Letter of Transmittal

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Dear Dr. Labossiere,

The report ‘Oversized Panel Transfer Project’ was written for the mechanical engineering course, MECH 4860 – Engineering Design. The objective of this project is to move large cabinet panels from the panel saw table to a mobile prototype cart. The objective of writing this report is to propose an optimal solution for this project. Team 13, self named the Decor-Ators, is responsible for this project, which consists of four mechanical engineering students; Rylan Groening, Trenton Klimack, Jesse Mack and Siyuan Sun. The project started on September 5, 2019, and the project was completed on December 5, 2019. Upon completion, preliminary engineering drawings, a CAD model created in SolidWorks, a bill of materials and a final report were produced.

The final design report includes the project definition, concept development, and the final design selection. The detailed specifications, engineering drawings, recommendations for outsourced parts and bill of materials of the final design are proposed upon completion of the detailed design.

The final design of this project is an adjustable height mobile cart which has a maximum height equal to that of the saw table which allows the operator to slide panels straight from the saw onto the cart. Operating within the project budget of $15000 and space constraints of Decor’s facility, this design successfully meets key requirements by transporting panels horizontally and offers an ergonomic method of handling large, heavy panels. The design also complies with Occupational Health and Safety standards for wheeled push carts.

Our team is excited to present to you our work and hope you will find our analysis thorough and explanations of design choices clear. We believe, given the constraints placed on this project, you will be satisfied with the adjustable height mobile cart as a solution for moving heavy cabinet paneling.

Best Regards,

Team 13 – Decor-Ators
Signed,

Rylan Groening	Trenton Klimack	Jesse Mack	Siyuan Sun
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MECH 4860: Engineering Design

Team 13: Decor-Ators

Oversized Panel Transfer Project

Final Report

Prepared for: Dr. Paul Labossiere

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Submitted: December 4th, 2019

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Executive Summary

This report outlines the design process followed to create a solution for Decor Cabinet Company's Oversized Panel Transfer project. In Decor's current manufacturing process, large panels are moved from a panel saw and placed vertically in mobile carts by a single operator. The objective of the project is to design an ergonomic solution for moving the large panels.

The final solution is to use an Adjustable Height Mobile Cart that utilizes a scissor lift powered by an electric linear actuator and assisted by four compression springs mounted on the corners of the cart. The adjustable height of the cart top allows the panels to be slid directly onto the cart, removing the requirement for the operator to raise or lower the panels. Using this method, the ergonomics of moving the panel is greatly increased, while preserving the integrity and finish of the panel. The cart will take the place of one of the current panel carts in the workspace by the panel saw. The stacked panels will maintain their horizontal position on the cart top while the cart is moved freely or over the roller tracks throughout the manufacturing process.

The Adjustable Height Mobile Cart has a total length of 72", width of 28.25", and the height adjusts between 21.75" and 36.5". The cart has a capacity of 500 lbs and a mass of 173 lbs. The frame is comprised of 6061-T6 aluminum while the scissor arms and scissor cross arms are 1020 steel alloy. The legs are spaced to fit over top of the roller track system while the castor wheels allow it to roll independently. There are fixed wheels in the center that allow the cart to pivot on a central point to accommodate the pivoting roller carts in the vicinity of the panel saw. The total cost of materials for this design is $2222.81.

This report describes the problem definition, concept development, and details the final design. Provided with this report are preliminary engineering drawings, CAD models and a bill of materials.

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1. Introduction

This report discusses Decor Cabinet Company and the University of Manitoba Idea Program project they sponsor. Decor Cabinet Company designs and produces cabinets for multiple settings, as such, the production of materials, specifically panels of the cabinets, currently undergoes challenges in transportation. Being too laborious for a single worker, yet a waste of resources to employ two people for this task, this team undertook the challenge of creating an economically friendly, ergonomic and more efficient method of material transportation. This report will overview the technical specifications of the project, such as ensuring the solution can accommodate the largest panels manufactured, keeping the project under budget, and completed in a timely manner. Lastly, the process in determining the development of a design to meet the Decor's requirements is discussed, how the final concept was selected, followed by a detailed analysis of the final design.

1.1. Background Information and Problem Statement

Decor Cabinet Company is a Manitoba based manufacturer, focused on producing beautiful, custom kitchen, bath and specialty cabinets since 1977 [1]. Decor Cabinet Company has a global mindset and wants to impact the lives of people in the community and around the world. Decor prides themselves on the sustainability of their resources. While many products come from wood, Decor's wood comes from a sustainable forestry program, and the stains go through a solvent reclaiming system.

Decor produce custom cabinets that are made from 0.75" thick medium-density fiberboard (MDF) with a veneer finish. The manufacturing process begins with panels being cut on a panel saw before being moved to the edger. The smaller panels require additional processing such as routing and drilling which the large panels do not. Having both large and small panels travel through the plant increases the work in progress and transporting them in a vertical position poses risks to factory workers and increases the risk of damaging the panels. Decor would like to transport these large panels separately from the small panels.

The sizes of the panels coming from the panel saw are different and come in no order relative to size. The largest of these panels can be a maximum of 10 ft x 4 ft and weigh up to 120 lbs. The current process of moving the oversized panels involves the operator lifting the panel from the saw table, as seen in Figure 1, to a vertical position and placing it in a cart that holds panels of various sizes, as seen in Figure 2. For some of the larger panels, two operators are required to lift and place the panel on the cart.

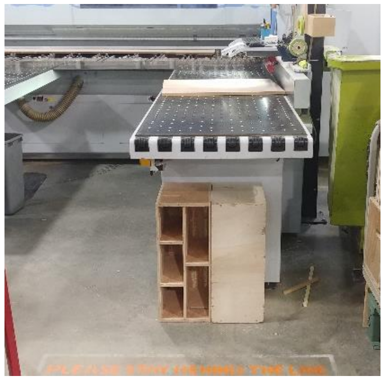


Figure 1: Panel saw

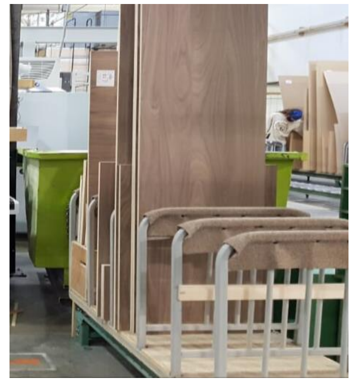


Figure 2: Vertical storage rack

The manufacturing space of interest is shown in Figure 3. The current time for two operators to move the panel from the panel saw to the cart is approximately 20 seconds. The panel saw table is denoted below by the green arrow and has a length of 10’. This area is used by the operator to move panels. The roller track system has a width of 8’ as denoted by the blue arrow.

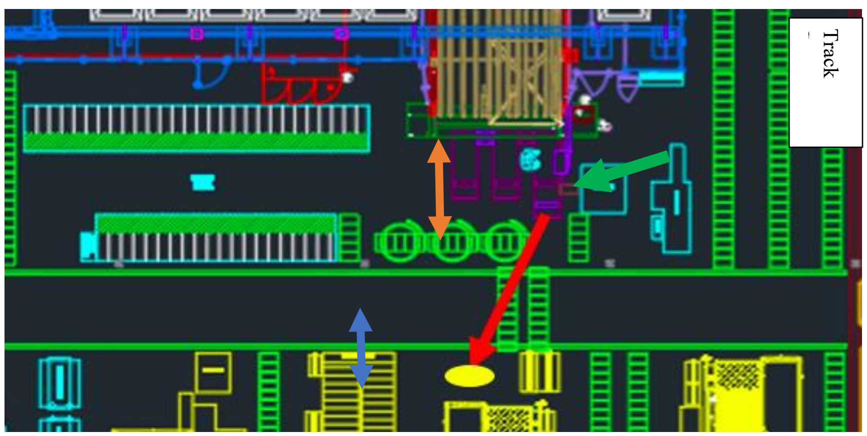


Figure 3: Plant layout

Prototype carts are being proposed by Decor as an alternative to the current method of using the vertical carts, shown in Figure 2. The prototype carts are shown in Figure 4 and the horizontal distance from the panel saw table (Figure 1) to the prototype cart location is approximately 15 feet from the saw table. The yellow ellipse in Figure 3 is where the prototype carts are proposed to be stored, and the red arrow denotes the path the panels must travel.

Figure 4: Prototype mobile cart

The purpose of the prototype cart is to move the panels over the rollers while maintaining the horizontal orientation of the panels. The rollers are represented in Figure 3 as green grids and are vertical in the plant layout. Normally, the panels are transported on the vertical storage panel carts which require the rollers for travel. The prototype carts are designed such that they will pass over top of the rollers and be able to move to other areas of the factory and not have to travel through the entire process.

1.2. Project Objectives

Decor would like to reduce the stress that a single operator experiences when attempting to move the larger panels on their own. As can be seen in Figure 5, the panels can be cumbersome for one person to lift. They need an ergonomic method of moving the oversized panels from the panel saw to a mobile cart, and eventually to the other side of the edger. Additionally, they would like the large panels to remain in a horizontal position throughout the rest of the manufacturing process for safety concerns. The objective of this project is to produce a method to move the oversized cabinet panels to a prototype mobile cart, which can improve the process and work environment. The design should be ergonomic for a single operator.

Figure 5: Panel saw with large panel

The project deliverables are as follows:

- Final design report
- Preliminary engineering drawings
- CAD Model
- Bill of Materials

1.3. Customer Needs

The customer needs are numbered and have been rated on an importance scale from 1-5, with 5 being the highest, as shown in table I.

TABLE I: CUSTOMER NEEDS

#	Customer Need	Importance
1	The design moves the panel from the saw to the cart	5
2	The design can move panels of varying sizes	5
3	The design maintains the surface finish of the veneer	5
4	The design maintains the integrity of the panel	5
5	The design places the panel horizontally on the cart	4
6	The design can be operated by one person	4
7	The design operates within the current manufacturing layout	4
8	The track remains clear when the design is not in use	4
9	The design allows for ergonomic use	4
10	Cycle time of the design is consistent with the current operation time	3
11	The design can place one panel on another	2
12	The design takes up the minimal space when it is not in use	2
13	The design keeps the order from the panel saw	1

1.4. Technical Specifications

After the customer needs were developed, a list of metrics and technical specifications were developed to ensure the design fully captures the scope of the project. The customer needs are examined, and a list of metrics is produced. This is a list that provides quantification to the customer needs. Once all the customer needs have been quantified, target values must be determined. This is done by examining the workspace and the problem definition to come up with values that are appropriate. For example, if the panels coming off the panel saw range up to 120” in length, the design must be able to accommodate panels up to that length. It is the target to be able to accommodate panels that range in length from 48” to 120”. If there is an unseen factor that prevents the target range from being achieved, a marginal range must be determined. In this example, the marginal range is from 80 to 120” in length. This number is determined by examining the record of large panels that were cut in the last year. In the last year, there were 3006 large panels cut from the panel saw, and 2439 of them were over 80” in length. This allows for the largest panels, along with most of all large panels, to be accommodated by the design. This methodology was used in determining the target and marginal values for all the data in table II.

TABLE II: TARGET AND MARGINAL VALUES

Metric #	Needs#	Metric	Units	Target Value	Marginal Value
1	2,7	Length of panel	in	48-120	80-120
2	2,7	Width of panel	in	24-66	24”-40”
3	6	Mass of panel	lbs	24-120lbs	50-120 lbs
4	6	Single operator	(Y/N)	Y	Y
5	10	Cycle time	s	15	20
6	3,4	Surface damage	(Y/N)	N	--
7	4	Stress	psi	478.62[2]	725.2[2]
8	1,5,11	Vertical range of motion	in	32	20
9	1,7,12	Horizontal range of motion	ft	16	12
10	12,8	Dimensions of base (in use)	ft^2	16	32
11	12,8	Dimensions of base (not in use)	ft^2	16	24
13	7,8,12	Track remains clear	(Y/N)	Y	N (but easily moved)
14	2,6,9	Mass required by the user to lift	lbs	0	30 lbs
15	6,9	Trunk rotation by user	°	0	45
16	1,9	Distance user must reach	ft	0	2’

1.5. Constraints and Limitations

In undertaking this design project, this team must work within boundaries imposed by the University of Manitoba and Decor Cabinet Company. Table III shows the constraints and limitations the team has for this project.

TABLE III: CONSTRAINTS AND LIMITATIONS

Ser	Constraints and Limitations	Description
1	Design must meet the client's needs	The design must meet the clients' requirements, and the team must keep in touch with the client in a timely manner, close communication with the client will help the team acquire the necessary information to develop a design that meets client's needs.
2	Deadlines	Several deliverables have deadlines that must be met. This includes project definition report, concept definition report and final report.
3	Budget	Research budget of $300 and prototype budget of $15,000 are given for this project. The cost of the final design should not be over the budget.
4	Manufacturing Layout	The design must be consistent with the current manufacturing layout. The current layout cannot be changed.
5	Team	The team is composed of students enrolled in MECH4860 – Engineering Design, and the design contribution to this project is limited to four team members.
6	Meetings with Decor Cabinet Company	The team needs 1.5-hour commute to Decor Cabinet Company, and site visits are limited to meetings approved by the company.
7	Storage time of panels	Panels may be stored for up to 4 hours on the cart in the horizontal position.
8	Project scope	The purpose of the final design is only concerned with moving the panels from the panel saw to the cart.

2. Concept Development Review

Concepts were developed based on the needs and specifications outlined in the project objectives. Internal searches such as brainstorming and gallery method were used as well as external search methods such as patent searching and researching current, commercially available solutions, yielding a sizeable pool of concepts. This section discusses how the concepts were generated and the analysis done to choose final concepts for detailed design.

2.1. Concept Generation

The earliest concepts were generated to meet the most basic of the customer needs; moving the panels from the panel saw table to the cart. These concepts included ideas such as using a robotic arm, a slide made of rollers bearings, or methods of rolling the panel along a track assembly. As more of the customer needs were approached and integrated into the concept generation, the design ideas shifted to lift assist methods where most of the weight of the panel is supported by a gas strut lift assembly and the operator supports the other end. Next ideas such as a vacuum lift, overhead winch system, or an adjustable cart were considered. The vacuum lift allows the operator to simply place the vacuum head on the panel and have the weight of the panel supported by a crane as it is guided towards the cart from the panel saw table. The overhead winch system has various methods of gripping the panel.

