially costing more.

### **Safety/Stability**

Safety is a very important aspect of this project. The machine we build must not put anyone in danger. For the machine to be safe, it must pick up the tire with no danger of dropping it, it must

place the tire gently with no danger of it sliding off the wall, and the machine must be stable and avoid tipping over or breaking. Placing just one tire instead of two seems to be a much safer design—there will only ever be one tire in the air, so the operators can focus all of their attention on that one tire rather than having a second tire also hanging high in the air causing a potential hazard. Placing one tire simplifies the process and minimizes the potential for a mistake such as accidentally releasing the wrong tire or knocking something down with the extra hanging tire. Furthermore, lifting just one tire makes for a much lighter load, and thus will make the machine more stable when the arm is extended out to place a tire on the wall.

### *Durability*

We need to design a machine that will be able to withstand the potentially harsh conditions of the worksite at which it will be used. The weather in New Mexico can range from very hot and sunny to very cold at night, and our machine must handle both of these issues (not because it will be operating at night, but simply because it will be sitting at the construction site overnight). More importantly, it must be able to perform its task of placing tires over and over again without trouble. Since we are building our machine primarily out of welded and bolted steel, good structural durability shouldn't be too hard to achieve because a well-designed steel truss is easily strong enough to support a few hundred pounds of loading.

Any moving parts must be designed and built in a way so that they do not wear quickly and continue to operate well through frequent use. Generally, a fixed crane would be more durable than the other designs because of its simplicity—there are no moving parts save for the motor/pulley/cable system that actually lifts the tire. Introducing a forklift-style track into the lifting process brings with it some wear issues because of the sliding friction present in the track.

The biggest durability issue we can see concerns the swiveling mechanism. Whatever type of swivel mechanism we design, whether it is a shaft in a sleeve or some sort of bearing, it must be strong enough to hold large loads and large moments. Since the tire will be hanging well off center from the swivel point, there will be rather uneven loading on this mechanism. For this reason, the design options that included swivel mechanisms were given lower durability ratings, and the heavier the load on the swivel mechanism, the lower yet the given durability rating.

### **Mobility**

Our machine must be mobile enough to be pushed by hand around the construction site so it can be repositioned to build different rooms. While giving our machine good mobility is very important to the overall success of the project, it was not given a particularly high weighting on this decision matrix because we figure that the mobility is not drastically dependent on what design we choose. We know what type of base the machine will have regardless of the other design factors, and the base is the main part of the design that affects mobility.

With this said, the larger the machine is, the less mobile it will become. If the machine must lift two tires, it will be larger than a one-tire machine, and thus will weigh more and be harder to push around. Designs with a swivel mechanism will also be harder to push simply because of the possibility of the truss swiveling around while it is being pushed.

### **Size**

Our machine will need to be fairly large. The truss will need to tower about 9 or 10 feet in the air in to lift the tire high enough to place it on the wall. The arm on the end of the truss will need to extend out 9 or 10 feet from the middle of the base. This means that the base is also going to have to be fairly wide in order to give the machine sufficient balance.

Our goal is to be able to build the smallest machine we can that will effectively perform the necessary task. The larger the machine is, the harder it will be to move, build, and do maintenance on, and the more it will cost. Basically, the more complicated the design, and the more tires we want it to lift, the larger the machine will be. In the cases of the swiveling forklift designs, the machine will be particularly large. This is because the forklift track, which will extend down toward the ground, will need to be able to clear the corners of the base in order to swivel and be useful. This makes the actual swiveling portion of the machine much larger than if the swiveling portion is just of a simple crane style.

### **Ease of Build**

Ease of build of our machine is not a top priority, but is nonetheless important to the success of the project. As inexperienced engineering students who are really getting our first big taste of an entire design and build process, we don't need to be taking on more than what we can realistically handle. We will be somewhat limited by the tools and building technology available to us, and also limited by our own developing abilities in fabrication. With that said, ease of build is not a huge concern,

because as long as we stay on course with our schedule, we should have plenty of time to construct our machine and overcome any obstacles that come up along away.

The simplest design, the one-tire fixed crane, is the easiest design to build. It requires the fewest parts, and has the least level of needed fabrication precision. Adding a vertical track to this basic design makes it only minimally more difficult to build, as does designing in the capacity to lift two tires (the only thing that does is make the machine bigger, but not more complicated). The swivel mechanism looks to be the most difficult aspect of fabrication.

### *Aesthetics*

Part of designing in engineering is to make a product that not only serves its purpose, but also looks nice. There is a certain pride that comes from designing a product, and part of that pride comes from successfully blending function with aesthetic. Unfortunately, when creating an inexpensive tire lifting machine out of steel, there might not be a lot that can be done concerning the sex appeal of the machine. Each of our alternative designs would likely look nearly the same as the others upon completion. We figure that even though the machines wouldn't be objects of beauty from an artist's perspective, they will have the beauty of raw industrial function; therefore all design possibilities receive a maximum rating of 1 for aesthetics.

### *Shalom*

A long-standing goal of the engineering department here at Calvin, and Calvin College as a whole, is to equip students to go out into the world and help restore shalom. If our tire lift is not able to help make a small contribution toward this restoration, we have failed as Christian engineers. To help restore shalom, our machine must truly make the lives of those building Earthships better than their lives before they had the tire lift. Some of our designs simply do not do this. If our lift had no swiveling device, it would not be easy to use—the tires to have to be rolled all the way to the tire wall, and the machine would need to be positioned perfectly in order to place the tire in the right place. This would make it very unfriendly to the people using it, and would not be restoring shalom. If our lift operated with a forklift style track, it would be difficult to also incorporate a telescoping arm into the top of the truss. This telescoping ability is vital to the machine's ability to place the tire with precision and speed, and also vital to being able to place more than one tire on the wall before the lift must be repositioned. With the track, the lift would again not make the process easier, and would not be restoring shalom.

These issues rule out all designs except for the swiveling crane. This design allows for the easiest and most precise placement of the tires. Doing two tires at once introduces some extra safety concerns, and putting people's wellbeing in danger cuts down on the machine's ability to help restore shalom. For this reason, the 1-tire swivel crane gets the maximum shalom points, and the 2-tire swivel crane gets half of the possible shalom points.

