Project 9:
Final Report

Surgical Lift Project for Dr. Muraszko

Dayna Anderson, Patrick Davis,
Leslie Savage, and Monika Skowronska
12/9/2008

Abstract

In the operating room, the patient lies on a stationary table while being operated on by many different surgeons and nurses of varying height. This causes ergonomic strains on the operating room personnel who are forced to work at suboptimal positions. This problem is magnified for Dr. Karin Muraszko, Head of the Department of Neurosurgery at the University of Michigan, who was born with Spina Bifida. The goal of this project was to supply Dr. Muraszko with a device which would allow her to operate at a height comfortable for all OR personnel. The device must also have optional seating, be easily moved and be suitable for use in the OR environment. The resulting product was a hydraulic lift with movable seating, manufactured out of sterile materials.

Executive Summary

The focus of this project is to design and build a lift for surgeons in the operating room. The project centers around one surgeon, Dr. Karin Muraszko, of the University of Michigan's Neurosurgery Department. Dr. Muraszko needs to be brought up to the level of her patients, because she is 4'8" tall and was born with Spina Bifida, which hinders her mobility. For over 20 years, Dr. Muraszko used the same lift until an ME 450 group in the winter term of 2008 designed a new lift for her. The current lift is an improvement over the old one; however, there is still room for improvement. The final design will be utilized by other surgeons or perhaps even in other professions. Protomatic, is involved with the project so that when the final design is completed, they can create the product for the emerging niche market.

Customer and engineering requirements were determined after talking with Dr. Muraszko and Protomatic. The most important of those requirements are shown in Table 1.

Customer Requirements	Engineering Requirements
Mobility	Rolling Resistance Coefficient (dimensionless) Diameter of wheels Weight
Stability	Coefficient of friction between wheels/base and ground when locked Force required to lock/unlock lift
Movable (Adjustable) Seating	Seating pushed aside quickly when not needed Seat can be adjusted to several heights and can be extended horizontally forward to the to enhance ergonomics

Table 1: From Customer to Engineering Requirements

We generated concepts for the design in pieces and using Pugh charts determined the appropriate system to be used for each portion of the lift. We determined that a hydraulic lift would be the best choice for our application. Other design concepts generated include the wheel locking mechanism, button type, lean bar design, seat implementation, and power cord containment.

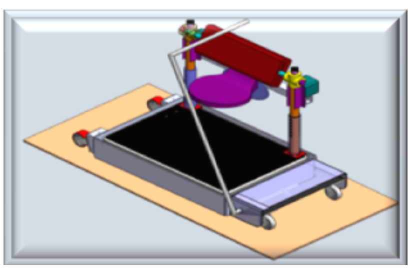

Figure 1: Alpha Design CAD Model

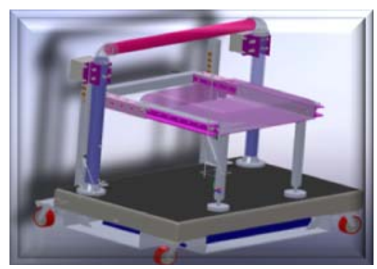

Figure 2: Final Design CAD Model

We began with an alpha design and purchased the hydraulic lift (Figure 1). We had several meetings with our sponsor to make sure she was pleased with the design, during which she clarified several design requirements. These meetings led us through several design iterations and finally to our final design. She clerified that it was very important for her to keep the platform size at 36 in by 24in, keep the lean bar a round bar and have the seat be able to adjust both forwards and backwards. Based on these new requirements we redesied our exisitng lift and produced our final design (Figure 2). We have analyzed our final design both manually and through the utilization of COSMOS, ordered the remaining parts and have passed on the engineering prints to Protomatic. Protomatic has manufactured the individual parts which we have subsequently assembled. The lift will be delivered to Dr. Muraszko the week of December 8, 2008.

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Introduction

The goal of Project 9 is to design and build a lift for surgeons in the operating room. The project centers around one surgeon, Dr. Karin Muraszko, of the University of Michigan's Neurosurgery Department. Dr. Muraszko needs to be brought up to the level of her patients, because she is 4'8" tall and was born with Spina Bifida, which hinders her mobility and causes her to wear a leg brace. For over 20 years, Dr. Muraszko used the same lift until an ME 450 group in the winter term of 2008 designed a new lift for her. The current lift is an improvement over the old one; however, there is still room for improvement. The final design can also be utilized by other surgeons or perhaps even in other professions. A manufacturing company, Protomatic, has created the lift for Dr. Muraszko and they will continue to produce the lifts for the emerging niche market.

Problem Description

The goal of our project is to redesign the current surgical lift used by the Chief of Neurosurgery, Dr. Karin Muraszko (Figure 3). Therefore, the company that we are working for is the University of Michigan's, Mott Children's Hospital. Dr. Muraszko was born with Spina Bifida which restricts her movement abilities. She has to wear a leg brace and because of her height requires a lift to stand on when performing surgery. The goal for our lift design is to allow Dr. Muraszko to perform surgery comfortably as any other surgeon. The design problem that we have to address is creating a more user friendly, comfortable and safe lift for Dr. Muraszko.

Figure 3: Current Lift in the OR

There are two very distinct goals for this project; the first looking at the short term and the latter looking towards the future. Our current chief concern is creating a lift that Dr. Muraszko feels comfortable using during surgery which can be easily transported. When looking towards the future, we envision a growing market for the lift as many women enter a variety of surgical fields. Since women are on average shorter than men, many "shorter" women will need assistance in some form to reach the proper operating height.

We hope that our lift will help them to achieve this. Also, our lift may be able to cross over to other industries where height adjustment is not just wanted but necessary.

Short Term Goal

The goal of our project is to redesign the surgical lift that Dr. Muraszko, is currently using, as discussed previously. Compared to her current lift, we want the improved design to have a more refined wheel locking mechanism, creating a more stable surface for the doctor to stand on. In addition, we hope to improve the mobility of the entire lift making it much easier to move around to the various operating rooms. We would also like to introduce several features to the lift that will increase the safety of not only the operator but also those working around the surgical lift.

As stated previously, the short term goal of the project is to create a surgical lift that caters to Dr. Muraszko's needs. However, we must keep in mind that this could potentially be massed produced to be used by other surgeons and perhaps even in other industries (the long term goal).

Long Term Goal

Already, there is demand by other relatively short surgeons (mainly female) for a lift of this type. They have expressed interest in Dr. Muraszko's current lift and would be interested in purchasing one of their own. Working in conjunction with Protomatic ensures that when we are done completing the lift for Dr. Muraszko, Protomatic can take our designs and manufacture additional lifts for other surgeons in need. In the future we also hope that this lift will be used by all surgeons (both female and male) to maintain a single operating height. This will ensure that all surgeons can stand in the position which is most comfortable for them without having to bend or stretch to reach the patient.

Not only could surgeons use this lift, but other professionals such as shop workers could use it as well. In addition the lift may be helpful to elderly consumers who have decreased mobility and need assistance reaching into high cupboards or even getting out of bed. The hope is that one day this lift could be used in all areas where assistance is needed to reach a certain height – it could enhance ergonomics in the work place thereby reducing worker/operator strain.

Customer Requirements and Engineering Specifications

In order to create a design which satisfies our customers, we had to determine what exactly the customers wanted. To create a succinct version of both the primary (Dr. Muraszo) and secondary (Protomatic) customers' needs and wants, we formed ten customer requirements. Then, we determined how to meet each of the customer requirements, thereby creating concise engineering requirements which we used as guidelines throughout the design process.

Customer Requirements

In order to determine a set of engineering requirements, which would be used to guide the design process and judge our final design, the needs and wants of the customer had to first be determined and categorized. In order to do this, we met with our primary customer, Dr. Muraszko, who along with her team helped us determine aspects of the current surgical lift that needed improvement. The top areas of concern for Dr. Muraszko were the stability and mobility of the lift. For example, during surgery the lift must be extremely stable and not move around, however during transport to other operating rooms the lift must be extremely easy to move. Another area of concern which surfaced during several of the design critiques dealt with the seat. Dr. Muraszko wanted to ensure that the seat could be easily stored when not in use along with being adjustable in both the horizontal and vertical directions. Several other areas of concern dealt directly with how the user interfaces with the device and what safety features should be installed.

We also took into consideration several requirements of our secondary customer, Protomatic. Protomatic is the prototyping company that will be assisting us with the manufacturing of Dr. Muraszko's lift. In addition, the company will be taking our designs and keeping them for future use. Other surgeon's have already expressed interest in a surgical lift, which Protomatic would build for them, so we need to be conscious of their requirements as well (Starred items in Table 2, page 4). The three largest concerns that Protomatic had were keeping the cost of the lift low, ease of manufacture/assembly, and the modularity of the design.

We took these areas of concern and refined them into customer requirements. For example, the lift must be comfortable since surgery is a long and grueling process. Therefore, we worked with the customer and concluded that a comfortable seat, which can be stored when not in use, is a very desirable feature. Also the height of the lean bar and seat should be adjustable to accommodate any number of positions the surgeon can operate in, but also to ensure the comfort of other potential users. The customer also felt that safety features which could limit the lift's operating height to 24" and operating weight limit to 300lbs should be considered.

Once the customer requirements were determined, they had to be weighted relative to importance [to the customer]. We therefore took the information Dr. Muraszko and Protomatic gave us and looked at what features were emphasized as important. This information was combined with our understanding of what was needed in the O.R. to create the weighting. According to the rankings, mobility and stability are the most important features to the customer while power cord containment is the least important because it is a "would be nice to see" feature rather than a necessity. Table 2 on page 4 lists the specific customer requirements that were used in the development of the QFD (in descending order of importance).

Customer Requirements	Assigned Weight
Mobility	10.0
Stability	10.0
Comfort	8.0
Low Cost*	8.0
Prominent User Controls	7.0
Easy to Manufacture/ Assemble*	7.0
Modularity*	7.0
Safety Features	5.0
Movable (Adjustable) Seating	5.0
Power Cord Containment	2.0
*Requirements for Protomatic	

Table 2: Customer Requirements

Engineering Requirements

After the customer requirements were defined, the engineering requirements had to be determined. In order to do this, we looked at each individual customer requirement and thought about how it could be met. We used broad engineering requirements as guidelines throughout or concept generation process (Appendix A: page 64). Once an Alpha design was selected we began to narrow the engineering requirements. We tried to determine "how" (using functions or properties) to meet each customer requirement. Table 3 shows the engineering requirements which will achieve each customer requirement.

Customer Requirements	Engineering Requirement
Mobility	Rolling Resistance Coefficient (dimensionless) Diameter of wheels Weight
Stability	Coefficient of friction between wheels/base and ground when locked Force required to lock/unlock lift
Comfort	Adjustable lean bar to facilitate different users Platform size limit the allow surgeons and nurses to comfortably travel around the surgery table
Low Cost*	*This will be directly affected by the other choices*
Prominent User Controls	Buttons stick out far enough from lean bar Button size
Easy to Manufacture/ Assemble*	Number of parts
Modularity*	Different modifications can be made using the same base architecture
Safety Features	Lift automatically shits off when too much weight is applied Lift will stop when a designated "safety" height is applied
Movable (Adjustable) Seating	Seating pushed aside quickly when not needed Seat can be adjusted to several heights and can be extended horizontally forward to the to enhance ergonomics
Power Cord Containment	Power cord will be contained within/around the lift

Table 3: From Customer to Engineering Requirements

However, as the QFD shows (Appendix B: page 65) many of the engineering requirements relate to several of the customer requirements in a strong, moderate, or weak way. For example, we created the engineering requirement “Seating can be adjusted to several heights to enhance ergonomics” with the “Movable (Adjustable) Seating” customer requirement in mind. However, this engineering requirement also directly affects the comfort of the lift, the ease of manufacturing, modularity potential, and the total number of parts. This multi-level interaction was used to determine the importance of the engineering requirements relative to one another.

We also created quantitative targets/limits that we wanted each engineering requirement to meet (Table 4, page 6). For example, we want the lift to stop rising once the operational “safety” height of 24” has been met. We therefore set a goal of 24” for this requirement. We also placed each requirement into a goal category: Do we want to minimize, maximize, or meet the target for this goal? We decided to place the operational “safety” height goal in the *Meet Target* category because it lifts the operator to the correct operating height. We do not want to minimize or maximize the lift height because this would not meet our overall goal of lifting the surgeon so she may operate at the correct height.

Lastly, the relative difficulty associated with meeting each engineering requirement was determined and entered into the QFD (Appendix B: page 65). For example, we felt that having the lift shut off when a great enough force is applied would be much harder than choosing a strategy to store the power cord. We therefore assigned the first requirement a difficulty rating of 8 (10 being the most difficult) and the latter a rating of 1. These difficulty ratings were used in conjunction with the relative importance of each requirement to determine what engineering requirements we should try to meet first. As seen in Table 4, page 6, the top three engineering requirements are as follows:

1. Rolling resistance coefficient
2. Coefficient of friction between wheels/base and ground when locked
3. Seat can be adjusted to several heights and be extendable forwards and backwards

Engineering Requirement	Target Value/ Limit	Goal: Minimize, maximize, or meet target	Relative Importance
Rolling resistance coefficient	Maximum: 0.0067	Minimize	12.2
Coefficient of friction between wheels/base and ground when locked	Minimum: 200 lb force	Maximize	11.2
Seat can be adjusted to several heights to enhance ergonomics	Range Vertical: 18” – 24” Extension Horizontal: 6 ’’	Maximize range	9.9
Number of parts	15 parts	Minimize quantity	8.4
Platform Size Limit	36’’ by 24 ’’	Minimize size	8.0
Adjustable lean bar to facilitate different users	Range: 24” – 30”	Maximize range	7.5
Different modifications can be made using the same base architecture	2 modifications	Maximize number of modifications possible	7.5
Lift automatically shuts off when too much weight is applied	200 lbs	Meet target weight	5.8
Lift will stop when a designated “safety” height is reached	24”	Meet target height	5.8
Diameter of wheels	Maximum: 7”	Maximize diameter	5.5
Weight	250 lbs	Minimize weight	5.5
Buttons stick out far enough from lean bar	Minimum: ½”	Minimize protrusion distance	3.8
Button size	Maximum: 1” diameter	Maximize diameter	3.8
Seating can be pushed aside quickly when not needed	Minimum” 3 seconds	Minimize time	3.6
Power cord will be contained within/around the lift	0” outside lift’s bounding box	Minimize distance	1.4

Table 4: Engineering Requirements’ Target and Goal

The first three engineering requirements are clearly the most important which makes sense because they greatly affect the stability and mobility of the lift, which are the top two customer requirements. The lift will have minimal mobility if the coefficient of rolling resistance is too high. We set a maximum rolling resistance coefficient of 0.0067 (dimensionless) after researching the various coefficients found when two surfaces come into contact with one another. For a detailed analysis of how we set this particular engineering target please see the Problem Analysis Section on page 48. Also if the lift cannot be unlocked easily, moving it around in or between operating rooms will be very difficult. Therefore we are focused on building a mechanism which can switch the "mode" of the lift from stable to mobile and vice-versa when very little force is applied by the user.

The second most important engineering requirement is that there is enough friction to secure the lift when locked so it will not slide around. We do not want the lift to slip and slid over the floor, but at the same time we do not want it to be too difficult to move when the mobility mode is activated. We will therefore focus on selected materials/mechanisms which will have a high enough coefficient of friction to prevent the lift from moving around when 300 lbs of force is applied.

The third most important requirement is for the seat to be adjustable in two directions (vertically and horizontally). We want to ensure that the seat can be adjusted to allow a better, more ergonomically correct position, for all doctors who wish to use this lift. Having adjustability would also allow the surgeon to adjust the seat (parallel with the lift top) when needed during surgery.

Based on the three most important engineering requirements we intend to create a mechanism, which will ensure user safety (lift is stable during surgery) and ease of use (lift is mobile during transport, adjustable seating).

Concept Generation

Concepts were first generated before the meeting with Dr. Muraszko. We generated these concepts as a team using the IDEO method of concept generation. We simply threw out as many ideas as quickly as possible – no analyzing or critiquing was done. These concepts were innovative and large in number; however after meeting with Dr. Muraszko and her team, were found to be infeasible. From the meeting with our primary customer we learned what lift characteristics were desired:

- Lift footprint
- Vertical travel distance
- Platform area
- Locking conditions
- User interface
- Potential safety features

From our meeting with Dr. Muraszko we were able to shift the scope of our project from designing a brand new lift to redesigning the current lift, while maintaining its likeable features. We therefore had a second concept generation session which focused on the new project scope. (Appendix C: page 66).

Once the scope of our project was determined we began to analyze the various components of the lift which needed to be improved. Combining this analysis with our customer requirements we determined that we needed to focus initially on redesigning the following features:

- Buttons
- Power cord containment
- Lean bar
- Lift power source
- Locking mechanism
- Lift Model

To generate concepts and/or find preexisting solutions, we researched and shopped individually to find solutions for each of the individual features listed above. After our individual research we met to compare the different solutions or products. Figure 4 illustrates the functional decomposition of the elements we focused on (decomposition includes the breakdown of the locking mechanism which we determined in a future phase of the design process –it is mentioned here for completeness).

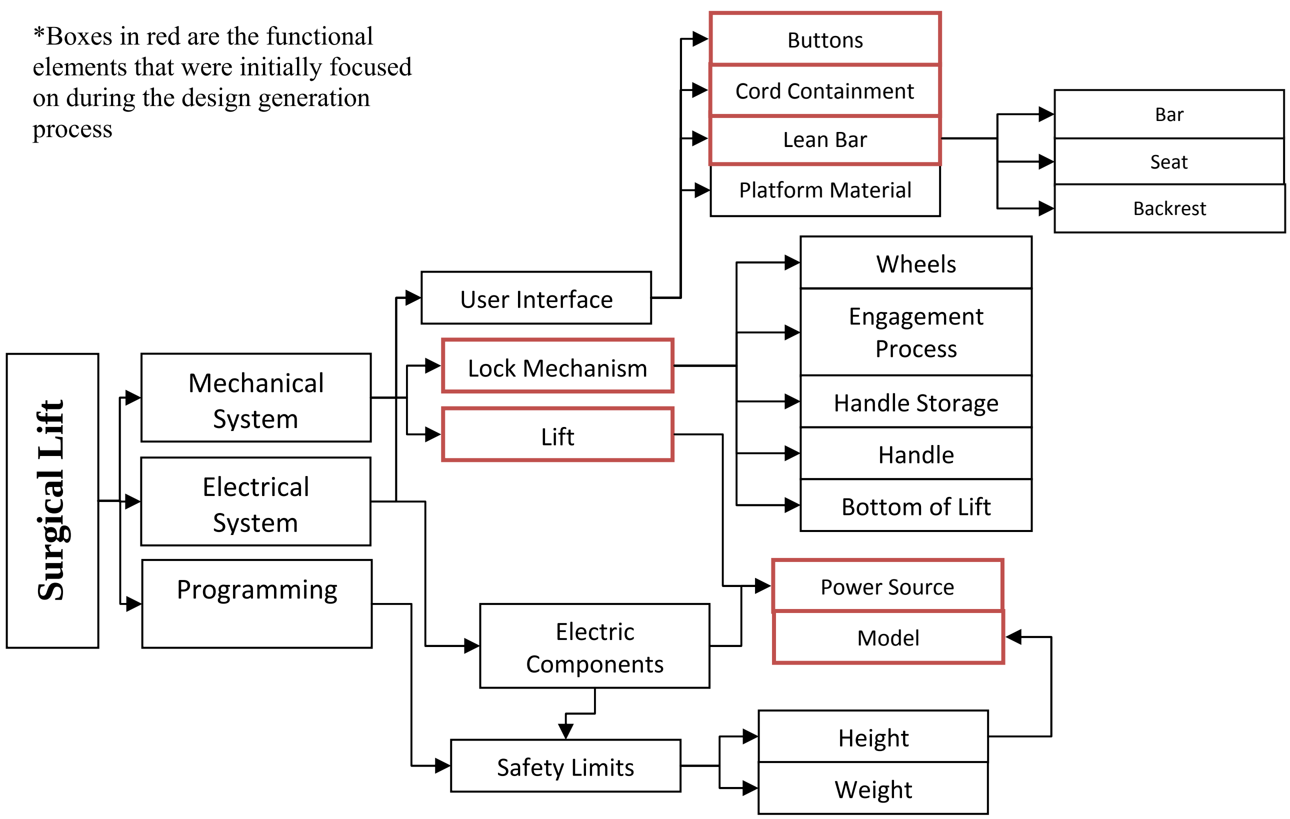


Figure 4: Functional Decomposition Diagram

Concept Generation - Buttons

Currently, the lift is draped with a sterile cloth and bag making the buttons difficult to find. We found four types of buttons which we thought easier to find under the drape. Others were found through internet and catalogue searches but offered no advantage over the current buttons. As shown in Figure 5 on page 9, the current control buttons are very small and once covered with a sanitary cloth are extremely hard to find. Also the buttons are close together and can therefore not be differentiated easily under the sterile draping.

Figure 5: Current Lift's Control Buttons

Figure 6 illustrates the four types of buttons considered (rocker, large scale, toggle, and rotational). A rocker button could be used to actuate the lift – the user would rock the button to either its up or down position to move the lift up and down, respectively (Figure 6a). A larger button could be used to increase the user's ability to find/differentiate between the buttons underneath the sterile drape (Figure 6b). We also considered a toggle, which functions much like the rocker, but it is activated by pulling or pushing the central tab (Figure 6c). Lastly we thought that a rotational switch could be used which would move the lift up and down when the tab was twisted either clockwise or counter-clockwise (Figure 6d).

-a- Rocker Button -b- Large Button -c- Toggle Switch -d- Rotational Switch

Figure 6: Styles of Buttons Selected for Analysis

Concept Generation – Power Cord Containment

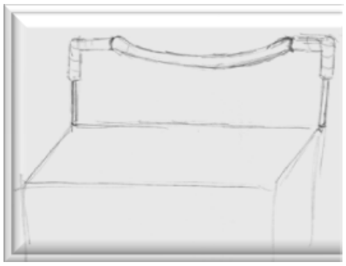
We found four different methods of containing the power cord. This containment is needed so the cord does not interfere with transport and can be out of the way, and not all over the floor, when the lift is not in use (Figure 7, page 10). The first method is a reel, which can be turned by hand using a crank, to store the power cord (Figure 7a). The second is an automatic cord retractor which is a spring loaded roller. These are typically found in workshops or garages and are similar to traditional window blinds that retract after the user tugs on the bottom (Figure 7b). The third method is to simply wrap the cord around 2 hooks like you would when storing the cord on typical vacuum cleaners (Figure 7c). The last method considered is to have the user wrap the cord around a cylinder (Figure 7d). This method of cord containment can usually be found in workshops when users wind up their electrical cords to store.

-a- Retractable by Hand -b- Automatic Retract -c- Hooks -d- Hose Reel

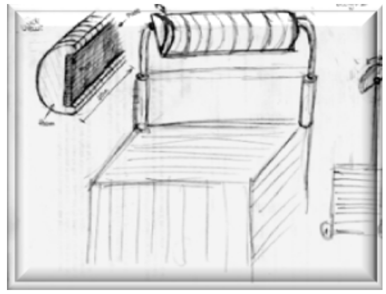
Figure 7: Cord Containment Options Chosen for Analysis

Concept Generation – Lean Bar

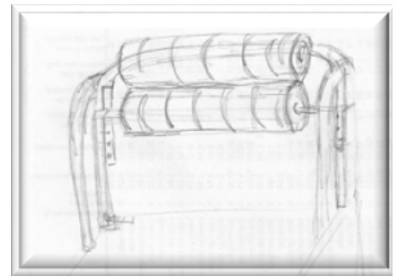
Many of the concepts we generated for the lean bar focused on adjustability and comfort. Several representative concepts are shown in Figure 8 below. (To view all backrest ideas see Appendix D: page 69. Below, Figure 8a illustrates a bent bar design, which is similar to the current lift's lean bar but it curved to better support the back when sitting or standing. The second design (Figure 8b) incorporates a large hemispherical cushion to provide lumbar support. This roll can be placed in different positions when sitting or standing to maximize comfort. The last design shown (Figure 8c) is a lean bar with two rolls so that they could be positioned independently for maximum comfort. The design of the lean bar will constrain the number of possible seat types. Therefore a design was selected before shopping for compatible seats. (See the Concept Selection Process Section on page 12 for selection process techniques and results). After meeting with Dr. Muraszko and presenting her with our design ideas we were informed that she felt most comfortable with the design she has currently which is a straight bar with foam padding on it.



-a- Bent Bar



-b- Adjustable Half Roll



-c- Double Roll

Figure 8: Lean Bar Design Concepts

Concept Generation –Lift Power Source

The next and perhaps one of the most important characteristic of our lift is the power element which actually raises the lift. There are four different driving mechanisms available on the market. They are hydraulic pistons, pneumatic pistons, electric motors, or airbags. The hydraulic pistons use fluid to transfer power from the pump to the piston. The pneumatic pistons do the same but with air. An electric system uses an electric motor to drive a gear set or chain and an airbag lift utilizes an airbag which is inflated using a pump. Also many power elements on the market do not fit purely into one category. For example, many lifts are electro-hydraulic.

Concept Generation –Lift Model

The power source selected to power our surgical lift was electro-hydraulic, the same source used to power the current lift (See the Concept Selection Process Section for selection process techniques and results, page 12). Once we determined that the lift would have an electro-hydraulic power source we started generating ideas (shopping around) for the actual lift we wanted to use. Three ideas we came up with are shown in Figure 9 below.

-a- Zero Ground Scissor Lift

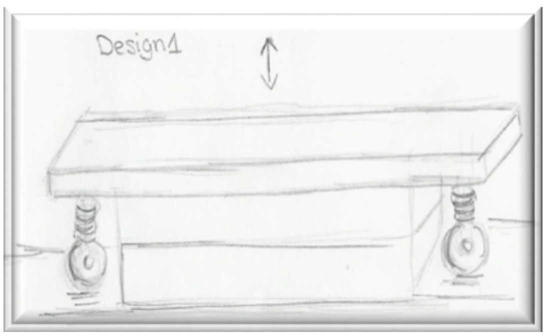
-b- Mobile Lift Table

-c- Lift Table

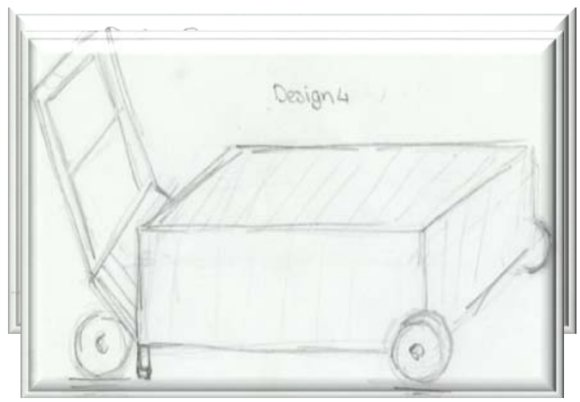
Figure 9: Lift Model Concepts

Concept Generation –Locking mechanism

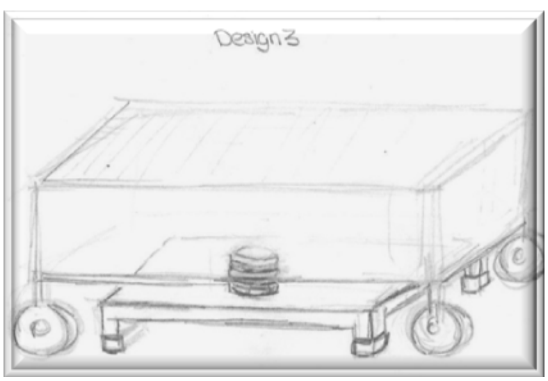
Lastly, the design element with which we had the most freedom was the locking mechanism and therefore we also had many contrasting designs. We came up with these designs through individual research and group discussion (see all locking ideas see Appendix D: page 71). The four most feasible designs are detailed in Figure 10 on page 12. The first design had its wheels mounted on the top platform such that when the lift was raised, the wheels would raise off the ground (Figure 10a). The second design uses four hydraulically actuated pistons to stabilize the base and raise the wheels off the ground when someone steps onto the lift. The pistons would have to be activated by a weight sensing pad (Figure 10b). In the third design, the lift is held up by a spring on top of the base. When an operator stands on the lift, it would sink down in relation to the base forcing a plate to the ground (Figure 10c). The fourth design makes use of a cam linked to a handle. This cam either forces the front wheel down or raises it up allowing the base to touch the ground (10d).



-a- Top Mounted Wheels



-d- Handle Actuated Cam



-c- Spring Loaded Plate

Figure 10: Locking Mechanism Design Concepts

Concept Selection Process

The concept selection process was performed with the exclusive use of Pugh matrices. These were used because they are an excellent method for quantifying and recording decisions made during the design process (For all Pugh matrices used in the design process see Appendix D: page 67. We discussed the necessary categories for judgment and discussed the scores for each category as a team. We also took notes and quantified decisions where appropriate. The characteristics for the buttons, the backrest, the power cord containment, lift type and wheel locking mechanism were analyzed using Pugh matrices and this section details the results.

Concept Selection Process – Large Buttons

We decided through Pugh analysis (Appendix D: page 67) to use the two large buttons (seen in Figure 6, page 9) mounted separately in our design. One of the advantages of using the large buttons is their size. Their size makes them easier to find under the sanitary draping needed over the top of the lift in the OR. Another advantage is that mounting them separately will allow for easy differentiation between the up and down buttons as long as the shapes indicate the direction of travel. Their size may however be a disadvantage because it allows for them to be easily pressed by accident. The next most desirable button was the toggle switch it had most of the advantages and disadvantages of the large buttons. However, the toggle switch however did not have the size of the large buttons and therefore would be harder to find under the sterile draping.

Concept Selection Process – Retract Power Cord via Hand Crank

We next found that the hand retractable reel (seen in Figure 7a, page10) was the best for our design (see Pugh matrix in Appendix D: page 68). The hand reel retractable power cord is easy to use, keeps the power cord fully stored, and fast. However, it does have the disadvantage of being bulky which may pose problems when finding an area to affix the holder to the platform. The hand reel retractable power cord was better than the hose reel design because the latter did not keep the cord contained and was not as fast or convenient. It was also more suited for long term use than the automatic retractable cord because the automatic retractable cord has a spring loaded mechanism which will wear over time.

Concept Selection Process – Adjustable Half Roll Lean Bar

The most advantageous lean bar design was also found through Pugh analysis (Appendix D: page 69). The adjustable half roll was chosen (Figure 8, page 11) because it was easily adjusted, integrated well with the seat, was large enough to provide comfort, and was visually appealing. Its drawbacks lie in the fact that it may not be easily padded and the adjustment mechanism may wear over time. The bent bar was not as well suited because it may have caused manufacturability and adjustability issues. The double roll design had no advantage that the half roll design lacked and the extra roll added weight without adding any discernable benefit. After presenting Dr. Muraszko with our choice for the design we learned that she would prefer to keep the old design of the bar which was a straight bar with foam padding on it. Therefore that was our final design choice.