A large list of concepts was developed and many of them were removed either because they don't meet the customer needs or because they simply are not efficient enough for an operator to want to use. Out of the original list of concepts, only ten of them were left as viable options. A preliminary sketch and description of each concept can be found in appendix D.

2.2. Concept Analysis and Selection

Concepts are compared to each other in a weighted decision matrix to determine the final design. The criteria in the decision matrix used to rank the concepts are derived from the customer needs as well as the constraints and limitations. The chosen criteria can be seen in table IV along with a description of each.

TABLE IV: SELECTION CRITERIA

Criteria		Description
A	Cycle Time	The time that takes the operator to move the panel from the panel saw table to the prototype mobile cart. The cycle time of the design should be consistent with the current cycle time of moving the panels to the vertical storage carts.
B	Takes up Minimal Space	The design should take up minimal space on the floor while in use and not in use. It should not be a disturbance to the operator or other employees as they are working.
C	Ergonomics	This reduces the stress on the operator. The design should take most of the weight of the panel and allow the operator to move as minimally as possible. It should also not be an annoyance for the operator to use and require them not to reach.
D	Cost	The cost required to manufacture, install, and maintain the design or purchase from an external source. This is kept in general terms until the final design is detailed.
E	Safety	The safety of the operator and other employees must be considered. Panels potentially causing workplace hazards must be avoided.
F	Likelihood of Surface Damage	The veneer on the panels is susceptible to scratches and other types of damage. Methods of moving it that may cause scratches, or other such damages must be minimized.

Using the derived selection criteria from table IV, a weighted value is assigned to each one in table V.

TABLE V: WEIGHTED SELECTION CRITERIA

		Cycle Time	Floor Space	Ergonomics	Cost	Safety	Surface Damage
Criteria		A	B	C	D	E	F
A	Cycle Time	A	B	C	D	E	F
B	Floor Space		B	C	B	E	F
C	Ergonomics			C	C	E	C
D	Cost				D	E	F
E	Safety					E	E
F	Surface Damage						F
Total Hits		1	2	4	1	5	3
Weightings		0	0.2	0.4	0.1	0.5	0.3
Adjusted Weightings		**0.1**	**0.3**	**0.5**	**0.2**	**0.6**	**0.4**

After comparing each selection criterion to one another and assigning a weighting to each one, table V shows that the highest-ranking selection criterion is safety, with a weight of 0.6, and the lowest ranking is cycle time, with a weight of 0.1.

The decision matrix scores each of the top concepts against each of the selection criteria on a scale of 1-5, with 5 being a top score in each category. That score is then multiplied by the weightings of the selection criteria to achieve a weighted score for a concept and a selection criterion. The weighted scores of all selection criteria for a given concept are then added together and compared to the total scores of the other concepts. The decision matrix can be viewed in table VI.

TABLE VI: DECISION MATRIX

Ser#	Concept Name	Cycle Time	Weighted Value	Space Required	Weighted Value	Ergonomics	Weighted Value	Cost	Weighted Value	Safety	Weighted Value	Surface Damage	Weighted Value	Total Weight
1	Edge Gripper	3	0.3	4	1.2	4	2	3	0.6	2	1.2	3	1.2	**6.5**
2	Phone Gripper	3	0.3	3	0.9	4	2	3	0.6	1	0.6	4	1.6	**6**
3	Easy Lift	5	0.5	2	0.6	2	1	4	0.8	4	2.4	3	1.2	**6.5**
4	Adjustable Cart	5	0.5	5	1.5	3	1.5	5	1	5	3	1	0.4	**7.9**
5	Vacuum Lift Gantry	4	0.4	3	0.9	5	2.5	1	0.2	3	1.8	5	2	**7.8**
6	Vacuum Lift Jib Crane	4	0.4	4	1.2	5	2.5	2	0.4	3	1.8	5	2	**8.3**
7	Lever Lift	3	0.3	1	0.3	3	1.5	4	0.8	4	2.4	2	0.8	**6.1**
8	L-Extension	4	0.4	1	0.3	2	1	4	0.8	4	2.4	2	0.8	**5.7**
9	Clamp Lift Assist	2	0.2	2	0.6	2	1	3	0.6	4	2.4	3	1.2	**6**
10	Jib Crane Straps	1	0.1	4	1.2	2	1	3	0.6	3	1.8	4	1.6	**6.3**

The ranking of the concepts is displayed in table VII.

TABLE VII: CONCEPT RANKING

Concept Name	Total Score	Rank
Vacuum Lift Jib Crane	8.3	1
Adjustable Cart	7.9	2
Vacuum Lift Gantry	7.8	3
Edge Gripper	6.5	4
Easy Lift	6.5	5
Jib Crane Straps	6.3	6
Lever Lift	6.1	7
Phone Gripper	6	8
Clamp Lift Assist	6	9
L-Extension	5.7	10

The highest-ranking design is a Vacuum Lift Jib Crane with a score of 8.3 as per the decision matrix in table VI. It has the highest rank for ergonomics of the operator, which is an important customer need. It also ranks highest in the minimization of surface damage of the panels' veneer. This vacuum lift will be required to be commercially purchased by a supplier and mounted on a jib crane. This will require the proper sizing of the crane and the vacuum, as well as a confirmation of a mounting point in or near the workspace of the panel saw. It is the second most expensive concept, next to a vacuum lift mounted on a gantry crane.

The Adjustable Cart ranked second, as per the decision matrix in table VI, and achieved a total score of 7.9. The Adjustable Cart achieved the top score in cycle time, space required, safety and cost. The cart can be in close enough range to the saw table for the operator to gently slide the panels horizontally onto the cart, which will be at the same height as the table, without requiring the panels to be lifted or lowered. The cart can then be lowered 0.75" to be ready for the next panel. There are multiple methods of lowering the cart, foremost of which are using either a lever jack system or a scissor jack system, both of which require little effort from the operator. This will require the design of the base of the cart, the jacking portion, the top table, and an ergonomic way of operating the jack.

Research began to source a vacuum lift and several quotes were provided by reputable companies, all of which were above the budget for this project. In a conference call with the Decor team, the budget was discussed for the vacuum lift and the team presented the information gathered about both lifts, explaining the methodology and why the lift is the best solution for this project. The adjustable height mobile cart was presented as less expensive alternative to the costly vacuum lift. A decision was made to develop the height adjustable mobile cart but also include any quotes given to the team for a vacuum lift.

3. Detailed Design

Having chosen the two concepts, a vacuum lift mounted to a jib crane and an adjustable height mobile cart, a final decision was made between the two based on customer needs, technical specifications and constraints, and limitations. Specific, functional requirements are then discussed for the concept. A failure modes and effects analysis was conducted for the concept and its operation. The components of the concept are specified, and initial dimensions chosen. Stress analysis was done on each component to ensure appropriate factors of safety. Any outsourced parts were specified and integrated into the design. Finally, a summary of the design components is given.

3.1. Summary of Design

The adjustable height mobile cart, as seen in Figure 6, is comprised of an upper frame and a lower frame connected by a scissor lift assembly. Mounted on a set of swiveling and rigid caster wheels, the cart can be pushed around the plant and easily maneuvered into position for loading and unloading panels. During loading, a linear actuator lowers the table top, assisted by four compression springs. This keeps the top of the stack of panels level with the panel saw for easy and ergonomic movement of the panels.

Figure 6: Adjustable height mobile cart

The scissor lift, along with the compression springs, support the weight of the panels on the table top. As the table top is lowered, the linear springs support a greater portion of the load and act as the main load bearing component leaving the actuator to control the height of the table top which can be done using a wireless remote.

The frames are made of aluminum square tubing and C-channel. C-channel on the sides of the frames makes a track for roller of the scissor. Square tubing allows for a flat surface to weld to the C-channel and a strong support for the horizontal forces experienced during lifting the panels.

A linear actuator provides a consistent and reliable method of controlling the height of the table top. Only requiring an electric source, the linear actuator has minimal moving components and no working fluids making it optimal for a dusty work environment.

The top table is 0.5" MDF to provide a smooth surface for the panels to be slid on and off the cart. This board is attached to the top frame with carriage bolts which are countersunk into the wood to prevent them from scratching the panels.

The specifications of the cart can be viewed in table VIII. Preliminary engineering drawings can be found in appendix A.

TABLE VIII: FINAL SPECIFICATIONS

Final Specifications	Unit	Value
Overall Length	Inch	72
Overall Width	Inch	28.25
Maximum Height	Inch	36.5
Minimum Height	Inch	21.75
Mass (unloaded)	Lbs	173
Capacity	Lbf	500
Factor of Safety	--	4.62

This cart will preserve the functionality of the prototype cart by travelling over the roller tracks similar to the cart in Figure 7. To keep the cart close to the panel saw, Decor would like the cart to be placed over a set of pivoting rollers seen in Figure 8. To maintain the pivoting functionality of the rollers, fixed casters were placed in the centre of the cart, with swiveling casters on both ends of the cart.

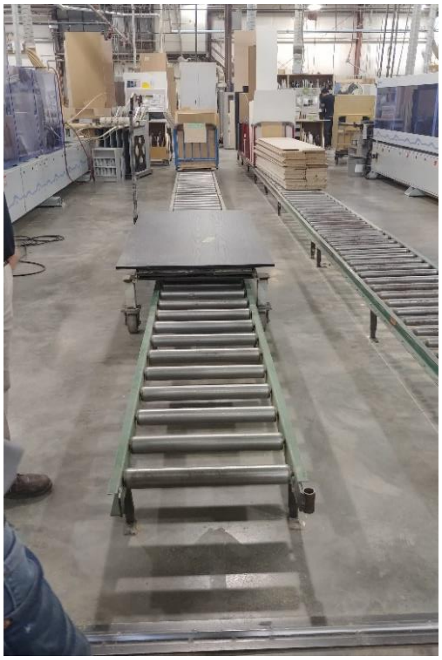


Figure 7: Roller track

Figure 8: Pivoting roller cart

Using an adjustable mobile cart will meet all of the needs as outlined in table I as well as the technical specifications as outlined in table II. It can accommodate any size of panel, up to the 120” maximum length, laying in the horizontal position. It will be located close to the saw at the saw table height to maintain ergonomic use by a single operator and will have an efficient method of raising and lowering the platform. The time it will take to move a panel from the saw table to the cart will be consistant with the current cycle time. It will not take up any more floor space than is currently being used because the dimensions of the cart are modelled after the current prototype cart.

3.2. Component Selection

Preserving functionality of the prototype cart is done by maintaining its key dimensions. The width and height of the Adjustable Height Mobile Cart are based on the prototype cart so that it is able to travel over the roller tracks. These dimensions and others are shown in Figure 9 in reference to the original prototype.

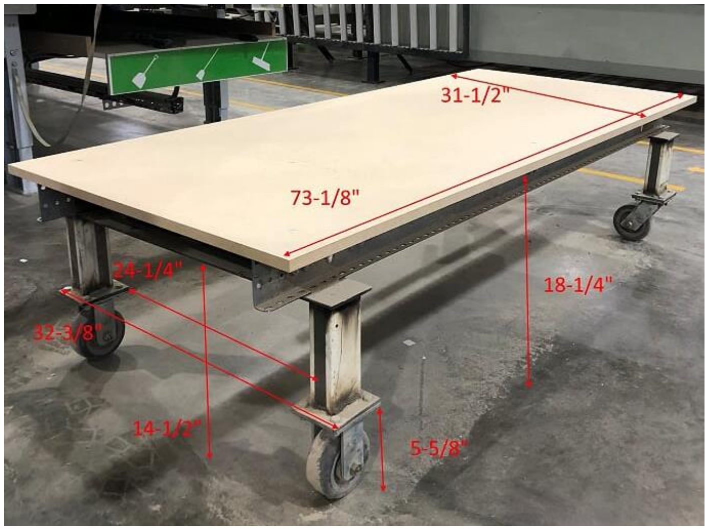


Figure 9: Current prototype cart

3.2.1. Lifting Mechanism

Several options were considered for a lifting device. These include a lever jack system, a hydraulic cylinder placed vertically, and a scissor jack system. The vertical hydraulic cylinder was ruled out due to large space requirements. The cart would require a 20" cylinder to achieve the required vertical range of motion. In reference to Figure 9, there is only 14.5" so a cylinder of this size could not be installed underneath the top frame and a shorter cylinder would not meet the range of motion requirements in table II. Additionally, if a mounting point were in the center of the platform, a leveling device would be required to keep the top platform level. This adds unneeded complexity to the system.

If a lever jack system were used, the same leveling device would be required to keep the platform level as the vertical hydraulic cylinder. The lever jack only moves in specific intervals, so the operator may not be able to place the platform at the needed height. Additionally, the lever jack would have a lever protruding from the side which will impede operations and could cause a tripping hazard for employees. The lever jack also has a significant portion of the lifting mechanism extending 3' to 4' above the table top. In this case, the jack will limit the width of panels stacked on the cart.

The advantage of a scissor lift is that it lifts the top frame parallel to the bottom frame. This eliminates the need for a levelling device. The lift would be central to the cart and would not have a lever sticking out. The nature of a scissor lift allows it to have a large range of motion, meeting the target values from table II. Thus, a scissor lift was chosen as the lifting device.

The team investigated a commercial solution for the scissor lift. These lifts are sold with a specific load capacity and can be integrated into the current system. The most suitable lift was rated for 1100 lbf but weighed 277 lbs [2]. A custom lift for the application of the cart was designed to reduce the weight of the overall system by integrating the top and bottom frames into the lifting mechanism. The scissor arm assembly can be seen in Figure 10.

Figure 10: Scissor assembly

Shown in Figure 10 are the scissor cross arms used to brace the scissor arms and mount roller wheels. These bars are tapped and threaded to accept the roller wheels which will travel within the frame, allowing the scissor to move. They are specified to fully span the internal width of the cart and allow for minimal lateral movement of the roller wheels in the frames. The scissor arms are welded to these cross arms to add rigidity to the mechanism. The opposite side of the scissor is mounted to the upper and lower frames using bolts through holes drilled in the scissor arms and laser cut aluminum tabs welded to the frames.

A large cylinder is mounted between the scissor arms to attach to the actuator. This was designed for a large moment of inertia as it will bear the load of the actuator. To lower the bending moment, the ends are welded to the adjacent scissor arms to improve the resistance to bending. It is connected to the actuator using two collars welded around the diameter and the bolt supplied with the actuator.