## **6. Component and Mechanism Details**

This section describes the current status of the design of each major component or mechanism.

### **Base**

The design of the wheel system on the base is fairly simple. At this time, our base is a sort of three-dimensional trapezoid with a small trailer wheel at each corner. The actual size of the base and wheels is not set for sure yet, because we are still working on obtaining wheels and axles for free. Once the proper wheels and axles are located, we will modify our basic design to accommodate the actual sizes of these.

The wheels on the base need to be able to lock in place to keep the machine stationary while in use. The wheels also need to be able to steer to make the machine semi-mobile on the construction site. Our idea for allowing the wheels to turn is to put one axle on a rotating joint and attach what effectively would be a wagon tongue to the front of the axle. To maintain stability, we will build flip down arms that lock in place against the ground to give the base a larger footprint.

Recently, we have begun to redesign our base to simplify the overall design of our lift. Instead of making the base a three-dimensional trapezoid, we are leaning toward making it a pyramid with a rectangular base. The top of the pyramid will form a support on which to mount the bottom of the vertical pipe found in the truss. The angled beams from the truss (discussed next in this section) will then be able to mount directly to bottom corners of the base near the axles. This design eliminates a substantial amount of steel compared to the trapezoidal base, and should also be stronger structurally. Our main concern at this point with this base is how to make it detachable from the truss.

### **Truss**

Our initial idea for the truss was to have vertical rectangular center with a triangular extension hanging to the side. Initial first-cut stress and buckling calculations showed that this sort of design

would be possible to do, in part because we are only lifting a load of a few hundred pounds. However, the truss design has changed substantially in recent weeks since our meeting with Chuck Spoelhof, our industrial design reviewer.

Our new design for the lift is a pyramid-shaped truss. The pyramid design essentially consists of a large vertically mounted center pipe with 4 legs angling down from the top, each one connecting to a corner of the base. The reasons for switching to a pyramid design were to both save weight and make the truss stronger. The pyramid design distributes the load better, and it uses substantially less steel. While our previous rectangular design likely could have held the required load, there was no reason to stick with it if we could make the design lighter, more balanced, and more durable. Furthermore, using a pipe in the center allows for easier integration of a swivel mechanism. We are still working on some baseline stress calculations for this truss and are making design changes to it where appropriate.

### **Winch**

Our original truss design called for the winch to be mounted inside the truss near the base, with the steel cable running up the middle of the truss and then through a system of pulleys that let it hang freely off the end of the triangular extension. However, along with the redesign of our truss, we have also reconsidered where we will actually mount the winch. In our most recent designs, the winch is mounted directly to the telescoping arm rather than being in the truss. Placing the winch in this spot greatly simplifies the way in which the winch interacts with the swivel and telescoping mechanisms. This design eliminates any pulleys that the cable must pass through. It eliminates twisting problems that could arise from the swiveling action of the top arm—if the winch were at the bottom, the swivel would make the steel cable twist around, which could potentially cause problems with alignment, strength, or tangles between the cable and the truss. It also eliminates a potentially huge problem involving the in-and-out telescoping motion of the arm. Telescoping motion would cause the tire to go down or up, depending on whether the arm was being brought in or extended out. One solution to this problem could be to do some tricky control programming to make the winch be automatically activated to keep the height of the tire constant as the telescoping arm moved, but this seems to be much more complicated than simply moving the winch to the end of the arm.

One might wonder why it would be a problem for the tire to move up or down as the arm telescopes. There are two main concerns: First, if the tire moves up while the arm telescopes out, the motor controlling the telescoping motion is actually lifting the tire, and thus must be strong enough to do so;

this would require that the telescoping motor be much larger than it needs to be in the case in which the tire does not move. Second, our reason for using a telescoping arm is to make the placement of the tire as easy as possible; if every time an adjustment to the arm was made, a second adjustment to the height of the tire also were required, the placement of the tire would become more complicated.

One downside to placing the winch on the telescoping arm is that the arm and truss must then carry a greater load. However, a winch weighs at most around 100 lbs, and since a tire weighs three or four times this, the winch is not adding all that much more load relative to the tire; the arm should be able to carry the load of both the winch and the tire.

From an electrical standpoint, our winch shouldn't be too difficult to integrate into our design. The manufacturers of winches base the power of the system on the amount of load that the winch needs to pull. Also, the winch we get will need to go in both the forward and reverse directions. This can be accomplished by reversing the polarity of the motor and this will make the motor turn in a different direction, though we still will need to look into making sure that the gearing and ratchet systems designed inside the winch can also work in both directions. Also, since the winch is going to be placed about 10 feet in the air, it will need to be controlled from a general console which will be placed at a reachable height for people operating the machine from the ground. This will require running any power supply wiring and control system wiring along the telescoping arm and through the truss. This poses a challenge simply because we will need to keep the wires from interfering with the swivel and telescoping mechanisms.

### Swivel

Our current design for our swivel mechanism involves a simple pipe and shaft. The pipe will be incorporated into the design of the truss, running vertically through the center with the legs angling off of the top down toward the corners of the base. A shaft will come down out of the bottom of the telescoping arm, and will fit inside the top of the pipe allowing the arm to swivel. This joint will either be lubricated with nylatron or will rotate with bearings. If bearings are used, the arm will rest on a thrust bearing at the top of the pipe, and a radial bearing will be used inside the pipe to maintain the shaft alignment. If nylatron lubrication is determined to be sufficient for rotation instead of a using thrust bearing, a radial bearing may still be used in the pipe to keep the shaft aligned. Our design at this point involves some of the parts we have taken off of the Post Revolution Solution project from last year, which has been sitting in the Engineering Building all semester doing nothing other than taking up space.

To power this swivel mechanism, we are considering a simple hand crank with a system of gears. While it would be possible to motorize this mechanism, one thing we must keep in mind is the “keep it simple” mentality, as emphasized by Chuck Spoelhof. Not only does this simplicity issue apply to the design of our machine, but also to the operation. While it might seem nice to have the operation be motorized, we must also keep in mind that the people who will be working with this machine might not be very technically-oriented; it is possible that they would feel more comfortable working a hand crank rather than a large electronic control module. If we do decide that we must motorize our swivel, we could try to integrate the motor and gears from Post Revolution Solution, though we are uncertain of how well this would work because of the rickety shape they are currently in.