Concept Selection Process – Hydraulic Lift

Our Pugh analysis (Appendix D: page 70) showed that the most suitable lift for the OR environment would be an electric driven lift (Table 5, page 14). An electric lift's main advantage was the low maintenance required and safe failure mode. Unfortunately, the lift we analyzed could not meet the minimum reach height of 24 inches. This requirement must be met to bring the 4'8" Dr. Muraszko up to the 6'5" height of a 95th percentile male surgeon. When we quoted electric lifts that could meet the height requirement, they were outside of the budget of the project. Therefore, the next two lift types, hydraulic and pneumatic were analyzed line by line to determine which would best meet our requirements. The hydraulic and pneumatic lifts differ in weight, noise level, maintenance and failure. If the hydraulic lift failed it would potentially contaminate the OR environment with hydraulic fluid. Conversely, we could not find a pneumatic lift which was of equivalent weight of the hydraulic. Weight significantly impacts the mobility of the lift and a pneumatic drive would add noise to an already intense OR environment. We made the decision to use the same model hydraulic lift as Dr. Muraszko is currently using because the chance of a catastrophic breakdown is small. The current lift is using hydraulics and is working well. We also know that other machines in the OR use hydraulics, including the hospital beds (See the Literature Review in Appendix E: page 74)

Characteristics	Hydraulic	Pneumatic	Electric	Airbag
Price	0	0	0	-1
Weight (Light=Good)	0	-1	-1	-1
24" Minimum Reach	1	1	-1	1
Maintenance + Failure	0	1	1	1
Noise Level	0	-1	1	-1
Volume (Size)	0	0	0	0
Stability	0	0	0	0
Minimum Collapsed Height (6")	0	1	1	0
Speed of lift	-1	-1	0	-1
Sum	**0**	**0**	**1**	**-2**

Table 5: Lift Type Pugh Chart

Concept Process Selection – Handle Actuated Cam for Locking Mechanism

The handle actuated cam design proved to be by far the best design based on our Pugh chart analysis (See Table 6, page 15). The cam design is stable because the entire base can rest on the ground and would fail in the down position. It also scores high in the user convenience and mobility categories because it has a handle for transport. It also has no parts which need maintenance checks. The next best design was the top mounted wheels and it had the disadvantage of wearing springs, and hand many of the same manufacturability, and mobility issue of the current lift. After presenting Dr. Muraszko with our cam design idea, we learned that she did not like the fact that the footprint of the lift would increase in size. Therefore, for our next iteration we decided to go with the second best option of the top mounted wheel design. We ran into another issue with this design when the lift was delivered to Protomatic. We found that the lift could not lift itself up off the ground which is required by this second design. We therefore revamped and decided to use a design similar to the benchmark which is discussed in the Engineering Changes Notice section on page 52. The Pugh charts can be found in Appendix D: page 71.

Characteristics	Benchmark	Top Mounted	Piston Legs	Spring Loaded	Handle Actuated
Stability	0	1	1	1	1
Manufacturability	0	0	0	-1	0
Failure Modes	0	1	0	0	1
Wear and Maintenance	0	0	-1	-1	1
Added Height	0	0	0	-1	0
User Convenience	0	0	0	0	1
Mobility	0	0	1	0	1
Sum	**0**	**2**	**1**	**-2**	**5**

Table 6: Pugh Chart for Wheel Locking Mechanism

The Alpha Design

The alpha design incorporates all of the "winning" features determined by the Pugh charts as previously discussed, however it does not take into consideration the new requirements we were made aware of after our meeting to approve it. Figure 11 below shows the front view of the design with the wheels in the locked position and the handle 6 inches up from the stored position. Figure 12 on page 16 shows the design from the back with the wheels down in the rolling position.

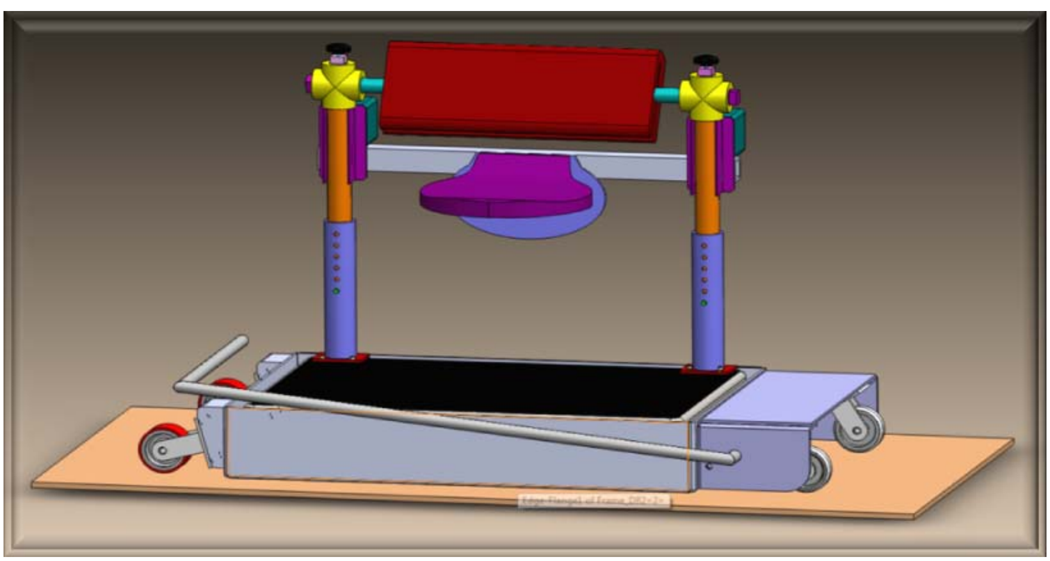


Figure 11: Front View of Alpha Design

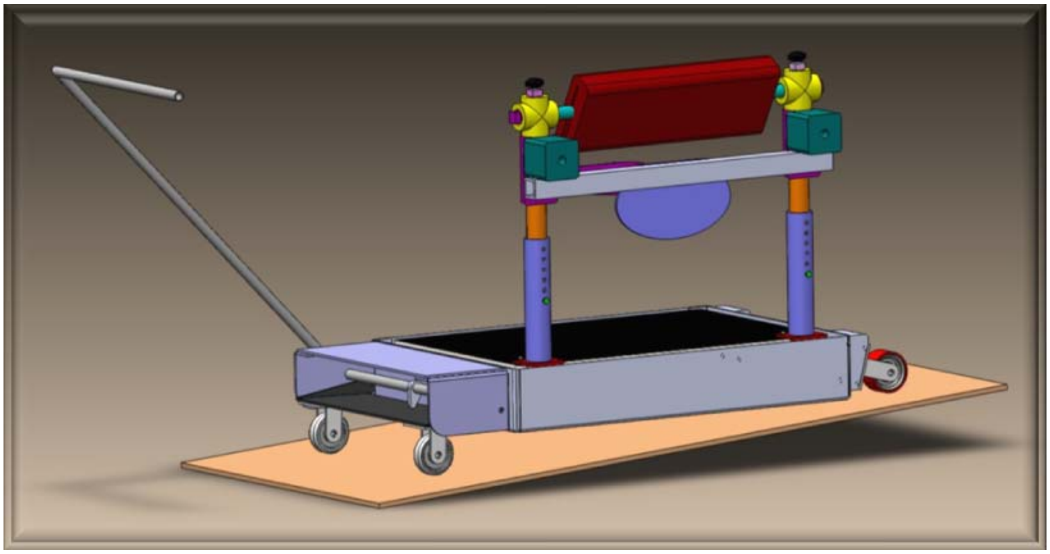


Figure 12: Back View of Alpha Design

The Chosen Lift

The alpha design incorporates the hydraulic lift which the current surgical lift utilizes. We decided to choose this particular lift because the price falls within our budget constraint and our customer is already familiar with it. The Myti-Lift Table, model CLTMYT-05-30-2436W, has been ordered from Solution Dynamics Inc. In addition we purchased the optional skirting which will hide the hydraulic components of the lift from sight and limit switch which is used to limit the vertical lift height to 24" (thus meeting one of our important engineering targets).

Additional Components of the Alpha Design

The alpha design created, also incorporates the other selected design features as previously discussed. It uses large buttons to control the lift which are in easy reach of the user and can be found easily when the lift is draped for surgery. The lean bar itself can also be adjusted to 6 different height positions spanning a six inch range. Attached to the lean bar is a seat which folds down (the current lift seat retracts up) which allows for a greater clearance between the top of the lean bar (where padding is located) and the seat. This will make it easier for the nurses to drape the lift with sterile cloth prior to surgery.

Also as previously discussed the mechanism used to transition the lift from a stable state (for surgery) to a mobile state (for transport) utilizes a cam and lever system. The handle (lever) is connected to the cam and rotates around the lift for storage. This handle is intended to be used to move the lift as well as lock it. Therefore, our design not only locks the wheels completely, but also increases the ease of mobility. The alpha design allows the entire base of the lift to be in contact with the ground when the lift is in the locked position.

Pictorial Explanation of the Alpha Design

Details of the design are shown in the following figures. Figure 13 below depicts the housing used to mount the large button which, when pressed, will move the lift up. The other side of the lift will have the same mount which will house the "down" button. The swiveling backrest and the chosen seat are detailed in Figure 14 below. To better understand the rotating mechanism for the backrest, Figure 15 below is a close up on this mechanism that allows the back rest to swivel. The wheel locking and unlocking mechanism is shown in a close up in Figure 16, page 18. Here it can easily be seen how the cam allows the front wheels to come into contact with the ground and then back again.

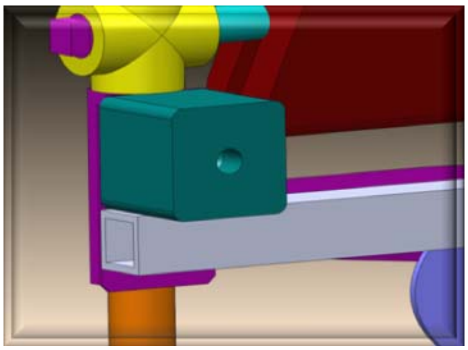


Figure 13: Button Housing

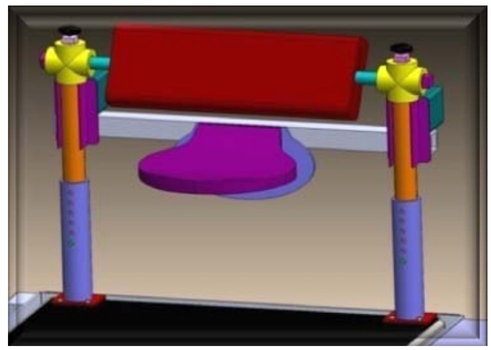


Figure 14: Lean Bar and Backrest

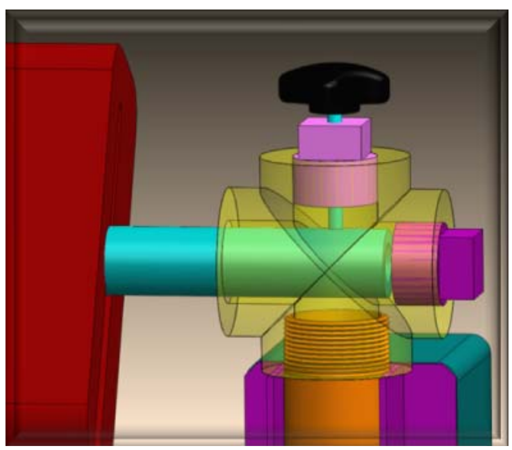


Figure 15: Cam Wheel Lock and Unlock Design

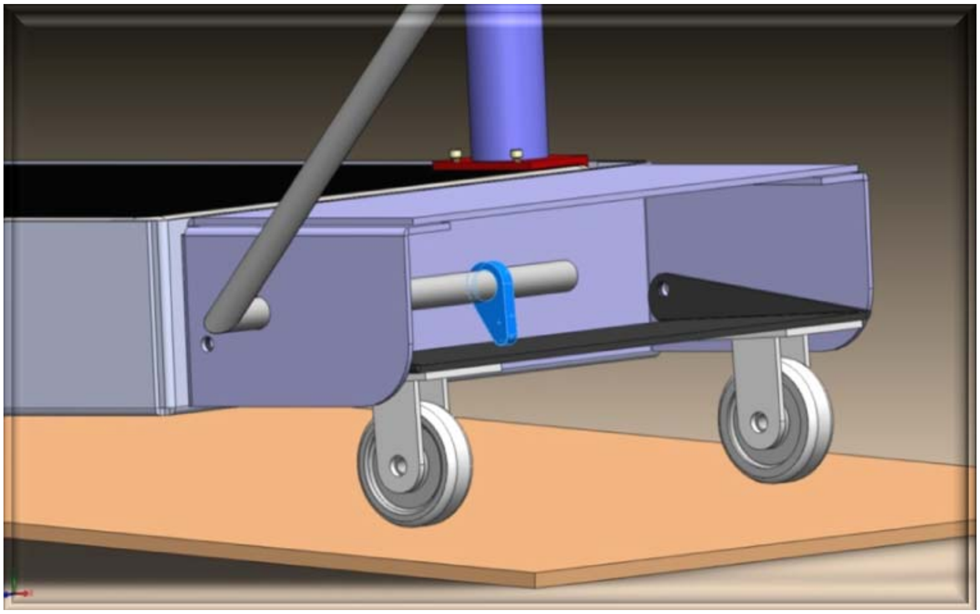


Figure 16: Cam Mechanism allowing Mobility and Stability

Customer and Engineering Requirements Met

The Alpha design meets many of our initial customer and engineering requirements. While using the Pugh charts to decide on the best options for the individual surgical lift parts, we kept in mind our initial engineering requirements. Once we were able to narrow down our design ideas we narrowed down our engineering requirements to those found in Customer Requirements Section, page 3.

The Lift

The lift chosen has a limit switch to assure that it stops at a height of 24 inches per our customer's request. This can be easily changed for other customers' applications, enhancing the modularity of the design. The lift itself only weights 208 lbs, much less than any of the others which were found having similar features. The low cost will help us stay well below our budget along with allowing other customers the lowest price option.

The Buttons

The large buttons we are considering will protrude at least ½ inch from the lean bar so that the customer can easily feel them under the sanitary drape. The buttons should and will be at least 1 inch in diameter and can be positioned on either side of the lean bar as illustrated in Figure 13, page 17 so they can be easily reached by the user.

The Lean Bar

Many engineering requirements are met with the current lean bar design. The seat height can be adjusted within a range of 18 to 24 inches. This will allow users to customize the seat height to maximize comfort. We have already chosen the seat that we wish to purchase; the best fit for the design is the Raja Wall-mounting Folding seat made by Pressalit.

The top of the lean bar can vary between 24 and 30 inches. The user can adjust the height of the bar depending on what the situation calls for. The swiveling backrest, in addition to the adjustable height makes the lean bar an extremely versatile feature of the alpha design. The bar could be adjusted to fit a variety of different users performing a variety of tasks (from surgery to cleaning gutters). This feature alone meets our engineering requirements of modularity and its goal of having at least 2 module lift features.

We would also like to have the seat be an optional feature which could be additionally purchased. Other users may not require or want a seat and should therefore not have to pay for. To meet our other engineering target for the seat, the seat being purchased can be quickly folded down within 3 seconds. Another potential option for customers is the type of padding making up the backrest. The padding could vary in both thickness and softness to cater to a large demographic of users.

The Wheel Locking Mechanism

The engineering requirements can be meet with this particular wheel locking mechanism. The rolling resistance coefficient depends on the type of casters chosen and those chosen meet the engineering target. By using the cam mechanism, the lift should be easy to lock/unlock from either moving the handle up from the stored position or picking it up from the floor. Currently, since the design is such that the entire base is on the ground when the lift is in the locked position, the coefficient of friction is large enough to prevent accidental movement of the lift. There are very few parts in this cam design and this helps to meet our target of 15 parts or less for the assembly. The diameter of the wheels is larger than the current design's wheels which will enhance the mobility of the entire lift.

Faults of the Alpha Design

After the completion of the α-design, we met with Dr. Muraszko and discussed the faults and successes of the design. There were several parts of our design which Dr. Muraszko did not find desirable. We were able to determine what changes needed to be made to the lift during this meeting and our subsequent communications with her, in order to create a successful final design.

First and foremost, the seat had to be changed; Dr. Muraszko desired an adjustable seat, not only up and down (as in the α-design) but also in the forward and back directions. The non-adjustable seat was therefore a flaw of the alpha design.

We were also instructed to maintain the current geometry of the lean bar. The current lean bar is a round tube which a cylindrical piece of foam padding slides over to create a more cushioned surface. Dr. Muraszko is comfortable with the current geometry (not the α-design which is a square tube) therefore we will ensure that the final design has a lean bar with a cylindrical geometry.

Another flaw of the α-design is the material used for it. Steel and aluminum were chosen as the materials which would be used to build the majority of the α-design. After lengthy discussions we decided that sterility was not an issue because the entire lift would be draped during surgery. However, cleaning technicians still wipe the lift down with a cleaning solution (typically Hydrogen Peroxide) after each surgery. Therefore it was suggested that we use a medical grade stainless steel instead, which we have incorporated into the final design.

Engineering Design Parameter Analysis

This section will give our approach used to determine the specific dimensions, shape and materials of our design. The simplest model possible will be used while still maintaining accuracy of our analysis. We will discuss what level of detail was chosen and how confident we are in the analysis.

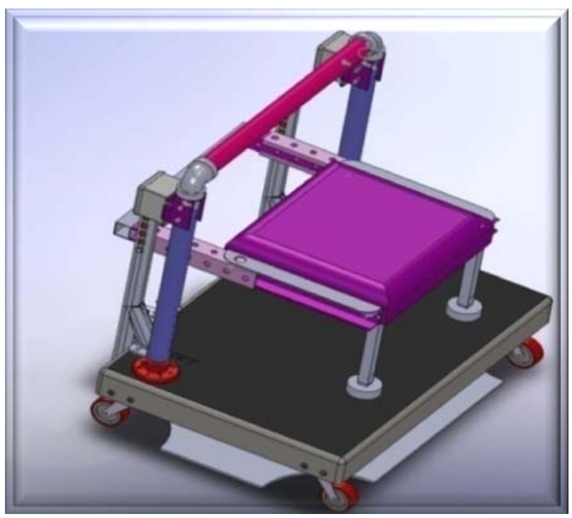


Figure 17: Final Lift Design

Adjustable Seat Design

The design process of the seat was the most involved part of our project. As we were working on our project we tried to cater our design to our customer. Unfortunately, after consecutive meetings with our sponsor we realized that our understanding of the design and the sponsors were quite different. Also, as we presented our sponsor with consecutive designs new requirements emerged.

Evolution of the Seat Design

Our design phase for the seat was extremely involved. Once, our alpha seat design was complete our sponsor requested to have the ability to slide the seat back and forth during surgery. We therefore had to go back and try to create something new. Through this process we have created a total of four new seat designs with Figure 21 on page 22 illustrating the final seat design being manufactured by Protomatic. Redesign 1 shown in Figure 18 has the cushion mounted on the top of the slides. Since the locking pin is located underneath the seat she would need to get off the seat to adjust it which is not the ideal situation for Dr. Muraszko.

This realization led to an idea of a ball bearing slider (Figure 19 on page 22). As we were designing the seat we were calling different ball bearing slider companies to find a slider which would work. Although sliders of the right dimension exist, we were unable to find a slider which could sustain the amount of torque created by a person sitting on the edge. Therefore we were forced to think of a different sliding solution.

This led us to redesign 3, the linkage construction (Figure 20 on page 22). This system would work similar to that of a foldable picnic table. The linkage design allowed the seat to fold down and then extend forward via the telescoping tubing. Although the concept of this design was good, after analyzing the stresses in the bars we found that it could not support the doctor. The analysis for this design can be seen in Appendix I We then decided to increase the size of the tubes, although this idea made the design stronger it also made it heavier. Another problem with this design was that we were forced to have the seat be at least 18 in above the lift platform which is too tall for Dr. Muraszko. Making the height of the seat shorter would not allow enough room for the 16 in cushion to fit underneath it.

This led us the realization that the seat must be extended up for storage, in addition to being foldable. We were able to finally create a seat that met all of Dr. Muraszko requirements and this can be seen in Figure 21 on page 22.The design is described in detail in the Final Design Section on page 29.

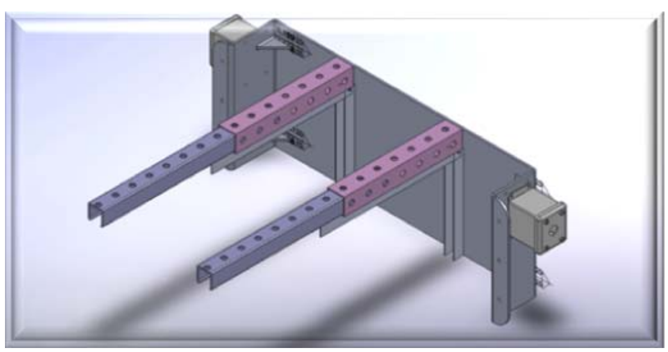


Figure 18: Redesign 1 - Seat Mounted on Top of Tubing

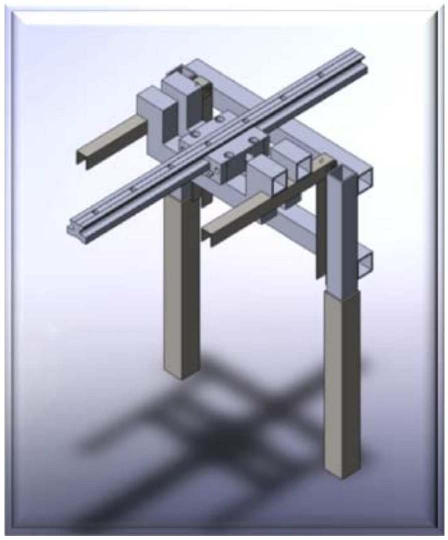


Figure 19: Redesign 2 - Ball Bearing Slide Mechanism

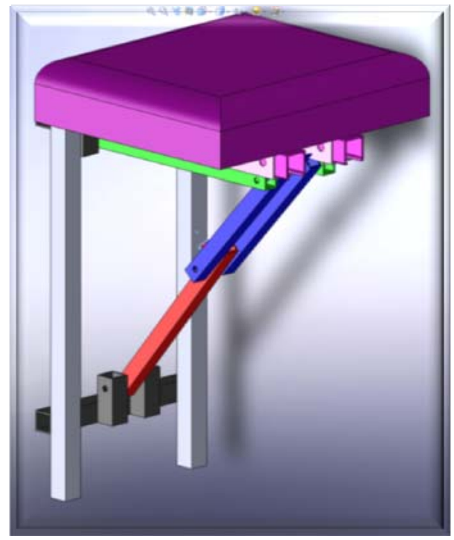


Figure 20: Redesign 3 - Linkage Design

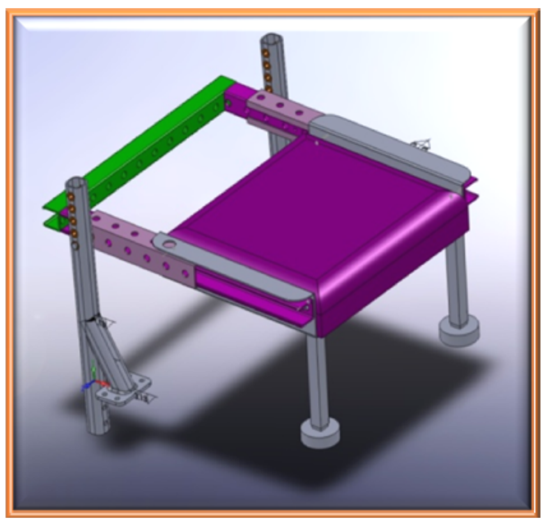
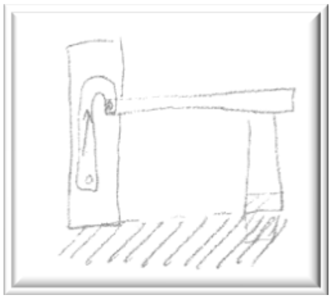


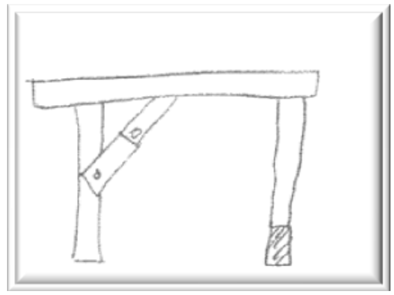
Figure 21: Final Design - Pivoting Seat with Support Legs

Once the seat design was analyzed it became clear that legs or another type of secondary support would be required to maintain the stability of the seat. We therefore generated several design concepts and performed a tradeoff analysis to determine that the design shown in Figure 22a, page 23. The design options are illustrated in Figure 22, page 23 and Table 7 on page 23 illustrates the Pugh chart used to determine the appropriate secondary support structure.

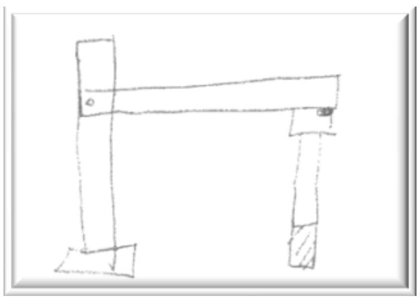
Figure 22a illustrates a vertical track which the seat would follow (a rigid leg would be attached to the underside of the seat). Another idea we had is shown in Figure 22b which depicts using a stationary leg and a table hinge. Both of these ideas were not ideal as shown by Table 7. Figure 22d depicts a surgical chair which we thought could be mounted directly to the lift but this would not be very compact and would take up a large portion of the work space (footprint of lift). The design chosen is shown in Figure 22c; an adjustable leg would be installed to the bottom of the seat via a hinge.



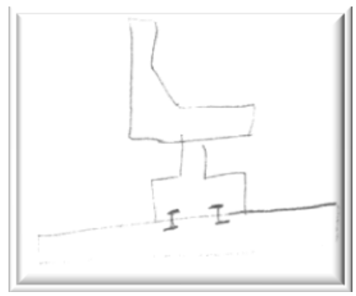
-a- Track vertical



-b- Upside down triangle



-c- Seat design with leg



-d- Surgical chair

Figure 22: Secondary Support Ideas for Seat

Characteristics	Track Vertical	Upside-down triangle	Similar Design w/leg	Surgical Seat
works with lean bar	1	-1	1	1
16 inches low height	1	1	1	1
weight	0	0	0	0
ease of forward adjustment	0	0	1	-1
probability failure	0	0	0	1
back rest integration	-1	0	0	1
obtrusiveness of storage	0	-1	0	-1
comfortable	0	-1	0	0
SUM	1	-2	3	2

Table 7: Pugh chart for the seat's secondary support structure

Analysis of Final Pivoting Design

A comprehensive analysis was made of our final design as seen in Figure 21 one page 22 to ensure that it meets our design and engineering requirements. The machinist hand book, COSMOS (Solidworks analysis program) and the Finite Element Analysis program Hypermesh were used for analysis. All equations were found in the Machinery's Handbook [1] and a complete analysis of the final design can be found in Appendix F: page 77.

Pin holding up the seat

In order to ensure the pin which the seat pivots about would not fail during use a sheer stress analysis was performed. We were able to determine that the critical diameter of the pin is 0.05" when a 200lb forces is applied to the seat. Therefore any pin having a diameter greater than 0.05" would be strong enough to sustain the forces created by the surgeon when he/she sits on the lift. Equation 1 was used to calculate the critical diameter.

Equation 1

$\tau = shear\ stress$
$F = force\ applied$
$A = area$

Support Legs – front and rear

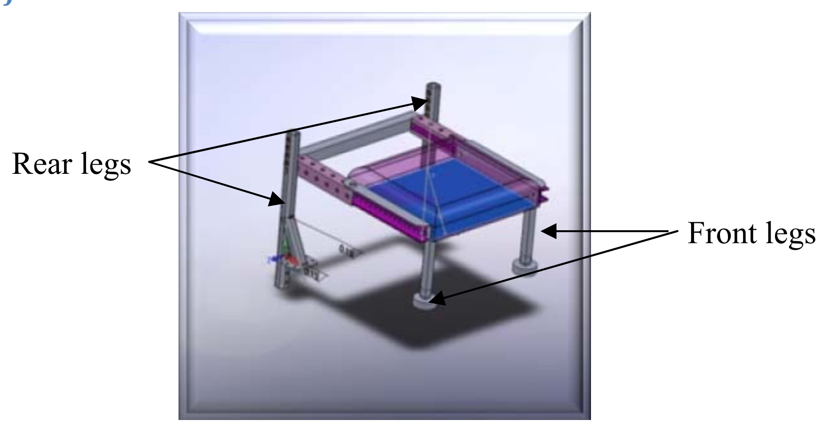


Figure 23: Support Legs for the seat

To ensure the rear and front legs (Figure 23) would not buckle under load a hand analysis was performed. Equation 2 was used to calculate the critical force which would cause the legs to buckle. Since the supports are made of stainless steel the buckling forces are very high 97,907lb for the front support legs to buckle and 74031lb for the rear supports to buckle. The calculations can be seen in Appendix F: page 78.

Equation 2

$P_{cr} = critical\ buckling\ force$

$E = modulus\ of\ elasticity$
$I = second\ moment\ of\ inertia$
$L = length\ of\ leg$

A bending calculation was also performed for the support legs to make sure they will not bend during normal use. The stress found in the support legs was 1873 psi which gives a safety factor of 16. Equation 3 below was used and the calculations can be seen in Appendix F: page 79.

Equation 3

$\sigma = bending\ stress$
$y = distance\ from\ nuetral\ axis$
$I = second\ moment\ of\ inertia$

Telescoping Tubing Analysis

Bending calculations were also done for the telescoping tubing. A force of 200lb was used and the maximum extended distance of 23". The tubing was modeled as the smaller tube to consider the worst case scenario. The stresses found in the telescoping tubing were 3032 lbs, yielding a safety factor of 9.79. Equation 4 below was used and the calculations can be seen in Appendix F: page 79.

Equation 4

$\sigma = bending\ stress$
$W = weight$
$L = length\ of\ tub$
$I = second\ moment\ of\ inertia$
$y = distance\ from\ nuetral\ axis$

Seat Plate

COSMOS analysis was used to analyze the plate which the seat cushion will be adhered to. The calculations were preformed with 200lb force and a safety factor of 2.4 was found. To create a worst case scenario the extra reinforcements were ignored and the plate was modeled at reduced depth. As shown in Figure 24 below, there are no stress concentrations and thus no points of failure present.

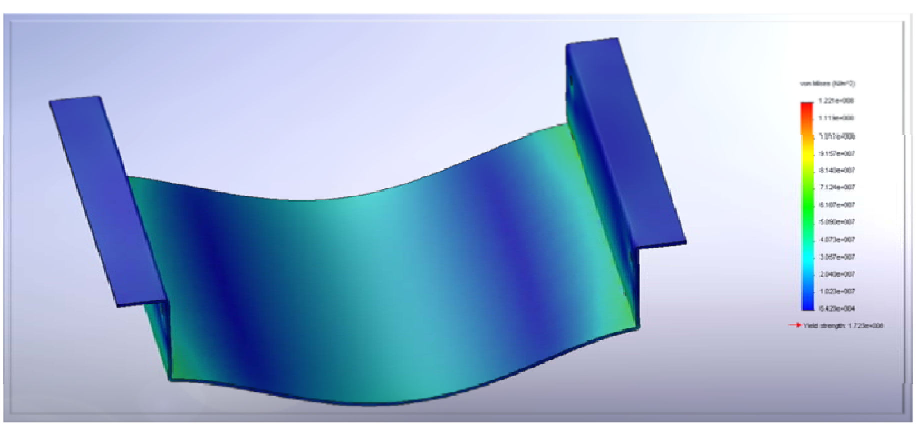


Figure 24: COSMOS analysis of seat plate - No points of failure are present

Lean Bar Selection

Similar to the seat, the lean bar design went through an evolution of its own. Although the changes were not as drastic as with our seat a great deal of thought was put into creating a design which Dr. Muraszko would be happy with. The final design can be seen in Figure 25 below.

Figure 25: Final Lean bar design

Evolution of Lean bar

The two main issues with our original lean bar deign were the material used for the bar (not suitable for sanitation) and that the original alpha design was not uniform. To solve these problems we created rounded corners at the tube joints and used stainless steel 304 which can be used with hydrogen peroxide (See Materials compatible with Hydrogen Peroxide section on page 48.). An aluminum version of the design was created first before we found out about the sanitation requirement (Appendix G: page 83).

Analysis of the Lean bar Buckling

Equation 2 on page 24 was used to calculate the likeliness of buckling. Figure 26 on page 27, illustrates the free body diagram utilized during these calculations. The critical force found was 80,966 lbs using 200 lbs of applied force. Therefore we concluded that we do not have to worry about bucking.