3.2.2. Lifting Power Source

The customized scissor lift will require a power source to adjust the height. The options considered for this application are a hydraulic cylinder, a pneumatic cylinder, and an electric linear actuator.

Hydraulic cylinders are used in a wide variety of applications as they offer high output force and can be bought as a closed-loop system, powered by an electric motor. The major drawback is that the oil they use can potentially leak, causing a slipping hazard for the operators and covering the panels. This does not comply with the need of maintaining panel integrity and more importantly operator safety, thus the hydraulic cylinder is rejected.

A pneumatic cylinder is another possible option for raising and lowering the scissor lift. A compressed air source is very close to the panel saw and can be connected to the cart to power the lift or a self-contained system, with an air compressor, installed on the cart. The disadvantage is that the pneumatic cylinder requires a constant air supply to maintain the pressure required to lift or hold the panels. If an electric compressor is used, the motor would be required to be running the entire time the cart is in use or the lift will bottom out. If the air supply suddenly stops the load could drop unexpectedly, causing a safety hazard. It is rejected for these reasons.

The final option considered is an electric linear actuator. It has a built-in electric motor that drives a crank, extending a screw similar to the screw on a car scissor jack which extends the cylinder. There are no fluids to leak and the motor will only be required to run when the lift is required to move up or down. It is also considered safer than the pneumatic cylinder because it will not drop the load if power is lost. An electric linear actuator is chosen as the lifting power of the scissor lift. A render of the installed linear actuator is shown in Figure 11.

Figure 11: Linear actuator

During the analysis, it was found that at the bottom of the range of motion, the force required by the actuator to move the load vertically increases towards infinity. To reduce the stress on the scissor arms and actuator, four compression springs were fitted at each corner of the cart. These springs are specified to take the entire load, 500 lbs, of the panels at the bottom of the range of motion. To give the springs stability, guiding cylinders are fitted inside and outside the spring. This will prevent the springs from buckling and act as a bottom stop for the top frame. The installed springs are shown in Figure 12.

Figure 12: Compression springs installed

3.2.3. Cart Frame

The top frame needs to support the distributed load of the panels as well as act as a track for the scissor lift rollers. In order to achieve both functions with minimal material, C-channel is chosen to run lengthwise across the top frame of the cart. For simple manufacturing, the same size will be used for both the bottom and top frames. The linear actuator will be installed in the center of the bottom frame creating a bending moment in the end beam. In order to make manufacturing simpler and to save on costs, it is desirable to have the front and rear ends on both the top and bottom frame of the same material stock. The most suitable type of standard stock material for this is square tubing. The legs of the cart can be constructed from the same stock of square tubing as the ends of the frame to save on costs and increase the upper and lower frames are shown in Figure 13 and Figure 14.

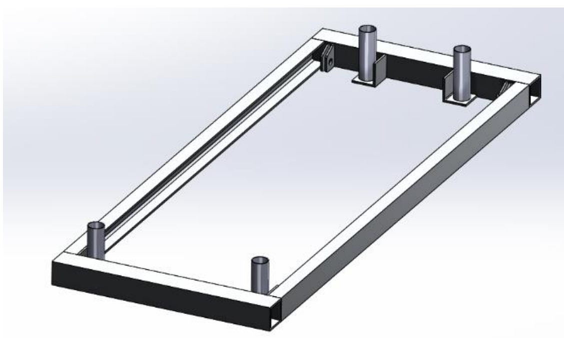


Figure 13: Upper frame

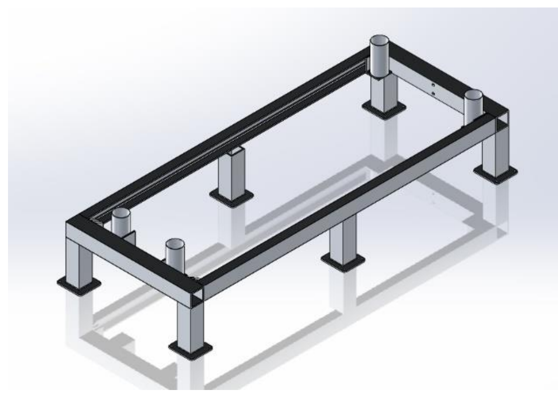


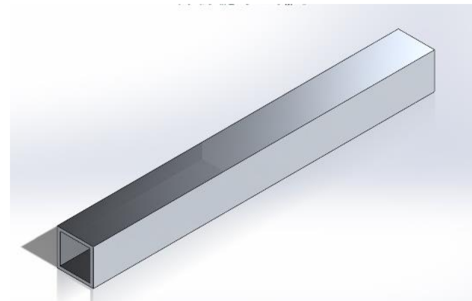
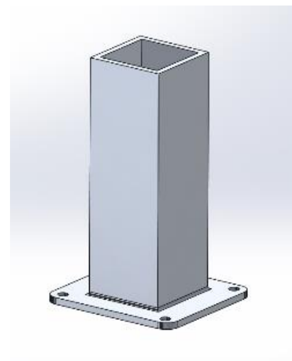
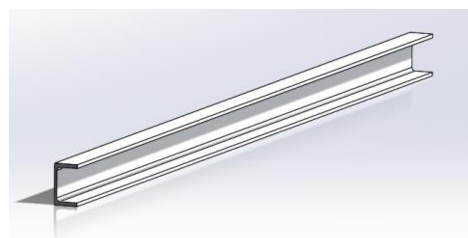
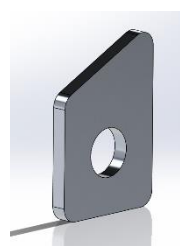
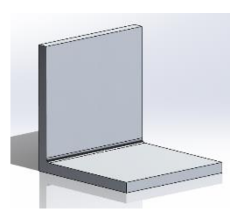
Figure 14: Lower frame

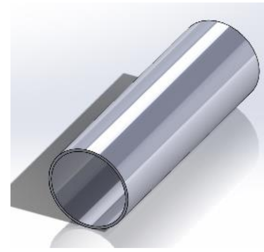
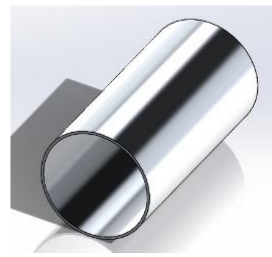
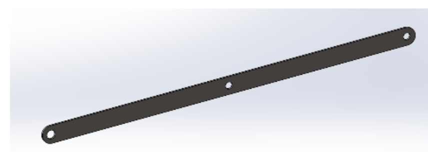
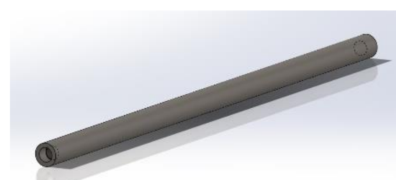
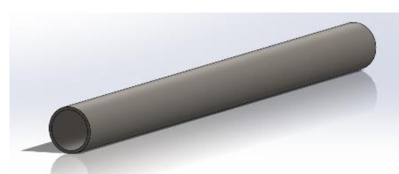
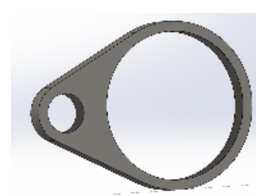
3.3. Outsourced Material

This section contains a list of cart components that require cutting, drilling and/or welding before it can be assembled on the cart. The required material and dimensions can be viewed in table IX.

TABLE IX: OUTSOURCED MATERIAL

Component	Quantity	Image
Tabletop MDF 72" x 28.25" x 0.5"	1	

Top and bottom frame ends 6061-T6 aluminum square tubing 3" x 3" x 0.25" x 28.25"	4	
Legs 6061-T6 aluminum square tubing 3" x 3" x 0.25" x 8.875" **Leg baseplate** 6061-T6 aluminum plate 5.5" x 5" x 0.25"	6	
Top and bottom frame sides 6061-T6 aluminum C-channel 3" x 1.75" x 0.17" web	4	
Scissor anchors 6061-T6 aluminum plate 3" x 1.5" x 0.25"	10	
Gussets 6061-T6 aluminum angle 3" x 3" x 0.25"	8	

Upper spring support 6061-T6 aluminum cylinder 3” x 0.065” x 2.87” x 6.25”	4	
Lower spring support 6061-T6 aluminum cylinder 2” x 0.065” x 1.87” x 6.25”	4	
Scissor arms Hot rolled A-36 steel flat bar 44” x 2” x 0.25”	6	
Scissor Cross Arm Hot rolled A-36 steel round 1” x 24.75”	2	
Actuator bar Hot rolled A-36 steel round 1.875” x 0.12” x 22.79”	1	
Bar collar Hot rolled A-36 steel plate Internal diameter - 1.875”, 0.53” Thickness – 0.25”	2	

3.4. Outsourced Components

This section provides a list and description of the components that are externally sourced and are ready to assemble to the cart frame with no modification listed in table X.

TABLE X: OUTSOURCED COMPONENTS

PA-17-24-2000 Linear Actuator [3]	[redacted]
[redacted]	
BRK-17 Mounting Bracket [4]	
[redacted]	
PA-31 Control Box [5]	
[redacted]	
PS-20-12 Power Supply [6]	
[redacted]	
Threaded Black-Oxide Steel Track Roller [7]	
[redacted]	

[redacted]

High Capacity Spartan Caster – Fixed [8]

[redacted]

High Capacity Spartan Caster – Swivel [9]

[redacted]

Compression Spring [10]

[redacted]

3.5. Material Selection

The material selection breaks down the final design to different parts, including the scissor arms, scissor cross arms and frame components. Mass, ultimate tensile strength (UTS), cost, Young's modulus, hardness, Poisson's ratio and machinability are taken into consideration when comparing materials for the application. The different material characteristics are compared in a criterion weighting matrix shown in table XI.

TABLE XI: MATERIAL CRITERIA WEIGHTING MATRIX

Selection Criteria		Mass	UTS	Cost	Young's Modulus	Yield Strength	Poisson's Ratio	Machinability
Mass	(a)		a	c	d	e	f	g
UTS	(b)			c	d	e	f	g
Cost	(c)				d	e	f	g
Young's Modulus	(d)					e	d	d
Yield Strength	(e)						e	e
Poisson's Ratio	(f)							g
Machinability	(g)							
Count		1	0	2	5	6	3	4
Weight		1	0	2	5	6	3	4

According to the performance of different properties of the material, the hardness and Young's modulus are the most important criteria and the UTS is the least important.

Typical material used in scissor lift table includes AISI 1020 carbon steel, alloy steel, aluminum alloy 6061-T6 and aluminum alloy 6063-T6 [11] .These materials all have different values when compared to the selection criteria. In the material weighting matrix, '+', '0'and '-' sign is given for good, moderate and bad performance respectively. The material weight from table XI is multiplied with the values from table XII and summed at the bottom of each column in table XII.

TABLE XII: MATERIAL SELECTION MATRIX

Selection Criteria	Aluminum Alloy 6061-T6	Aluminum Alloy 6063-T6	AISI 1020 Carbon Steel	Alloy Steel
Mass	+	+	-	-
Cost	0	0	+	0

Young's Modulus	0	0	+	+
Yield Strength	0	0	+	+
Poisson's Ratio	+	+	0	0
Machinability	+	0	+	-
Net Sum +'s	8	4	17	12
Net Sum –'s	0	0	-1	-4
Net Sum	8	4	16	8

As per table XII, AISI 1020 Carbon Steel scored the highest so it is the material used when strength is required. This includes the scissor arms, scissor cross arms, and actuator bar. For the frame, the mass is of more importance, therefore Aluminum Alloy 6061-T6 is chosen as the frame material [12] [13] [14].

3.6. Design Analysis

Stress analysis was conducted on the top frame, scissor arms, actuator mounting bar to the scissor, lower frame and legs. The weight of the panels is considered to be an evenly distributed load centered on the top frame.

Sizes, and therefore weights, of panels are inconsistent and can not be predicted. The applied load will increase as more panels are stacked on it but will not increase linearly for a given number of panels. The force required by the actuator to move or support the load is inversely proportional to $\tan(\theta)$, where θ is the angle between the long axis of the scissor arm and the bottom frame. The scissor, upper frame and lower frame were analyzed using the maximum load of 500 lbs to ensure a factor of safety at all table heights. Thus, the following analysis is done with an applied, distributed load of 500 lbs.

The top frame and scissor arms were analyzed using classical beam theory and calculations were done using MatLab. The lower frame has a complex geometry and was analyzed using finite element analysis (FEA) in SolidWorks.

Under the specified loading conditions, the maximum stress in the right scissor arm was calculated to be 11600 psi and factory of safety of 4.62 per arm. Similarly, for the left arm, the maximum stress is 4566.2 psi and a factor of safety of 11.76. Using the fixed beam approximation, the maximum moment is 2304.2 lbf*in. The maximum stress in the actuator bar is calculated to be 8441.54 psi with a factory of safety of 6.36. The lower frame was put under a 2000 lbf load in a finite element analysis in SolidWorks. The maximum Von Mises stress is 8056 psi, resulting in a factory of safety of 4.95. Following the procedure outlined in Rolling Resistance and Industrial Wheels [15], the team found the sustained pushing force and the starting force to move the cart to be acceptable for one operator. Detailed calculations and analysis can be found in appendix E.

3.7. Failure Modes and Effects Analysis

Failure modes and effects analysis is used to evaluate possible failures and to prevent them by action recommendations [16]. The description and ranking of the severity of the effect are shown in table XIII. The description of the detection rating scale is shown in table XIV.