### **Telescoping Arm**

At this point, we have two ideas that we are still debating over for the telescoping arm. One is a rack-and-pinion system, and the other is a belt-driven linear rail system. Both of these designs have some unanswered questions.

The rack-and-pinion system would consist of a motor driving a worm gear that meshes with teeth that are fixed directly to the beam. The beam would likely be an I-beam or a T-beam. While this design is fairly simple to motorize, it has some issues with how exactly to mount the beam in a way that would allow it to hold the necessary load. Since the beam is sliding, it cannot be fixed to anything, but instead must slide on a track that also holds it steady as it slides. This could potentially be done with some rollers on the top and bottom of the beam, or it could be done with some sort of lubrication. The lubrication idea, however, might not work well in a dusty environment, so a roller system would probably be the best solution.

The belt-driven linear rail system would consist of a 3-meter section of linear rail track, a linear rail bearing cart, and conveyor belt-style drive system for the cart. The track would be fixed to the truss so that it extends out 3 meters from the middle of the base. A motor would drive a belt that would wrap all the way around the track. This belt would also be attached to the cart so that it could drag the cart along the track. The winch would then be attached to the cart and hang down off the bottom of the track. Linear rail systems are designed to carry heavy loads and large moments, so they would be perfect for this application as long as we can find a way to sufficiently support the track. The big trouble area with this design is that the longest track we can find is only 3 meters. While this is approximately the length we have in mind for the reach of the arm, it would be difficult to mount this to the truss with enough support for it. If we could find a longer beam that could overhang on both

sides of the truss, the moment on the bolts or welds used to attach the beam would be much smaller because the overhang on the back side would help to cancel out the moment caused by front overhang. However, with a shorter beam that can not overhang on both sides, the moment on the bolts or welds becomes extremely large. Furthermore, we are still waiting to hear about a quote from a vendor for such a system; if the cost is too high, this design will have to be ruled out.

## **7. Cost Estimates**

Cost is a very important issue to the success of this project. Each group is allowed approximately \$500 total for their project; this includes not only materials but also the printing of any needed reports and posters. With this limited budget, it is important that we find as many of our needed materials for as little cost as possible. At the same time, we must make sure that our materials are of high enough quality to ensure that the machine works well and is durable.

Our initial cost estimates totaled around \$900, obviously well over budget. The steel and winch alone cost an estimated \$460, nearly all of our budget, so we are currently in the process of contacting dealers and looking into the possibility of donations or discounts. It is possible that we will be able to obtain steel cheaply or nearly free through Genzink Steel, though until we know exactly what we need, we will not have a verdict on whether this is possible. We have also looked into winches on ebay, and have found a number of them that would likely work for around \$50, but again, we will not buy one until we are certain of our lift design and the functionality of the winch.

Aside from the winch, we need motors to operate the swivel and telescoping arm. These motors need not be overly large, because they will not be lifting any heavy loads like the winch does. We have found some motors we may be able to use in the junk room upstairs in the Engineering Building, but we are still waiting on a verdict as to whether they will actually work right for our purposes. If these motors do work out, it is another huge cushion to our budget. Furthermore, we now think that we will be able to use the motor and swivel mechanism from the rotating sign group last year if we want to. After getting permission from Prof. Nielsen, we began stripping that project apart to look at how their swiveling mechanism was actually put together. We found that the larger vertical shaft, the motor, the gear train, and the bearings should all be of great use to us, helping greatly with our material costs.

We hope to be able to obtain our axles and wheels for the base for nearly free. We are currently in contact with some area junk yards to see what we can get from them. We got this idea from last

year’s group “The Road Less Traveled”, which obtained wheels and axles for their road grader for free. We have received confirmation from one company, Rowell Inc., that we should be able to obtain wheels and axles from them as long as we remove the hubs first.

The next large cost to consider is the cost of the necessary electronic control components. We are going to be controlling three different types of motion, and we need a system that can use joysticks, switches, and/or buttons to turn particular motors on and off. We had been looking into potential prices of batteries, because at one time we thought that battery power might be necessary for our machine to be used on the worksite. However, generator power should be available, so battery costs are not an issue.

The table below shows the breakdown of the costs of the electrical components:

Table 7.1: Electrical Component Costs

| s/n | Item            | Quantity | Unit Price | Price |
|-----|-----------------|----------|------------|-------|
| 1   | Motors          | 2        | free       | free  |
| 2   | Wires           |          | free       | free  |
| 3   | Controllers     | 1        | 44.95      | 44.95 |
| 4   | Power Converter | 1        | 49.95      | 49.95 |

Our other expenses are going to be smaller things like bolts, nuts, etc. These should not cost too much, and if we get other major materials for free, we should be able to easily afford these smaller things. The engineering lab is also another good resource for smaller components.

## 8. Safety Concerns

At this point in our project, there are still some safety issues that we have to make sure we tackle in the rest of our design work. It was mentioned previously that safety is a top priority for us. Bluntly put, if our machine fails while lifting a tire, it has the potential to kill somebody. We must target potential trouble spots and make absolutely sure that failure will not happen.

### Winch

If our winch fails, the machine will be useless. If it not only fails, but rips away from its mounting position or simply loses its ability to hold a load, it creates a potential for a falling tire. We must be sure that the winch we buy is in good working shape and can indeed lift the load over and over again without wearing out. It must be mounted very securely to the telescoping arm with bolts that will not fail—this is an area where a large factor of safety is desirable. The steel cable must also not fail,

though this should be a relatively small concern because of the high tensile strength of braided steel cable.

### **Tire Gripping Device**

If the device we design to hold the tire fails, a very dangerous situation could be created. Our device will likely be some bended pieces of metal that hook under the edges of the tire. If this metal yields under the load of the tire, the tire could eventually fall out. To make sure this doesn't happen, we must be sure that the metal is thick enough to avoid bending stress levels that could cause plastic deformation. The amount of elastic deformation should also be kept to a minimum, because as the machine is used often, this elastic deformation becomes a cyclical stress that will decrease the strength of the part due to metal fatigue.