The lean bar was also analyzed to make sure it would not fail in bending. This calculation utilized Equation 3 on page 25. A Safety factor of 19 was calculated with the stress of 1578 psi. We are therefore confident that the lean bar will not bend. The complete set of calculations can be seen in Appendix F: page 77.

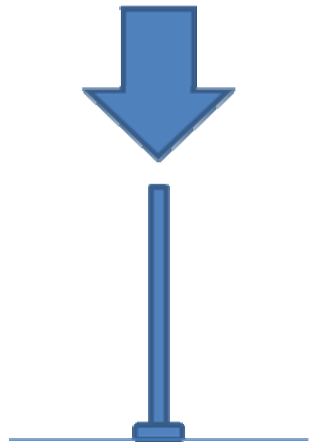


Figure 26:Free Body Diagram used to determine buckling/bending of tubes

Wheel Locking Mechanism selection

As our original design was not feasible after learning Dr. Muraszko does not want the lift to extend beyond the 36" by 24" footprint we decided to manufacture our second best design. In this design the wheels are attached to the top of the lift allowing for stability when the lift is extended up while still allowing for mobility (Figure 27 below). Calculations were performed for the lift to prove that the design would work. The details of these calculations can be seen in Appendix F: page 77. After receiving the lift it became clear however that this design would not be feasible (the lift cannot elevate itself) so we once again had to reevaluate our design. Please see Engineering Changes Notice section, page 52.

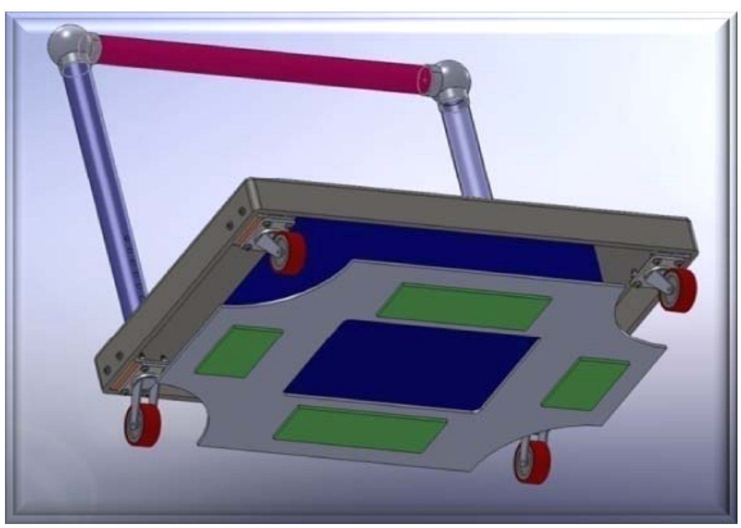


Figure 27: Selected Wheel Design

Analysis of angle brackets

Stresses were calculated in each individual bracket holding up the wheels (Appendix F: page 78). The stresses found were 10400 psi which yielded a safety factor of 3.5 .The analysis for the brackets was confirmed using COSMOS (yielded a safety factor of 3.4). A picture of the analysis can be seen in Figure 28. Shear stresses in the bolts holding up the lift were found to be 1400 psi giving a safety factor of 98 to this portion of the design.

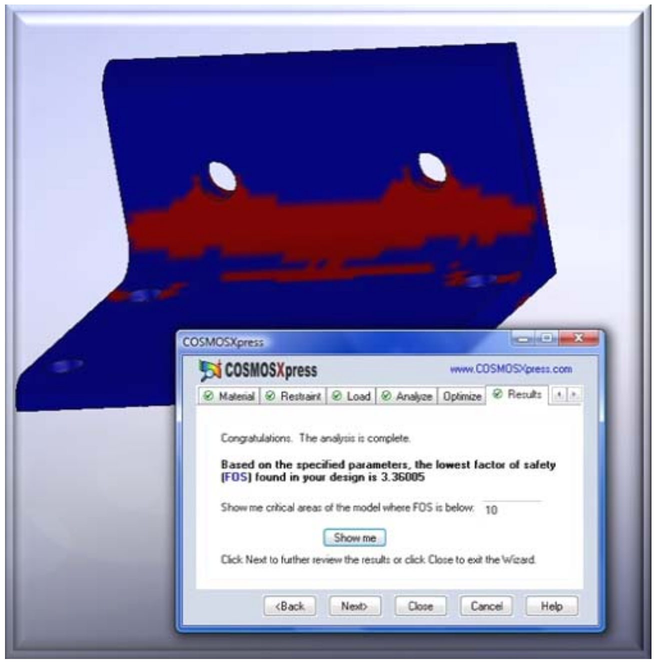


Figure 28: COSMOS Analysis of bracket

Tipping Calculations

In order to make sure the surgical lift would not tip over we performed a force balance analysis to calculate the weight required to tip the lift (Appendix F: page 79). According to our analysis a force of 300lb would need to be exerted on the lean bar to make the lift flip. As we do not expect anyone above the weight of 300lb to be using the lift we concluded that the lift is safe and will not tip over. In case our assumed force of 300lb is not enough of a safety factor to keep the lift form tipping we will add a counter weight on the front of the lift to balance the lift. Figure 29 on page 29 shows the free body diagram which was used to calculate the required force.

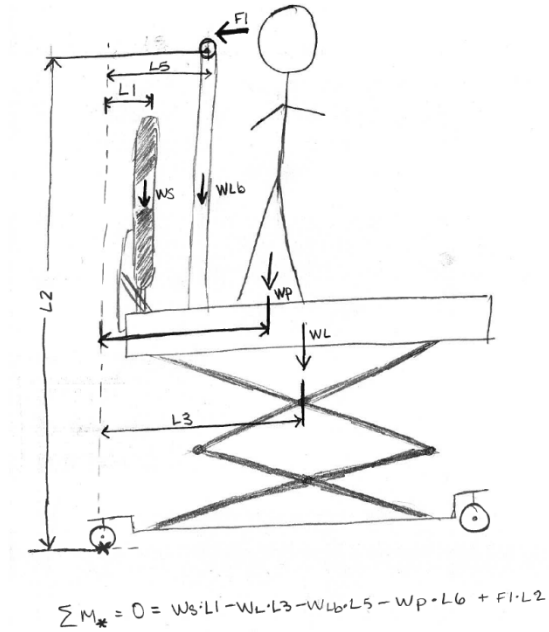


Figure 29: Free Body Diagram used to determine the stability of the lift

Final Design Description

After meeting with Dr. Muraszko we developed a final design that will meet her customer requirements. Our final design varies in many ways from our alpha-design as there were three design requirements that we were not made aware of until completion of the alpha design.

Adjustable Seat Design

The one feature which Dr. Muraszko did not like about her current seat was the fact that it was very far from the front of the lift, not allowing her to use the seat while operating. To accommodate this we came up with a foldable seat design. In our current design the seat folds down allowing for a greater cushion size adding to the comfort.

The final seat design was analyzed and agreed upon. Our final seat design can be seen in Figure 30, page 30.

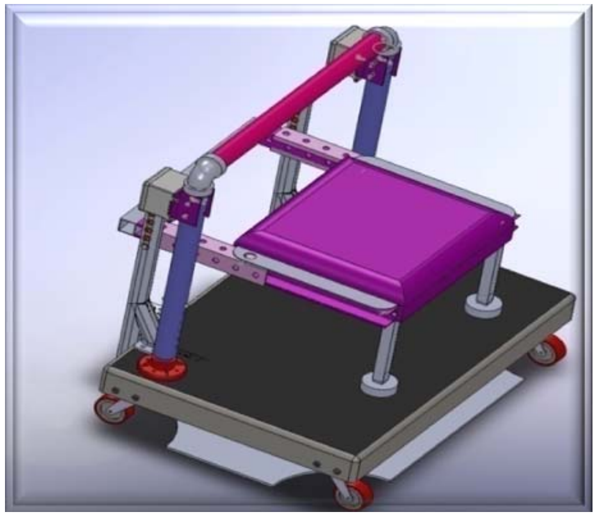


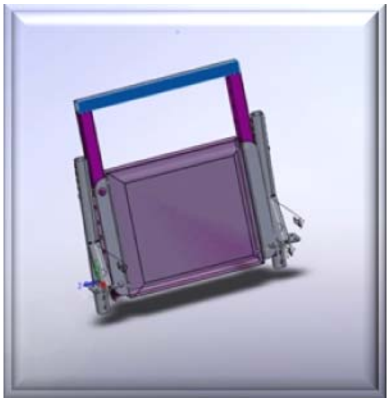
Figure 30: Final Seat design

Sliding Seat Mechanism

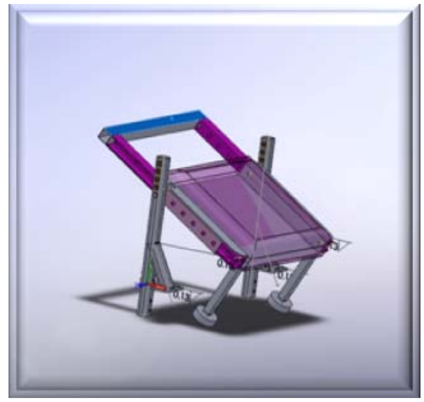
Perforated telescoping tubing will be used to allow the seat to slide back and forth. The seat will pivot over a pin attached to the rear stainless steel support legs which are attached to the lift in the back. The rear support legs themselves have supports which are attached to the top of the lift.

The seat will also be supported by two stainless steel front support legs. These were put in place since our analysis showed that without them the seat will collapse when extended. The legs are attached on locking hinges to allow for easy storage when the seat is folded up (Legs are locked in both their down and stored positions). The back support legs have 5 holes on either side in order to allow for seat adjustment (vertically) between 16.5 and 20.5 inches in 1 inch intervals. The seat itself was designed to slide back and forth 9 inches in 1.875" intervals.

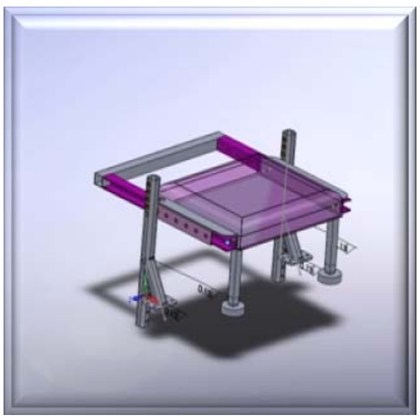
A pin on the left side of the lift will lock the seat in place. Figure 31 on page 31 shows in steps how our seat design will fold up and extend out. Our engineering analysis and our many unsuccessful attempts of our seat design prove that this final design is an optimal solution to our sponsors request and will not fail.



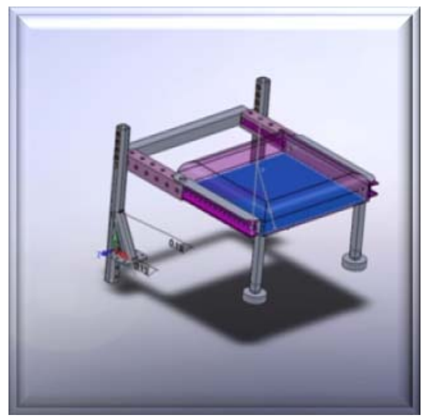
-a- Folded up position



-b- In-between position



-c- Folded out-seat all the way back



-d- Folded out-all the way out

Figure 31: Seat in its various positions from stored to in-use

Appendix H: page 88 contains all of the engineering drawings of our design that have been submitted to Protomatic for production. The bill of materials has been generated and lists the part number of each part where to find it (most of our parts are from McMaster) and a detailed description (Appendix I: page 135). This was given to Protomatic along with the engineering drawings to ensure the correct materials were purchased for the fabricated/purchased parts. Figure 32 on page 32, illustrates several of the parts required for the seat design.

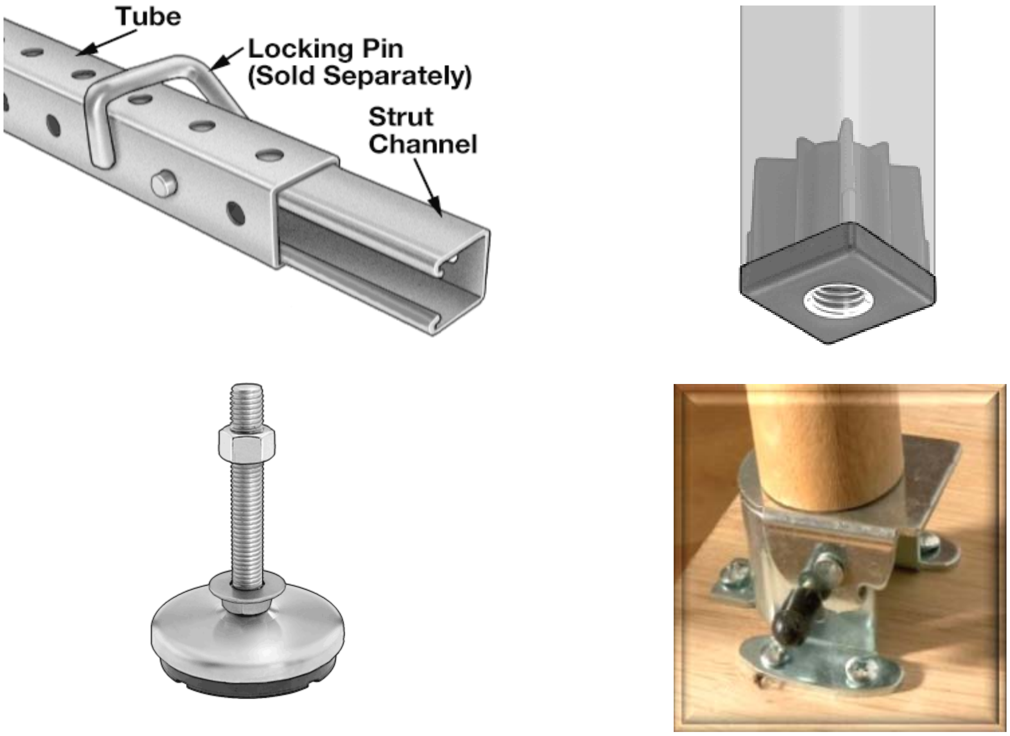


Figure 32: Parts for final extendable seat design

Final Cushion Selection

Many types of cushions were investigated before selected the one shown in Figure 33. A complete listing of the cushions we considered are located in Appendix J: page 139. Eventually a design was chosen which was comfortable, moisture-resistant, easily attachable and covered with Neoprene. According to our research Neoprene is resistant to Hydrogen Peroxide which is used in the hospitals to sanitize the equipment. In addition, it is used to relieve pressure for wheelchair users while sitting which should guarantee comfort for our sponsor. We will use the Velcro attachments that the seat comes with to attach it to the supporting plate. The seat will be purchased from PHC-online store for $250. The seat which we will purchase is 16 in x 18in long and 3in thick. We felt that this design will please Dr. Muraszko since it meets all of her requirements with regards to both comfort and ease of sanitation.


Figure 33: Final Cushion Selection

Bar Padding

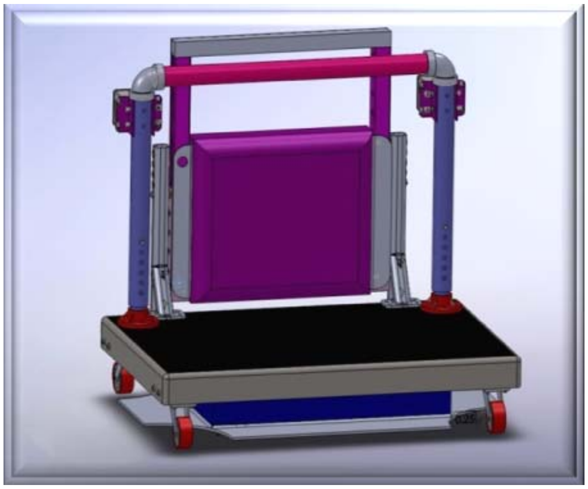
Padding like all the other components of our design was researched in great detail. Foam and gel padding of many different applications was researched. We finally decided on padding used for overhead roll bars in off-road vehicles as seen in Figure 34 below. This padding was selected because it comes in custom lengths and is to be used with bars with a diameter of two inches. These use a high density closed cell poly foam which is ½" thick. The fabric which we use is sport utility quality and is stain resistant which is conducive for an O.R. environment. The padding is also removable and is enclosed with a corrosion resistant zipper. We will use this padding for both the lean bar and the back bar of the seat.

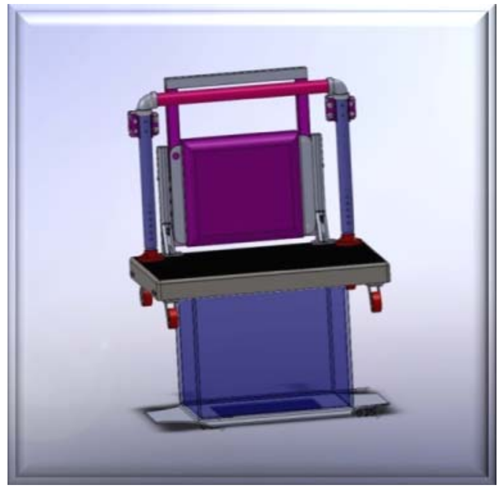
Figure 34: Padding for lift used in off-road vehicles

Wheel Locking Mechanism Design

The final design of our wheel locking mechanism was our second best design choice according to the Pugh chart created. The purchased scissor lift will be mounted onto a plate which will have Teflon pads attached to it. The Teflon will allow the surgical lift to slide slightly while in the stationary position, which is a feature desired by Dr. Muraszko. The casters used will be attached to the top of the lift and will have an option to lock for added safety (Figure 35, page 34).

Compared to the alpha design, this lift meets the revised customer requirements because it does not increase the footprint of the lift. In addition, having the wheels attached to the top of the lift add an additional factor of safety making the lift extremely stable when it is in the extended position – the wheels are up off the ground (Figure 35b, page 34). The Bill of Materials for this design can be found in Appendix I: page 135 which describes each of the parts required to manufacture this lift.





-a- Collapsed movable position

-b- Extended stable position

Figure 35: Final wheel locking mechanism design

Lean Bar Design

After completing our design analysis for the lean bar we confirmed that the lean bar would not bend or buckle under normal loading conditions. The final design will be made of stainless steel an will weigh a total of 11lbs.The CAD model of the final lean bar design can be seen in Figure 36 below.

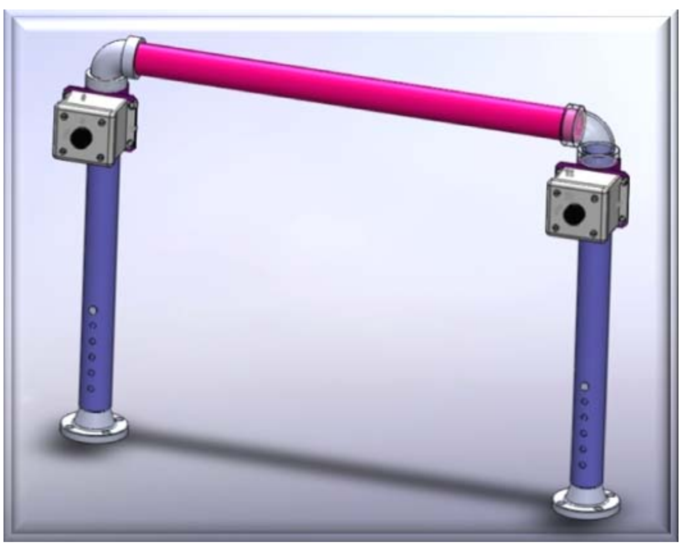


Figure 36: Final Lean Bar Design

Power Cord Containment Design

Containment of the power cord was another issue the previous lift had. The power cord was often used to pull the lift around and therefore has already had to be replaced. We have decided to add hooks which the cord can be wrapped around to prevent this from happening (Figure 37). This hook will be attached to the lean bar via four screws. The hook's dimensions were designed to ensure that 10 ft of power cord can be wrapped easily around them. The hooks, like most of our components, will be made form 304 stainless steel sheet metal of thickness 0.125".

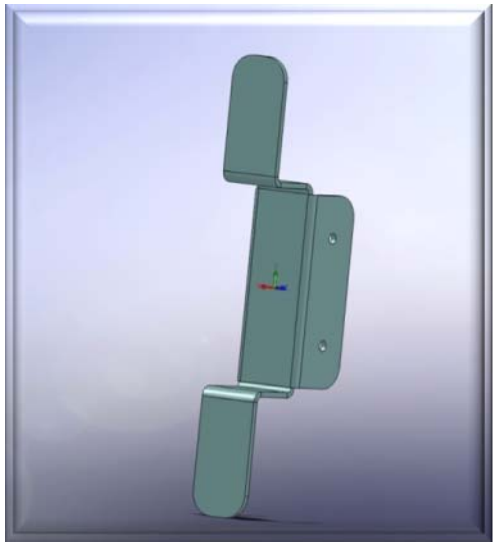


Figure 37: Power Cord Containment

Button Design

To provide a solution to Dr. Maruszko's difficulty of distinguishing between the up and down button when the lift is draped we placed the buttons on two opposite lean bar supports. We chose a 304 Stainless Steel 3.5x 4.5x2.4 inch (McMaster: 2 x $129.72) button box. The boxes were placed on the back of the support bars as to not interfere during surgery (Figure 38, page 35). The two buttons are 22mm in diameter (McMaster 2x 8.04) and spring back momentarily.

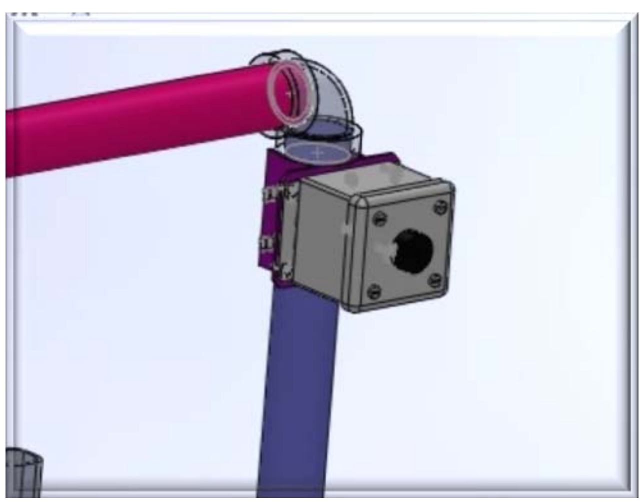


Figure 38: Button Box attached to lean bar

Comfort Mat

To provide additional comfort for Dr. Muraszko we will place a comfort mat on the lift (Figure 39).

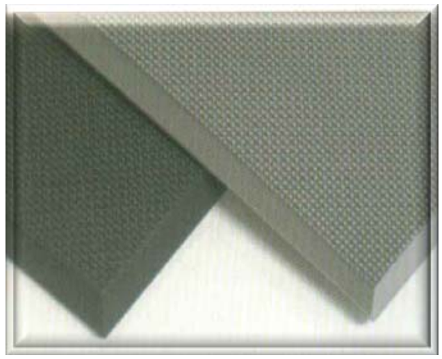


Figure 39: Comfort Matting

Cost Analysis

For the bill of materials each part was looked up and the total price of the design was determined. Appendix I: page 135 has our compiled bill of materials which shows that the majority of our material comes from McMaster. The total price of our design is $6816.49. Half of this cost $3,454 went into purchasing a scissor lift. The components for our lift are almost entirely made of stainless steel accounting for other half of the budget. The specialty material such as Teflon pads for sliding ($143.13) and Rulon Sleeve Bearings ($366.4) make our design expensive. The reason for this high cost is the requirement of making our lift hydrogen peroxide resistant for sanitation purposes. As we hope to produce this lift for future costumers the price potentially could be brought down significantly if the costumer will not require the lift to be hydrogen peroxide resistant.

Prototype Description

Our final design is meant specifically for Dr. Muraszko; however we have created a very versatile and modular lift in the hopes that many different surgeons along with other professionals can utilize it. When creating our design we made it a priority to make the lean bar and seat adjustable to different heights. The intention of our final design is to have our manufacturing company Protomatic be able to take orders from other surgeons who have already expressed their interest in Dr. Muraszko's Lift.

Initial Manufacturing Plan

In order to manufacture the surgical lift design we had to determine what processes would be used to create each part. We looked at what processes Protomatic and ourselves were capable of when selecting the processes which would be used. The Bill of Material listed in Appendix I: page 135 includes the processes which should be used to create each part along with the assembly processes required to join all of the parts together once made.

Protomatic has created a general process planning sheet for all of the parts they will be manufacturing for us. For a prototyping company, the steps needed to create the part are determined simply by looking at the engineering print and since the parts they create are typically not massed produced a very detailed manufacturing plan, such as a control chart, is not required. The process plan, or routing summary, that Protomatic will follow to create our parts is found on the following two pages.

Routing Summary
Protomatic, Inc.

Date: 11/05/08
Time: 3:00:19PM

Part No: ME 450 LIFT
Descrip: Lift Cart
Alt Part No:
Customer: UOM - University of Michigan
Estimator: 70 - PIERCE, BENJAMIN
Bin Location:
Revision:
Quantity Ordered: 1.00
Rev Date: 11/05/08

Step Num	Dept	Work Cntr / Vendor	Oper Code	Description	Setup Time	Cycle Time	Total Time	Pieces per Hour
10	OFFICE	PLAN	PLAN CK	Planning G1	.0000 H	.000 H	.00 H	
				Plan Check- Must be performed prior to start of job by any employee other than order originator. Record here and on Material Worksheet as applicable. -Compare Shop Traveler and Dwg. for; Pt Name, Pt No., and Rev. ____________ Initial/Date. -Material Ordered? Cust. Sup or Stock or Ordered ____________ Circle/ Initial/Date -Tools Ordered or Needed? Special/Custom/GenReq/GenStk ____________ Circle/ Initial/Date -Fixture Prepared? New/Repeat ____________ Circle/ Initial/ Date -Special Gauges Required? Available/Ordered ____________ Circle/ Initial/ Date -Supply FRM1004.xls w/ items labeled. ____________ Circle/ Initial/ Date DO NOT PROCEED UNTIL COMPLETED.				
20	REST OF S	SAWSHEAI	SAW/SHEA	Saw or Shear G1	.0000	.000	.00 H	
				Material Traceability is required. Verify Mill certs are on file. Record Material PO# on Material Worksheet. per INS0801.xls				
30		MCMASTEF		MCMASTER-CARR SUPPLY COMPANY Purchased Componets	.0000	.000	1.00 D	
40	LATHE G3,	LATHE G3	INSPECT 2	Lathe (CNC) G3,G4	.0000	.000	.00 H	
				Turn parts to print 1st Pce checked by Inspection. Remaining by machinist. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag Parts per INS-10-03 Forward Good Parts with a Yellow Tag. Forward Bad Parts with a Red Tag. Forward Spare blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:____________ Material PO:____________Record here and on Material Worksheet.				
50	MILL G3, G	MILL G3	INSPECT 2	Milling (CNC) G3, G4	.0000	.000	.00 H	
				Mill part to print 1st Pce checked by Inspection. Remaining by machinist. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag Parts per INS-10-03 Forward Good Parts with a Yellow Tag. Forward Bad Parts with a Red Tag. Forward Spare blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:____________ Material PO:____________Record here and on Material Worksheet.				
60	REST OF S	MISC G3	INSPECT 2	Misc. Shop Task G3	.0000	.000	.00 H	

Routing Summary
Protomatic, Inc.

Date: 11/05/08
Time: 3:00:19PM

Part No:	ME 450 LIFT				
Descrip:	Lift Cart				
Alt Part No:			Bin Location:		
Customer:	UOM	- University of Michigan	Revision:		Rev Date: 11/05/08
Estimator:	70	- PIERCE, BENJAMIN	Quantity Ordered:	1.00	

Step Num	Dept	Work Cntr / Vendor	Oper Code	Description	Setup Time	Cycle Time	Total Time	Pieces per Hour
				Metal Finish parts 1st Pce checked by Inspection. Remaining by machinist. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag Parts per INS-10-03 Forward Good Parts with a Yellow Tag. Forward Bad Parts with a Red Tag. Forward Spare blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:_____________ Material PO:______________Record here and on Material Worksheet.				
70	REST OF S	WELDHERE	INSPECT 1	Welding (inhouse) G1 Weld Parts to Print 1st pce & run checked by machinist. Use QC as required. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag parts per INS-10-03. Forward Good parts with a Yellow Tag. Forward Bad parts with a Red Tag. Forward Spare Blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:____________ Material PO:______________Record here and on Material Worksheet.	.0000	.000	.00 H	
80	QUALITY	INSPFINAL	RPT NONE	Inspection Final G2 1 Final - No Report required 2 No Red or Orange Tags. 3 Replace Yellow Tag with Green Tag. 4 Forward to Packaging.	.0000 M	.000 M	.00 H	
90	QUALITY	PACKAGE (	PACKAGE	Packaging G2 Standard Packaging 1 Generate Label. 2 Bag, Tag & Box (leave box top open) 3 Sales to arrange delivery. 4 See individual customer spec for changes to above (1-3)standards.	.0000 M	.000 M	.00 H	
100	QUALITY	SHIP G2		Shipping G2	.0000 M	.000 M	.00 H	
				Time per Piece (HR):	.0000	.00000	.00	.00
				Total Time for Job (HR):	.0000	.00000	.00	

Designsafe Analysis

The program *Designsafe* was used to analyze possible failure modes of manufacturing the lift. Most issues arise with the weight of the material used and general manufacturing safety habits. As students manufacturing this product, we would have to take extra care when handling the heavy material. Since Protomatic is manufacturing the parts for us, they have lift trucks and proper lifting tools when they are needed. The operators at Protomatic have plenty of experience with the machines that they work with so the risk of them hurting themselves on these machines is very low when the proper safety precautions are taken. *Designsafe* results can be seen in the Appendix K: page 141.

SimaPro Environmental Impact

According to the SimaPro program, the 304 stainless steel that we are using in our design will have the biggest impact on human health, the ecosystem, and resources. This can only be because stainless steel has rare minerals in it which makse it "stainless" and this uses up natural resources and causes health concerns for humans and the ecosystem alike. Steel is the next highest issue for human health, the ecosystem, and resources, but is only about 1% of stainless steel. Neoprene was modeled as the synthetic rubber "Polybutadiene E" because neoprene was not an option in SimaPro. However, this material has the smallest effect on the three categories listed. This rubber does have the biggest impact on organics, but that is to be expected of a synthetic material. Graph output from SimaPro can be seen in the Appendix M: page 149.

Project Plan

To initiate the design phase of this project we began with a preliminary brainstorming session. This session was held to start a flow of ideas without restriction. After this, a meeting with Dr. Muraszko was held to figure out the customer requirements, after which we continued to brainstorm, but this time with the requirements/constraints in mind. Once we determined the critical design requirements, we were able to develop a project plan, which would be used to schedule the remainder of the project. We created a Gantt Chart (Appendix N: page 155), which has helped us schedule the important deadlines we must meet and the tasks, which must be completed in order to meet those deadlines. Table 8 on page 41 is a high level view of the tasks we have completed to create our final design.