TABLE XIII: DESCRIPTION AND RANKING OF SEVERITY OF EFFECT

Severity of Effect (SEV)		Ranking
Minor	It's unreasonable to expect the minor nature of this failure to cause serious effect on the service operation. It is unlikely that the customer can notice the failure.	1
Low	Low severity due to nature of failure causing only a slight annoyance [16]. It is possible that the customer will notice only a minor degradation of the service operation.	2,3
Moderate	Moderate severity due to nature of failure causing customer dissatisfaction. It is possible that the customer will experience some noticeable inconvenience of the service operation.	4,5,6
High	High severity due to nature of failure causing high degree of customer dissatisfaction. It does not involve safety or noncompliance to government regulations [16]. This failure mode may require major rework or loss to customer and/ or create significant financial hardship [16].	7,8
Very High	This failure mode involves serious safety hazards.	9,10

TABLE XIV: RANKING OF DETECTION RATING SCALE

Detection Rating Scale (DET)		Ranking
Very High	It is possible that the current process will automatically prevent most failures.	1,2
High	Current controls have a high chance of detecting the failure [16].	3,4
Moderate	Current controls have a moderate chance of detecting the failure.	5,6
Low	Current controls have a low chance of detecting the failure.	7,8
Very Low	Current controls will not likely detect the failure.	9
Non-Detection	Current controls cannot detect the failure.	10

TABLE XV: OCCURRENCE RANKING AND DEFINITIONS

Probability of Failure	Ranking	Possible Failure Rates
Remote: Failure is unlikely. No failures ever associated with almost identical processes.	1	< 1 in 20,000
Very low: Process is in statistical control. Only isolated failures associated with almost identical processes.	2	1 in 20,000
Low: Process is in statistical control. Isolated failures associated with similar processes.	3	1 in 4,000
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions. Process is not in statistical control.	4 5 6	1 in 1,000 1 in 400 1 in 80
High: Generally associated with processes similar to previous processes that have often failed. Process is not in statistical control.	7 8	1 in 40 1 in 20
Very high: failure is almost inevitable.	9 10	1 in 8 1 in 2

The risk priority number (RPN) is the product of the severity (SEV), the occurrence (OCC) and the detection rating scale (DET).

TABLE XVI: FAILURE MODES AND EFFECTS ANALYSIS

Process Step/ Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
Lift the panel from the panel saw table and place on the cart	The panels not lifted from the panel saw table	Surface damage to panels, Process delay	8	The size and weight of panels	5	Training done by the supervisor	2	80
	The panel not placed on the cart	Process delay	8	The panel dropped during the transfer	3	Training done by the supervisor	3	72
Adjust the height of the cart	Fail to adjust the height of the cart	Process delay	6	Overloading the cart, poor maintenance of the cart	4	No procedures	7	168
Maximum number of panels are placed on the cart	Cart fails	Process delay, damage to panels, repair costs	9	Overloading the cart	2	Operator training	3	54
When cart is full, rotate and move onto roller tracks	Fail to rotate the cart	Damage to the cart, Process delay	5	The design of cart of rotation is not ergonomics, the load on the cart is too heavy	3	No procedures	5	75
	Fail to transfer the panel to the track system	Process delay	6	The size and weight of the panel	2	No procedures	4	48

By referring to table XVI, the failure mode which has the highest RPN inability to adjust the height of the cart. This may be due to the cart being overloaded or poor maintenance of the cart assembly. It is recommended that the operators receive the proper training on the maximum load capacity of the cart as well as the proper maintenance procedures. Proper monitoring of the processes that have an RPN of less than 100 is sufficient.

3.8. Vacuum Lift

As per the decision matrix in table VI, the foremost design selection is the Vacuum Lift mounted on a Jib Crane. The team must determine the desired specifications for the jib crane to meet the technical specifications set out in the project definition. The mounting location of the jib crane must be determined first as this will affect the other specs of the cane. The team found three possible mounting locations for the crane, behind the operator's station, by the panel storage, and on the far side of the tracks. The far side of the tracks was ruled out because of the long distance to the saw table and the lack of obstruction free mounting locations. Of the remaining two options, mounting the crane behind the operator's station would allow for the shortest span crane. As well, mounting the crane by the panel storage has the disadvantage that it could get in the way of the operator if he needs to move panels from the panel storage past the carts of panels. For these reasons the team chose that it would be best to mount the crane behind the operator's station. Shown in the figure below are two possible locations the crane can be positioned, denoted by white boxes.

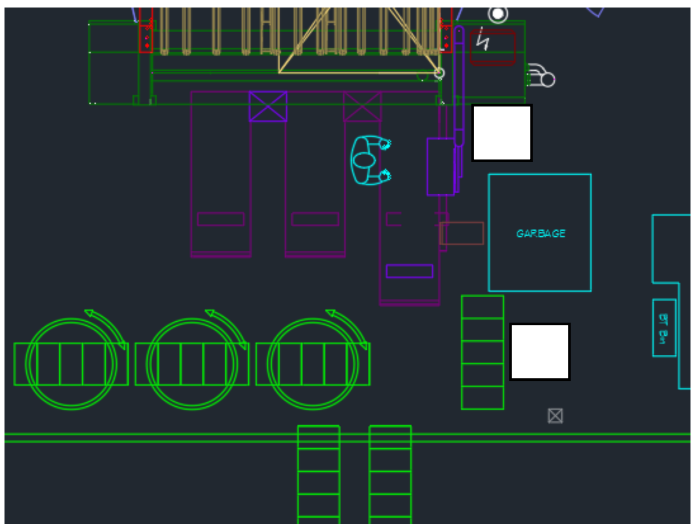


Figure 15: Possible locations for the crane anchor

With the mounting location of the crane known the team can now determine the specifications for the crane. To meet the specifications set out for the project the crane must reach from the panel saw to the location of the cart. From the CAD model of the plant layout the team determined the distance from the crane mounting location to the cart to be approximately 10 feet. Since the exact mounting location would not be known until further inspection of the plant and the concrete that the crane would be mounted on, the team decided that a span on 12 feet would be adequate to give some room for movement of the final location, and so the crane won't be at the stop while the operator is lowering the panel on the cart.

For the height of the crane there were two technical specifications that needed to be met, the vertical range of motion to allow enough panels to be stacked on the cart, and for the crane to be out of the way when not in use. For the crane to be out of the way when not in use it would have to be above the operator's head, which would allow for enough vertical range of motion, so the driving criteria here is for the

Preliminary sourcing for commercially available vacuum lifts provided the information that a top end company that retails these systems is Schmalz. They offer semi-custom solutions for nearly all applications and have a wide variety of designs to choose from. Schmalz was contacted and a representative provided a quote for a final cost of $21,000 -$25,000. A Winnipeg based company, Acculift, produces similar systems and provided a quote of approximately $20,000. This quote is provided in appendix C.

The team investigated sourcing components to assemble its own vacuum lift system to try and reduce the cost over the quoted systems. The team found a Gorbel jib crane for $1780 which was the most inexpensive option that met the required specs while still being from a reputable company. This cost however does not include the cost of shipping, exchange, and any duties and taxes that may be applicable to the procurement of the crane. This cost already takes up 11.68% of the given budget and the vacuum lift itself would cost $8,000 to $10,000, there would not be much if any budget leftover for the inspection and installation of the crane components.

The crane found by the team is a similar model to the crane quoted by Acculift. Given that Acculift has a standing relation with Gorbel, retails various vacuum lift manufacturers and has regular shipments from these companies, the cost per unit and reducing shipping expenses would be reduced compared to a one time purchase directly from the manufacturer. The team then decided that if the final design was the be a vacuum lift on a jib crane the cheapest and most effective solution would be to source a complete solution from Acculift.

As part of the constraints in table III, the budget that Decor is willing to use on a prototype design is $15,000. Since the preliminary quotes are above the allotted budget, our contingency option was pursued.

4. Supplementary

The finalized design has been detailed and verified to meet the customer needs and metrics developed at the onset of this project. Custom parts and off-shelf-parts have been sourced to build the design. This section discusses the assembly of the cart, maintenance of key areas, operating instructions and safety guidelines as well as a final bill of materials as per the project deliverables.

4.1. Assembly Instructions

This section describes the assembly process for the Adjustable Height Mobile Cart. The dimensions on the individual components can be found in the engineering drawings in Appendix A and weldment drawings for the frames can be found in Appendix B.

The first step in the assembly process is to construct the top frame. This is done by welding the square tubing to the ends of the c-channel as shown in Figure 16 and Figure 17. The open face of the C-channel is facing inward.

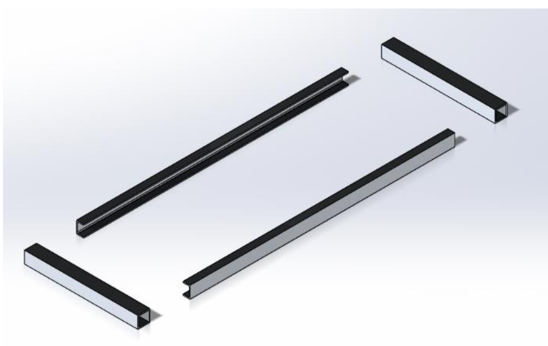


Figure 16: Top frame square tubing and c-channel

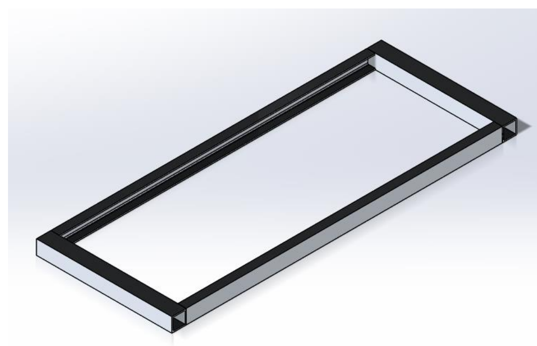


Figure 17: Top frame welded

The top frame requires four scissor anchors to be welded to the front end. By this point, the frame is symmetrical so an end can be selected as the front. The steep slope on the anchors will be facing downwards. There will be rear gussets welded to the rear of the top frame, flush with the C-channel and the rear square tubing. The orientation is shown in Figure 19.

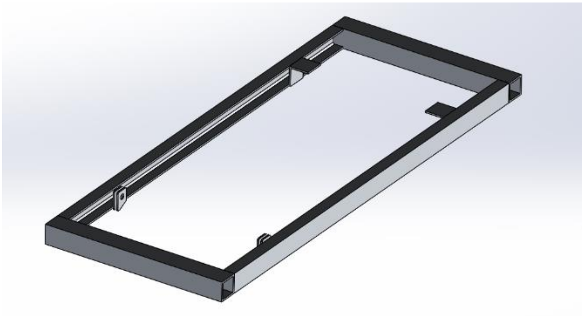


Figure 18: Top frame scissor anchors and rear gussets

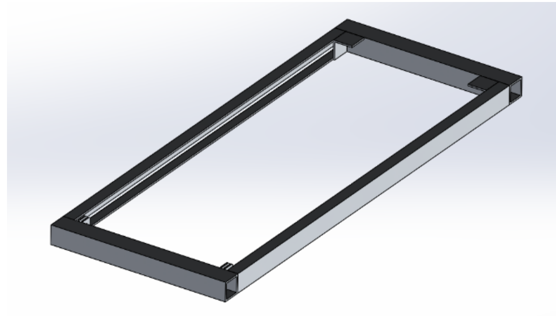


Figure 19: Top frame anchors and gussets welded

Two more gussets are required for the front of the top frame. They will be welded to the front square tubing on the opposite side of the scissor anchors from the C-channel. The orientation is shown in Figure 20.

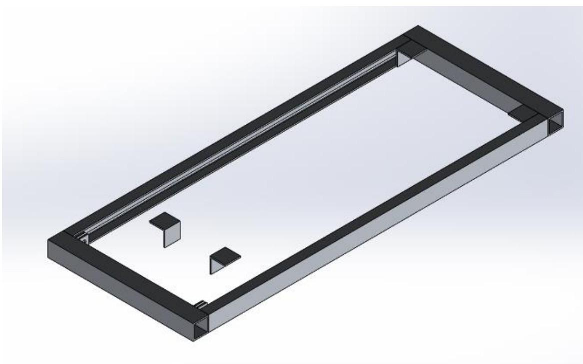


Figure 20: Top frame front gussets

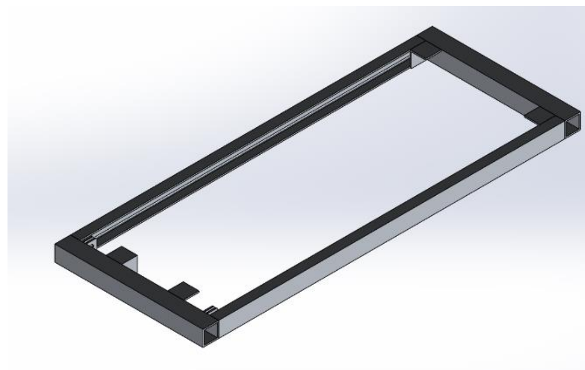


Figure 21: Top frame front gussets welded

The top frame requires four upper spring mounts. The frame is flipped upside down and the upper spring mounts are to be welded to the underside of the top gussets.

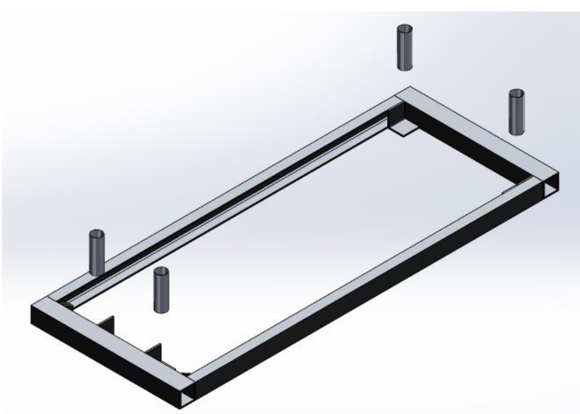


Figure 22: Upper spring mounts

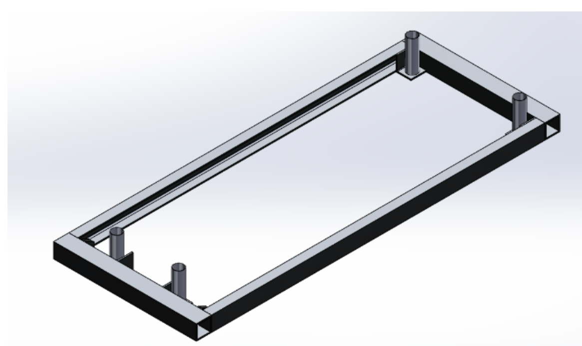


Figure 23: Upper spring mounts welded

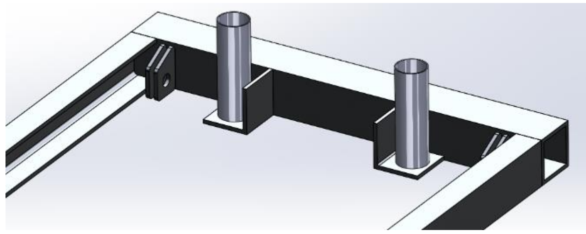


Figure 24: Upper spring mounts welded to gussets

The bottom frame is constructed from two lengths of C-channel and two lengths of square tubing. One of the lengths of square tubing will have holes drilled in it for the actuator mount. This is to be the rear of the bottom frame. The square tubing is to be welded to the ends of the C-channel with the open side of the C-channel facing inwards. This is depicted in Figure 25 and Figure 26.