### **Telescoping Arm**

The telescoping arm must withstand large bending moment loads—it will have a tire hanging at one end, and a counterweight at the other. The beam must be sufficiently thick so that it will not break under the bending stress caused by these loads. With both of the designs we are considering, we are not worried so much about the arm bending as we are about the way it is attached to the truss. We are certain that an I-beam, a T-beam, or a linear rail track is very capable of withstanding a few hundred pounds of loading at one end. However, we are still uncertain about how strong the welds and/or bolts will have to be that are mounting the arm to the truss. These mounts will have to withstand great moments, or else the arm will break off the truss, causing a very hazardous situation.

### **Swivel**

The pipe and shaft of the swivel mechanism must also be able to withstand the moments on them from the load on the telescoping arm. With the use of a counterweight opposite the load, the moment acting on the swivel joint will be lowered, but it still must be considered. If we make the shaft thick enough, this should not be a problem.

### **Truss**

The truss obviously must support the load without any yielding. This will partly be made possible by the design of the truss, and partly by the type of steel beams that we use. We wish to use L-beam to save weight and cost, but if it is found that this is not strong enough, we may be forced to switch to box beam or pipe. Our preliminary stress calculations show that L-beam should provide the

necessary strength to avoid buckling under the load of the tire, though we also need to perform some fatigue tests to see if prolonged use could have a detrimental effect on the strength of our truss.

### **Base**

The base has the same stress concerns as the truss, but more importantly, it absolutely must allow the machine to stay balanced. Our machine will be 10 to 11 feet tall, and if it tips over, the results could be disastrous. We will use our CAD model to check for the center of mass of our entire machine when it has a tire lifted with a fully extended arm to ensure that the center of mass stays within the footprint of the base.

## **9. Schedule and Method of Approach**

At this point in the project, we are behind schedule. We simply do not have as much done as we desire to have done, and we do not see our project getting back on schedule until after interim starts in January. This is a problem. Our master project schedule says that by now, we should have a substantial amount of our electrical design, structural design, and CAD model drawings done. We are certainly behind on our structural design, mainly because our preliminary designs have not been set for sure yet. Our CAD models are taking shape more or less on schedule as of the last few weeks of the semester, but since not a lot was done on those until recently, our structural analysis has not gotten very far yet. Furthermore, our electrical design depends a fair amount on the way our mechanisms work. Since our mechanisms are not totally designed yet, the electrical design is still somewhat ambiguous. The communication within our group between those working on the mechanisms and those working on the electrical controls has not been strong for much of the semester, which has also hurt progress on the electrical systems.

Our project is ambitious from a physical standpoint, simply because we are building such a large machine with many components. Construction will take a long time, so it is absolutely necessary to be on schedule or even ahead of schedule by the time we start construction. To do this, we will need to work many more hours each week than what we have done thus far.

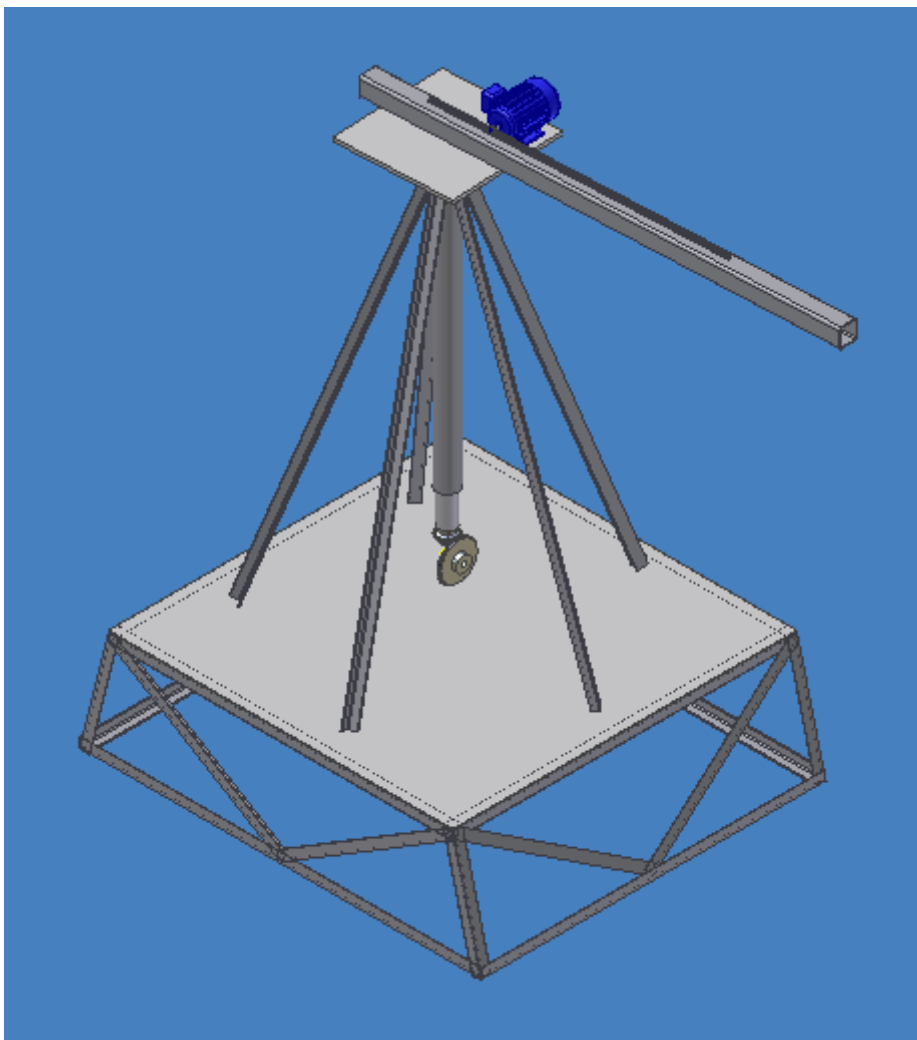
Our long term plan for major milestones on the project is this: By the end of interim we will have all design done and all parts ordered so that we can start construction right away after interim break; we will then work on construction all of February and the beginning of March so that our lift is completely constructed by the beginning of spring break. This will leave much time for testing and modifying after break, as well as writing the user manual and final report.