Gantt Chart

	ℹ	Task Name	Start	Finish
1	✓	⊟ **ME 450 Project**	**Wed 9/17/08**	**Fri 12/5/08**
2				
3	✓	⊟ **Design Review 1**	**Wed 9/17/08**	**Sun 10/12/08**
4	✓	Design Expo Abstract	Fri 9/26/08	Mon 9/29/08
5	✓	QFD	Sun 9/21/08	Mon 9/22/08
6	✓	Written Presentation	Tue 9/23/08	Thu 9/25/08
7	✓	Oral Presentation	Fri 9/26/08	Tue 9/30/08
8	✓	Meet with Dr. Muraszko	Wed 9/17/08	Wed 9/17/08
9	✓	Meet with Protomatic	Fri 9/26/08	Fri 9/26/08
10	✓	⊞ **Filtering Concepts**	**Mon 9/29/08**	**Sun 10/12/08**
19				
20	✓	⊟ **Design Review 2**	**Wed 10/1/08**	**Wed 10/15/08**
21	✓	⊞ **Develop Design**	**Wed 10/1/08**	**Tue 10/14/08**
24	✓	⊞ **Modeling**	**Wed 10/8/08**	**Mon 10/13/08**
26	✓	Validation Plan	Wed 10/8/08	Wed 10/15/08
27	✓	Written Report	Thu 10/9/08	Wed 10/15/08
28	✓	Oral Report	Fri 10/10/08	Sun 10/12/08
29	✓	⊞ **Engineering Requirements**	**Wed 10/1/08**	**Mon 10/13/08**
32				
33	✓	⊟ **Design Review 3**	**Sun 9/21/08**	**Tue 11/11/08**
34	✓	Sponsor Critique I (Alpha design review)	Wed 10/29/08	Wed 10/29/08
35	✓	⊞ **Seat Redesign 1**	**Sun 9/21/08**	**Fri 10/31/08**
40	✓	⊞ **Locking Mechanism Redesign 1**	**Wed 10/29/08**	**Fri 10/31/08**
44	✓	⊞ **Lean Bar Redesign 1**	**Wed 10/29/08**	**Fri 10/31/08**
49	✓	Cut sheets created	Wed 10/29/08	Fri 10/31/08
50	✓	Prints have been started	Fri 10/31/08	Fri 10/31/08
51	✓	Sponsor Critique II (alpha redesign review	Fri 10/31/08	Fri 10/31/08
52	✓	⊞ **Redesign everything in stainless ste**	**Wed 10/29/08**	**Fri 11/7/08**
73	✓	Prints meeting with Protomatic	Wed 11/5/08	Wed 11/5/08
74	✓	⊞ **Redesigns per Protomatic suggestic**	**Wed 11/5/08**	**Fri 11/7/08**
77	✓	Design Expo Abstract Review	Fri 11/7/08	Sun 11/9/08
78	✓	DesignSafe Analysis of Final Design	Fri 11/7/08	Sun 11/9/08
79	✓	SimaPro Analysis of Final Design	Fri 11/7/08	Sun 11/9/08
80	✓	⊞ **Written Report**	**Tue 10/28/08**	**Sun 11/9/08**
87	✓	Oral Report	Wed 11/5/08	Mon 11/10/08
88	✓	Written report due	Mon 11/10/08	Mon 11/10/08
89	✓	Oral report due	Tue 11/11/08	Tue 11/11/08
90				
91	✓	⊞ **Design Review 4**	**Sun 11/23/08**	**Tue 11/25/08**
94				
95	✓	⊟ **Design Expo**	**Mon 11/17/08**	**Fri 12/5/08**
96	✓	⊞ **Locking Mechanism Redesign**	**Mon 11/17/08**	**Fri 11/21/08**
101	✓	Protomatic manufacturing	Mon 11/24/08	Tue 12/2/08
102	✓	Assembly at Protomatic	Mon 12/1/08	Wed 12/3/08
103	✓	Testing at Protomatic	Tue 12/2/08	Wed 12/3/08
104	✓	Final Manufacturing Plans documented	Mon 12/1/08	Wed 12/3/08
105	✓	Testing results documented	Thu 12/4/08	Fri 12/5/08
106	✓	Shipping	Wed 12/3/08	Wed 12/3/08
107	✓	Design Expo	Thu 12/4/08	Thu 12/4/08
108	✓	⊞ **Final Paper**	**Sun 11/23/08**	**Thu 12/4/08**
112	✓	⊞ **Poster for Design Expo**	**Thu 11/20/08**	**Wed 12/3/08**

Table 8: High Level Overview of Schedule followed to build a robust surgical lift in the time allotted

As the number of redesigns required to satisfy our customer has increased so too has the complexity of our schedule. As seen in Table 8, page 41, a schedule for each redesign was created in Microsoft Project which laid out the deadlines for material selection, CAD models, and design analysis. We have been able to meet our major milestones (Design Review and Sponsor Critique deadlines).

Budget

Throughout the design process we had to be conscious of the budget. We had roughly $10,000 to work with, given to us by our sponsor. We must be able to create this new lift while staying within the budget requirements. Therefore, when selecting the type of lift to be used we were wary of its cost because this was be the most expensive component of the surgical lift. We made sure to set aside enough money so that we could purchase a lift which will meet our requirements but still leave us with enough money to purchase the other necessary components such as padding, a seat, and operator controls.
With this in mind we purchased a lift for $2,650.00 from Solutions Dynamic Inc. We also purchased the skirting to go with this lift at $599.00 and the limit switch to stop the lift at 24 inches for $205.00. Together these three items accounted for roughly 1/3 of our budget. We therefore had to continue to be conscious of the cost of many of our products. With the changes in customer requirements, came the changes in material selection. The most significant of these changes with regards to cost is the change from mild steel to stainless steel. This change has increased the cost of the total project to roughly 200% times our given budget. However our budget has been increased to accommodate the changes in material. The total cost for the materials is roughly 30% of the total cost of the prototyping process. The materials for the final design came to roughly $6816.49 Therefore the estimated cost of the project including labor is $22721.60. For a complete breakdown of the materials budget please see Appendix I: page 135. Once Protomatic has completed their cost breakdown for the project a final, total cost which includes material, labor, and transportation can be provided.

Information Sources

One of the benchmarks for our surgical lift came from the previous team's lift design. Since the type of lift requested by Dr. Muraszko currently does not exist on the market, we gathered information by visiting her at the Children's Hospital. Later we researched ergonomics and safety in operating rooms. We then also benchmarked types of lifting mechanisms that we could use along with other important information about hydraulic lifts, which is the type of lift we decided to purchase.

Ergonomics and Safety of Operating Rooms

In order to better understand the working conditions of an operating room we looked into literature on operating room safety and ergonomics. According to the Food and Drug Administration poor designs in the operating rooms may potentially account for 1.3

million unintentional patient injuries in the US every year [2]. Therefore, a well thought out design that caters specifically to the surgeons needs is vital. Proper posture is a very important factor for surgeons as it increases comfort, efficiency of movement, and minimizes musculoskeletal injuries. A study by Kant which explored the posture positioning of surgeons during surgery found that general surgeons are at a high risk of back/neck and shoulder disorders which is due to prolonged bent head and bent back postures [3]. Mirbond found that there is a prevalent complaint among surgeons about shoulder pain, about 32% of surgeons in the study had experienced this pain [4]. Furthermore, the height of the operating table relative to the height of the surgeon is key to improving the ergonomics of surgery and to potentially help this shoulder pain cease. The surgeon should be at a height so that the angle between the lower and upper arm is between 90 and 120 degrees throughout the surgery [5]. An adjustable lift will allow surgeons to choose this position for optimal comfort.

A sitting posture can be a possible answer to the strain that a surgeon sustains during surgery. Seating provides a way to rest during lengthy surgeries; it also provides a better stable posture for controlling surgical instruments [6]. Although it has been suggested that surgeons should adopt the sitting position during surgery, this type of practice is uncommon in the United States today [7]. In our lift design we plan to include a foldable seat to give Dr. Muraszko an option to sit during prolonged periods in the OR.

According to article "Safety, hazards and ergonomics in the operating room", surgeons often find the current conditions in the operating rooms to be unsafe and not adequately catered to their needs. 83% of surgeons reported having cables and tubes in the OR which could be potential tripping hazards [8]. To avoid this power cord safety hazard we will contain our cord by either hooks, retractable or hand reel cord containment.
This same study shows that 45% of the surgeons studied used a foot stand to adjust for better working posture. Unfortunately, 49% of those surgeons have reported almost slipping off the stands [9].

Common devices used as lifts in the OR are risers (Figure 40, page 44) and stools (Figure 41, page 44). An Add-A-Level Riser is a stackable platform used to compensate for height differences at the operating table with an anti-fatigue mat for comfort [10]. The Stacking Interlocking Step Stool is another solution for the height distribution among surgeons [11]. This stool is made of stainless steel, has a slip proof surface, is tip-resistant and has side locks for creating a larger custom work platform. These are the current competitive products found on the market. By designing the surgery lift we hope to eliminate the aforementioned potential slipping hazards by extending the platform size and adding a backrest with an optional seat for the additional stability.

Figure 40: Add-A-Level Riser Set

Figure 41: Stacking Interlocking Step Stool

Review of Lift Systems

Four main types of lift systems were considered: electro-mechanical, mechanical, hydraulic and pneumatic.

Electro-mechanical and Mechanical Systems

The electro-mechanical system has many advantages over current hydraulic systems. Hydraulic lifts have hydraulic fluid which is toxic to the environment and could leak. Therefore, it has to be handled with special care and disposed of properly. Figure 42 shows an electromechanical lift table found in a researched patent. This table has faster speeds, smoother controls and is more precise compared to a common hydraulic lift. Compared to lifts currently found on the market, this lift has two separate laterally adjacent scissor arms that are actuated by one motor [12].

Solely mechanical lifts are another interesting option as they don't require any energy input. An example of solely mechanical lift is shown in Figure 43, page 45. This lift automatically adjusts to a set height taking into account the weight of the object that is place on it [13]. By eliminating the need for hydraulics or pneumatics the table becomes more portable and can be used in places without electricity. These tables have many applications in multiple industries; however, this specific lift is not practical for our application.

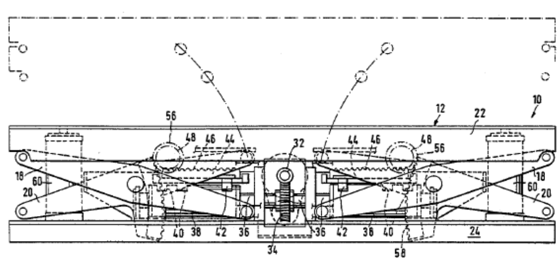


Figure 42: Electro-mechanical Scissor Lift Table

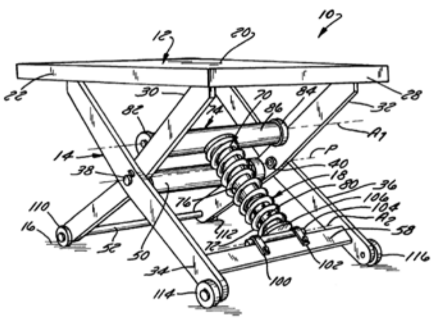


Figure 43: Mechanically Operated Lift Table

After learning of the advantages of an electric lift, we searched for electromechanical lifts that would meet our needs. The lift in Figure 44, page 45 met our weight limit, platform size, and lowered height. Unfortunately, this lift only goes up 14 inches which is not high enough for Dr. Muraszko's needs. After researching further we were able to find an electrical lift which met all of our requirements. This lift has the lowered height of 7 inches and a desired lift height of 24 inches. In addition it has rubber matting and a lean bar. The price of the lift ($21,500) regrettably is out of our budget of $10,000. The quote for this lift can be seen in Appendix O: page 162.

Figure 44: Linearizer Electric Worker Platform

Hydraulic Lift Mechanisms

Hydraulic lifts are the most common and affordable system for actuating scissor lifts. Hydraulic scissor lifts are broadly used in construction, industry (car assemblies and warehouses) and commercial sectors such as at hotels. Many innovative patents exist which promise to make the hydraulic scissor lift more efficient. Our main concern as we started designing was whether the lift would be allowed in the OR, taking in to account the toxic hydraulic fluid. Surgical beds were researched and all of the beds that we found were actuated by hydraulics. Appendix E: page 75, shows examples of three such hydraulic beds.

After patent searching, we wanted to look into the current innovations in the hydraulic scissor lift market. Numerous hydraulic patents and products were researched to make sure we would not overlook any new and upcoming technologies. An interesting patent for a hydraulic scissor mechanism is shown in Figure 45 on page 46. In order to achieve a low profile yet strong lift, this lift utilizes a bell crank to actuate the scissor lift. Using a bell crank is an improvement over traditional low profile scissor lifts which use a bearing cam follower. An addition to a bell crank, this mechanism claims to reduce the amount of work required and a more even distribution of strength between a retracted and extended position. Another innovation in the scissor lift design is shown in Figure 46 on page 46. This scissor lift has the hydraulic actuator located vertically unlike others which have the actuators attached pivotally to the frame. Common hydraulic actuators are at a disadvantage because the actuator has to exert a high amount of thrust on the mechanism to turn the lower most arm and start vertical extension. The new vertical placement of the actuator allows for the thrust put on the lift to be constant in the direction of the load. This allows the mechanism to perform the same function with less trust. Additional scissor lift innovations can be seen in the Appendix E: 76.

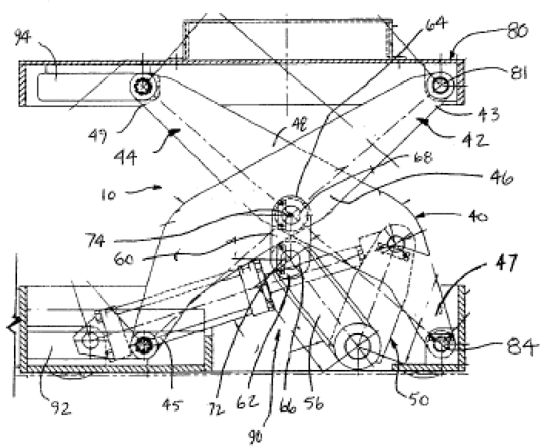


Figure 45: Scissor Lift Mechanism

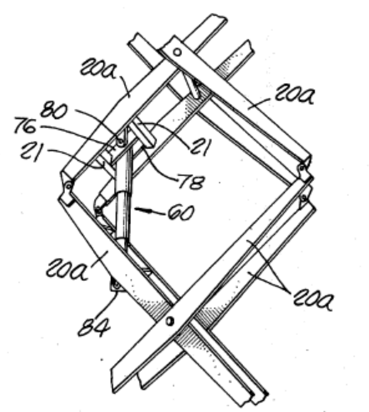


Figure 46: Scissor Lift

After researching current advances of hydraulic lifts we researched lifts currently on the market. Since hydraulic lifts are often used in industry, many of the lifts we found had lifting capacities much greater than what we required. For example, a suitable lift seen in Figure 47, page 47 meets our lower height requirement of 7 inches and raised height of 24 inches. Its lift capacity of 2,000 lbs is much greater then our need for 250 lbs. A quote was obtained for another hydraulic lift called Myti-Lift Table (Figure 48, page 47) This lift has a capacity of 500 lb, a 6 inch lowered height, and 36 inch raised height, and costs $ 2,650 (Appendix O: page 164).

Figure 47: Work Platform

Figure 48: Myti Lift

Pneumatic lifts were also researched to find the characteristics of current products. These lifts are often used in the manufacturing setting. Figure 49 shows a pneumatic conveyer for the assembly of car doors. The patent for lift in Figure 50 is one of the few lifts that avoid a scissor lift design and utilizes a simple hinge design and air bladder. The air bladder can be activated by electric pump or foot operated bellows. This lift may serve many purposes; for example it can be stored in the trunk of a car to aid in loading heavy objects to the car.

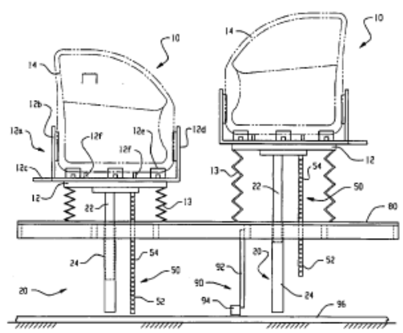


Figure 49: Pneumatic Conveyer

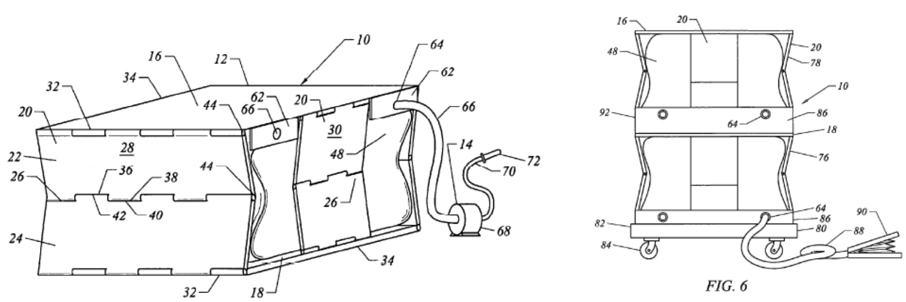


Figure 50: Pneumatic Lift Device

After searching through current pneumatic lifts on the market, one that met most of our engineering requirements was a lift from Southworth (Figure 51, page 48). This lift can handle up to 2000lb of force, has a lowered height of 8 inches, a raised height of 32 inches, and the time to elevate is 30 seconds. The drawback of it is that it has to be connected to shop air; the cost is comparable to hydraulic lifts that we looked into.

Figure 51: Southworth Pneumatic Lift

Materials allowed in the Operating Room

Cleanliness is a very important to the safety and health of both patients and workers in the O.R. Therefore a great deal of consideration was given to selecting materials that can be easily and safely sanitized.

Materials compatible with Hydrogen Peroxide

First we looked in to the type of materials that are commonly used in the O.R. The current lift that Dr. Muraszko used is made of aluminum which as we found cannot be sanitized with hydrogen peroxide. According to Solvay Chemicals Information on "Materials used for Construction of Storage Containers for Hydrogen Peroxide" only high purity aluminum of 95% or higher can be safely used without corroding the aluminum. Materials which we have to make sure to avoid are: brass, copper, nickel, iron and steel, bronze, synthetic rubber, polypropylene and zinc. [18] Acceptable materials are stainless steel of types 304,304L, 316 and 316L also chemical ceramics, Polyterafluoroethylene (Teflon), and PVC. To justify the use of stainless steel we also found that most surgical tables are made of stainless steels [19]. According to the FMC Material Safety Sheet for Hydrogen Peroxide there are certain fabrics which are recommended and compatible with hydrogen peroxide: SBR Rubber, Gore-Tex, nitrile, neoprene. Cotton, wool and leather should be avoided because they rapidly react with high concentrations of hydrogen peroxide [19].

Problem Analysis

The following is a discussion of the problems we thought would arise in the latter half of November 2008. We were concerned about manufacturing our prototype with amply time for assembly and testing. It was written during the second week of November, 2008. We believe that we have been successful in meeting the challenges stated because we have been able to create a fully functional prototype which meets the customers needs and wants.

There are several types of problems which could present themselves in the coming month. The type of these problems fall under the general categories of manufacturing, documentation and analysis. The manufacturing problems may be logistical or practical in nature. Problems with documentation on the other hand may purely be due to lack of experience in certain areas. Any problems with analysis will most likely not present themselves due to the high safety factors present in our current calculations, but analysis problems have presented themselves previously in the project.
Firstly, manufacturing presents logistical complications because of the involvement of Protomatic. Protomatic is located off campus and has different hours of operation then University of Michigan students are generally accustomed. This will present difficulties getting to and from Protomatic between classes and will present us with difficulties. If this becomes too much of an inconvenience we will move the lift to the shop at the University of Michigan and complete manufacturing there. Manufacturing may present practical complications because of the lift, the materials, and the tools. The lift's size makes it difficult to use in conjunction with traditional mills and other traditional machining equipment. It is our hope that the expertise of Protomatic will come in handy when tackling these problems. If we have other problems we will approach Bob Coury for his help. He assisted last year's team with similar specialty machining operations and his experience is invaluable. The long lead time on some of the materials used may also present us with a problem. If these materials and parts do not arrive on time we will have to make do with the materials available to us through Protomatic and the Undergrad Shop at the University. This also applies to tools. The manufacturing of the lift should not require any non-standard tools, which would not be available through Protomatic or the University.

Secondly, documentation problems may arise either with our blueprints or our electrical schematics. Only around half of our teammates have experience with the ANSI standard blueprints. It is inevitable that problems will therefore arise. We will therefore default to the advice and experience of Protomatic in regards to these matters. It is also required by Protomatic that electrical schematics are supplied with the blueprints. We as a team have little experience with electrical engineering matters. To avoid providing and incorrect final schematic to Protomatic, we will revise the schematic several times and if help is needed with the actual design we will solicit the help of Protomatic's resident engineers.
Finally, we do not anticipate the need for any other analysis to be done for the remainder of the project, because our current design has very large safety factors. However, when attempting complex modeling in Solidworks and FEA using Nastran, we have already come across problems. If further FEA analysis is for any reason necessary we plan on soliciting the help of Professor Richard Scott and his GSI Jaewon Lee. Having looked at the possible hurdles for us to overcome we are confident that we have the necessary resources to deal with any of them if they were to present themselves.

Description of Validation Approach

Basic Test Plans

In order to ensure that our prototype meets our engineering requirements we have performed a series of tests. While initially we wanted to perform both qualitative and quantitative tests as our test plans with show, we were unable to carry out several of the tests. Specifically the equipment required was unavailable fro the first and second tests. We therefore performed a qualitative analysis instead. In the following sections we describe each test, provide optimal values for each test and equipment used.

1. Test for the coefficient of friction between wheels and the ground when locked

1. Place the lift on a surface with the same coefficient of friction as in the OR and lock wheels in place
2. Attach a strain gauge to the base of the lift if available
3. Apply enough force to the lift to overcome static friction (repeat twice, once pulling once pushing) , record the peak forces achieved, repeat three times and take an average
4. Measure the weight of the lift, take three measurements, calculate the average
5. Calculate the coefficient of friction for both pushing and pulling between the wheel and the surface. If the strain gauge not available use qualitative analysis to make sure the lift does not slip when breaks are applied.

2. Test for the Rolling resistance coefficient

1. Place the lift on the same surface as used in the O.R.
2. Attach a strain gauge to front of the lift if available
3. Push on strain gauge for 5 seconds with a constant force allowing the lift to roll, record the top force reached, repeat the test three times
4. Pull on the strain gauge for 5 seconds with a constant force allowing the lift to roll, record the top force reached, repeat three times take averages
5. Calculate the dimensionless rolling resistance for both pulling and pushing, take the averages. If stain gauge not available use qualitative analysis to make sure the lift can be easily movable.

3. Test for Stability of the Lift

1. Lift the lift to the maximum height possible
2. Have three different individuals stand on the lift and walk on the edges of the lift ,
3. Have them rate how stable they feel on a scale form 1-10, take the averages of the results.
4. Have the three individuals lean on the lean bar while the lift is all the way up

5. Record how stable and safe they feel on a scale 1-10, take averages
6. Have the three individuals sit on the seat while lift is all the way up
7. Record how stable and safe they feel on a scale 1-10, take averages

4. Test for designated safety height

1. Raise the lift up until the lift reaches its maximum height and shuts off
2. Measure the distance from the floor to the top of the platform, repeat three times and record the results

5. Test for ease of seat mobility and ease of use of buttons for adjustability of the seat

1. Have three different individuals stand on the lift and extend the seat to desired position, lock the seat, extend the legs and sit down.
2. Have them record on a scale of 1-10 how easy it is to (1) extend the seat, (2) lock the seat, (3) extend the legs, (4) how safe and stable they feel sitting.
3. Drape the lean bar as it is done in the OR make sure the buttons are covered if draping is available
4. Have a person get on the lift and have them adjust the lift to the desired height
5. Record the time it take from the moment the person gets on the lift to the time the lift begins moving
6. Repeat the experiment three times with different people and after each trial have the person record the easy of finding the buttons seat on a scale from 1 to 10.

Equipment Used

Test	Equipment List
1. Coefficient of Friction- Locked Wheels	Qualitative analysis
2. Rolling Resistance	Qualitative analysis
3. Stability of Lift	Qualitative analysis
4. Safety Height	Tape measure
5. Ease of Seat Mobility	Qualitative analysis
6. Bar and seat height	Tape measure

Table 9: Equipment required for testing

Test Results

Test	Target Parameters	Results
1. **Coefficient of Friction : pushing and pulling the lift when wheels are locked**	Minimum Force : 300lb Maximum: 0.0067	Qualitative Results: Lift cannot be slid when wheels are locked
2. **Rolling Resistance: measuring the ease of mobility when wheels are unlocked**	Maximum Force : 200lb Optimal Rolling Resistance:	Qualitative Results: Able to be rolled with only one hand, easy to maneuver
3. **Stability of Lift: measuring users stability**	Optimal 10	Average Ratings: Standing on edge: 7 Leaning on Lean Bar: 8 Sitting on Seat: 9
4. **Safety Height: Lift shuts off at designated height**	Shut off at 24 in	Target height reached 24 in: 100% success rate
5. **Ease of Seat Mobility**	Optimal 10	Average Rating: 6.25

Table 10: Test Results

According to our tests the locks on the casters lock the lift in place as it does not slide when they are locked. Therefore our lift passes the first test. The rolling resistance is small enough to allow the user to maneuver the lift with one hand. This test proves that our lift for Dr. Muraszko is a big improvement over her old lift as it meets one of her main requirements of effortless mobility. The three subjects who measured the stability of our lift came up with an average of 7 when standing on the edge of our lift, average of 8 when leaning on the lean bar and average of 9 then sitting on the seat. These tests prove our lift is stable for the user. The lift was raised to the height at which it shuts off and the height was measured to be the required 24 inches with 100% success rate. Three subjects tested the east of mobility of the seat. They came up with 6.25 rating for the ease of moving the seat from it's stored to down position. These tests prove that the mobility of our seat is acceptable for the user. Also since our test subjects never folded the seat before a more experienced user might give a higher rating for the ease of seat mobility. Overall our lift passed all our tests and can be considered safe and user friendly.

Engineering Changes Notice

There has been a major change in our design since design review three. This change has dealt with how we will lock the wheels of the surgical lift. However, there have been no changes to the other portions of the lift design (lean bar and seat).

Wheel Locking Mechanism

Our lift required one major change since the last design review. The entire wheel locking system had to be redesigned because of the unfortunate property of our scissor lift which did not become apparent until the lift arrived on November 17th. Our previous wheel locking mechanism relied on the power of the lift to raise the lift off the floor. Unfortunately, the way that the current lift is wired it does not use the motor to lower the lift but simply releases the hydraulic valve allowing gravity to it.

To redesign our lift we had to attach the wheels to the base of the lift. We designed a plate with compartments for the wheels as it is important for Dr. Muraszko to have the wheels covered as they can be a tripping hazard in the O.R. The lift will use locking mechanisms on the casters to ensure the lift does not move during surgery. This concept was approved by Dr. Muraszko and therefore has been manufactured by Protomatic. The plates where designed in such a way to allow the wheels to rotate freely without hitting the sides of the base. The back wheel containment was extended along the length of the entire lift to increase stability (Figure 52). The base is made out of ¼ in steel plates. Stainless steel is not required since the base will not interact with or come near the patient. The plate has also been reinforced with several gussets to increase its rigidity.

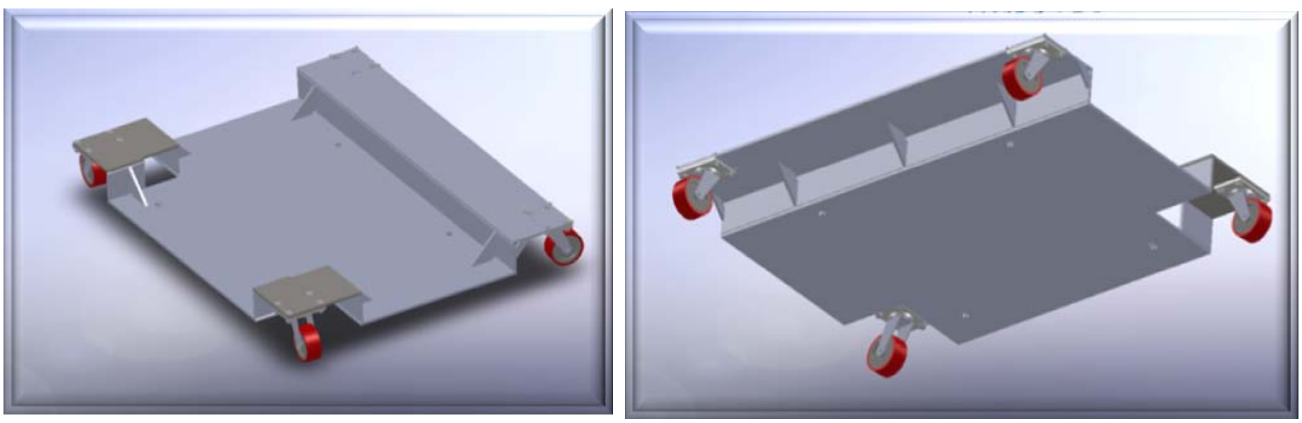


Figure 52: Plate attached to bottom of lift which casters will mount to

COSMOS analysis was performed on the plates supporting the front wheels and a safety factor of 2 was found proving the plate will not deform under normal use (Figure 53, page 54). Our final design can be seen in Figures 54 and 55 on page 54.

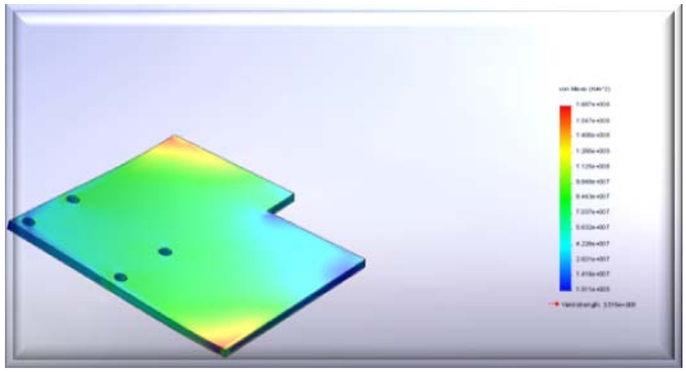


Figure 53: COSMOS Analysis of front wheel plate

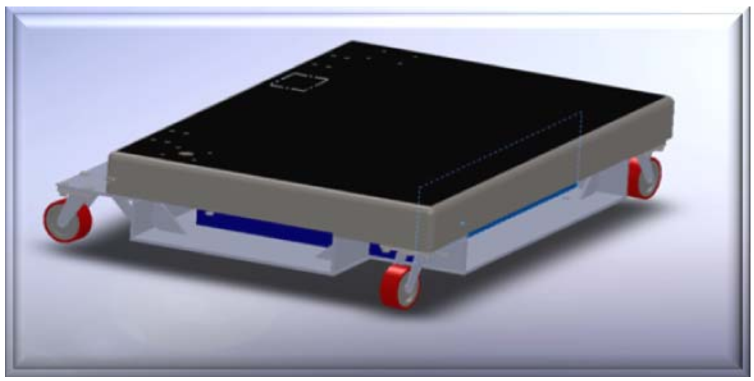


Figure 54: Base attached to the scissor lift

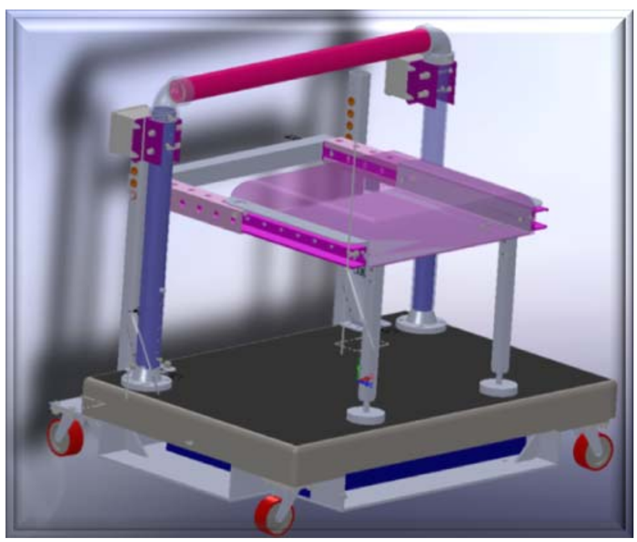


Figure 55: Final Lift design

Discussion and Recommendations

After the completion of this project we feel that several aspects of the design should be further investigating to determine if a redesign is desired. We address the main features of the lift which we feel could be improved upon and suggest that in the future, these recommendations be investigated. By doing so we hope to encourage the further development of the surgical lift to ensure that the best product can be developed for not only Dr. Muraszko but other surgeons as well.