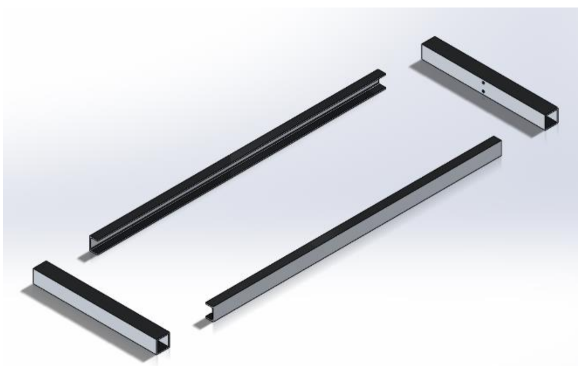


Figure 25: Bottom frame square tubing and c-channel

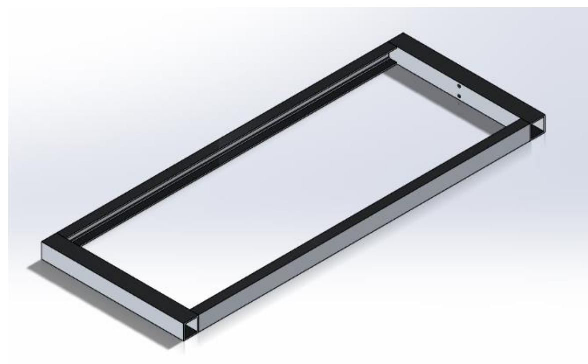


Figure 26: Bottom frame square tubing and c-channel welded

The legs are made of the same size of square tubing as the ends of the frame and have base plates welded on that the wheels can be fastened to. The open ends of the legs are to be welded to the underside of the bottom frame. The center two legs are spaced halfway down the C-channel while the rest of the legs are to be flush with the corners of the bottom frame.

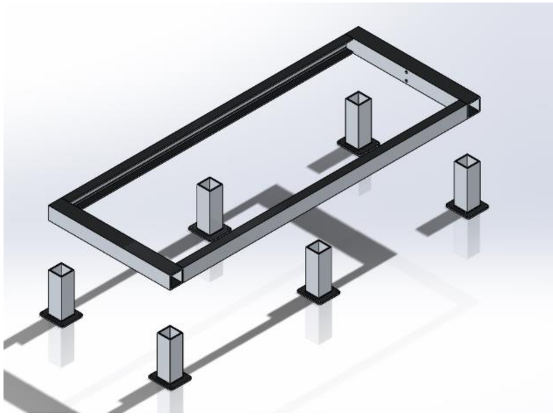


Figure 27: Legs

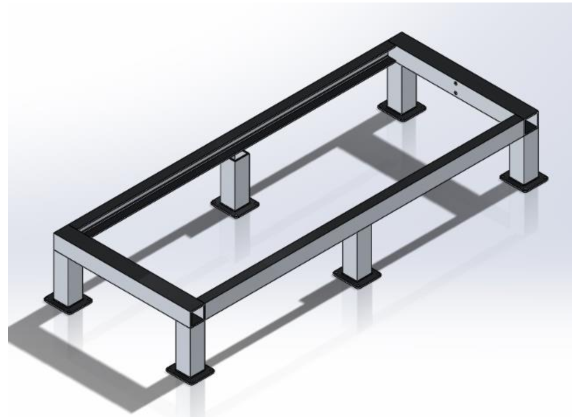


Figure 28: Legs welded to bottom frame

The bottom scissor anchors are now welded to the front square tubing on the bottom frame. The sloped side of the anchors must be facing upwards. This can be viewed in Figure 30 .

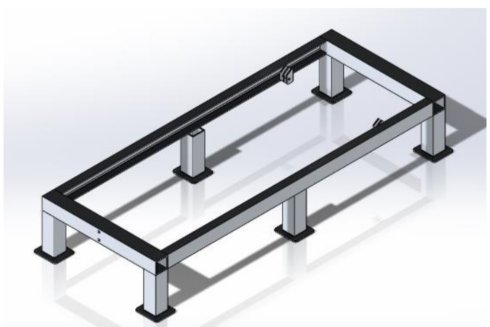


Figure 29: Bottom frame scissor anchors

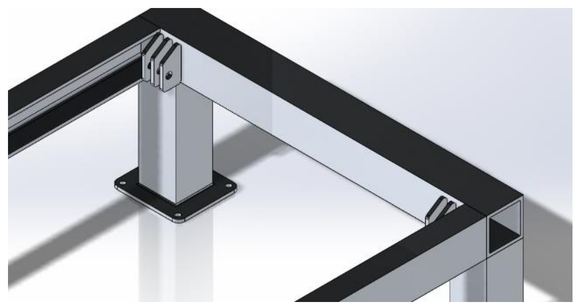


Figure 30: Bottom frame scissor anchors welded

The bottom frame gussets are placed against the square tubing at the ends of the frame, as shown in Figure 32. At the rear end of the frame, the gussets are placed flush to the square tubing and the C-channel. At the front of the frame, they are placed so that the scissor anchors are between the gussets and the C-channel and welded to the square tubing. The orientation can be viewed in Figure 31 and Figure 32.

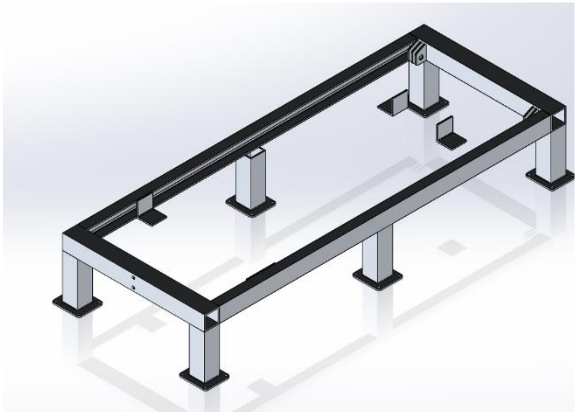


Figure 31: Bottom frame gussets

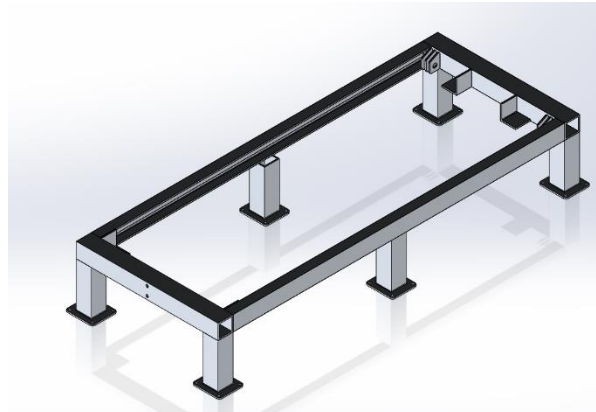


Figure 32: Bottom frame gussets welded

The lower spring mounts are welded to the bottom frame gussets. It is important that they are concentric with the location of the upper spring mounts on the top frame.

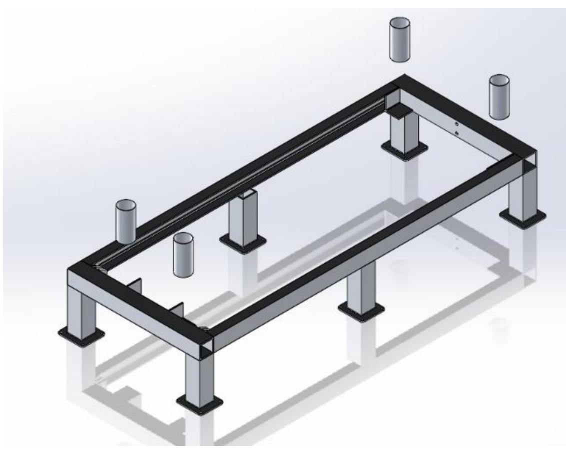


Figure 33: Bottom frame spring mounts

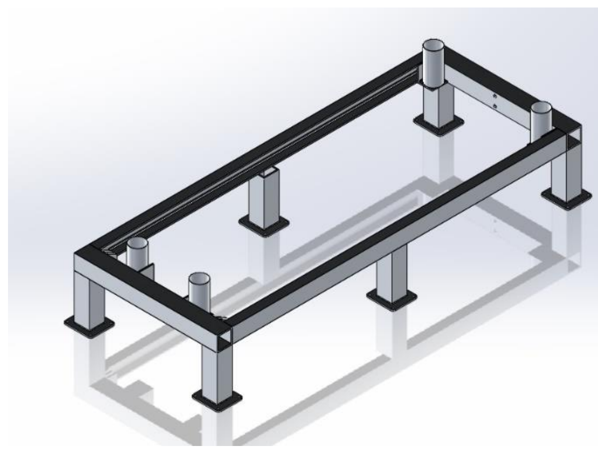


Figure 34: Bottom frame spring mounts welded

The pushing handle can now be welded to the rear square tubing on the bottom frame.

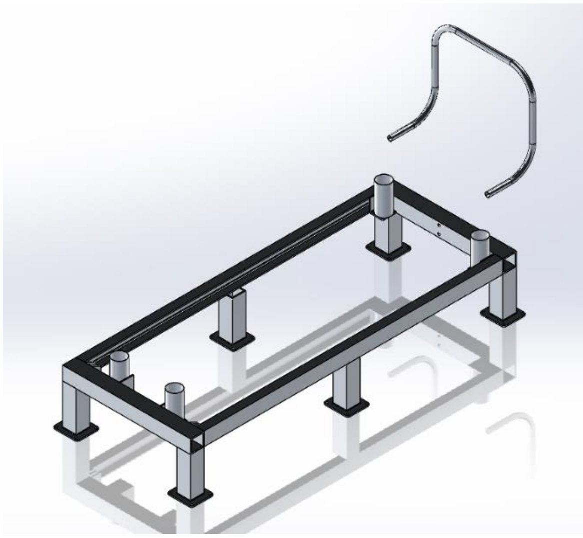


Figure 35: Handle

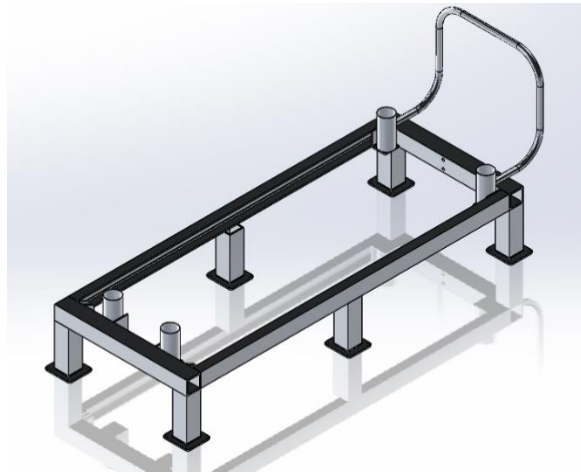


Figure 36: Handle welded to bottom frame

The actuator bracket can now be mounted to the rear square tubing of the bottom frame using two hex bolts (0.5”-20x4.5”x1.25”) and the corresponding hex nuts. The orientation of the bracket is shown in Figure 37 and Figure 38.

Figure 37: Actuator bracket

Figure 38: Actuator bracket bolted to bottom frame

The scissor arms can now be assembled to connect the top and bottom frames together. A scissor cross arm is slid through the larger holes of four scissor arms. The scissor arms are then welded in place directly to the scissor cross arms. The roller bearings are threaded into each end of the scissor cross arm. This is to be the roller bearings that are mounted in the top frame C-channel.

Figure 39: Duel scissor arms and top scissor cross arm

Figure 40: Duel scissor arms mounted on top scissor cross arm

The bar collars are slid onto the actuator bar and welded in place. The bottom scissor cross arm is slid into the actuator bar, but is not fixed in place.

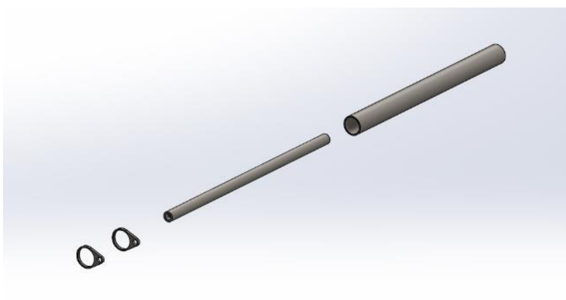


Figure 41: Bottom scissor cross arm and actuator bar

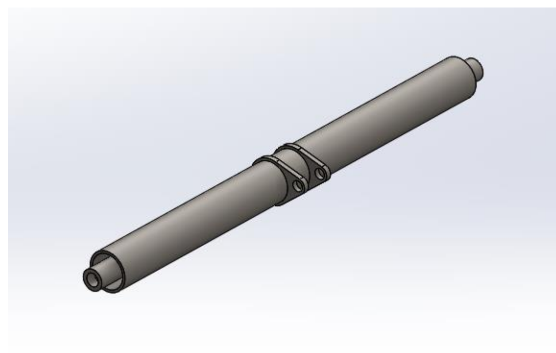


Figure 42: Bottom scissor cross arm and actuator bar assembled

The remaining two scissor arms are slid over the scissor cross arm and butted up to each end of the actuator bar. The scissor arms are welded to both the actuator bar and the scissor cross arm. The roller bearings are threaded into the ends of the actuator bar.