Ideally, we would have our entire basic design done by the time Christmas break begins, including fairly detailed plans for each mechanism. Three of our group members are taking the Finite Element Analysis course during interim, so ideally we would have ready-to-analyze models done going in to this class. As it stands right now, we have a rough CAD sketch of a base design, a rough sketch of a truss, and a rough sketch telescoping arm that magically telescopes and floats in space on its own. Our mechanisms are just starting to take shape on CAD, but much more detail is needed in all of our designs than what currently exists. Furthermore, first cut stress calculations need to be done on these designs to check for trouble spots in our design so that our design could be updated before doing an FEA analysis on it. Unfortunately this has not been done either.

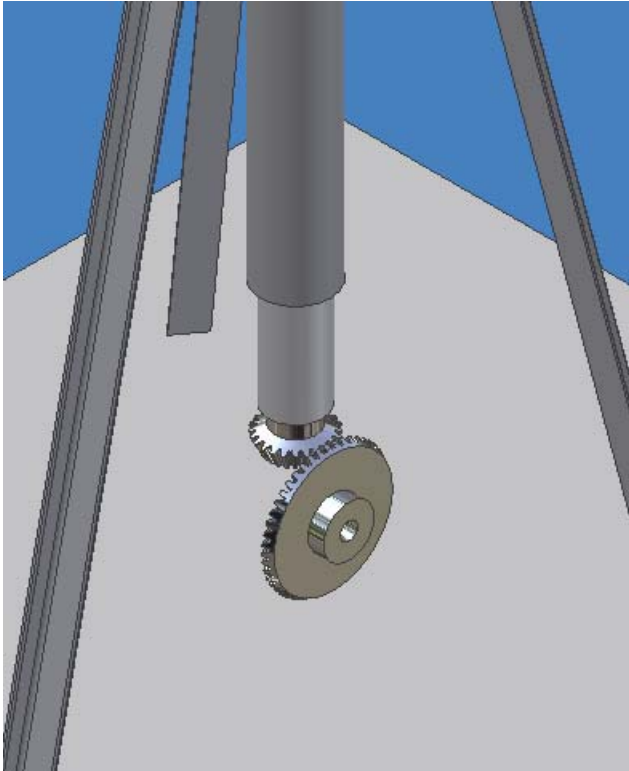
Our plan for the rest of the semester is to attack our truss design and each mechanism in detail and leave for Christmas break with a solid idea of how each will function, as well as fairly detailed CAD drawings of each. We have been using LEGOs to help ourselves visualize our ideas for the swivel and telescoping arm, and they have really helped us make some progress in seeing physically how some of these designs can realistically be done.

We have also begun to strip down the rotating sign project from the Post Revolution team last year to see how we can utilize some of the parts from it in our swivel mechanism. Thus far, we have determined that the entire swivel mechanism consisting of a shaft, pipe, motor, and gear train can potentially be of use to us for our swivel mechanism. This has helped to spur on the design process, because it has set some specifications on some major components that previously had been free variables. By eliminating some of these free variables, we have some key dimensions that we can begin designing around rather than having no set dimensions for our machine.

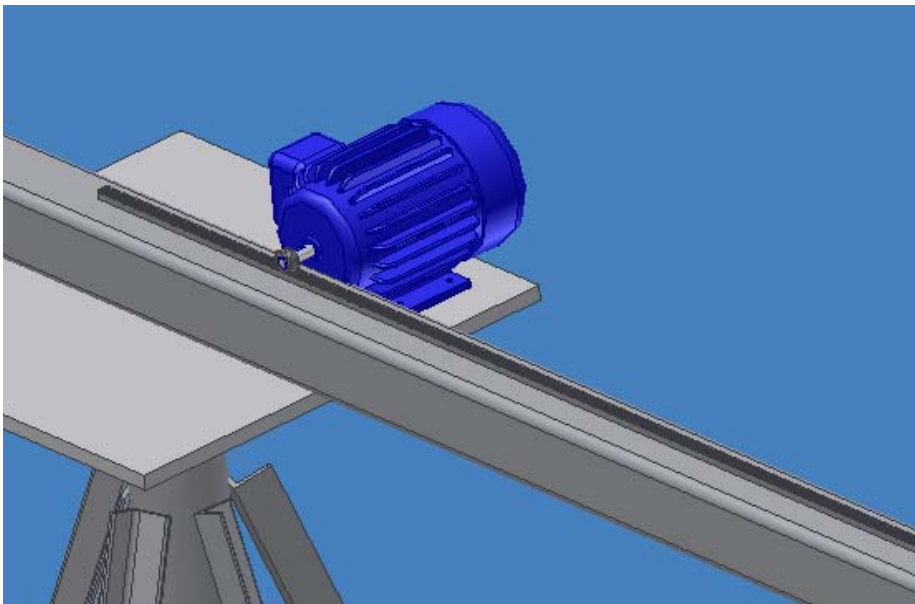
## Appendix A: CAD Drawings



Entire Lift Design



Swivel Mechanism Detail



Telescoping Rack and Pinion

## Appendix B: Motor Power Calculations

These calculations show what the necessary motor size is for the load that we wish to lift. Since we will be using a winch, our winch must have at least this amount of power, or it will operate slower than our target lift time.

### Calculating Lift Motor Power

Load := 400 lbf      Height := 9 ft      Time := 90 s

Work := Load · Height      FS := 2.5

$$\text{Power} := \frac{\text{Work}}{\text{Time}} \cdot \text{FS}$$

$$\text{Power} = 0.182 \text{hp}$$

## Appendix C: Stress Calculations

All of our stress calculations are done to check for the worst possible case of loading. They basically assume that most of the load is concentrated on one specific piece of our machine.

The pipe we have in the center of our truss is a standard 2" pipe. It must not buckle or bend too much under the load of the top arm and the tire. The Euler critical buckling load calculation is shown below. It shows that our pipe can hold almost 25,000 lb directly on top of it without buckling, and it obviously won't ever be faced with this level of loading, so our pipe passes the buckling test.