Design Process Improvements

Our product has clearly involved many design changes. Therefore, the number one process improvement we would make is to define our customer requirements more clearly before creating a detailed CAD design. Our first detailed design required a complete redesign after showing it to Dr. Muraszko. The second time around, we would have showed her our initial sketches for approval before spending time making a second detailed CAD design. Overall if we could have done the design over we would have kept Dr. Muraszko more involved in the whole process asking her for approval of each design idea before committing the time to modeling and analysis. We have learned that it is very important to learn the customer's requirements early on in the design process even if this means meeting several times and working through the concept designs with the customer.

Looking back, we also would have implemented a Design Freeze for the CAD model. After this point, design changes would no longer be accepted. This would have reduced that amount of pressure felt by the team when constantly trying to alter subsystem designs to more accurately reflect customer needs and wants. Ensuring that the needs of the customer are met is extremely important while the 'nice to have' features or wants could have been left alone after this Design Freeze.

Overall, we would have asked more questions. We learned that clear and constant communication is extremely important when we were trying to create a seat that was comfortable for Dr. Muraszko and at the same time met our engineering requirements. At first our understanding was that Dr. Muraszko did not use the seat and the seat will not be a large part of our design. However, after showing her our first design we learned that the reason she did not use the seat is that it not user friendly. At the meeting for the approval of our alpha design we were told that Dr. Muraszko would like the seat to extend out, have a much bigger cushion and still be capable of being folded in a vertical position. The wheel locking mechanism also required redesign as Dr. Muraszko liked the idea of the wheels being contained underneath the lift and not be out in the open. These and other redesigns which did not become apparent until our hospital meetings would have made our semester less stressful if they were defined at the beginning of the semester.

We recommend that the customer is updated often and communication lines are open at all times to ensure the product is developed in a timely manner with as little rework as possible.

Product Improvements of the Lift

The improvements of our design would include (1) choosing wheels which have more prominent locking mechanisms, (2) rewiring the lift to have the motor be engaged as the lift is lowered, (3) adding arm rests and a back rest, (4) safety strips to prevent lift from tipping the hospital bed, (5) keeping crevasses to a minimum such as where the buttons attach to the lean bar, (6) obtaining a smooth metal finish for easy cleaning and crisp appearance, (7) providing a stop at the front of the seat so that it cannot accidently slide out when being folded and stored, (8) finding all stainless steel parts for the seat and screw attachments, (9) changing the way the seat moves forward and back, and (10) changing to an electric lift.

Caster Improvements

To make it easier to lock and unlock the wheels we would suggest for a future design to include wheels with more prominent locking pedals. This design aspect is limited by the size of the wheel openings underneath the lift. The front openings which are currently 5.56 by 6.81 inches could be made larger. However this would increase the footprint of the lift which is not something the customer wanted at the time. Similarly, the back plate containing the wheels sticks out from the lift by 5.5 inches and houses the wheels within this area could be expanded for larger wheels but at the same time expanding the platform size. The wheels spin out from under both the front and back plates and this could end up being a problem for the customer in the future.

We began investigating casters from the following companies: Shepherd Caster Corporation, Magnus Motion Control Solutions and the Jilson Group. From the Jilson Group we chose the Single Wheel Nylon Casters shown in Figure 56a which are 5” in diameter have a convenient wheel locking mechanism and have a load capacity of 220 lbs. These are equipped with “splash-proof” double-row ball bearings for easy and quiet pivoting. Figure 56b shows Twin-Wheel Nylon Casters which come in 3” and 4” diameters and include a Maxi-Lok break. They are especially designed to keep out debris from jamming the wheels, which is very important for our application. Another option from Magnus Motion is Floor Locks shown in Figure 57 below which plants a rubber pad on the floor. Magnus also designs custom made casters with unique locking mechanisms and mounting systems.

- a - Single wheel casters

- b - Twin Wheel Casters

Figure 56: Casters

Figure 57: Floor Locks

From Shepherd Caster Corporation the twin Lock series casters are specifically designed for medical applications. These are made of nylon, have a 225lb load capacity each, are 4 inches in diameter, and the break locks both the wheels and the swivel motion. Locking the swivel motion would be ideal for extra stability.

Figure 58: Shepherd Caster Corp. Twin Lock Casters

Rewiring the Lift

In order for our original wheel locking design to work (See Figure 27Figure 17, page 27) our hydraulic lift would need to be rewired in order to engage the motor as it travels both up and down. This original locking design was modeled with the intention that the wheels would be attached to the top of the lift so that they would rise with the lift as it moved up. Then the wheels would raise the base of the lift off the ground as the lift traveled down to its collapsed position. Currently there is a flow control valve in place which limits the flow of hydraulic fluid to the extending motion of the piston. If this was removed and the motor rewired to allow the piston to move in both directions under pressure our original locking mechanism would become feasible. To do this we suggest hiring a professional electrician/ hydraulic specialist or simply purchasing a scissor lift which requires hydraulic pressure for both the extending and retracting modes.

Arm Rests and Back Rest

As Dr. Muraszko mentioned, she would like her chair to have a back rest. We therefore purchased a used chair with a back rest. We recommend that a backrest be designed into the surgical lift from the beginning. We tried to incorporate a backrest late in the design phase and were unsuccessful. For the arm rests we suggest purchasing either used or new arm rests for a surgery chair as it will meet the OR requirements.

Safety Strips to Prevent Surgery Bed from Tipping

There are two safety strip companies which we looked into - OMRON and Larco. The OMRON strips that we looked into are the SGE-88 series. These are the smallest and will not obstruct movement on the platform. Three strips can be integrated together to cover the front and side edges of the lift or just one strip could be used to cover the front edge.

Safety mats were also investigated however these are made primarily to be actuated with small forces (~50lbs). This matting would not be able to distinguish between Dr. Muraszko stepping onto the lift and the lift becoming stuck under an operating table.

In addition, when our seat design was changed to have additional support legs, the safety mat was no longer a feasible solution. We also considered making our own button actuation device shown below which would be covered by the mat. Additional solutions could include two plates with a spring in between, to sense the pressure applied or a tube filled with water with a pressure sensor at the end to detect the force of the surgery bed.

Figure 59: OMRON Safety Strips

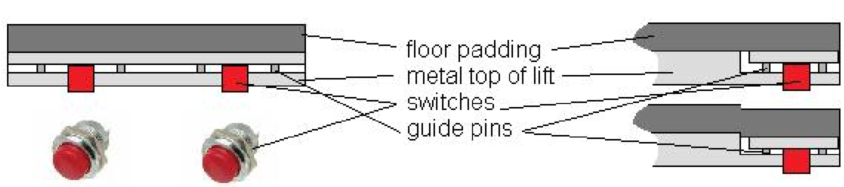


Figure 60: Guide Pins for Floor Auction

Keep Crevasses to a Minimum
There are a few places on the lift where creases could be a potential sanitary issue. While the lean bar and seat will be covered with a sanitary cloth, some places on the seat and lean bar have sharp corners or crevasses. New attachments could be made by changing bolts to welds and sharp pockets rounded out. Caps should be added to the ends of the seat struts to keep the inside of them closed off from the OR debris.

Metal Finish
There was not enough time to create a smooth metal finish to the parts of this design. The finished product should have a smooth surface, not only for easy cleaning, but also for a finished appearance.

Stop for Front of Seat
The seat is detachable where the telescoping struts are. While there is a stop that prevents the seat from moving too far towards the front of the lift, there should also be a pin that stops the seat from moving too far back. This would have to be a removable stop like a pin so that the seat can still be taken out at these struts for lubrication or other adjustments.

Stainless Steel Parts
One of the main concerns for this project was getting all stainless steel parts so that the entire lift could be sanitary. While this was possible for the entire lean bar and most of the seat, a few products were difficult to find in stainless steel. The telescoping struts of the seat are not stainless steel because it was not possible to find these in stainless steel. The hinges for the legs of the seat are also not stainless steel because stainless steel hinges are also difficult to find. These parts may need to be fabricated for this lift. While the parts should all be stainless steel, the bolts, nuts, and washers should match and also be stainless steel. This was not the case for some of our attachments due to quick design changes towards the end of the project.

Change Seat Telescoping Struts to Ball Bearing Gliders
For the seat horizontal movement we looked into using a mechanical system similar to that of a cabinet or drawer with ball bear gliders. The ones that we found online could not handle the torque that was going to be put on the seat when someone sat on it. However, these calculations were done with a previous seat design without the supporting legs that the final design has. Other bearing gliders that we found were actually not being made by the companies anymore. We therefore kept with the telescoping struts. It would be much easier to use the seat during surgery if these struts were changed to ball bearing gliders.

Electrical Lift
Another part that could be changed is the lift itself. We looked into electrical lifts, but they were all either too big or too expensive for our original budget. It may be safer for the lift to not have hydraulics at all. An electrical lift would remove all fear about the

hydraulics leaking. An electric lift could be looked into if the budget was increased to accommodate such a change.

Conclusion

The need exists for a lift designed specifically for use in the operating room. Our first customer is Dr. Muraszko of the Mott Children's Hospital who needs the lift due to her short stature and disability due to Spina Bifida. While this prototype has been designed specifically for her, these needs are representative of other potential customers. We have focused our efforts on improving her current lift's design. Her requirements included proper wheel choice for mobility, prominent user controls, sterile materials, stability while in use, power cord containment, and comfort of the platform, seat, and lean bar. Emphasis was placed on stability, mobility, wheel locking systems, and user interface. We have successfully created a surgical lift which Dr. Muraszko can use in the O.R. when she is either performing surgery or observing one. We have performed a variety of analysis including, COSMOS, FEA, and hand calculations to confirm the safety and feasibility of this design.

Acknowledgments

1. Protomatic
    - Doug Wetzel (Vice President and General Manager)
    - Ben Pierce (R and D Engineer)
    - Matt Maj (R and D Engineer)

Thank you for your patience and guidance through the design, manufacturing, and assembly portions of this project. We would not have been able to complete the project without your support.

2. Professor Shih and Grant Kruger - Thank you for your guidance in our design and supporting us in the meetings at the hospital and with Protomatic.

3. Dr. Muraszko, Suzie Hines, and surgical team – Thank you for your guidance in determining what features the lift should have and your patience throughout the design process.

References

[1]Oberg, Erik. Machinery's Handbook : Combo, CD-Rom V1.0 and Toolbox Edition Set. New York: Industrial P, Incorporated, 1999.

[2] Burlington DB. Human factors and the FDA's goals: improved medical device design. *Biomed Instrum Technol.* 1996; 30:107-109.

[3] A survey of static and dynamic work postures of operating room staff I.J Kant 1 , L C G M de Jong 2, M van Rijssen-Moll 3 , and P J A Borm 11Department of Occupational and Environmental Medicine and Toxicology Int Arch 1991 *6 l* 493-42 R

[4]Mirbod S, Yoshida H, Miyamoto K, Miyashita K, Inaba R, Iwata H. Subjective complaints in orthopedists and general surgeons. *Int Arch Occup Environ Health.* 1995;67:179-186

[5] Ergonomics in Laparoscopic Surgery, Ramon Berguer M.D.

[6] Meuli-Simmen C, Szabo Z. Video plastic surgery**.** In: Szabo Z, Lewis J, Kerstein M, eds. *Surgical Technology International*. 3rd ed. San Francisco, Calif: Universal Medical Press; 1994:515-522

[7] Bendix T, Krohn L, Jessen F, Aaras A. Trunk posture and trapezius muscle load while working in standing, supported-standing, and sitting positions. *Spine.* 1985;10:433-439.

[8] Surgery and Ergonomics, Ramon Berguer MD, Arch Surgery 1999: 134:1011-1016

[9] Safety, Hazards and Ergonomics in the Operating Room, Ulrich Matern, Sonja Koneczny, Experimental –OR Ergonomics, University Hospital Tuebingen, Tuebingen, Germany , May 5, 2007

[10] Add-A-Level Riser Set: http://healthcare.marketlabinc.com/products/details/3064

[11] Stacking Interlocking Step Stool http://healthcare.marketlabinc.com/products/details/3066

[12]Work Platform Patent: Enchin L. Newin, PN 6044927, Sept 23 1998

[13] Reinfried Moller, Patent Number 4511110

[14] Serway, Raymond A. and Jewett Jr, John W. Physics for Scientists and Engineers. 6th Ed. Thomson Brooks/Cole. Belmont, CA. 2004. p. 132.

[15] Transportation Research Board Special Report 286 – Tires and Passenger Vehicle Fuel Economy. National Research Council of the National Academies. 2006. P. 78. http://onlinepubs.trb.org/onlinepubs/sr/sr286.pdf

[16] Dowling, Norman E. Mechanical Behavior of Materials. 2nd Ed. Prentice-Hall Inc. 1999. p. 781

[17]Hibbeler, R. C. Statics and Mechanics of Materials. Pearson Prentice Hall. 2004. p. 743

[18] Solvay Chemicals: Materials of Construction for the Storage of Hydrogen peroxide. http://www.solvaychemicals.us/static/wma/pdf/6/6/0/4/HH-2323.pdf

[19] SOMA technology: Nuvo Volante Surgical Table http://www.somatechnology.com/https://ctools.umich.edu/access/content/group/813d8133-4c5c-44b9-957e-4497ce4ed83b/Design%20Review%203/Paper/Refrences/surgical_table.pdf

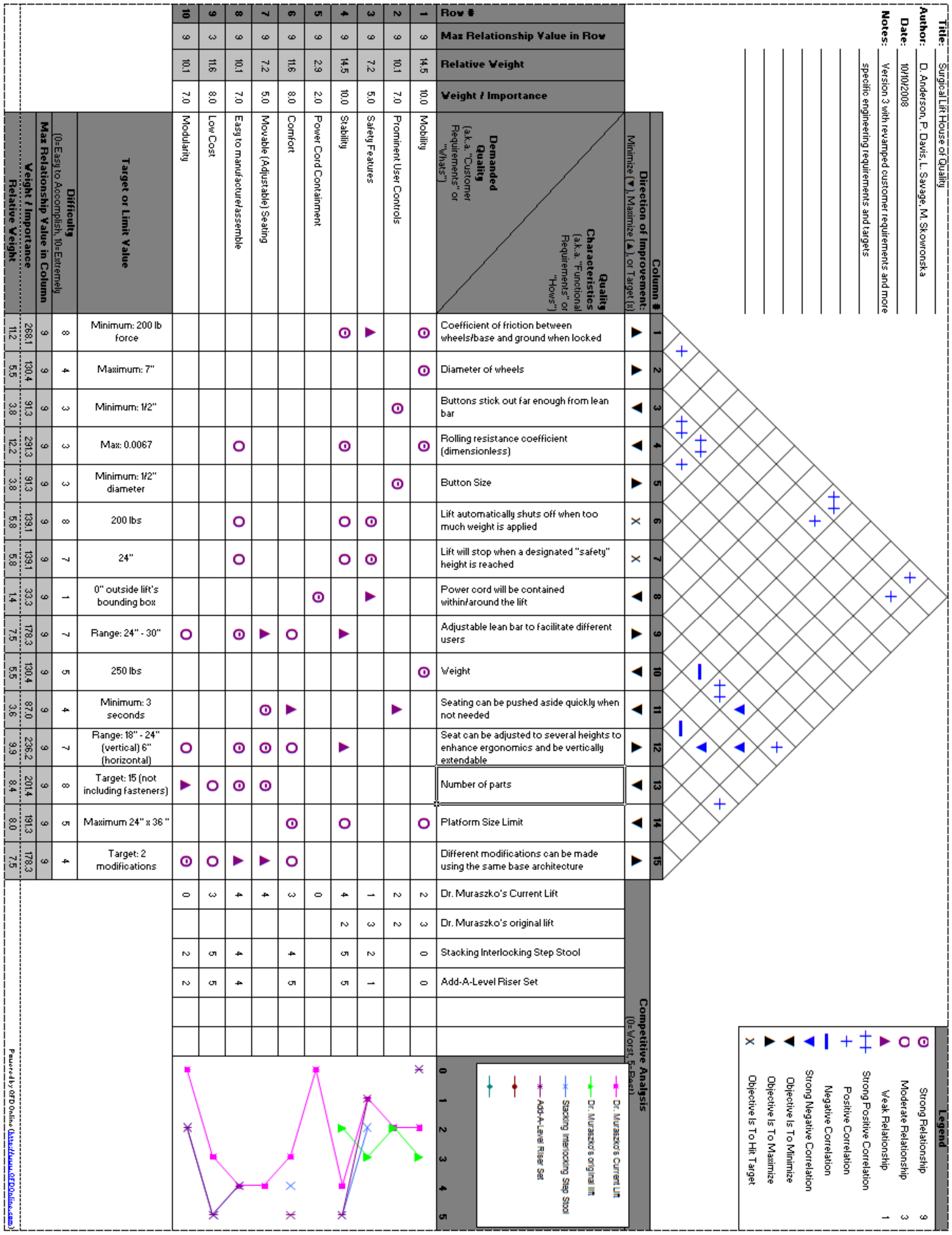
Appendix A: Preliminary Design Requirements

Design Requirements
Use sterile materials – where sanitary draping is not used
Storable power cord
Electrical/cord housing
Wheel Size
Mechanism to lock wheels
Weight - minimize
Button Size
Padding
Platform Traction
Pressure sensor
Adjustable Seating
Height Sensor
Noise Level
Use sterile materials

Table 11: Preliminary Design Requirements

Appendix B: QFD

Our QFD chart quantifiably takes into account the customer needs, engineering requirements and competitive benchmarks. It can be seen below.



Appendix C: Preliminary Lift Concepts

Below is a compilation of initial ideas which our team developed after meeting with Dr. Muraszko.

C.1 - Dolly Style Lift

This lift would only have two wheels and be lifted up by the handle in the same manner that a dolly does.

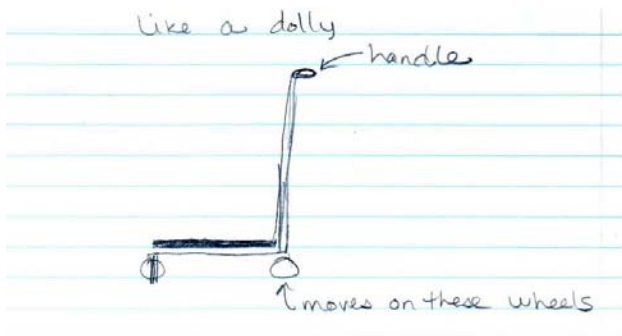


Figure 61: Dolly Style Lift

C.2 - Lift with Pull Out Handle

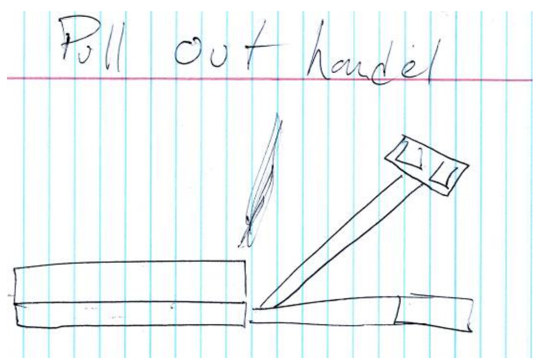


Figure 62: Lift with Pull Out Handel for Easy Transport

C.3 - Flip Down Rubber Pegs

This model had pegs with rubber feet that flip down and hold the lift in place when in use.

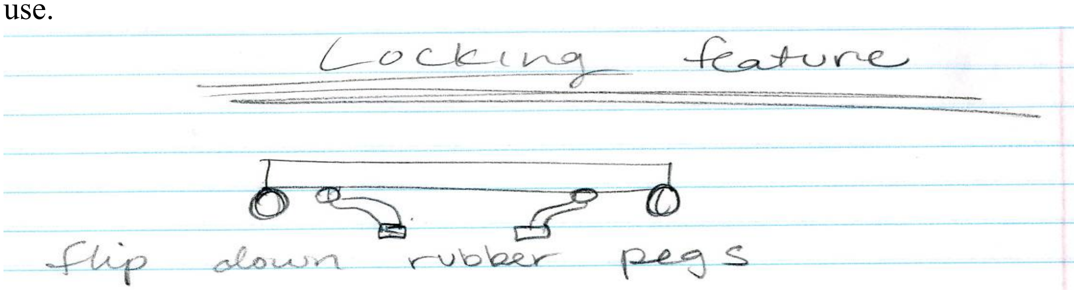


Figure 63: Flip down locking legs

Appendix D: Pugh Charts

D.1 - Buttons Pugh Charts

-a- Rocker Button   -b- Large Button   -c- Toggle Switch   -d- Rotational Switch

Figure 64: Pictures of Buttons

Characteristics	***Benchmark***	***Rocker***	***Really Big Button***	***Toggle***	***Rotational Switch***
Size	0	1	1	1	1
Easy differentiation of directions	0	-1	1	1	-1
Easy to grip/actuate under draping	0	-1	1	0	-1
Return to neutral when user not interfacing	0	0	0	0	0
Timed delay	0	0	1	0	0
Total	0	-1	4	2	-1

Table 12: Button Choices Pugh Chart

D.2 - Cord containment Pugh Chart

Design1 – retractable by Handle

Design 2- Automatic handle

Design 3 –Hooks

Design 4- Hose Reel

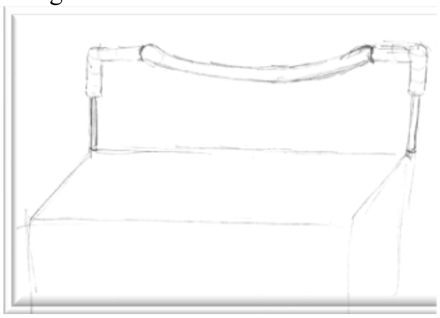
Figure 65: Cord Containment Picture Examples

Characteristics	*Design 1- Benchmark*	*Design 2- Retractable by Hand*	*Design 3- Retractable -Automatic*	*Design 4- Hooks*	*Design 5- Hose Reel*
Ease of winding	0	1	1	-1	1
Stationary after wound	0	1	1	-1	0
Size	0	0	0	0	0
Weight	0	0	0	0	0
Failure/wear	0	0	-1	1	0
Speed	0	1	1	-1	1
Sum	**0**	**3**	**2**	**-2**	**2**

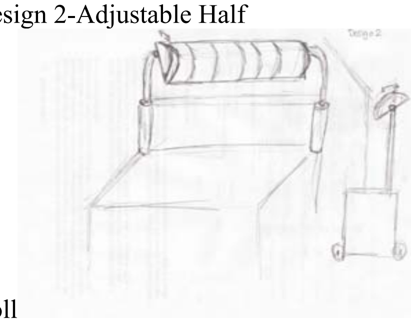
Table 13: Cord Pugh Chart

D.3 - Lean bar

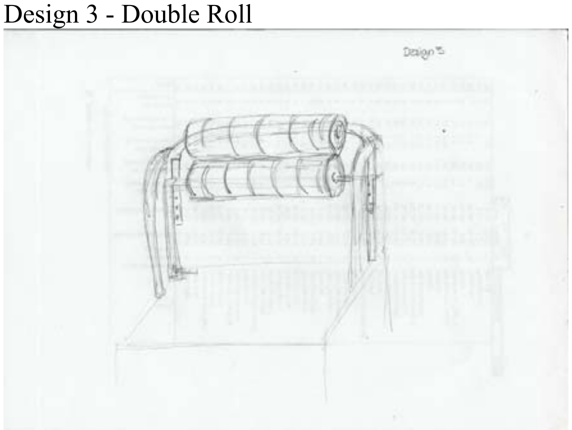
Design1 –Bent Bar



Design 2-Adjustable Half Roll



Design 3 - Double Roll



Design 4- Wing Nut Design

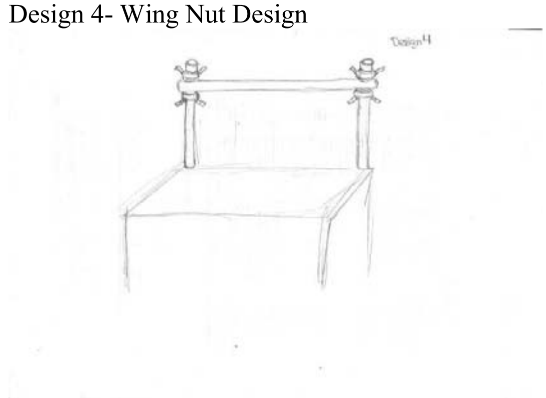


Figure 66: Lean Bar Choices

Characteristics	*Benchmark*	*Design 1-Bent bar*	*Design 2-Adjustable Half bar*	*Design3-Double Roll*	*Design 4-Wing Nut Design*
Strength/ Yield	0	0	0	0	0
Visual Appeal	0	1	1	1	0
Manufacturability	0	-1	0	0	1
Comfort	0	0	1	1	0
Adjustability	0	0	1	1	-1
Failure and Wear	0	0	-1	0	0
Weight Added	0	0	0	-1	0
Easily Padded	0	0	-1	0	0
Seat Integration	0	0	1	-1	-1
sum	**0**	**0**	**2**	**1**	**-1**

Table 14:P Lean Bar Pugh Chart

D.4 - Power Sources

Characteristics	*Hydraulic*	*Pneumatic*	*Electric*	*Airbag*
Price	0	0	1	-1
Weight (Light=Good)	0	-1	-1	-1
24" Minimum Reach	1	1	-1	1
Maintenance + Failure	0	1	1	1
Noise Level	0	-1	1	-1
Volume (Size)	0	0	0	0
Platform Footprint				
Stability	0	0	0	0
Minimum Collapsed Height (5")	0	1	1	0
Speed of lift	-1	-1	0	-1

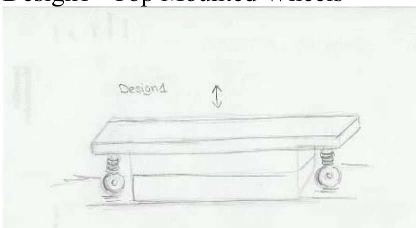
Table 15: Power Sources Pugh Chart

Characteristics	*1*	*0*	*-1*
Price	$1,000	$2,000	$3,000
Weight (Light=Good)	100lb	200lb	300lb
24" Minimum Reach	24-30	>30 in	<24 in
Maintenance + Failure	non-catastrophic	non-catastrophic but inconvenient	catastrophic + inconvenient
Noise Level	silent	mild	high
Volume (Size)			
Platform Footprint	Current Size	Slightly smaller or larger	Too small or large
Stability			
Minimum Collapsed Height (5")	<5	5-6	>6
Speed of lift	3	5	10

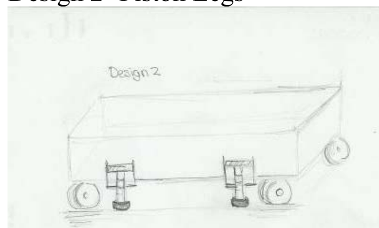
Table 16: Power Sources Characteristics

D.5 - Locking Mechanism

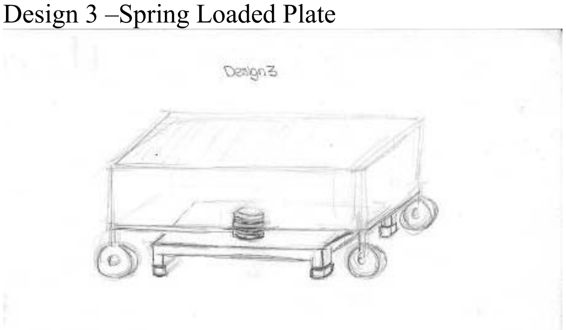
Design1 –Top Mounted Wheels



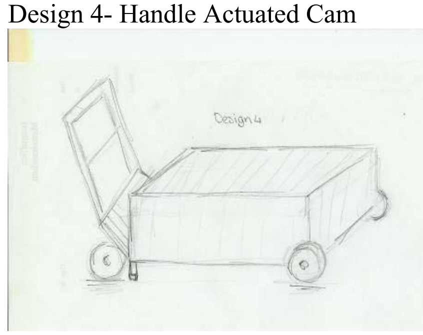
Design 2- Piston Legs



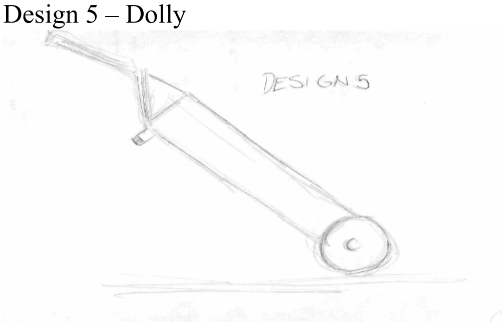
Design 3 –Spring Loaded Plate



Design 4- Handle Actuated Cam



Design 5 – Dolly



Design 6- Hydraulic Casters

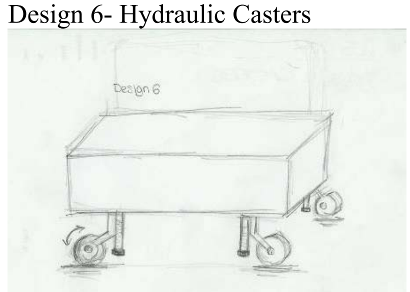
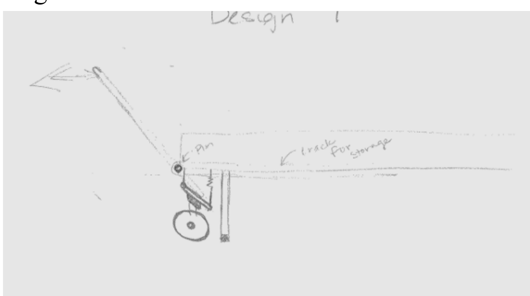


Figure 67: Locking Mechanism Concepts

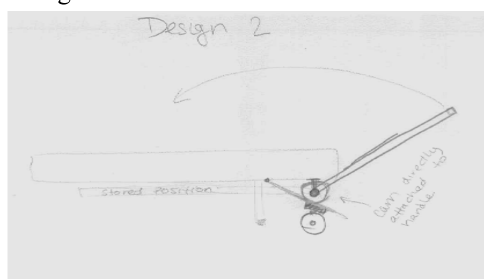
Characteristics	*Design 1 Top Mounted Wheels*	*Design 2- Piston Legs*	*Design 3- Spring Loaded Plate*	*Design 4- Handle Actuated Cam*	*Benchmark*	*Design 5-Dolly*	*Design 6- Hydaulic Casters*
Stability	1	1	1	1	0	1	1
Manufacturability	0	0	-1	0	0	1	-1
Failure Modes	1	0	0	1	0	-1	0
Wear and Maintenance	0	-1	-1	1	0	1	-1
Added Height	0	0	-1	0	0	0	0
User Convenience	0	0	0	1	0	-1	0
Mobility	0	1	0	1	0	-1	0
	2	1	-2	5	0	0	-1

Table 17 : Locking Mechanism Pugh Chart

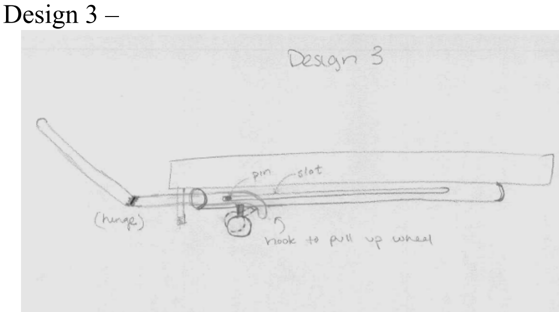
Design1 –



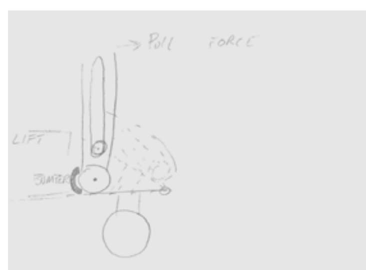
Design 2-



Design 3 –



Design 4-



Design 5 –

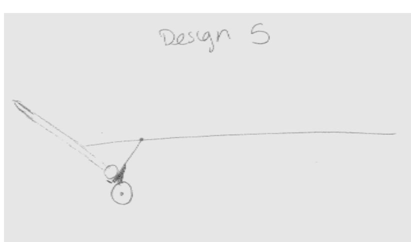


Figure 68 : Handle Locking Mechanism Concepts

Characteristics	***Design 1***	***Design 2***	***Design 3***	***Design 4***	***Design 5***
Manufacturability/ Assembly	0	1	-1	0	0
Number of moving parts	0	1	0	0	0
Does it fail with wheels down?	1	1	0	0	0
Ease of use	0	0	0	1	1
Ease of storage	1	-1	1	-1	-1
Push and Pull Capability	-1	1	-1	-1	-1
Lift drops to ground when handle dropped	1	0	1	-1	-1
	2	**3**	**0**	**-2**	**-2**

Table 18: Handle Locking Mechanism Concepts Pugh Chart

Characteristics	*Design 1-Seat Flips behind and over the lift*	*Design 2-Purchased Flip down Seat*	*Design 3-Linakage Design Flip down seat*
Ease of use	-1	1	0
Comfort	0	-1	1
Compatible with Lean bar	-1	1	1
Stability	0	-1	1
Weight	0	1	0
Adjustability	-1	0	0
Total	-3	1	3

Table 19: Seat Design Pugh chart

Appendix E: Literature Review Patents and Products

E.1 - Work Platform Patent

Work Platform Lift Machine with Scissor Lift Mechanism Employing telescoping electro-mechanical based lift actuation arrangement, Enoch L. Newin PN:6044927 Sept 23 1998. (The patent drawing can be seen below in Figure 69.)