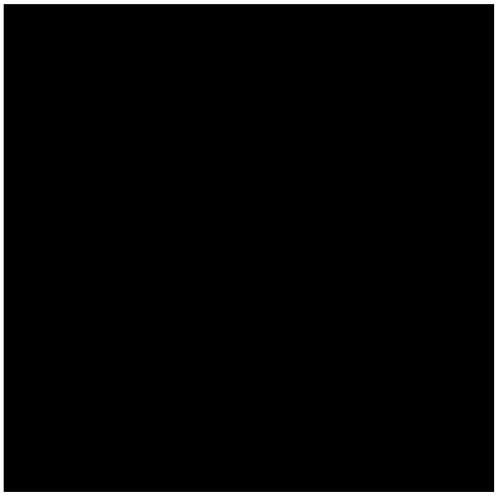


Figure 43: Single scissor arms and actuator bar assembly

Figure 44: Scissor arms mounted on actuator bar assembly

The two sets of scissor arms are connected together in the middle by two hex bolts (0.4375”-20x2”x1.125”), four washers, and the corresponding nuts. The scissor arms connected to the actuator bar fit in between the duel scissor arms connected straight to the top scissor cross arm. The washers are fitted in between the scissor arms to give space for rotation and prevention of the scissor arms from rubbing against each other.

Figure 45: Scissor arms

Figure 46: Scissor arms assembled

Figure 47 shows the connection between the two sets of scissor arms. The center arm is the one connected to the actuator bar while the outside two arms are the duel arms connected straight to the top scissor cross arm.

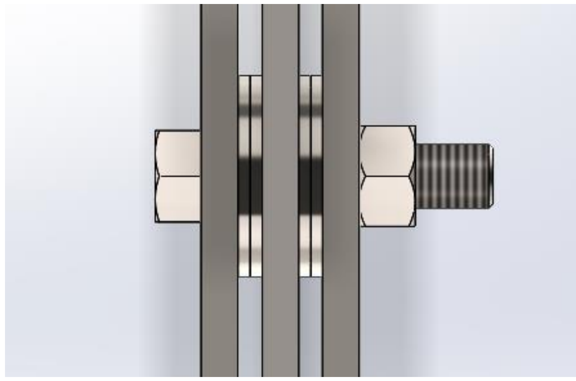


Figure 47: Scissor arms joint

Now that the scissor arms are assembled, they can be used to connect the top and bottom frames together. The top frame is turned upside down and the scissor assembly is placed here first. The scissor arms connected to the actuator bar will be the ones connected to the top frame anchors. The roller bearings connected to the top frame scissor cross arm must be placed within the C-channel track before the opposite scissor arms can be connected to the anchors. Once in place, the scissor arms are to be placed between the top frame scissor anchors and fastened with hex bolts (0.4375”- 0 x 1.375” x 1.125”) and the corresponding hex nuts.

Figure 48: Scissor arms and top frame

Figure 49: Scissor arms mounted to top frame

The top frame must now be inverted and placed on the bottom frame. The roller bearings connected to the actuator bar are to be placed within the C-channel track before the duel scissor arms are placed between the bottom frame scissor anchors.

Figure 50: Top and bottom frame assemblies

Figure 51: Top frame mounted to bottom frame via scissor arms

The scissor arms are fastened to the anchors using two hex bolts (0.75”-16 x 2.5” x 1.75”) and four washers. The washers are placed in between the center anchor and the scissor arms. The nut is placed on the side closer to the C-channel. Figure 52 shows a top view of one of the anchors mounting locations. The C-channel is on the left in a transparent view so the hex nut can be viewed.

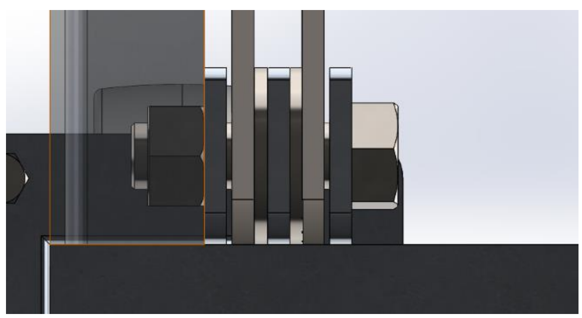


Figure 52: Bottom frame anchor-scissor assembly

The castor wheels are mounted on all six legs of the bottom frame. The wheels on the ends of the frame are pivoting castor wheels and the wheels in the center are fixed. They are each mounted to the baseplates of the legs using four hex bolts (0.3750”-24 x 1” x 1”) and the corresponding hex nuts.

Figure 53: Castor wheels pre-installation

Figure 54: Castor wheels bolted to leg plates

The compression springs must be added before the linear actuator to allow the top frame to reach a maximum height. Once the top frame is at a maximum height, the springs can be placed within the bottom frame spring mounts and around the outside of the top frame spring mounts. Once all springs are in place, as per Figure 55, the top frame may rest on them.

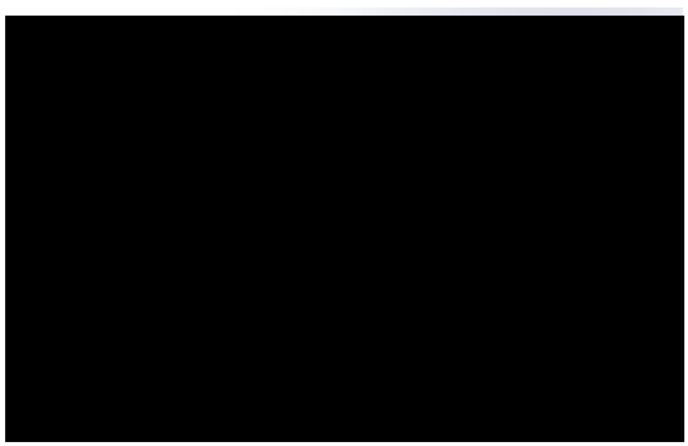


Figure 55: Compression springs

With the weight of the top frame on the compression springs, the linear actuator may be installed. The base of the actuator is mounted to the bracket on the bottom frame using the bolts that are supplied with the bracket. The actuator arm is extended to the actuator bar and fastened to the bar collars using a socket head cap screw (0.5”-13 x 2.25” x 1.5”) and the corresponding hex nut.

Figure 56: Linear actuator

Figure 57: Linear actuator mounted

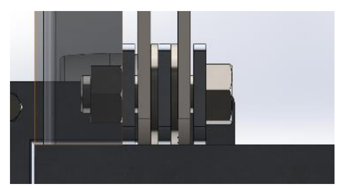
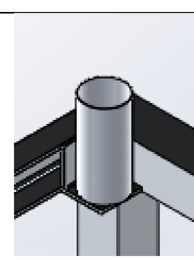
A wooden tabletop can now be bolted onto the top frame of the cart through the square tubing using carriage bolts.

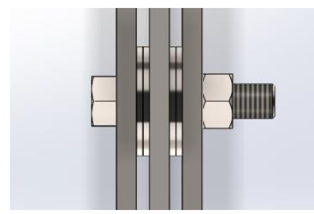
Figure 58: Adjustable cart complete

4.2. Maintenance

It is recommended to create an in-house maintenance schedule for the adjustable cart. Like any mechanical system, the cart will be subject to wear, notably at the locations of moving components. This section provides a list of components to maintain awareness of. The cart should be visually inspected daily to check for any obvious defects. Every 6 months the cart should be disassembled and the following components should be inspected as outlined in table XVII.

TABLE XVII: BIANNUAL INSPECTION

1.	**Castor wheels** Check the tightness of the connecting bolts. Confirm that the wheels bearings are operational and that the pivoting castor wheels are free of debris and damage and are able to turn easily.	[redacted]
2.	**Compression spring** Check that the springs are maintaining their stiffness. Disconnect the actuator and place a 100 lb weight on the cart table. The cart table should depress 3.2” from it’s resting position.	
3.	**Linear actuator** Check that the connecting bolts on both the actuator bar and the bracket are tight. Consult with the operators’ manual for further maintenance on the actuator.	
4.	**Scissor anchor assembly** Ensure that the hex bolts are not coming loose. Inspect the weld on the scissor anchors and ensure it is not cracking. Ensure that the washers and the ends of the scissor arms are not wearing or cracking.	 Figure 62: Scissor anchor assembly
5.	**Spring mounts** Check the welds connecting the spring mount to the gusset and from the gusset to the frame. Ensure there are no cracks and that the gusset is not bending.	 Figure 63: Spring mount

6.	**<u>Actuator bar assembly</u>** Check the integrity of the welds on the actuator collars, the scissor arms to the actuator bar and the scissor arms to the scissor cross arm. Ensure that the roller bearings are operating smoothly and that the threads are not coming loose from the scissor cross arm.	[redacted]
7.	**<u>Scissor cross arm assembly</u>** Inspect the welds connecting the scissor arms to the scissor cross arm have no cracks. Ensure the roller bearings are operating smoothly and the threads are not coming loose from the scissor cross arm.	
8.	**<u>Scissor arms joint</u>** Inspect the integrity of the washers. Ensure that the hex bolt is not coming loose. This is a moving part so ensure that the scissor arms are not wearing. This may require the removal of the washers for inspection. Do not overtighten the hex bolt because it will increase the friction and create more wear on the scissor arms and the actuator.	 Figure 66: Scissor arms joint

4.3. Operation and Safety

This section outlines the proper operation of the Adjustable Height Mobile cart, as well as safety considerations to be followed.

4.3.1 Operation

1. Park the cart over the pivoting roller cart in vicinity of the panel saw.
2. Plug in the power supply for the cart lift mechanism.
3. Raise the cart table so that the top is level or just below level with the panel saw table.
4. Slide the panel off the saw table and on to the table of the cart. Ensure that the panel is centered on the cart table.
5. Use the control module remote to lower the cart table so that the top of the panel stack is level or just below level with the saw table.
6. Slide the next panel onto the top of the panel stack.
7. Repeat steps 5 and 6 until the desired number of panels are stacked on top of the cart.
8. Lower the cart to the lowest possible position for transport.
9. Disconnect the power supply and safely stow the cord of the power unit.
10. Push the cart to the next location of the plant.
11. Plug in power supply.
12. Raise top of cart so that the bottom of the top panel is level or above the desired offloading station.
13. Slide the top panel off of the panel stack.
14. Repeat steps 12 and 13 until all of the desired panels are removed from the panel cart.
15. Unplug power supply and safely stow the cord of the power unit.
16. Return the cart to the panel saw.

4.3.2. Safety Considerations

- Always park the cart as close as possible to the end of the panel saw table while maintaining position over the pivoting roller. This allows the user to keep the majority of the weight of the panel on the saw table or the panel cart reducing the force required by the user to lift the panel. This also minimizes any trunk rotation required by the operator to move the panel.
- Keep all body parts clear of the scissor mechanism, springs, and between the top and bottom frames while raising or lowering the table. These present pinch points which could seriously harm the operator if used incorrectly.

- Always keep the cart in the lowest possible position while transporting panels. This keeps the centre of gravity low to lessen the chance of a possible tip over.
- When no panels are placed on the cart, keep the table in a higher position to keep springs relaxed. Forcing the springs down with no weight on the cart places extra strain on the actuator, scissor arms, and springs decreasing the lifespan of these components.
- It is important that the panels are centered on the cart. If too many panels are placed off centre in any direction, excess stress is placed on the scissor arms and the linear actuator. This can decrease the lifespan of these cart components, or lead to potential failure for the cart.
- Ensure the load on the cart does not exceed 500 lbs. This is over the capacity the cart is designed for which will increase the risk of failure, potentially causing injury to the operator or bystanders. Overloading will also increase the risk of losing control of the manoeuverability of the cart which can cause potential injury.

4.4. Bill of Materials

In this project, a bill of materials includes a list of raw materials, sourced parts, sub-components, intermediate assemblies which are needed to manufacture. The bill of material of this project is listed in table XVIII.

TABLE XVIII: BILL OF MATERIALS

PART NUMBER	PART NAME	DESCRIPTION	QUANTITY	PART IMAGE	UNIT COST	AMOUNT
1	Heavy Duty Linear Actuator [3]	The heavy-duty linear actuator with optional feedback provides cost effective high force capabilities. And it is provided with adjustable limit switches which allows the user fully to control where to start and stop the actuator. And the speed is 0.33"/sec.	1	[redacted]	$ 394.94	$ 394.94
2	Heavy Duty Mounting Bracket for PA-17, PA-13 [4]	The bracket is used to mount with the linear actuator, and it is also designed to have a full 180-degree rotation. All required screws are provided as well.	1	[redacted]	$ 29.99	$ 29.99
3	High-Capacity Spartan Caster with 5-1/2" *5" Plate (Rigid with 4" Diameter Phenolic Wheel) [8]	They are good general casters for heavy loads, and the polyurethane wheels combine the abrasion resistance of plastic with the impact resistance of rubber.	2	[redacted]	$ 28.02	$ 56.04

4	High-Capacity Spartan Caster with 5-1/2" *5" Plate (Swivel with Open Bearing and 4" Diameter Phenolic Wheel) [9]	Casters with wheel brake apply pressure to the wheel to stop movement with a press of the foot pedal. Shielded bearings protect the bearing from dust and debris.	4	[redacted]	$ 46.64	$ 186.56
5	R11- Hot Rolled A-36 Steel Round with 1" diameter [17]	It is a hot rollered, mild steel solid bar that is ideal for fabrication, manufacturing and repairs. It is also easy to weld, cut, form and machine.	2	[redacted]	$ 10.52	$ 21.04
6	Scissor Arm F2142-1/4*2 Hot Rolled A-36 Steel Flat [18]	It is used for fabrication and repairs in industrial maintenance, agricultural implements.	4	[redacted]	$ 6.68	$ 26.72
7	12 VDC Control Box - 1 Channel - 20A - Wireless Remote [5]	It is used to control the linear actuator, and the user is able to extend, stop, and retract the actuator up to 30-50 feet away.	1	[redacted]	$ 107.49	$ 107.49

8	Power Adapter - 110-240 VAC - 12 VDC - 20A [6]	This adapter can be used in conjunction with the rocket switches or any other control device that requires up to 20 amps of 12VDC power.	1	[redacted]	$ 85.99	$ 85.99
9	Threaded Black-Oxide Steel Track Roller, Flat [7]	It is used to support loads while guiding and positioning work.	4		$ 41.71	$ 166.84
10	3 x 3 x 1/4 wall 6061-T6 Aluminum Square Tube [19]	It is an extruded aluminum that are widely used for fabrication.	10		$ 50.90	$ 50.90
11	3 x 1.75 x .170 web 6061-T6 Aluminum Channel (AS) [20]	It is an extruded aluminum product with inside radius corners that is extended for all structural applications.	4		$ 45.67	$ 182.67
12	Compres sion Spring-DIN2098 PART1 (LCD500Q 05M) [10]	Compression springs are open-coil helical springs wound or constructed to oppose compression along the axis of wind.	4		$ 33.30	$ 133.2
13	Spring Mount 3 x 3 x ¼ 6061- T6 Aluminum Angle [21]	This aluminum angle is use for mounting the spring, and it is widely used in fabrication where lightweight and corrosion resistance is a concern.	8		$ 2.75	$ 22.0
14	Lower Spring Guide 2 x 0.065 x 1.87 ID Aluminum Round Tube 6061-T6 -Drawn [22]	Aluminum round tube 6061-T6 exhibits above the average corrosion resistance, good machinability, and the ability to be heat treated for even higher strength.	4		$ 15.05	$ 60.2

15	Upper Spring Guide 3 x 0.065 x 2.87 ID Aluminum Round Tube 6061-T6 – Drawn [23]	Aluminum round tube 6061-T6 exhibits above the average corrosion resistance, good machinability, and the ability to be heat treated for even higher strength.	4	[redacted]	$ 31.83	$ 127.32
16	Scissor Anchor ¼ inch thick 6061-T651 Aluminum Plate [24]	This scissor anchor offers a combination of increased strength, corrosion resistance and machinability. And it is heat treatable, easy to weld and machine, but limited on formability.	10	[redacted]	$ 10.92	$ 109.2
17	Actuator Bar Collar ¼ inch carbon steel plate [25]	¼ inch carbon steel plate is chosen to be used for the actuator bar.	2	[redacted]	$ 1.80	$ 3.60
		TOTAL PARTS	70		**TOTAL**	$ 2222.81

The final cost for the cart is $2222.81. However this does not include the cost of labour for welding and assembly of the cart as it is outside the scope of this project.