PIPE

$$E := 29 \cdot 10^6 \cdot \text{psi}$$

$$R := 2.375 \text{ in} \quad r := 2.067 \text{ in}$$

$$I := .666 \text{ in}^4$$

$$L := 87.5 \text{ in}$$

Buckling Load:

$$P_{cr} := \frac{\pi^2 \cdot E \cdot I}{L^2} \quad P_{cr} = 2.49 \times 10^4 \text{ lbf}$$

When the load of the tire is extended out to its maximum of 10 feet, the pipe will have a large moment on it. The worst case scenario for the pipe is to assume that the carries this entire moment (rather than assuming some of the moment is carried by the truss supports). This scenario shows that the pipe probably would not be able to withstand the moment loading just on its own even with a counterweight—the tensile strength of our steel is estimated to be around 36 ksi, while the maximum tensile stress due to the moment loading is 90 ksi. However, it won't have to hold the load on its own, because it will have four support legs to help stabilize it from holding the entire moment load.

Moment Load:

$$\text{Load} := 500 \text{ lbf} \quad \text{CW} := 200 \text{ lbf}$$

$$\text{Arm} := 10 \text{ ft} \quad \text{CWarm} := 4 \text{ ft}$$

$$M := \text{Load} \cdot \text{Arm} - \text{CW} \cdot \text{CWarm}$$

$$\sigma_{\text{bend}} := \frac{M \cdot \frac{D}{2}}{I} \quad \sigma_{\text{bend}} = 8.986 \times 10^4 \text{ psi}$$

$$\text{strength}_{\text{tensile}} := 36000 \text{ psi}$$

To determine how much each leg of the truss would need to hold to support the pipe, the theoretical deflection of the pipe can be calculated using the worst case scenario loading:

$$\delta_{\max} := \frac{M \cdot L^2}{2EI} \quad \delta_{\max} = 9.36 \text{ in}$$

The job of the truss supports then becomes providing enough force to the top of the pipe to keep it counteract this large deflection. First, a total force needed at the top can be calculated, and then using the geometry of the legs, the force in each leg can be determined.

$$P := \frac{\delta_{\max} \cdot 5 \cdot E \cdot I}{L^3} \quad P = 892.562 \text{ lbf}$$

$$F_{\text{leg}} := \frac{\frac{P}{4}}{\sin(50 \cdot \text{deg})} \cdot \frac{1}{\sin\left(\text{atan}\left(\frac{4}{10}\right) \cdot \frac{180}{\pi} \cdot \text{deg}\right)} \quad F_{\text{leg}} = 784.32 \text{ lbf}$$

Two of these legs will be in tension with this force, and two will be in compression this amount if the arm is hanging out in a way that the legs are evenly loaded. However, the arm could also hang out over just one leg, making effectively just one leg in compression and one in tension.

$$F_{\text{legworst}} := \frac{\frac{P}{2}}{\sin\left(\text{atan}\left(\frac{4}{10}\right) \cdot \frac{180}{\pi} \cdot \text{deg}\right)} \quad F_{\text{legworst}} = 1.202 \times 10^3 \text{ lbf}$$

So our best estimate of the maximum force in one of the truss legs due to the moment on the pipe is about 1200 lb. If we also assume that the worst possible loading on the legs due to the weight of the beam and tire would be if all 500 lbs were held on one leg, the maximum force in a leg is around 1700 lb. To make sure a leg will hold this, we need to find the maximum Euler buckling load for a leg, which is made of 2 x 2 x 1/4 inch angle beam. This calculation shows that it should hold the worst case load.

$$E := 29 \cdot 10^6 \cdot \text{psi}$$

$$I := .348 \text{ in}^4$$

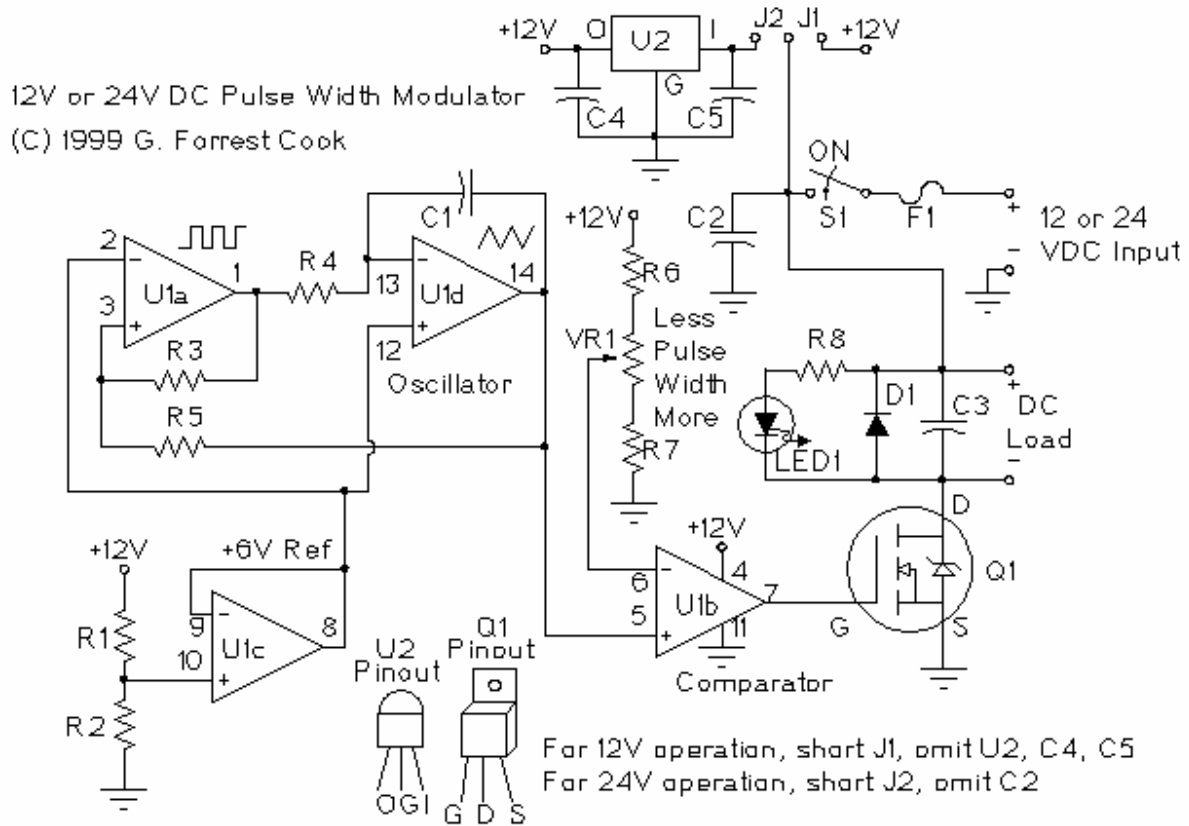
$$L := 116 \text{ in}$$

Max Buckling Load:

$$P_{\text{cr}} := \frac{\pi^2 \cdot EI}{L^2} \quad P_{\text{cr}} = 7.402 \times 10^3 \text{ lbf}$$