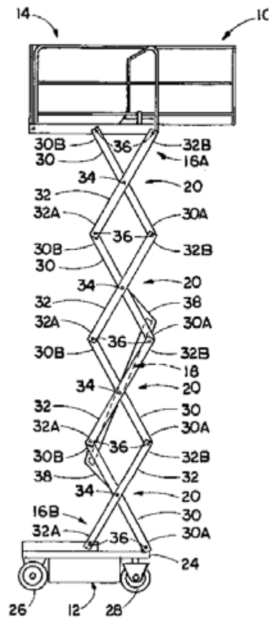


Figure 69: Work Lift Platform

E.2 - Scissor Lift

Reinfried Moller, Patent Number 4511110, Scissor lift comprises of two adjacent scissor lift arms the drive comprises of one cylindrical roller which is motor driven. (A picture of lift can be seen in Figure 70.)

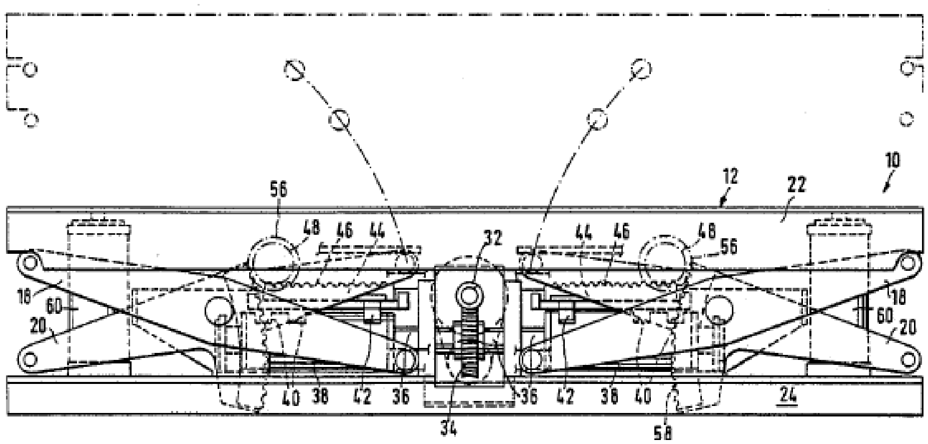


Figure 70: Electromechanical Scissor Lift

E.3 - Mechanically Operated Lift Table Alton Graets, Patent Number 5833198

A scissor lift mechanism which is raised and lowered by a spring assembly which acts without a hydraulic or pneumatic actuator.

E.4 - Hydraulic Surgical Beds

The diagram below (Figure 71) is from U.S. Patent number 2795694 which was issued in June of 1957. It discusses a hydraulic lift which is used to raise and lower the operating table. It is entitled, “Surgical Operating Table with Hydraulic Actuating Means.”

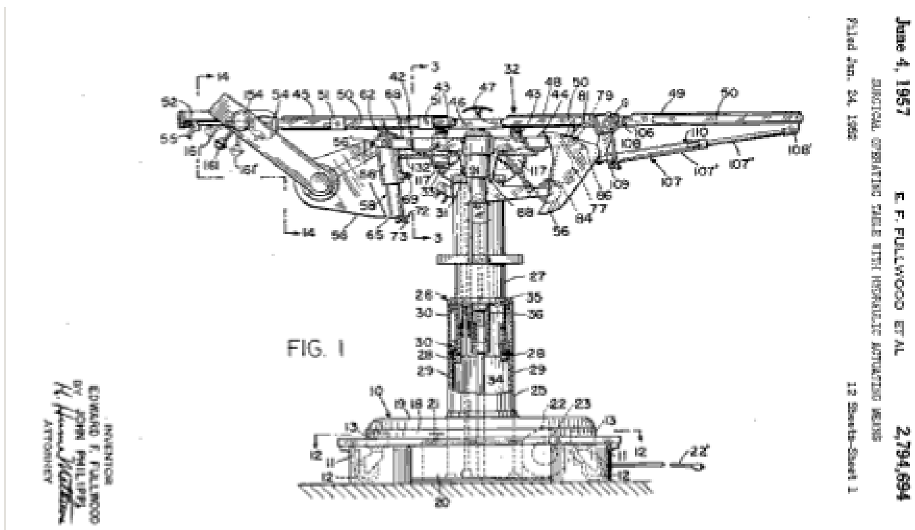


Figure 71: Surgical Operating Table Hydraulically Actuated

Figure 72 illustrates another patent for a hydraulically operated hospital bed. The bed utilizes a hydraulic actuator to raise the lift up and down. Entitled, “Hydraulic Control Apparatus for a Hospital Bed,” was issued as patent number 6352240 on March 5, 2002.

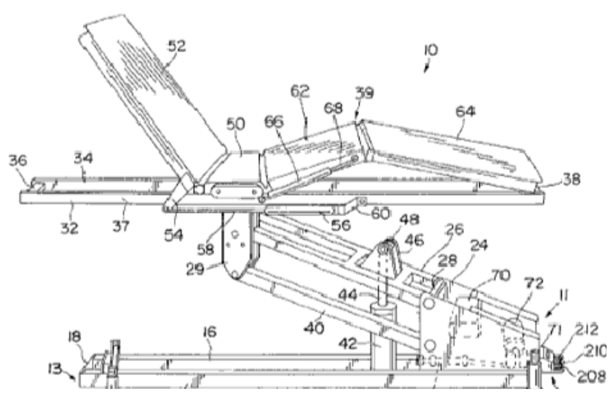


Figure 72: Hydraulic Control Apparatus for a Hospital Bed

E.5 - Scissor Lift Apparatus: Patent Number: 4930598 William D. Murrill.

This is a scissor lift with a wheel tube chassis and a platform connected by more than one arm (Figure 73 below). The design claims to reduce lateral sway when scissor lift is erected in the operating position, lower the center of gravity, and permit the use of smaller hydraulic cylinder for raising and lowering the lift.

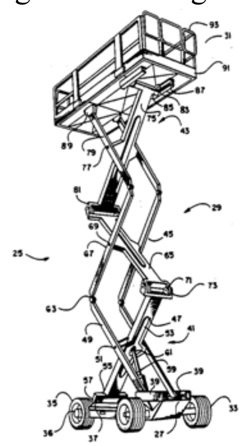


Figure 73: Scissor Lift Apparatus

E.6 - Meditech Hydraulic Operating Table

Figure 74 illustrates that hydraulic operating tables are currently on the market today. There are many others that are sold by a variety of companies as well, illustrating that there is a large demand for hydraulic operating tables.

» Side End Control Super Deluxe Hydraulic Operating Table (MI - 2003)

Features

1. Five Section Stainless Steel Top
2. Base and Columan Covered with Stainless Steel Fitting
3. Base Auto Floor Locking Device
4. Detachable Leg Section
5. Cancelled Gear Mechanisum
6. Electrically Sealed Blue Rubberized Mattress thickness 50mm

Specifications

Length of Table Top	L1830 x 497mm
Lifting Position	762 to 787 mm
Height Adjustment	225 mm
Lateral Tilt	20° Both Side
Flex / Reflex	90° / 220°
Trendelenburg & Rev	30° / 25°
Head Section UP/DOWN	30° / 90°
Back Section UP	80 to 90°

Standard Accessories

Anaesthetic Screen Frame	1 Pc
Shoulder Supports	1 Pair
Lateral Supports	1 Pair
Arm Rest (S.S.Top)	1 Pair
Knee Crutches	1 Pair

Figure 74: Hydraulic Operating Table Currently on the Market

Appendix F: Calculations for Validation of Design

F.1 - Calculations for Lift and Lean Bar

	Equation		Symbol	Max	Min	Units
Stability of base:						
Coefficient of friction of steel [1] [4]			μ	0.8	0.6	-
Coefficient of friction of hospitol floor [2]			μ	0.7	0.7	-
Normal force			N	280	240	lb
Force required to move base	$\mu = F/N$		**F**	**224**	**144**	**lb**
Shear force in pins in lean bar: (new equation to replace old) [3]	τ = Fs/A [3]					
r		*0.1875*				
Shear force			Fs	200	150	lb
Cross sectional area			A = πr^2	0.11044662	0.110447	in^2
Shear stress in pins			**τ**	**1810.82957**	**1358.122**	**psi**
Ultimate shear strength of aluminum [7]			**τult**	**30000**	**11000**	**psi**
Buckling force:						
D		*1.5*				
d		*1*				
Youngs modulus of aluminum [8]	$F = \frac{\pi^2 * E * I}{KL^2}$		E	10600000.00	9000000	psi
Area moment of intertia of hollow cylinder			I = π(D^2 - d^2)/64	0.06135923	0.061359	in^2
Constant of bending			K	2	2	-
Length of beam	(check these numbers)		L	24	30	in
Force on beam			**F**	**5572.28144**	**3027.957**	**lb**
Buckling force max						
Yield stress check:						
Force down on seat						
Moment arm						
Moment						
Distance from neutral axis of seat						
Area moment of inertia of thin rectangle						

References:
[1] http://hypertextbook.com/facts/2005/steel.shtml
[2] SECTION 09 66 16, TERRAZZO FLOOR TILE. http://www.wbdg.org/ccb/VA/VAASC/VA%2009%2066%2016.doc
[3] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 203.
[4] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 189.
[5] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 190.
[6] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 1413-1414.
[7] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 569.
[8] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 193.

F.2 - Angle Bracket Calculations

Yield stress check of angle iron bracket holding casters to platform:				$\sigma = \frac{M*y}{I}$
Force up on angle iron bracket	F	131	lb	
Moment arm	R	3	in	
Moment	M	393	lb*in	
Distance from neutral axis of seat	Y	0.125	in	
Height of angle iron bracket	H	0.25	in	
Width of angle iron bracket	B	3.63	in	
Area moment of inertia of thin rectangle	I	0.004727	in^4	
Stress	**S**	**10393.39**	**psi**	
Yield stress of steel check:	**Sy**	**36300**	**psi**	
Safety Factor	**SF**	**3.492605**		

Shear force in bolt hoding angle bracket to lift: [3]			τ = Fs/A [3]	A = πr^2
Minimum diameter of bolt	**d**	0.2464	**in**	
Shear force	Fs	65.375	lb	
Cross sectional area	A	0.047684	in^2	
Shear stress in bolt	**τ**	**1371.009**	**psi**	
Ultimate shear strength of steel [10]	**τult**	**135000**	**psi**	
Safety Factor	**SF**	**98.4676**		

[3] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 203.
[10] Oberg, Erik, et. al. Machinery's Handbook. 25th Ed. Industrial Press. New York. 1996. p. 479.

F.3 - Calculations for Seat Design-Buckling of support legs

Calculations for the bucking of the support legs

Formula : P=(pi^2*E*I)/Le^2

L	20	inches	*15-20
Le	10	inches	
bi	1		
hi	1		
bo	0.87		
ho	0.87		
E	2.79E+07	Lb/in^2	
I=1/12*b*h^3	0.035591866		
P(cr)	97,907.12		

F.4 - Calculations for Seat Design -Stresses in Support Legs

Calculations For the Moment at the bottom of the chair support

Stress =M*y/(Ix)		
max Moment	2000	
y	1	
ho	2	
hi	2	
bo	1.76	
bi	1.76	
Ix	0.53373952	
Stress	3747.146173	lb/in^2
Force	14502.95455	

F.5 - Calculations for Seat Design -stresses for telescoping tubing

W	200
L	24
bi	1.5
hi	1.5
bo	1.625
y	0.8125
ho	1.625
Ix	0.159200033
Z=(I/y)	0.195938502
Stress	3062.185304
yield stress	30000
Safety factor	9.79692508

F.6 - Calculations for Tipping

F_1	180.8339474		
Added Distance	4		
L_1	-1	Ws	47.85
L_2	38		
L_3	16	WL	270.64
L_4	22	Ww	0
L_5	8	WLb	30.45
L_6	15	Wp	150

Appendix G: Evolution of Lift Design

G.1 - Wheel locking mechanism

G.1.1 - Evolution of the Wheel Locking Mechanism: Alpha Design

The alpha design of the wheel locking mechanism involved a cam attached to a handle that would wrap around the lift. This design would not work according to the customer because the lift has to be able to sit next to the side of the bed and the handle in this model would be in the way. She also said that she would like to be able to move the lift during surgery sometimes to get into a better position. Another issue with this lift was the fact that the footprint was too large and had crevasses in which brain matter could get lodged.

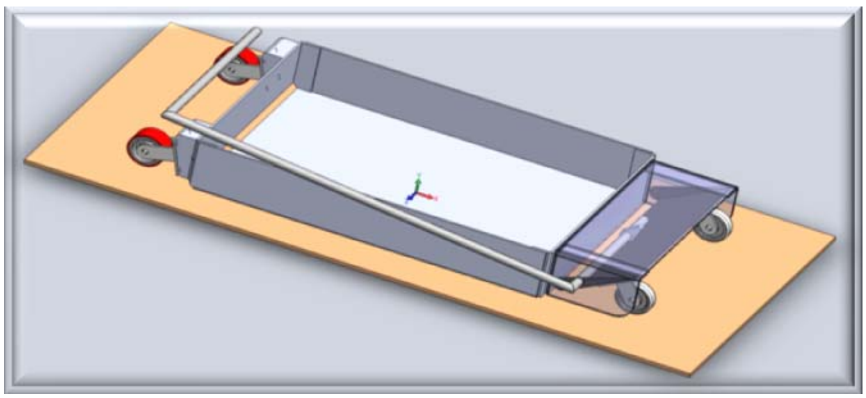


Figure 75: Top of wheel locking mechanism alpha design

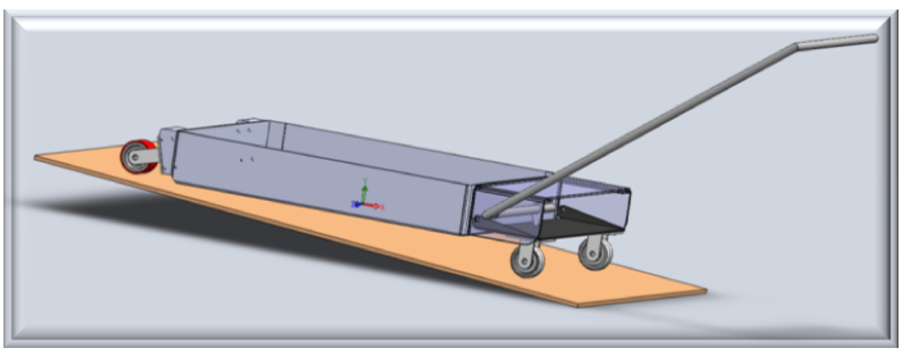


Figure 76: Cam engaged on alpha design of wheel locking mechanism

G.1.2 - Evolution of the Wheel Locking Mechanism: Final Design

The final design of the wheel locking system has the wheels attached to the top of the platform so that when the lift is raised, the wheels come off the ground and the lift will then be immobile. There are Teflon sheets attached to the bottom of the lift so that it can be slid easier along the floor when the customer wants to move it during surgery.

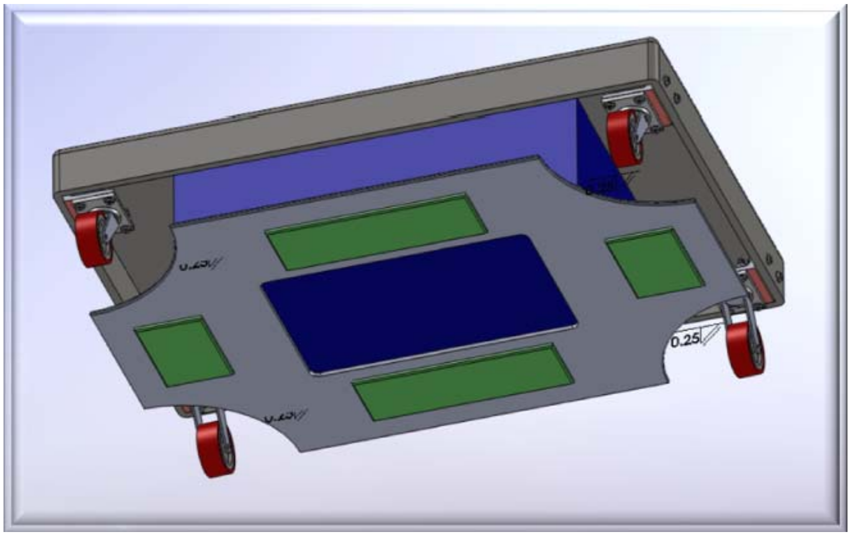


Figure 77: Bottom of final wheel locking design

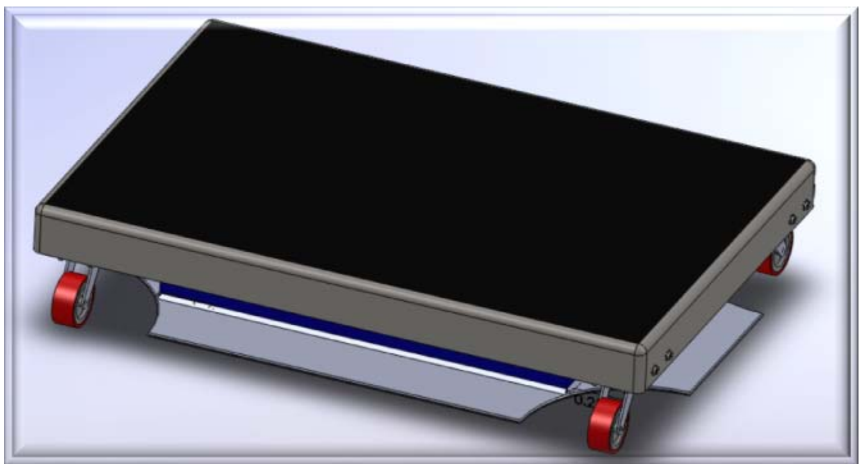


Figure 78: Top of wheel locking design

G.1.3 - Evolution of the Wheel Locking Mechanism: Final Design after ECN

The design submitted to Protomatic for fabrication, final design after engineering changes have been implemented since Design Review 3 is shown on page 82.

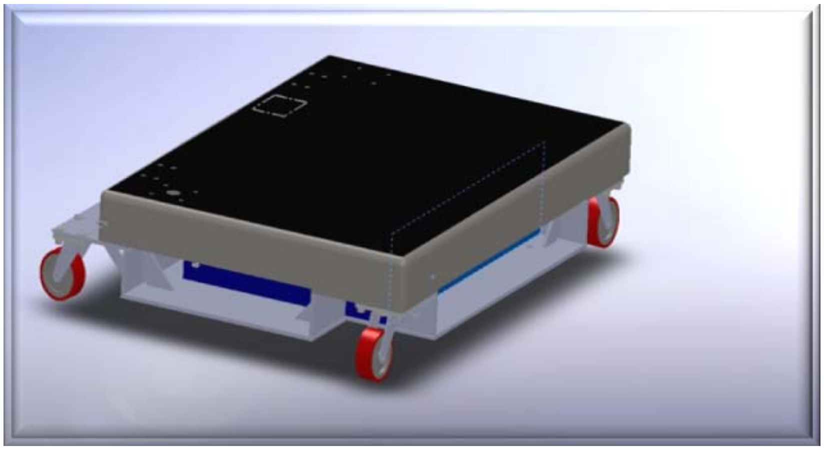


Figure 79: Top of wheel locking mechanism after ECN

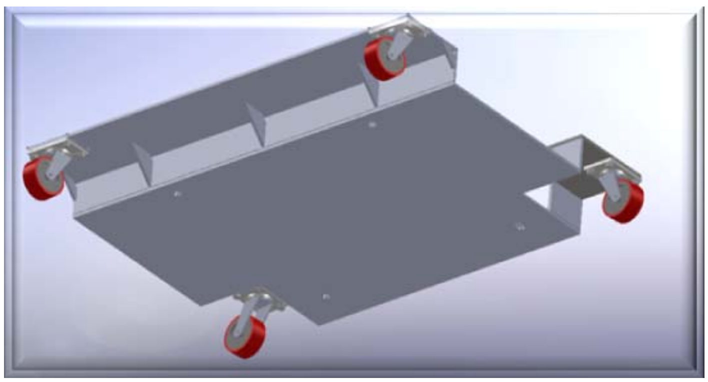


Figure 80: Underside of wheel locking mechanism after ECN

G.2 - Lean Bar

G.2.1 - Evolution of the Lean Bar: Alpha Design

The first design of the lean bar included an adjustable padding roll that would be much larger than the rod used in the current design. The height was adjustable as required by the customer. However, this design was made of steel (not stainless steel) and the customer was not sure the change in the padding shape would feel comfortable to her.

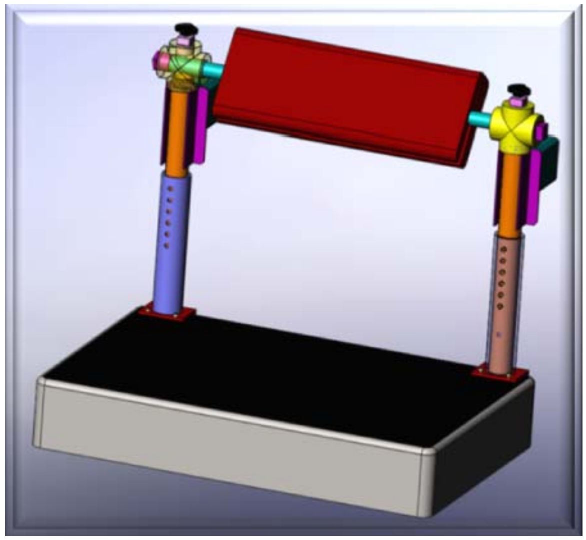


Figure 81: Front of lean bar design 1

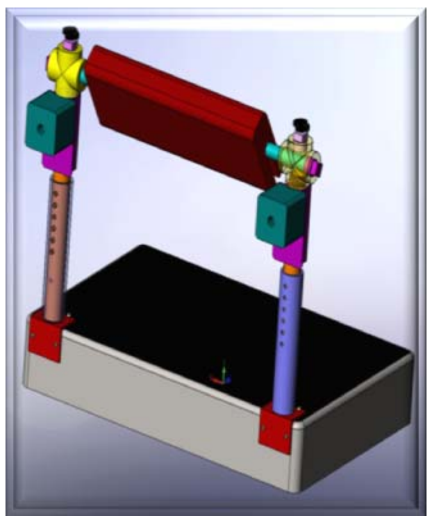


Figure 82: Back of lean bar design 1

G.2.2 - Lean Bar Evolution: Design 2

The second lean bar model was designed with the customer's input in mind and the back was kept round. This time the adjustable tubing used on the side was aluminum telescoping tubing. This made for a light and compact design. However, it was soon discovered that the material for all parts above the platform of the lift must be stainless steel.

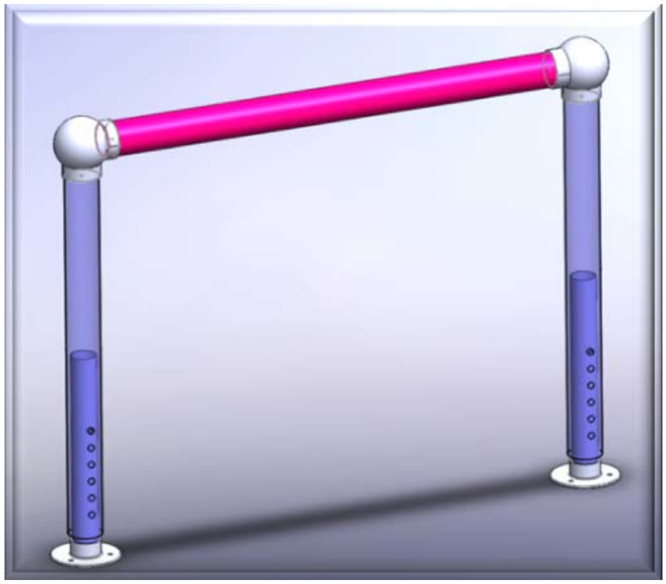


Figure 83: Lean bar design 2

G.2.3 - Lean Bar Evolution: Final Design

The third and final design for the lean bar was entirely stainless steel and kept a similar shape as that of design 2 above.

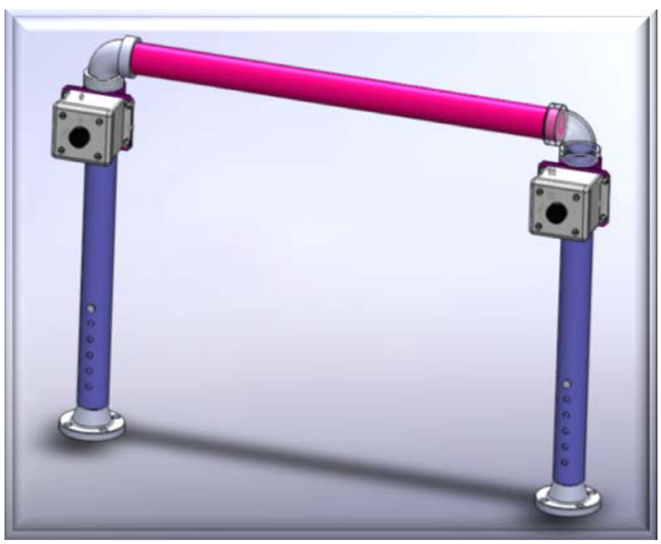


Figure 84: Lean bar design 3 – final

G.3 – Seat

G.3.1 - Evolution of the Seat: Alpha Design

The first design of the seat was similar to that of the previous lift. A foldable seat would be attached to the lean bar in which Dr. Muraszko could sit upon when needed. However, after our first design review with Dr. Muraszko it was discovered that a more versatile seat was desired; specifically, one which could slide parallel with the lift platform.

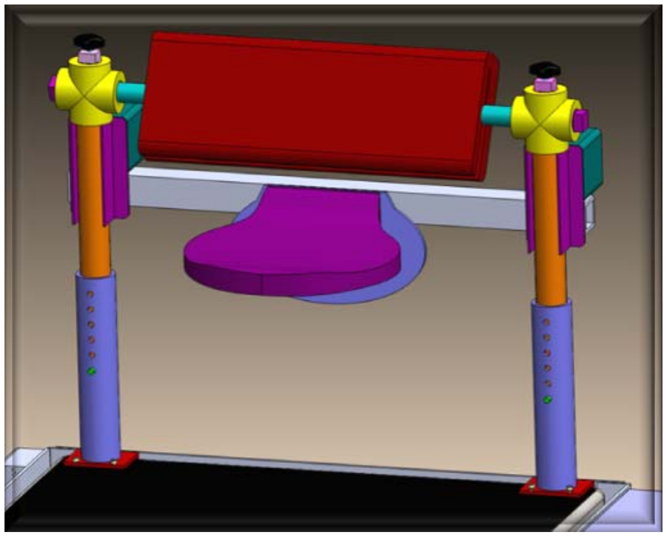


Figure 85: Alpha design for the seat

G.3.2 – Seat Evolution: Design 2

The second seat design had the cushion mounted on the top of slides which could be used to move the seat back and forth. Since the locking pin is located underneath the seat Dr. Muraszko would need to get off the seat to adjust it which is not the ideal situation during surgery

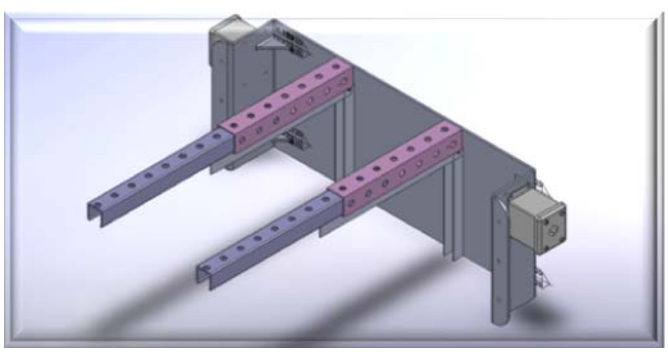


Figure 86: Redesign 1 - Seat Mounted on Top of Tubing

G.3.3 – Seat Evolution: Design 3

The third seat design involved a ball bearing slider As we were designing the seat we were calling different ball bearing slider companies to find a slider which would work. Although sliders of the right dimension exist, we were unable to find a slider which could sustain the amount of torque created by a person sitting on the edge.

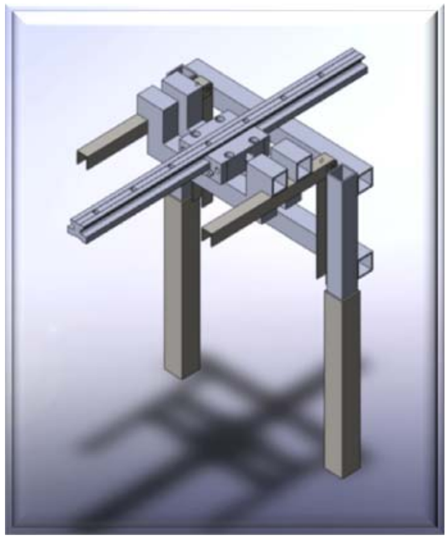


Figure 87: Redesign 2 - Ball Bearing Slide Mechanism

G.3.4 – Seat Evolution: Design 4

This system would work similar to that of a foldable picnic table. The linkage design allowed the seat to fold down and then extend forward via the telescoping tubing. Although the concept of this design was good, after analyzing the stresses in the bars we found that it could not support the doctor.

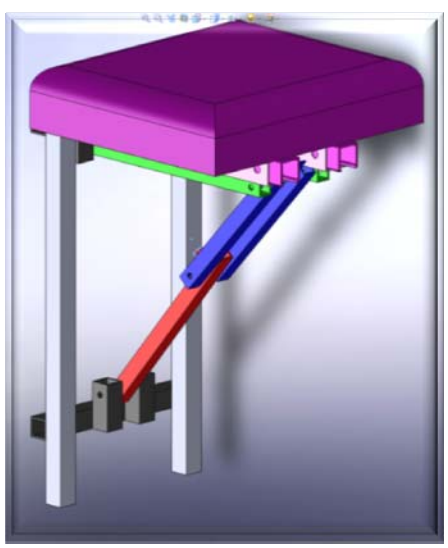


Figure 88: Redesign 3 - Linkage Design

G.3.5 – Seat Evolution: Final Design

The final seat design allows for a thick, 16", cushion to be stored. This is possible by extending the seat prior to folding for storage. This design also incorporated two legs which are used to support the weight of the surgeon. The length of the legs can be adjusted to reflect the height of the seat and lean bar.