5. Recommendations

This cart is designed to comply with the health and safety standards for four-wheel push carts as per the CCOHS [26]. Within the same guidelines as the maximum weight for the cart is a guideline for the height of 91 to 112 cm (35.86” to 44”) [26]. A render of a possible push handle has been shown throughout the images of the report. This handle is 18.5” tall and when added to the bottom frame, it reaches 36” from the ground, meeting the safety standard.

The handle is made from 1”, hollow aluminum tube, bent to form the handle shape. Each bend is 90° and has a radius of 5”. The total length of the tube is 69.42” with the flat sections being 5”, the vertical sections 8” and the push bar being 12” long. A render of the push handle is shown in Figure 67.

Figure 67: Push handle

This handle could be used to move the cart through the workshop by pushing from the back. The current prototype cart has a removeable bar that is attached to a corner when moving the cart. The operator pulls the cart and steers using this bar. A similar design could be used on the adjustable height cart as well.

A difficulty with this push hand is the distance from the top frame. With short horizontal arms, panels will most likely contact the handle but with long arms, the bending moment at the mounting point will be large possibly cause failure. It is recommended that Decor attach a handle they deem suitable for their employees and their workshop.

While manufacturing instructions are detailed in the report, specific welding instructions such as weld bead thickness, length location are not discussed. It is recommended that a welder with knowledge of creating aluminum weldments be consulted in stitching together the upper and lower frames.

Due to possible pinch points in the spring coils, it is recommended that a cover be placed over the springs to negate this hazard.

6. Conclusion

Decor is looking for a solution to move oversized panels from the panel saw to the prototype mobile cart using a single operator and ergonomic means. The solution is the Adjustable Height Mobile Cart.

This is a cart modelled after the current prototype carts that allow the panels to be stacked on top in a horizontal position. This cart utilizes a scissor lift mechanism electronically controlled by the operator. With its 14.75” vertical range of motion, it is able to reach the bed height of the panel saw table, allowing the operator to shift the panels directly onto the cart bed without having to lift or lower the panels. As more panels are stacked on, the cart table can be lowered by the push of a button to maintain the height of the stack to be even with the saw table. The power source is an electric linear actuator that raises and lowers the scissor lift. There are four compression springs that decrease the load on the actuator so that at the lowest point, the actuator is experiencing no force given a recommended load of 500 lbf on the cart. The cart is able to operate over the rollers in the shop as well as independently, allowing it to skip over the unnecessary processes of the smaller panels. It can be stationed over the current pivoting roller carts, in vicinity of the saw table, and is able to pivot with them on a central point due to the pivoting castor wheels at either end of the cart. It is able to be pushed or pulled in a straight line due to the fixed castor wheels in the center. The table of the cart is made of MDF to prevent the scratching of the veneer on the panels. The 28.25” x 72” platform can accommodate the target panel sizes coming off of the saw. When the cart is not in use, it can simply be rolled out of the way. The total material cost for the cart is $2222.81.

This design complies with the needs laid out at the onset of this project. The adjustable height mobile cart is capable of stacking panels horizontally in an ergonomically safe manner. It integrates into the manufacturing layout with no changes needed for its use and does not impede the process flow in or out of use. The budget of $15000 dollars is kept with a material and parts cost of $2222.81. Stress analysis was conducted and found that the design has a minimum factor of safety of 4.62 and was deemed satisfactory for use by Decor in their production of high-quality cabinetry products.

Should Decor want to pursue a more expensive option, the quote detailing a vacuum lift system is found in appendix C.

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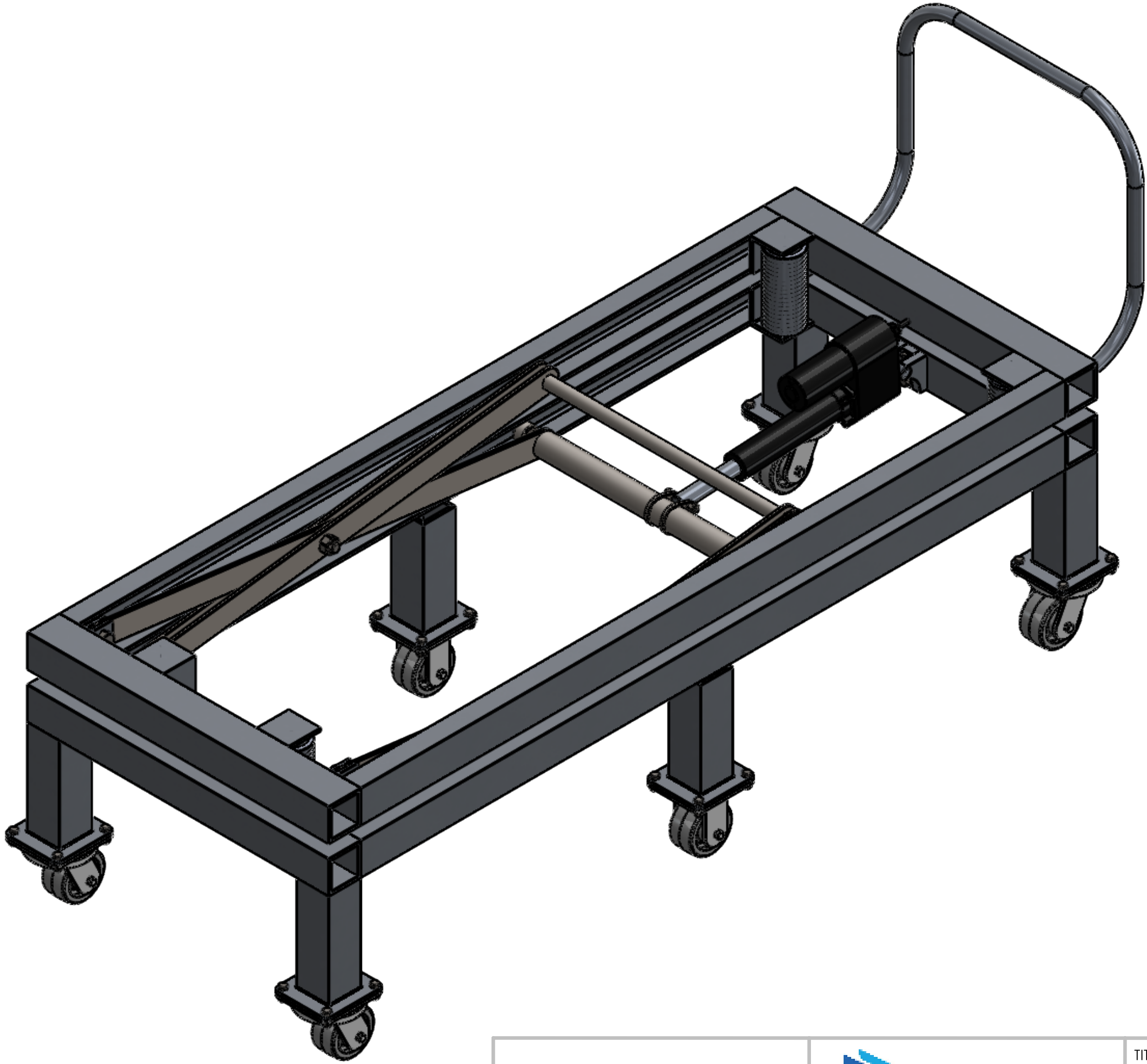
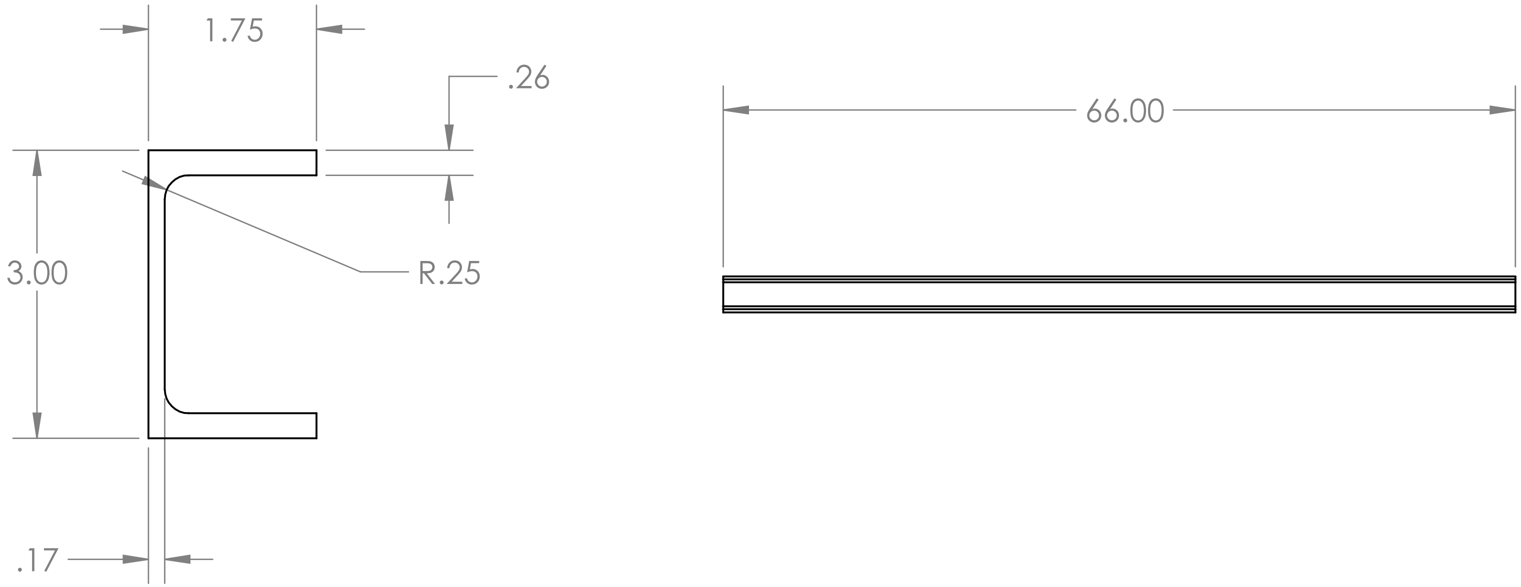
Appendix A: Engineering Drawings

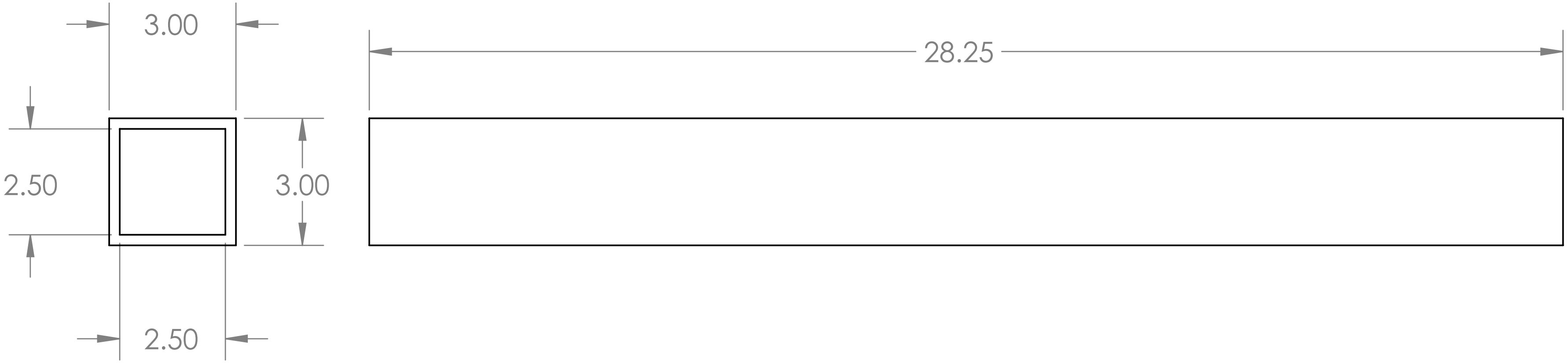
Solidworks was used to model the custom components used in the adjustable height mobile cart. Drawings of the 14 components that make up the final design are shown in the following pages. All weights are in pounds and lengths and measured in inches.