## Appendix D: Circuit Diagrams

This Diagram shows a general circuit for a Pulse Width Modulator (PWM) control system:



## Appendix E: Budget Report

At this time, we have not purchase any parts, so our budget fund still has the full \$500 remaining in it to buy the rest of the parts that we don't find for free.

| <b>ENGR339/340 Senior Design Project</b> |                  |                         |      |                |
|--|------------------|-------------------------|------|----------------|
| <b>2004-2005</b>                         |                  |                         |      |                |
| Team Number:                             | 13               |                         |      |                |
| Team Name:                               | TIREd            |                         |      |                |
| Today's Date:                            | 11/30/2004       |                         |      |                |
| Date                                     | Item Description | Vendor                  | Cost | Out of Pocket? |
| 29-Nov-04                                | Shaft            | Post Revolution Project | Free | N              |
| 29-Nov-04                                | Thrust Bearing   | Post Revolution Project | Free | N              |
| 29-Nov-04                                | Radial Bearing   | Post Revolution Project | Free | N              |
|  |                  |                         |      |                |
|  |                  |                         |      |                |
|  |                  |                         |      |                |
|  |                  |                         |      |                |

## Appendix F: Prototype Pictures



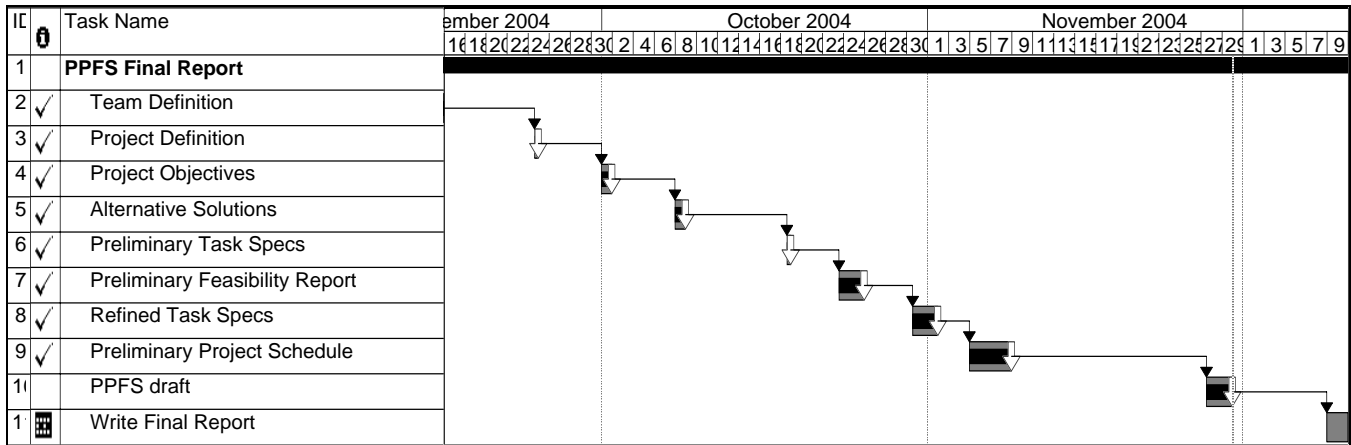
Lego Model Prototype

This prototype has fully functional swiveling, telescoping, and lifting mechanisms.