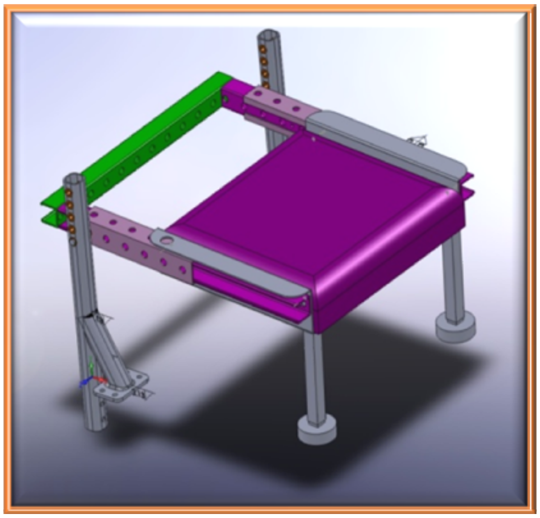


Figure 89: Final Design - Pivoting Seat with Support Legs

Appendix H: Engineering Prints

The following pages contain the engineering prints which were submitted to Protomatic. This set of drawings pertains to the final versions of the seat, lean bar, and lift models which can be seen when the physical lift is viewed.

Please note that the engineering prints for the wheel locking mechanism have changed since Design Review 3 and are considered a part of the Engineering changes section. They have been included in this section for clarity.

Appendix I: Bill of Materials

I.1 - BOM prior to ENC

ITEM NO.	PartNo	DESCRIPTION	Material	QTY.	PRICE ($)
1 to 2	LIFT	HYDRAULIC MYTI-LIFT 24X36	Myti-Lift: CLTMYT-05-30-2436W	1	3454
3	BASE PLATE	STEEL PLATE 24X36 1/4 in thick	METALS DEPOT: P114	1	98
4	BASE_MAT2	TEFLON SHEET 4X6 1/4 in	MCMASTER: 7998K63	2	143.13
5	BASE_MAT3	TEFLON SHEET 4X12 1/4 thick	MCMASTER: 7998K63	2	
6	BASE_MAT4	ANGLE IRON 2X3	METALS DEPOT: A23214	4	106.56
7	Caster Base	Part of Caster which is all one part, plate thickness 3/16in, plate lenght 3-5/8in width 2-1/2 in	McMaster:9949T21	4	163.16
8	Caster base Attach	part of whole caster assembly	McMaster: 9949T21	4	
9	Caster Wheel	300lb capacity, wheel diameter 3 in, wheel width 1-1/4in, 4 bolt holes, wheel material polyurethane	McMaster: 9949T21	4	
10	5-16 Washer	5/16 Steel Washer, Zinc Plated, Inside Diameter .328 in, Outside Diameter .625in	McMaster: 91090A110	48	4.34
11	5/16 1.25in Screw	5/16 - 18(Thread size) X 1.25 (lenght) Hex Head Steel Screw, Fully Threaded, Plain Tip, Black-Oxide Finish	McMaster: 92220A224	24	8.26
12	5/16 NUT	5/16 - 18 Steel Nut, Width 0.5 in, Height 17/64 in	McMaster 90499A030	24	3.78
13-16	beads for welding			1	1
17	Support Strut	1.5 X 1.5 Stainless Steel Tubing	Mcmaster: 89825K423	2	45.32
18	Sleeve Bearings	For shaft with diameter 3/8 in, outside diameter 11/16in, lenght 1/2 in, flange thinkness 3/64in, load max 1000, Material Rulon 641	McMaster: 6371K115	20	366.4
19	Pin Seat Height	3/8 in diameter, Stainless Steel, recomended pin diameter 1/8in	McMaster: 92390A722	2	13.08
20	Preforated tube	5ft tube can be used for tubes, tubes 1-7/8 square with 9/16 dimater holes on all sides spaced on 1-7/8 centers, to be used with 1-5/8 x1-5/8in strut chanel	Mcmaster: 3138T21	2	153.1
21	Telescoping Strut Channel	measures 1-5/8x 1-5/8 in and has 8/16 diaSlemeter holes opiosite the open face of the channel,	Mcmaster :3138T51	2	326.74
22	Bushing	Bushing to go on the pin about which the seat rotates	McMaster: 6371K413_A20081104	2	9.32
23	Recess box	Recess Box for seat cushion 1ftx4ftx 1/8 in made from stainless steel sheet metal	MetalsDepot: P518FP	1	271.4
24	SeatConnectorScrew	Socket Head Cap Screw OD 0.25 L 1 T 20	Mcmaster: 9219542	4	11.46
25	washer (inside strut channel)	washer to go inside the strut channel	McMaster: 3088A509	4	4.88
26	washer	waher to be used with the seat design, SS	McMaster 93852A101	6	3.95
27	Nut Seat palte	SS, thread szie 1/4in 20, Hex Nut type, width 7/16in, height 3/16in	McMaster: 91841A029	6	9.5

28	cushion	Jay Triad Cushion, 18 wide by 16 deep($265), addition of neoprene cover ($46)	Preferred HealthCare: Model 1286	1	296
29	SEAT LEG	SEAT LEG, SST TUBE, 1X1	MCMASTER 2937K111	2	31.56
30	Threaded Inserts	overall height 1-1/16in, fits tubing of wall thickness 0.065in, load per adapter 1100lbs, Outside tubing dimnesions 1 in square, tap into place with a rubber hammer	McMaster: 60945K57	2	11.08
31	Swivel Mount	diameter of base, thread size 1/2in -13	Mcmaster: 6221K45	2	83.16
32	top tube	used to keep the seat form falling out, 0.83 in thick, 1.5x1.5 in comes in 6ft	MCMASTER 89825K229	1	85.8
33	Quick_Release Pin	Diameter 1/2in, usable length 4-1/2in, hole size 1/2in, 36800lb double sheer strenght	McMaster: 93750A727	1	33.43
34	Hooks	4 x12x.125 in 304 Stainless Steel	McMaster: 8992K166	1	25.36
35	Hook Screw	18-8 Stainless Steel Button	McMaster: 92949A551	2	5.94
36-39	beads for welding			1	1
40	LEAN_MAT1	TUBING, 1.50D, 1.38ID, 12.0 LONG, SS	MCMASTER 7427K23	2	38.88
41	LEAN_MAT2	TUBING, 1.9 OD, 1.61 ID, 22.0 LONG, SST	McMaster: 44635K438	2	212.56
42	LEAN_MAT3	TUBING, 1.9 OD, 1.61 ID, 28.0 LONG, SS	MCMASTER 44635K438	1	106.28
43	PIPE FITTING	FEMALE ELBOW, 90, PIPE SIZE 1.5, SST	McMaster 44965K418	2	136.76
44	MOUNT PLATE	FRONT MOUNT BUTTON ATTACHMENT, 304 SST	MCMASTER 9085K42	2	71.02
45	MOUNT SIDE	SIDE PLATE BUTTON ATTACHMENT, 304 SST, .125 in thick, annealed	MCMASTER 9085K42	4	
46	Push Button Box	NEMA 4X Push-Button Enclosure, Box 2.8x3.5x2.8in, attachment plates 4.5in,hole for button .88in	McMaster: 5639K11	2	259.44
47	FLANGE LEAN BAR	Flange for bottom of lean bar, to be milled out form 4in, 1.5 in long plate	MCMASTER: 9208K67	2	125.34
48	Pins	SST, 3/8in Diameter, Lenght 2-13/16in, usable lenght 2-1/4in, inside claerance 1-1/2in	McMaster: 98480A019	2	12.72
49	Push Button	22mm Push Button, Spring Back (Momentary), Flushed	McMaster 9209K11	2	36
50	Washer for Button Box	SST, fro screw size 10, 13/64in ID,7/16in OD	McMaster: 90107A011	16	4.55
51	Screw for Button Box	SST, .5 in, Fully Threaded, Palin Head and Pan Head style, 10-24 in thread size, head diameter .373in	McMaster 90604A242	8	6.14
52	Nuts for Button Box	SST, width 5/16 in, height 7/64in, 10-24 in thread size	McMaster: 90205A313	8	10.87
53	Washer for Button Box and Pipe	ID .265in, OD .5in, SST, for screw size 1/4in	McMaster:98017A660	8	5.28
54	Screw for Button Plate and Pipe	SST, lenght 3in, 1/4-20 in thread size, head height 1/4 in, head diameter 3/8in	McMaster: 92185A557	4	8.98
55	Nuts for Button Box to Pipe	SST, Width .5 in, Height 15/16in,	McMaster: 94252A703	4	10.96

I.2 - FINAL BOM (after ECN)

ITEM NO.	PART NUMBER	PartNo	DESCRIPTION	Material	QTY.
1	SupportStrut_V01	Support Strut	1.5 X 1.5 Stainless Steel Tubing	Mcmaster: 89825K423	2
2	Bushing_6371K115_A20081104	Sleeve Bearings	For shaft with diameter 3/8 in, outside diameter 11/16in, lenght 1/2 in, flange thinkness 3/64in, load max 1000, Material Rulon 641	McMaster: 6371K115	20
3	Pin_92390A72220081104	Pin Seat Height	3/8 in diameter, Stainless Steel, recomended pin diameter 1/8in	McMaster: 92390A722	2
4	92185A624	Screw Seat Support to Scisssor Lift	Socket Head Cap Screw, 3/8 in -16, 1 in lenght, 316 stainless steel, hex socket	McMaster92185A624	8
5	97022A541	Washer Seat Support to Scissor Lift	Stainless Steel, 3/8 in, OD 5/8in,	McMaster 97022A541	16
6	90257A063	Nut Seat Support to Scissor Lift	Machine Screw Nut, 3/8in, 316 Stainless Steelm, heigth 1/4	McMaster: 90257A063	8
7	92196A542	SeatConnectorScrew	Socket Head Cap Screw OD 0.25 L 1 T 20	Mcmaster: 9219542	4
8	PerforatedBar3_Seat520081104	Preforated tube	5ft tube can be used for tubes, tubes 1-7/8 square with 9/16 dimater holes on all sides spaced on 1-7/8 centers, to be used with 1-5/8 x1-5/8in strut chanel	Mcmaster: 3138T21	2
9	StrutChannel_Seat520081104	Telescoping Strut Channel	measures 1-5/8x 1-5/8 in and has 8/16 diameter holes opiosite the open face of the channel	Mcmaster :3138T51	2
10	Bushing_6371K413_A20081104	Bushing	Bushing to go on the pin about which the seat rotates	McMaster: 6371K413_A20081104	2
11	RecessBox20081104	Recess box	Recess Box for seat cushion made from stainless steel sheet metal	MetalsDepot: P518FP	1
12	Washer_3088A50920081104	washer (inside strut channel)	washer to go inside the strut channel	McMaster: 3088A50920081104	4
13	Washer_94773A710	washer	waher to be used with the seat design, SS	McMaster 94773A710	6
14	91841A029	Nut Seat palte	SS, thread szie 1/4in 20, Hex Nut type, width 7/16in, height 3/16in	McMaster: 91841A029	6
15	Threaded Inserts20081104	Threaded Inserts	overall height 1-1/16in, fits tubing of wall thickness 0.065in, load per adapter 1100lbs, Outside tubing dimnesions 1 in square, tap into place with a rubber hammer	McMaster: 60945K57	2
16	FOOT ADJUST20081104	Swivel Mount	diameter of base, thread size 1/2in -13	Mcmaster: 6221K45	2
17	Seat Leg Inserts	Insert Seat Leg	.25 in thick Stainless Steel Plate	Stainless Steel Plate	2
18	98164A134	Screw for Support Legs (small)	8-32 stainless steel screw to attach support legs to hinge, 3/8 long.	McMaster: 98164A134	14
19	98164A211	Screw for Support Legs (large)	1/2 -20 stainless steel screw to attach support legs to hinges, 3/8 long.	McMaster: 98164A209	4
20	JayTriadSeat20081104	cushion	Jay Triad Cushion, 18 wide by 16 deep($265), addition of neoprene cover ($46)	Preferred HealthCare: Model 1286	1
21	Top_Tube	top tube	used to keep the seat form falling out, 0.83 in thick, 1.5x1.5 in comes in 6ft	MCMASTER 89825K11	1
22	bead9				1
23	bead10				1
24	bead11				1
25	bead12				1
26	90730A009	Nut Seat Leg to Plate	18-8 Stainless Steel	McMaster: 90730A009	12
27	hooks3	Hooks	4 x12x.125 in 304 Stainless Steel	McMaster: 8992K166	1
28	92949A550	Hook Screw	18-8 Stainless Steel Button	McMaster: 92949A551	2
29	LEAN_MAT1	LEAN_MAT1	TUBING, 1.50D, 1.38ID, 12.0 LONG, SS	MCMASTER 7427K23	2
30	LEAN_MAT2	LEAN_MAT2	TUBING, 1.9 OD, 1.61 ID, 22.0 LONG, SST	McMaster: 44635K438	2
31	LEAN_MAT3	LEAN_MAT3	TUBING, 1.9 OD, 1.61 ID, 28.0 LONG, SS	MCMASTER 44635K438	1
32	44965K418	PIPE FITTING	FEMALE ELBOW, 90, PIPE SIZE 1.5, SST	McMaster 44965K418	2

33	Mount Plate	MOUNT PLATE	FRONT MOUNT BUTTON ATTACHMENT, 304 SST	MCMASTER 9085K42	2
34	Mount Side	MOUNT SIDE	SIDE PLATE BUTTON ATTACHMENT, 304 SST, .125 in thick, annealed	MCMASTER 9085K42	4
35	5639K11	Push Button Box	NEMA 4X Push-Button Enclosure, Box 2.8x3.5x2.8in, attachment plates 4.5in,hole for button .88in	McMaster: 5639K11	2
36	INPROGRESS FLANGE LEAN BAR	FLANGE LEAN BAR	Flange for bottom of lean bar, to be milled out form 4in, 1.5 in long plate	MCMASTER: 9208K67	2
37	92988A770	Pins		McMaster: 92988A770	2
38	9209K11	Push Button	22mm Push Button, Spring Back (Momentary), Flushed	McMaster 9209K11	2
39	90107A011	Washer for Button Box	SST, fro screw size 10, 13/64in ID,7/16in OD	McMaster: 90107A011	16
40	90604A242	Screw for Button Box	SST, .5 in, Fully Threaded, Palin Head and Pan Head style, 10-24 in thread size, head diameter .373in	McMaster 90604A242	8
41	90205A313	Nuts for Button Box	SST, width 5/16 in, height 7/64in, 10-24 in thread size	McMaster: 90205A313	8
42	98017A660	Washer for Button Box and Pipe	ID .265in, OD .5in, SST, for screw size 1/4in	McMaster:98017A660	8
43	92185A557	Screw for Button Plate and Pipe	SST, lenght 3in, 1/4-20 in thread size, head height 1/4 in, head diameter 3/8in	McMaster: 92185A557	4
44	94252A703	Nuts for Button Box to Pipe	SST, Width .5 in, Height 15/16in,	McMaster: 94252A703	4
45	base_plate_V02	Base Plate	Steel Plate of .25 in thick	Steel Plate	1
46	side_plate_part_2	side plate 2	1/4 steel plate	1/4 steel plate	2
47	side_plate_part3	side plate 3	1/4 in steel plate	1/4 in steel	2
48	Front Top Plate	Front Top PLate	Steel plate 1/4 in thick	Steel Plate 1/4 thk.	2
49	Back Plate 1	Back Plate 1	Vertical Steel Plate for Rear Casters	Steel Plate 1/4 thk.	1
50	Back Plate 2	Back Plate 2	Steel Plate to Attach Casters	Steel 1/4 thk.	1
51	CasterBase_DR3 v02	Caster Base Plate	Part of Caster Assembly, 3/16 in thick, palte lenght: 3-5/8in plate width 2-1/2in	McMaster: 9949T21	4
52	CasterBase Attach V01	Caster Wheel Attachment	Wheel Attachment for Casters	McMaster:9949T21	4
53	Wheel_DR3 V02	Caster Wheel	300lb capacity, 3 in wheel diameter, 1-1/4in bolt holes, polyurethane wheel material	McMaster:9949T21	4
54	Cylinder of Revolution				4
55	Gusset Front 1	Gusset Front 1	Gusset to welded to the base and side plates	Steel Plate 1/4 thk.	9
56	Gusset Back 2	Gusset Back 2	to be welded to the side plates	Steel Plate 1/4 thk.	2
57	Platform V02_DR2	LIFT	HYDRAULIC MYTI-LIFT 24X36		1
58	Myti-Lift Table Scissors	Myti-Lift Table Scissor	Myti-Lift Table Scissor		1
59	91255A582	Screw for Casters	4 screws to be used to attach each caster to the top plate	McMaster: 91255A582	16
60	5-16 washer	Washer for Caster Assembly	5/16 WASHER STEEL	MCMASTER: 91090A110	32
61	90499A030	Nut for caster attachments	5/16 - 18 STEEL NUT	Mcmaster: 90499A030	16

Appendix J: Final Seat Cushion Design Selection

J.1 - Seat Cushions Selection

1. **Design 1** TEMPUR-PEDIC: $80, 16x16x2 inches
2. memory foam cushion absorbs and distributes weight evenly, needs protective covering
3. **Design 2:** Skil-Care Gel Foam: $61, 16x16x2.5in
4. Bottom layer has resilient foam to prevent bottoming out, gel filled top chamber evenly distributes weight to relieve pressure, sealed in incontinence-proof vinyl, washable polyester cloth cover with ties
5. **Design 3:** Posely Delux Gel-Foam Cushion $85 18x16x2 in
6. Relieves pressure and soreness, pressure reducing gel bladder, Sure-Check water resistant cover
7. **Design 4**: QualCare Gel: $53 16x16(18)x2 in
8. Comfortable high-density foam cushion increases sitting comfort Pressure-Reducing Gel Heat-dissipating gel evenly distributes weight to reduce interface pressure. Incontinent-Proof Cover Factory-sealed cover protects foam against urine absorption.
9. **Design 5:** JADMED Surgical Stool: $250
10. Designed to relieve pressure from legs when they are in the parted position. Designed especially for surgeon applications, armrests designed to be adjusted to give stable reference base for precise movement.
11. **Design 6: Ergonomics Saddle Stool $169 16x16**
12. Pneumatic Drafting/Saddle Chair w/FootRing Padded Saddle Seat Pneumatic Gas Lift for Instant Seat Height Adj Adjustable Seat Angle W/Locking Center Pivot Seat Siz

Design 1

Design 2

Design 3

Design 4

Desi

gn 5

Design 6

Figure 90: Seat Options

Appendix K: Protomatic Manufacturing Plans

Job Traveler
Shop Copy
Protomatic, Inc.
Job Number: ***16616-01***

Date: 12/03/08
Time: 5:34:03PM

Sold To: University of Michigan Bio Re
,

Ship To: Attn:J.Moore WuMRC-MechEngDpt
Univ.of Mich.-GG Brown LabBldg
2350 Hayward St.
Ann Arbor, MI 48109-2125

Order No:	16616	**Dated:**	11/11/08	**Quote No:**	
Customer:	UOMBRL			**PO Num:**	Verbal Albert Shih
Ship Via:				**Priority:**	50
Part Number:	UOFM-MAIN ASSY_V04			**Product Code:**	GOODS - FINISHED
Description:	Lift Main, Assy				
Alt Part No:				**Revision:**	**Dated:**
Drawing Number:				**Master Job No:**	
Start Date:	12/03/08	**Finish Date:**	12/03/08	**Phone:**	(734) 763-5302
Contact:				**FAX:**	(734) 763-0459
Total Qty Open:	0 EA	**Qty Posted:**	0 EA	**Qty To Make:**	0 EA

Job Notes

Delivery Schedule

Order Quantity	Release Type	Release Quantity	Due Date	Ship Date	Packing List	MFG Job No	Destination Job No	Comments
1	CUST	1	11/28/2008	12/3/2008	18915			

Routing

Routed By: **Quantity** 0

Step No / Dept	Work Cntr / Vendor / Operation	Description	Setup Time	Cycle Time	Total Time	Pieces per Hour	Scheduled Start	Scheduled End	Run Qty
10	PLAN	Planning G1 Plan Check- Must be performed prior to start of job by any employee other than order originator. Record here and on Material Worksheet as applicable. -Compare Shop Traveler and Dwg. for; Pt Name, Pt No., and Rev. ____________ Initial/Date. -Material Ordered? Cust. Sup or Stock or Ordered ____________ Circle/ Initial/Date -Tools Ordered or Needed? Special/Custom/GenReq/GenStk ____________ Circle/ Initial/Date -Fixture Prepared? New/Repeat ____________ Circle/ Initial/ Date -Special Gauges Required? Available/Ordered ____________ Circle/ Initial/ Date -Supply FRM1004.xls w/ items labeled. ____________ Circle/ Initial/ Date DO NOT PROCEED UNTIL COMPLETED.					12/03/08	12/03/08	0
OFFICE	PLAN CK								
20	MCMASTER	MCMASTER-CARR SUPPLY COMPA					12/03/08	12/03/08	0

30	ASSEMBL G1	Assemble G1 1st pce & run checked by machinist. Use QC as required. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag parts per INS-10-03. Forward Good parts with a Yellow Tag. Forward Bad parts with a Red Tag. Forward Spare Blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:____________ Material PO:______________Record here and on Material Worksheet.	12/03/08	12/03/08	0
REST OF SHOP	INSPECT 1				
40	INSPFINAL	Inspection Final G2 1 Final - No Report required 2 No Red or Orange Tags. 3 Replace Yellow Tag with Green Tag. 4 Forward to Packaging.	12/03/08	12/03/08	0
QUALITY	RPT NONE				
50	PACKAGE G2	Packaging G2 Standard Packaging 1 Generate Label. 2 Bag, Tag & Box (leave box top open) 3 Sales to arrange delivery. 4 See individual customer spec for changes to above (1-3)standards.	12/03/08	12/03/08	0
QUALITY	PACKAGE				
60	SHIP G2	Shipping G2	12/03/08	12/03/08	0
QUALITY					

Time per Piece (HR):	**.00**	**.00**	**.00**	**.00**
Total Time for Job (HR):	**.00**	**.00**	**.00**	

Materials List

Quantity: 1

Needed	On Hand	Posted	Short	Unit	Part Number / Description	Sub-Assy	Vendor
2.0000		2.0000	.0000	EA	9209K139 Switch Quantities from Bins/Lot Number: (2.0)		MCMASTER
1.0000		1.0000	.0000	EA	95005K377 Velcro 2", 30' roll Quantities from Bins/Lot Number: (1.0)		MCMASTER
1.0000	1.0000	1.0000	.0000	EA	UOFM-LEAN_BAR_SUB_ASSEMBLY Lean Bar Asembly Quantities from Bins/Lot Number: (1.0)	YES	
1.0000	1.0000	1.0000	.0000	EA	UOFM-LIFTASSY DR3 VO1 Lift Assembly Quantities from Bins/Lot Number: (1.0)	YES	
1.0000	1.0000	1.0000	.0000	EA	UOFM-SEAT5ASSEM20081104 Seat Assembly level 1 BOM and Isometric Quantities from Bins/Lot Number: (1.0)	YES	

Sub Assembly List

Job Number	Part Number	Part Description	Quantity	Due Date
16616-03	UOFM-LEAN_BAR_SUB_ASSEMBLY	Lean Bar Asembly	1	2008/11/11 00:00:00.00
16616-02	UOFM-LIFTASSY DR3 VO1	Lift Assembly	1	2008/11/11 00:00:00.00
16616-04	UOFM-SEAT5ASSEM20081104	Seat Assembly level 1 BOM and Isometric	1	2008/11/11 00:00:00.00

Part History

Qty	DateComplete	JobNo	CustCode	PONum	DueDate	Revision
1	12/3/2008	16616-01	UOMBRL	Verbal Albert Shih	11/28/2008	

Job Traveler

Shop Copy

Protomatic, Inc.

Job Number: ***16616-04***

Date: 12/03/08

Time: 5:35:34PM

Sold To: University of Michigan Bio Re
,

Ship To: Attn:J.Moore WuMRC-MechEngDpt
Univ.of Mich.-GG Brown LabBldg
2350 Hayward St.
Ann Arbor, MI 48109-2125

Order No:	16616	**Dated:**	11/11/08	**Quote No:**	
Customer:	UOMBRL			**PO Num:**	Verbal Albert Shih
Ship Via:				**Priority:**	50
Part Number:	UOFM-SEAT5ASSEM20081104			**Product Code:**	GOODS - FINISHED
Description:	Seat Assembly level 1 BOM and Isometric				
Alt Part No:				**Revision:**	**Dated:** 11/11/2008
Drawing Number:				**Master Job No:**	16616-01
Start Date:	12/03/08	**Finish Date:**	12/03/08	**Phone:**	(734) 763-5302
Contact:				**FAX:**	(734) 763-0459
Total Qty Open:	0 EA	**Qty Posted:**	0 EA	**Qty To Make:**	0 EA

Job Notes

Delivery Schedule

Order Quantity	Release Type	Release Quantity	Due Date	Ship Date	Packing List	MFG Job No	Destination Job No	Comments
1	STOCK	1	11/11/2008	12/3/2008	18915			Sub-Assembly For Job No: 16616-01

Routing

Routed By: Matt Maj

Quantity 0

Step No Dept	Work Cntr / Vendor Operation	Description	Setup Time	Cycle Time	Total Time	Pieces per Hour	Scheduled Start	Scheduled End	Run Qty
10	PLAN	Planning G1					12/03/08	12/03/08	1
		Plan Check- Must be performed prior to start of job by any employee other than order originator. Record here and on Material Worksheet as applicable. -Compare Shop Traveler and Dwg. for; Pt Name, Pt No., and Rev. ___________ Initial/Date. -Material Ordered? Cust. Sup or Stock or Ordered ___________ Circle/ Initial/Date -Tools Ordered or Needed? Special/Custom/GenReq/GenStk ___________ Circle/ Initial/Date -Fixture Prepared? New/Repeat ___________ Circle/ Initial/ Date -Special Gauges Required? Available/Ordered ___________ Circle/ Initial/ Date -Supply FRM1004.xls w/ items labeled. ___________ Circle/ Initial/ Date DO NOT PROCEED UNTIL COMPLETED.							
OFFICE	PLAN CK								
20	MCMASTER	MCMASTER-CARR SUPPLY COMPA					12/03/08	12/03/08	1

30	ASSEMBL G1	Assemble G1	12/03/08 12/03/08	1
		1st pce & run checked by machinist. Use QC as required. Deburr and Wash per instructions above sink INS-09-03. Segregate and Tag parts per INS-10-03. Forward Good parts with a Yellow Tag. Forward Bad parts with a Red Tag. Forward Spare Blanks (good parts not machined in this step) with an Orange Tag. As Applicable: CAM stored in Directory:____________ Material PO:_____________Record here and on Material Worksheet.		
REST OF SHOP	INSPECT 1			
40	INSPFINAL	Inspection Final G2	12/03/08 12/03/08	1
		1 Final - No Report required 2 No Red or Orange Tags. 3 Replace Yellow Tag with Green Tag. 4 Forward to Packaging.		
QUALITY	RPT NONE			
50	PACKAGE G2	Packaging G2	12/03/08 12/03/08	1
		Standard Packaging 1 Generate Label. 2 Bag, Tag & Box (leave box top open) 3 Sales to arrange delivery. 4 See individual customer spec for changes to above (1-3)standards.		
QUALITY	PACKAGE			
60	SHIP G2	Shipping G2	12/03/08 12/03/08	1
QUALITY				

Time per Piece (HR):	**.00**	**.00**	**.00**	**.00**
Total Time for Job (HR):	**.00**	**.00**	**.00**	

Materials List

Quantity: 1

Needed	On Hand	Posted	Short	Unit	Part Number / Description	Sub-Assy	Vendor
2.0000		2.0000	.0000	EA	93750A727 Pin Quantities from Bins/Lot Number: (2.0)		MCMASTER
2.0000	2.0000	2.0000	.0000	EA	UOFM-SEAT 5 SUB ASSEM20081104 Support Assem BOM and Isometric Quantities from Bins/Lot Number: (2.0)	YES	
.0000		.0000	.0000	EA	UOFM-SEAT 5 SUB ASSEMBLY support assembly Quantities from Bins/Lot Number: (0.0)		PINNACLE
1.0000	1.0000	1.0000	.0000	EA	UOFM-SEAT5ASSEM20081104 SLIDER SliderTraid assembly Level2 BOM and Isometric Quantities from Bins/Lot Number: (1.0)	YES	
.0000		.0000	.0000	EA	UOFM-SEAT5ASSEMBLY ARM Arm assembly Quantities from Bins/Lot Number: (0.0)		PINNACLE
1.0000	1.0000	1.0000	.0000	EA	UOFM-SEAT5ASSEMHOOK Hook Aseembly BOM and Isometric Level 2 Quantities from Bins/Lot Number: (1.0)	YES	

Sub Assembly List

Job Number	Part Number	Part Description	Quantity	Due Date
16616-15	UOFM-SEAT 5 SUB ASSEM20081104	Support Assem BOM and Isometric	2	2008/11/11 00:00:00.00
16616-17	UOFM-SEAT5ASSEM20081104 SLIDEI	SliderTraid assembly Level2 BOM and Isometric	1	2008/11/11 00:00:00.00
16616-16	UOFM-SEAT5ASSEMHOOK	Hook Aseembly BOM and Isometric Level 2	1	2008/11/11 00:00:00.00

Part History

Qty	DateComplete	JobNo	CustCode	PONum	DueDate	Revision
1	12/3/2008	16616-04	UOMBRL	Verbal Albert Shih	11/11/2008	

Appendix L: Design Safe Results

L.1 - Risks and Failure Modes

Identify Hazards | Assess and Reduce Risk

	Item Id	User	Task	Hazard Category	Hazard	Cause/Failure Mode
10	1-1-10	All Users	All Tasks	material handling	excessive weight	Heavy material could cause injury