## Appendix G: Schedule Breakdown

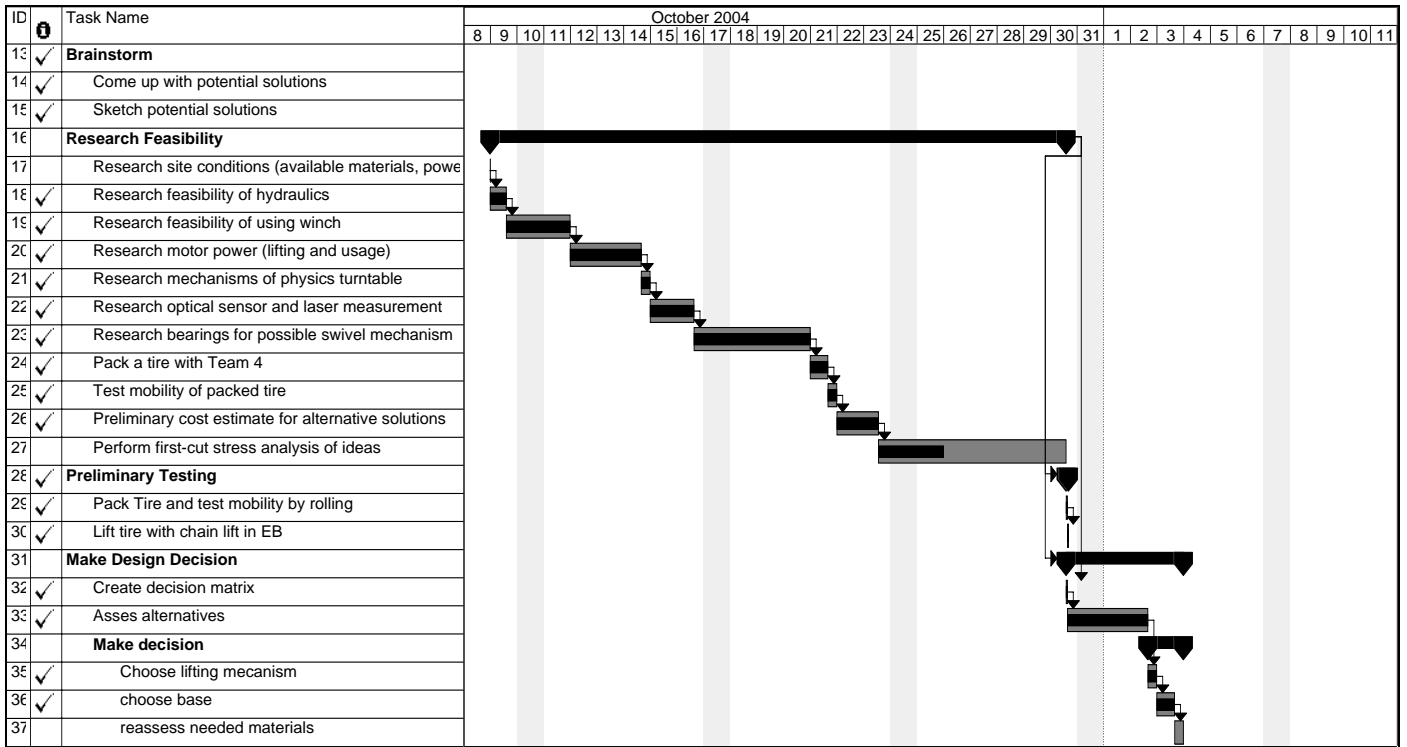
### Produce a PPFS

The structure of ENGR 339 helps us to gradually create the components of our PPFS throughout the entire first semester. We started preparing in the second week of the semester and the final PPFS report is due on the last day of the semester.



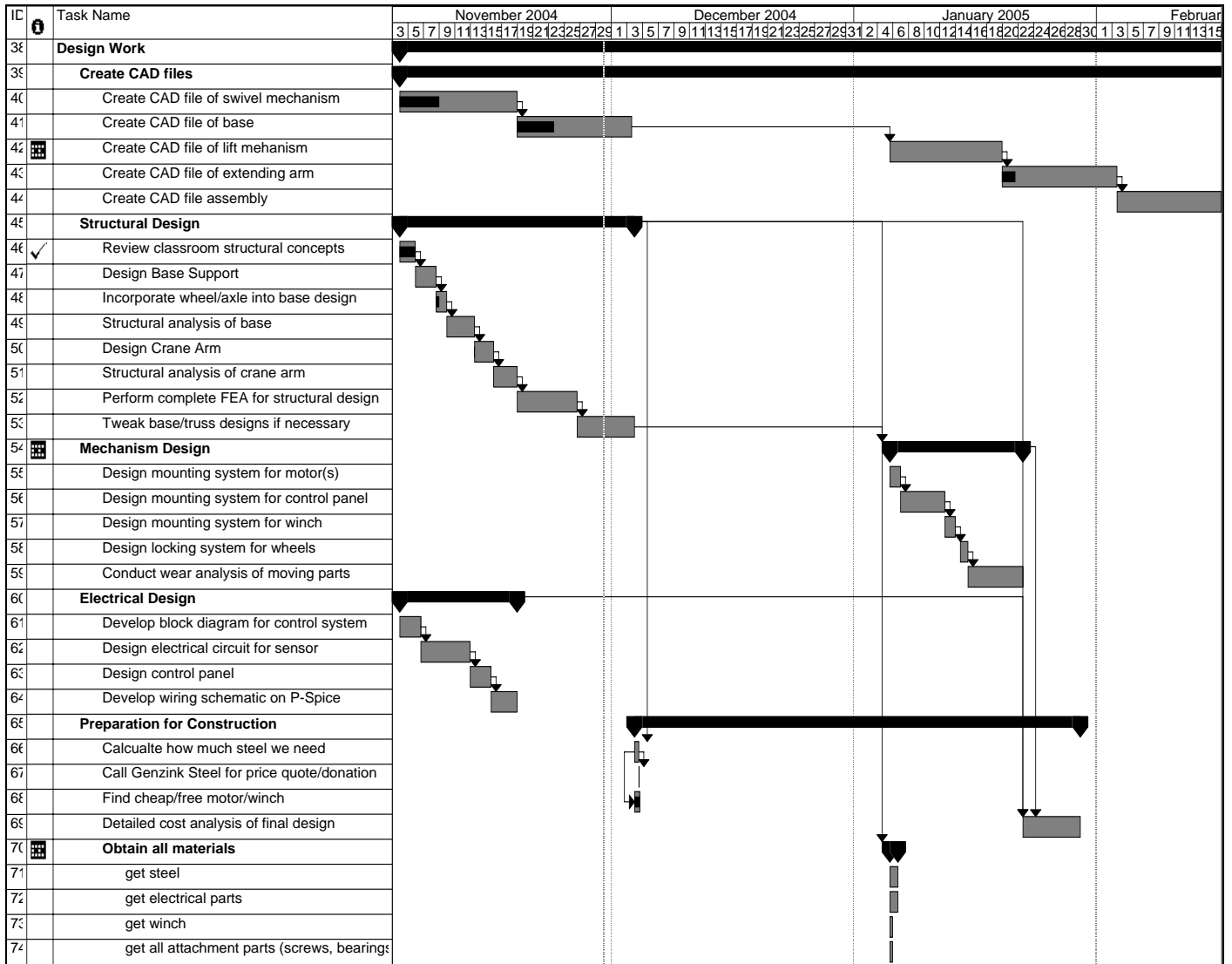
### Preliminary Project Work

The first couple of months of the semester, outside of our continuous PPFS work, we had a lot of preliminary tasks to accomplish. They ranged from brainstorming design alternatives, to lots of research, to some preliminary testing, to making a design decision. We scheduled to have our brainstorming done by the first week of October. Our research would take us until the rest of October to complete. The preliminary testing was done in 2 days and our design decision was made by the first week in November.



## Design Work

Included in Design Work are such things as creating the CAD files of our designs, designing the structural components, designing the mechanical components, designing the electrical components, and preparing for construction. We hope to have all of our structural and electrical design completed as well as a good portion of our CAD work done before Christmas break. After the break we will finish the mechanical design and get more CAD work done. We do not anticipate being able to finish the CAD drawings until February, but we will be ready for construction before interim break.



## Construction

We will attempt to have our machine completely constructed and ready for testing by spring break, including all welding and integration of the mechanical and electrical components.