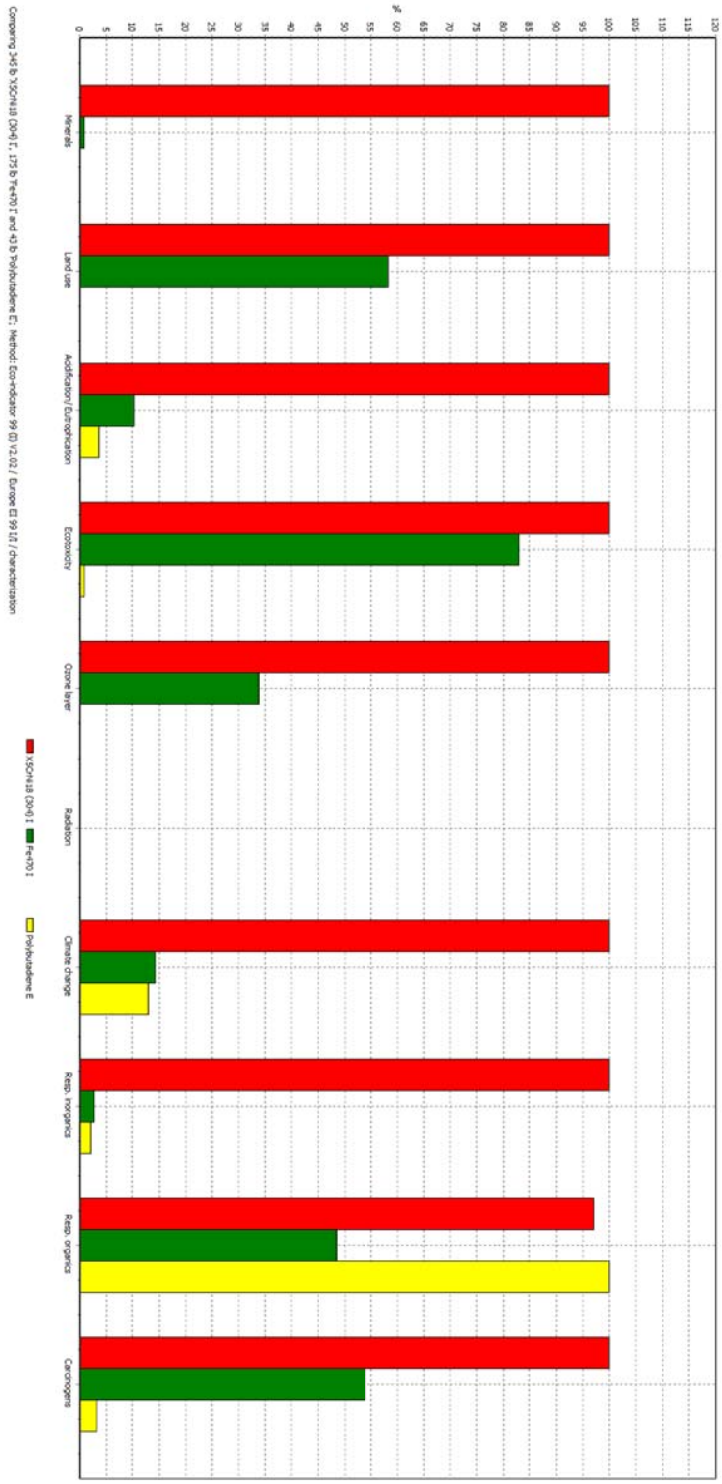
	Item Id	User	Task	Hazard Category	Hazard	Cause/Failure Mode
1	1-1-1	All Users	All Tasks	mechanical	crushing	Parts are heavy. Lift is heavy.
2	1-1-2	All Users	All Tasks	mechanical	cutting / severing	Many parts need to be cut to size.
3	1-1-3	All Users	All Tasks	mechanical	pinch point	Some sheet metal must be pressed into shape
4	1-1-4	All Users	All Tasks	mechanical	stabbing / puncture	Many holes must be put into parts via milling or drilling
5	1-1-5	All Users	All Tasks	electrical / electronic	improper wiring	Buttons on lean bar have to be rewired from supplied buttons to bigger purchased buttons.
6	1-1-6	All Users	All Tasks	ergonomics / human factors	posture	With the many heavy parts, incorrect posture when holding materials could cause injury
7	1-1-7	All Users	All Tasks	ergonomics / human factors	lifting / bending / twisting	With many heavy parts, twisting with heavy objects could cause injury
8	1-1-8	All Users	All Tasks	ergonomics / human factors	deviations from safe work practices	Incorrect posture, not cleaning up work area, not wearing proper protection on hands and eyes are all examples of practices that could cause injury
9	1-1-9	All Users	All Tasks	material handling	movement to / from storage	Heavy material could cause injury to person or persons in the immediate area
10	1-1-10	All Users	All Tasks	material handling	excessive weight	Heavy material could cause injury

L.2 - Risk Level and Reduce Risk Suggestions

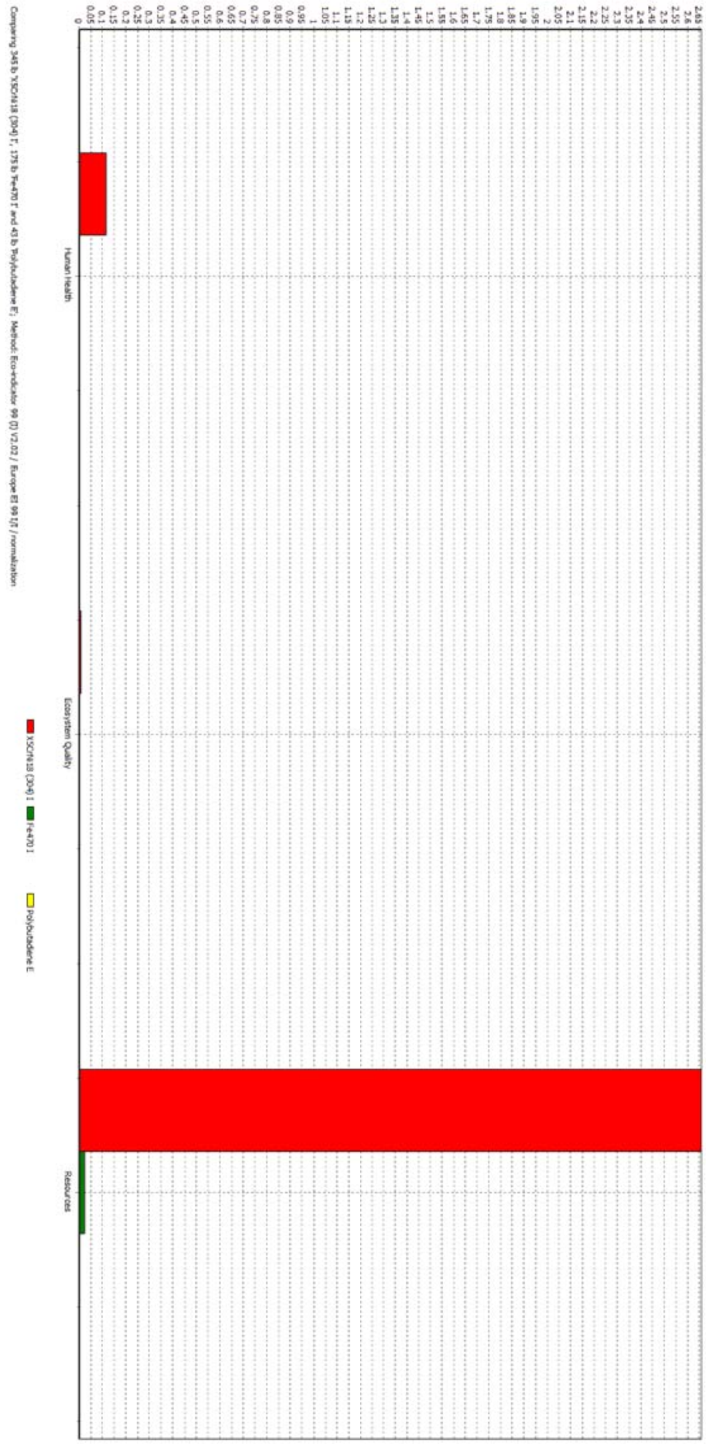
Severity	Exposure	Probability	Risk Level	Reduce Risk	Severity	Exposure	Probability	Risk Level
Serious	Remote	Unlikely	Moderate	Proper lifting mechanisms and machine help.	Slight	Remote	Unlikely	Low
Serious	Frequent	Possible	High	Use proper cutting techniques such as keeping hands away from blade by using extra block of material.	Slight	Remote	Unlikely	Low
Serious	Remote	Unlikely	Moderate	Use proper pressing techniques and keep hands away from press while in use.	Minimal	None	Negligible	Low
Serious	Frequent	Unlikely	High	Use proper drilling techniques and keep hands away from bit.	Minimal	Occasional	Unlikely	Low
Serious	Remote	Unlikely	Moderate	Protomatic will be wiring this. Their skills should be high enough to wire the lift proporly.	Minimal	Remote	Negligible	Low
Slight	Occasional	Possible	Moderate	Keep correct back posture when holding parts	Minimal	Remote	Negligible	Low
Slight	Occasional	Possible	Moderate	Keep correct back posture when lifting. bending, twisting	Minimal	Remote	Negligible	Low
Serious	Occasional	Possible	High	Keep correct posture, clean up work area, protect eyes with safety glasses, and hands with gloves when handling sharp objects	Minimal	Remote	Unlikely	Low
Slight	Remote	Possible	Moderate	Handle material with correct posture and with a lift when necessary	Minimal	Remote	Unlikely	Low
Serious	Remote	Possible	Moderate	Handle material with correct posture	Minimal	None	Negligible	Low

Appendix M: SimaPro Environmental Impact

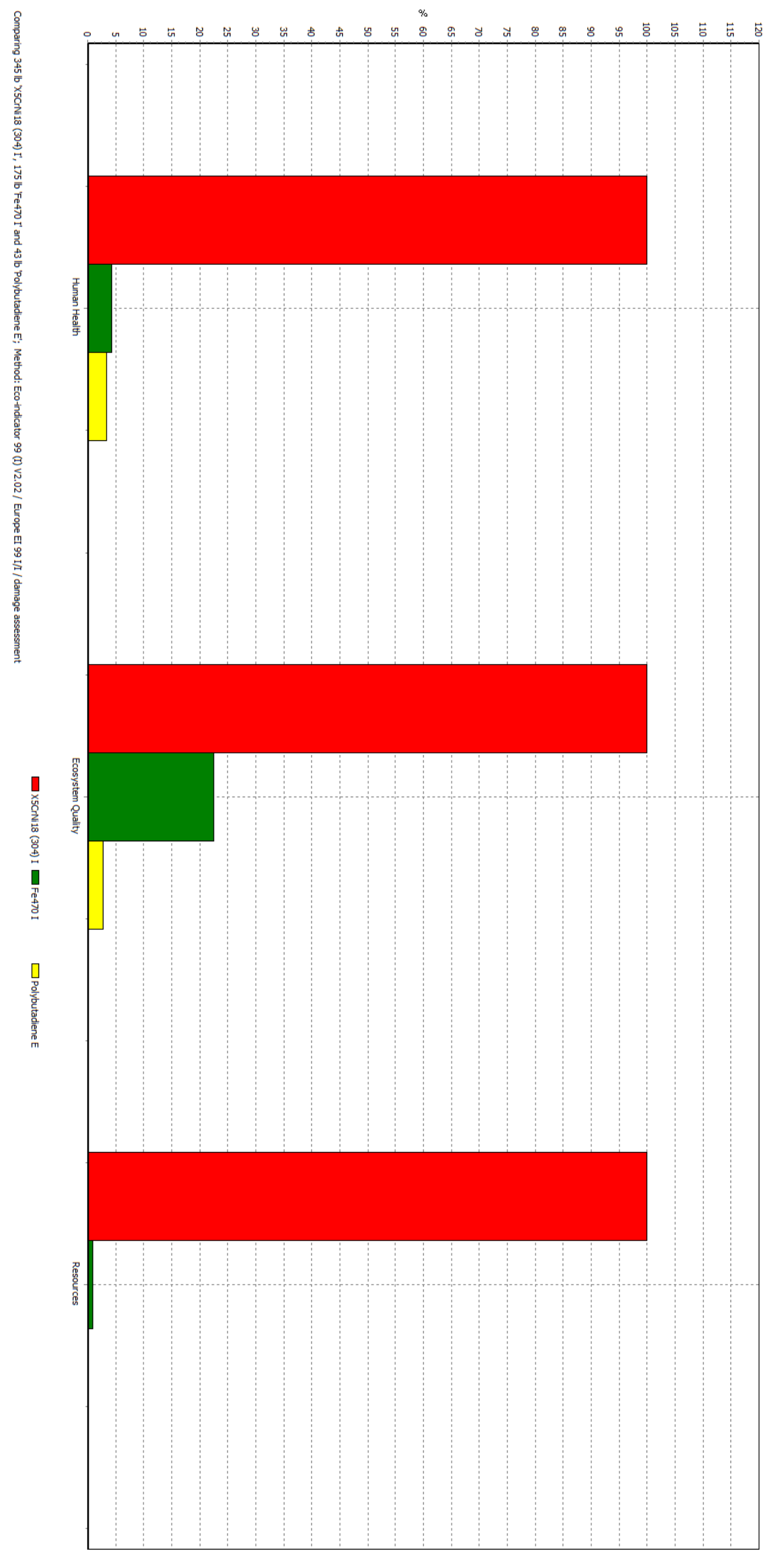
M.1 -Impact Assessment



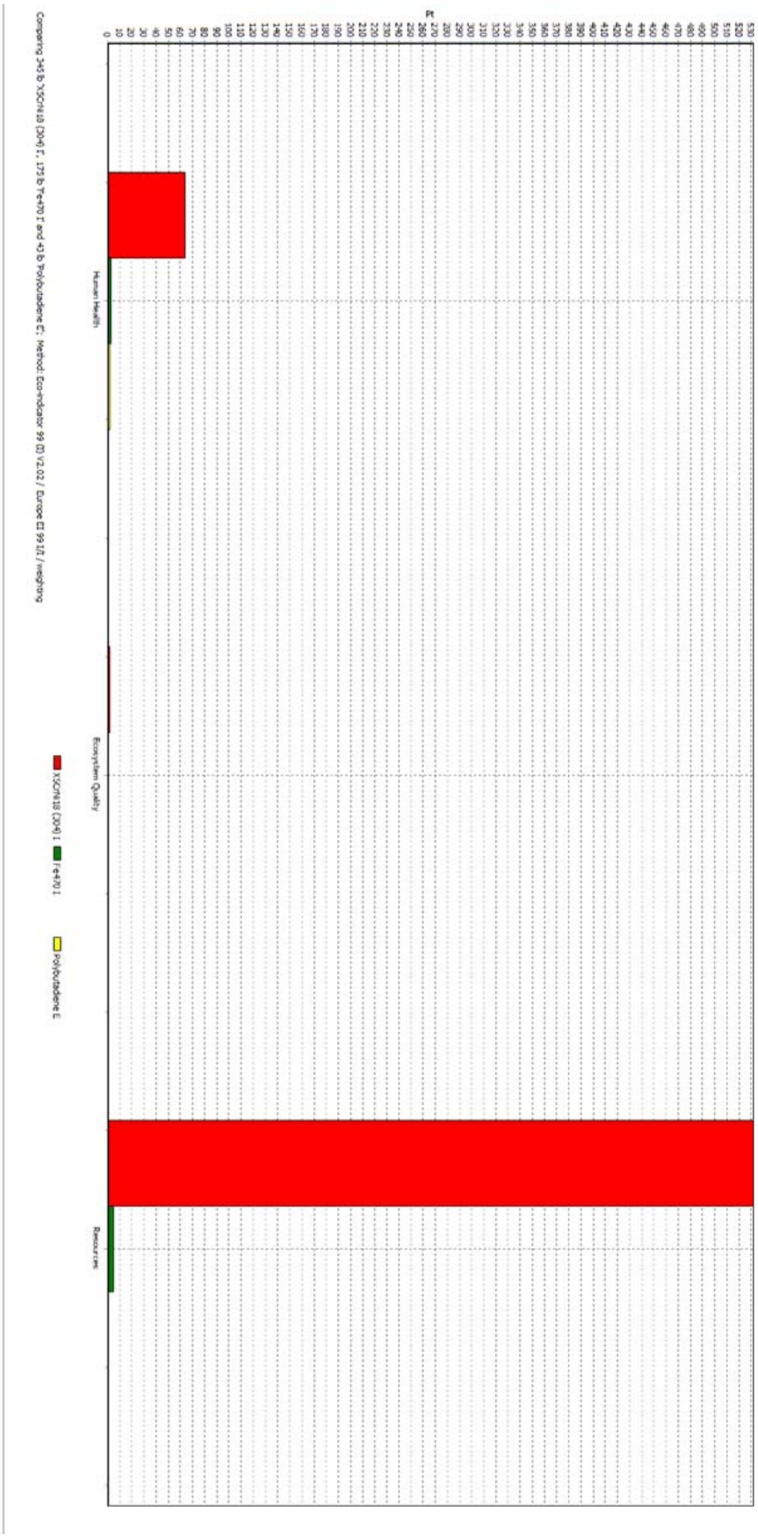
M.2 - Normalization of Impact Assessment



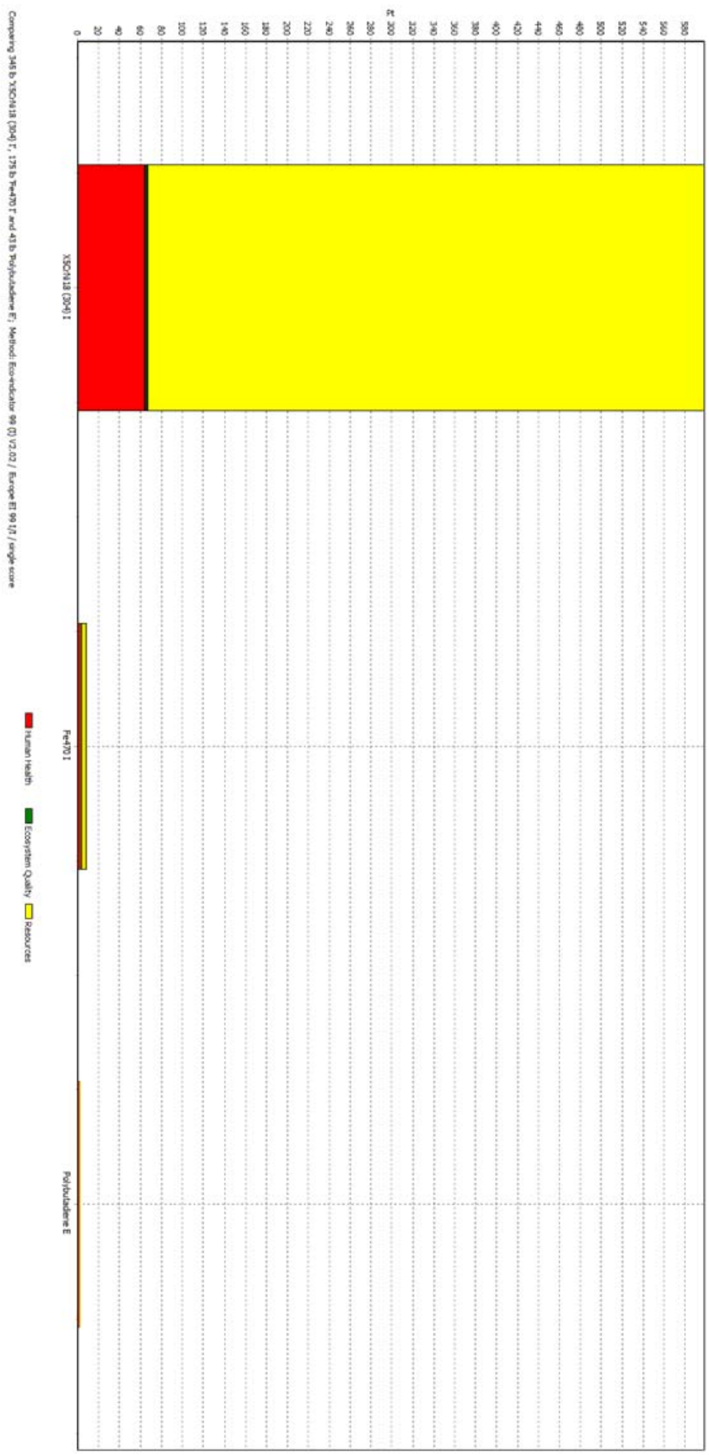
M.3 - Damage Assessment of Impact Assessment



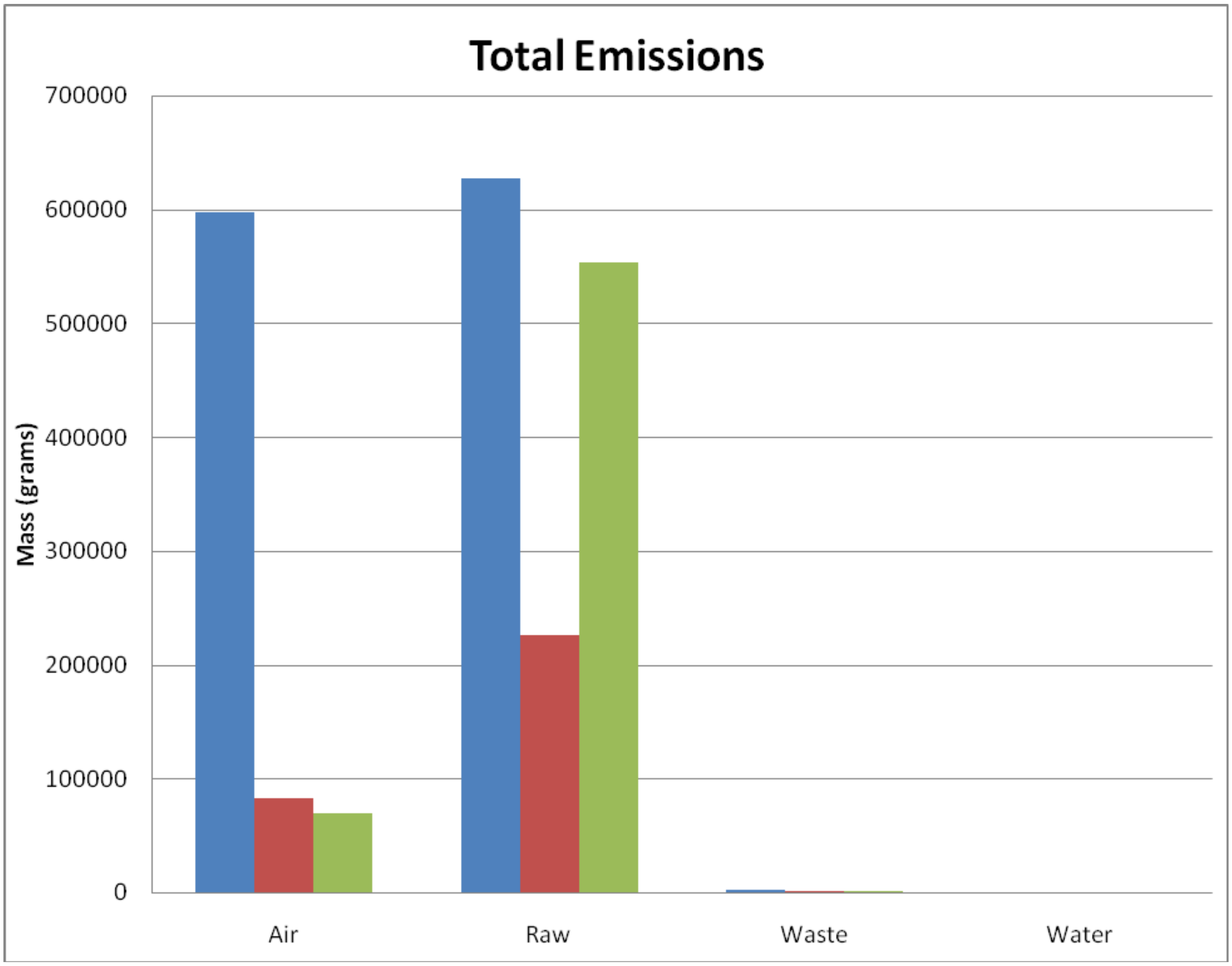
M.4 - Weighting of Impact Assessment



M.5 - Single Score of Impact Assessment



M.6 - Total Emissions Analysis



Appendix N: Gantt Chart

The following pages contain the schedule we used to complete our project on time. It was updated and changed many times throughout the semester to reflect design changes, manufacturing setbacks, etc. The schedule was also altered to reflect when tasks were completed ahead of schedule. We have however been able to meet the project milestones (unmovable events) such as design reviews and sponsor critiques.

Appendix O: Existing Products Researched

O.1 - Electrical Lift: Serapid

SERAPID

DATE: October 7, 2008

Quotation: 08-1006-2GJI

TO: Patrick Davis

COMPANY: U of M Medical Center

FROM: Geoff James / nc
Cc:

REF:

PHONE: 810-240-0835 pfdavis@umich.edu
FAX:

Quote is valid for 30 days

ITEM NO.	QTY	PART NO.	DESCRIPTION	UNIT PRICE	TOTAL
A	1	LL30-24-GM/ BMG-CS4 with Scissor Lift	**Serapid LL30 lift system** System includes: Link lift 30 chain for 24" stroke (1) housing for LL30 (1) storage magazone (1) Gear motor with brake (1) Cam 4 possition cam limit switch (1) Standard 24" X 48" Scissor lift table to include (2) rigid casters (2) swivel casters and floor locks Lowered height of 7" Controls with pendent and 120VAC to 3 phase converter	$21,500.00	$21,500.00
			Optional Non-standard 24" X 36" table adder	$1,900.00	
			Optional Bellows adder	$930.00	
				Subtotal	$21,500.00
				Total	$21,500.00

Terms: 50% due with order, 50% after Shipping (Net 30)
OUR STANDARD TERMS
AND CONDITIONS APPLY
(SEE REVERSE)

Fob: STERLING HEIGHTS, MI.

Delivery: **6-8 weeks +**
Engineering Approvals

THANK YOU FOR THE OPPORTUNITY TO QUOTE.
BEST REGARDS.

Serapid USA Inc.
5400 18 Mile Road
Sterling Heights, MI 48314

Internet: www.serapid.com
Mail: info-us@serapid.com

Tel: (586) 274-0774
(800) 663-4514
Fax: (586) 274-0775

F-SAL-110 Rev02 2/9/05

O.2 - Quote: Max-Lift Heavy Duty Scissor Lift Table

Following is the quote from Solution Dynamics Inc.
Lift Products Max-Lift Heavy Duty Scissor Lift Table

Specifications:

- **Model:** LPT-020-24
- **Capacity:** 2,000 lbs
- **Table Size:** 24" x 36"
- **Base Size:** 24" x 36"
- **Lift:** 24"
- **Lowered Height:** 7"
- **Raised Height:** 31" (can be set to 24")
- **Motor:** 1.5 HP triple duty motor
- **Voltage: (please specify)**
    - 115 or 230 single phase (115 v may require dedicated 30 amp circuit)
    - 230 or 460 three phase

Standard Features:

- Trapped top and bottom scissor arms
- Grease fittings on pivot points and cam rollers
- Teflon seals in cylinder for longer life
- Magnetic backed Hand Controls box
- **Upper lift limit switch**
- Built-in safety bars
- All welded construction meets AWS standard service. Meets ANSI & OSHA requirements
- High quality cam rollers, pivot pins and bearings
- Motor and controls are easily accessible
- Thermo overload protection with auto reset
- Ergonomically designed to reduce awkward bending and lifting
- Made in USA with all quality components
- 4" cylinders with Teflon seals

Max Lift Scissor Lift Table Pricing:
Price F.O.B. Waupun, WI ………………………………..……$ 3,065.00
Options:

- Foot Controls …………………………………………….$ 145.00
- Accordion Safety Skirting ……………………………….$ 468.00

- Full oil pan under table…………………………………..$ 535.00

Delivery: Approx.3-4 weeks

  - *** Table includes lift limit switch that can be set to 24”

- This quotation is valid for Thirty (30) days
- The Lift Products Max-Lift Tables can be viewed at:
  www.sodyinc.com/index.php?main_page=product_info&cPath=3&products_id=187

O.3 - Lift Quote: Myti-Lift Table

Below you can find the quote provided by Myti-Lift table, which is the lift we have purchased.

Myti-Lift Table

- Model: CLTMYT-05-30-2436W
- Capacity: 500 lbs
- Platform Size: 24” x 36”
- Base Frame: 16” x 24”
- Lowered Height: 6”
- Raised Height: 36”
- Up Speed: 20 seconds
- Motor: 1/2 HP
- Weight: 208 lbs
- 10 ft. power cord
- Smooth Steel Top
- Price: …………………… $2,650.00 each

Options:

- Safety Skirting: (blue & yellow) ………… $599.00
- Lift limit switch (set to 24”) ………………$205.00
  - Easily adjusted to different heights

Lead Time: 3-4 Weeks

O.4 - Scissor Lift Company Websites

Other company websites and catalog searches can be found below.

http://www.beacontechnology.com/scissorlifts/
http://www.liftproducts.com/lifttables/mobile/max_mini_lift.html
http://www.denniskirk.com/1/1/2173-motorsport-mx-scissor-lift-mxscissor

Appendix P: About by Authors

The following are short summaries of each team members' lives and careers thus far.

Dayna Anderson

I grew up in Howell, Michigan, and graduated from Howell High school in 2004. My interest in mechanical engineering started with my love for my physics 1 class. I am now interested in design and thermodynamics.

I am graduating with my undergraduate degree in April, 2009. I plan to continue my education with the SGUS program for mechanical engineering and earn my masters by April 2010. During my stay here at the University of Michigan, I would like to get involved with some research and see if this is something I would like to do with my life. I am currently looking for an internship for this coming summer, but if I don't find anything interesting, I will go back to the same place I have been at for 2 summers, Williams International. I have no idea where I want to work once I have a full time job, nor do I have any idea of where I want to live after I graduate.

I have been obsessed with Star Wars since the 7th grade and I have a massive collection of toys, card board stand-ups, posters, and pretty much anything one can think of to put a Star Wars character on. I also love dance. I have been dancing since I was 3 and I have found that I have to keep dance as a part of my life or else I just don't feel like the same person. Dance is a part of who I am and I hope to keep dancing until I am old and frail.

Patrick Davis

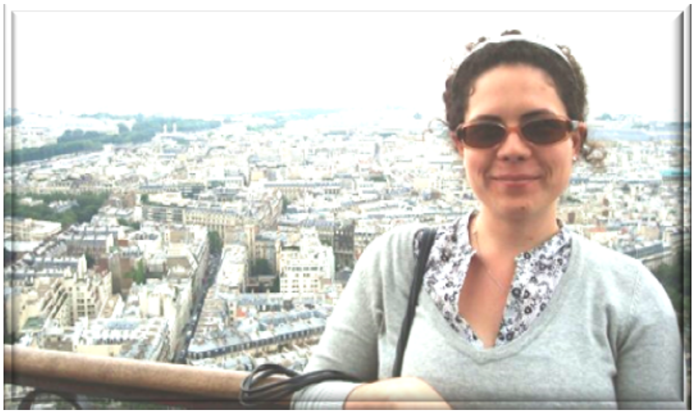
I grew up in Flushing, MI and graduated from Flushing High School in 2004. I did a study abroad in Germany in 2006 and worked in Germany at an assembly machine company in 2007. When I came back I got a job through the German Department at U of M. This job entails running the German language residence hall on north campus. I will be graduating with my Bachelors in Mechanical Engineering in December 2008, and will be pursuing my Masters in Industrial and Operations Engineering Graduating December 2009 as part of the Engineering Global Leadership Program.

I have had a varied career thus far and worked in a quality laboratory, designing assembly machine layouts, and developing marketing strategies. I am currently looking for an internship for the summer and will be looking for a job in the energy sector, specifically in renewables when I graduate. I recently got engaged to my girlfriend of three years who lives currently in London, England and I will be looking to relocate there if possible.

Leslie Savage

I am currently a senior in mechanical engineering and am looking forward to graduating in December 2008. I am originally from Dearborn, Mi and I hope to work full time in the defense industry in southern California. I became a mechanical engineer because I enjoy "tinkering." Throughout high school I was exposed to many different design and manufacturing processes through the F.I.R.S.T. robotics program. This program encouraged me to become an engineer and gave me the fundamental engineering skills I have used throughout and built upon in college. I decided to concentrate in manufacturing systems while at school because if you can't build it, why design it. Following this path has allowed me to obtain several great internships at top Fortune 500 companies: John Deere where I took on the role as a manufacturing engineer on the factory floor and Walt Disney World where I worked to maintain the existing rides/attractions.

Monika Skowronska



I was born in Warsaw, Poland and moved over to the U.S when I was ten years old. When I moved here I didn't speak English very well so it took me couple months in the beginning to learn it. In high school I enjoyed math and science and I was drawn problem solving aspect of engineering. Over the summer I worked at the University of Michigan Transportation Research Institute where I analyzed wheelchair crash tests. Together with another student we co-wrote a paper titled Patterns of Wheelchair Frontal Sled Tests which we got to present at RESNA (Rehabilitation Engineering Society of North America) in Washington D.C. Currently we are working on getting it published.

At Michigan I am involved in M-Heal where currently we are trying to figure out how to build a surgical lamp out of old car parts to be used in developing countries during surgery.   I am graduating in December and am planning to do an internship for the remaining part of the school year and then go to graduate school for Industrial Design.