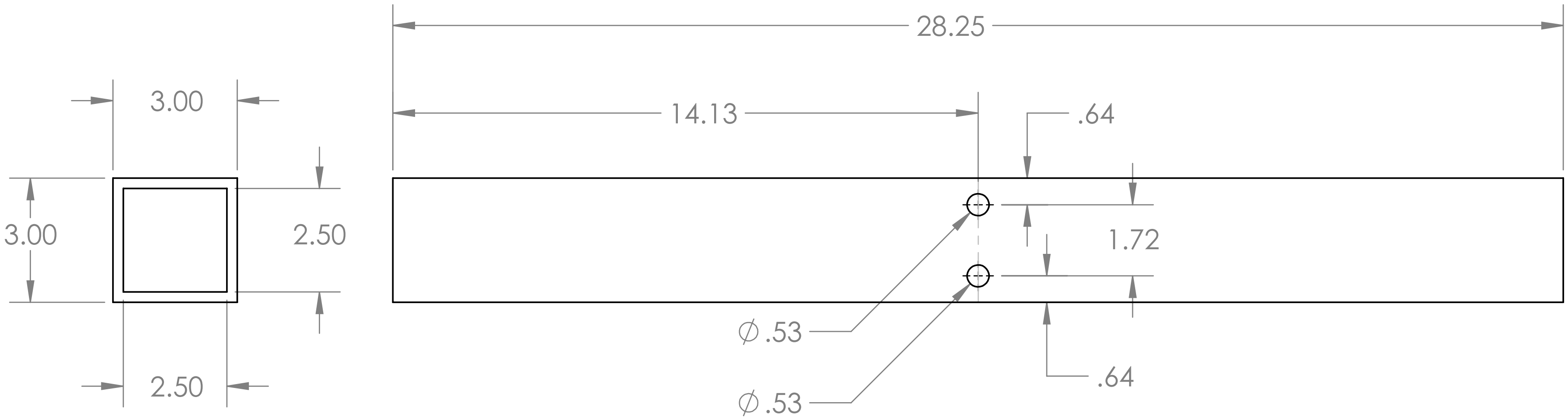
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**	
PEPARED FOR: **JUHA KEINANEN**	MATERIAL:	DWG NO. Adjustable Height Mobile Cart	A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT:	SCALE:1:32	SHEET 1 OF 14



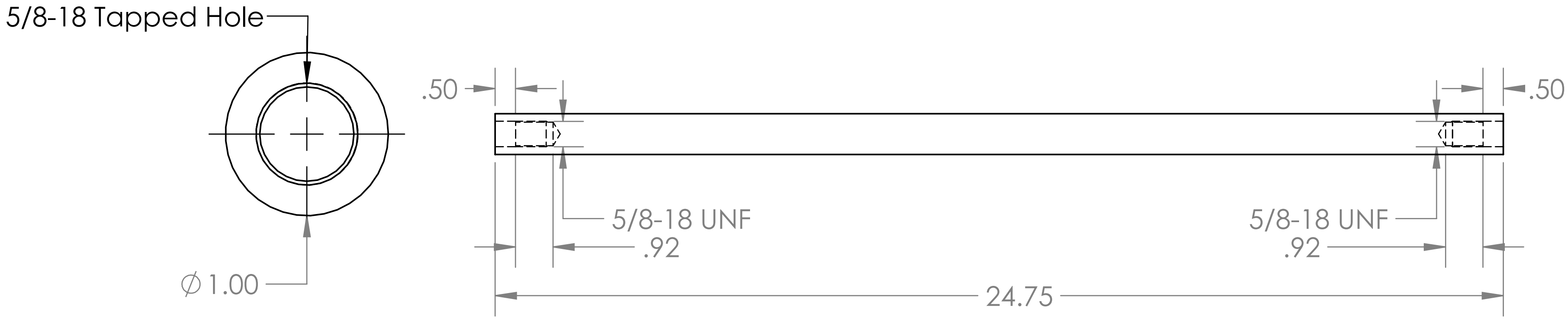
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Roller C-Channel — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 8.75	SCALE:1:16 — SHEET 2 OF 14



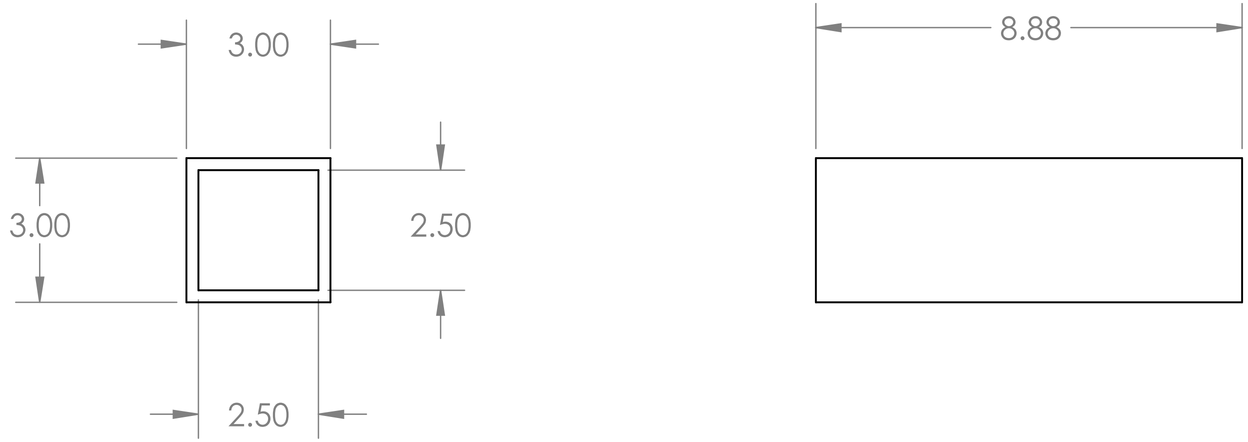
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Frame End — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 7.58	SCALE:1:8 — SHEET 3 OF 14



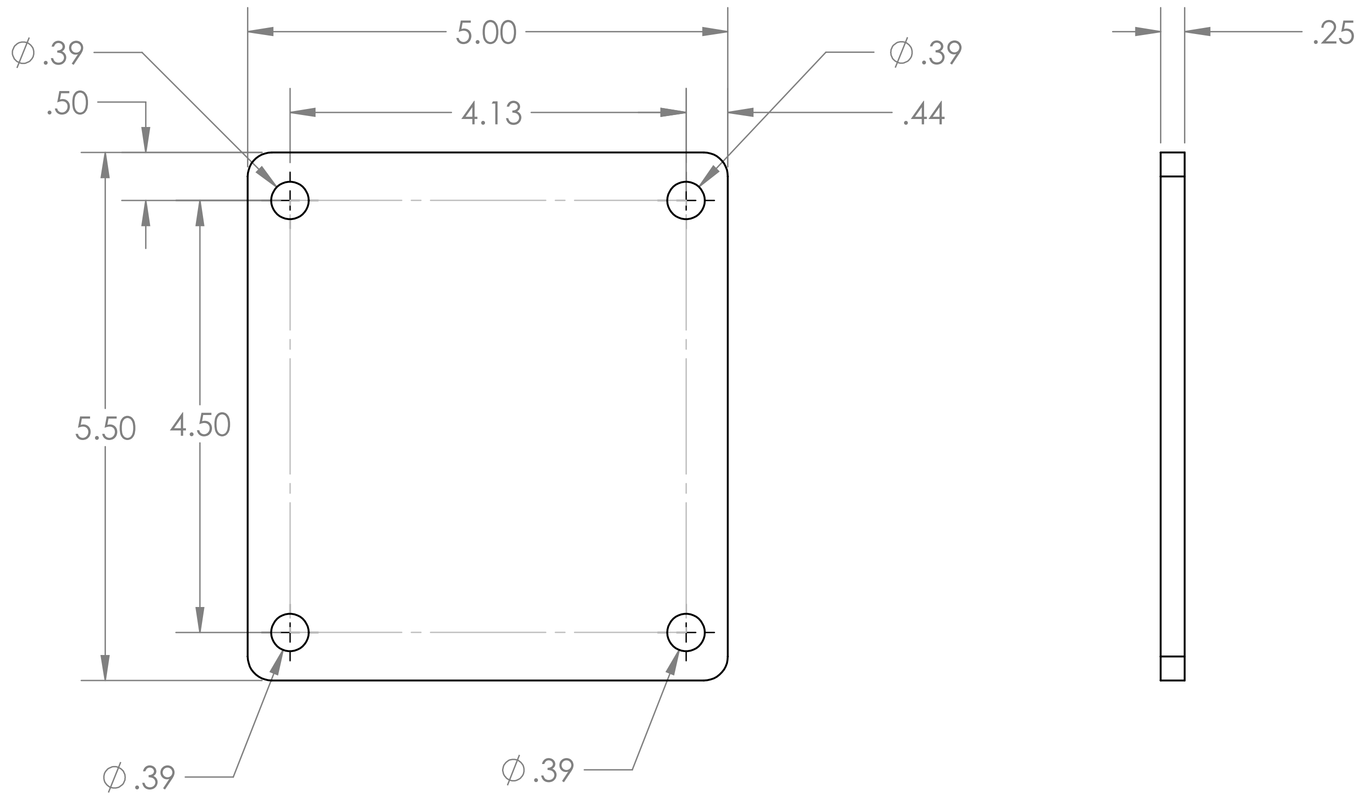
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Actuator Frame Mount — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 7.56	SCALE:1:8 — SHEET 4 OF 14



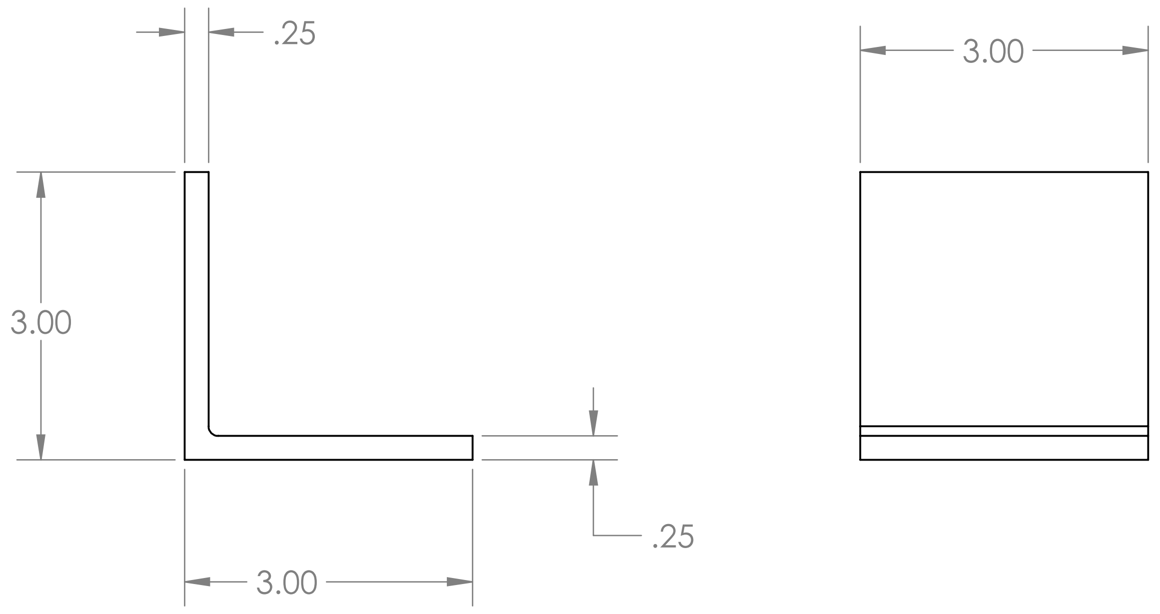
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: AISI 1020 Steel, Cold Rolled	DWG NO. Scissor Cross Arm — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 5.29	SCALE:1:8 — SHEET 5 OF 14



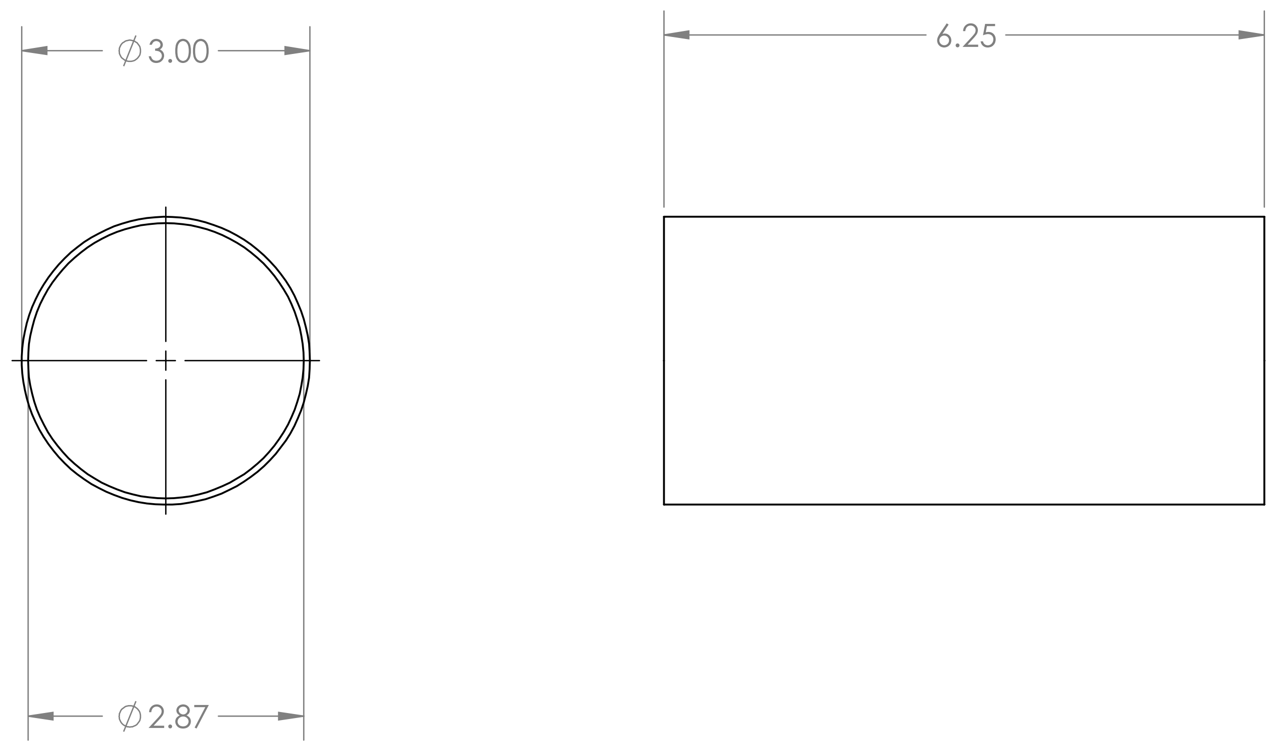
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Cart Leg — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 2.38	SCALE:1:4 — SHEET 6 OF 14



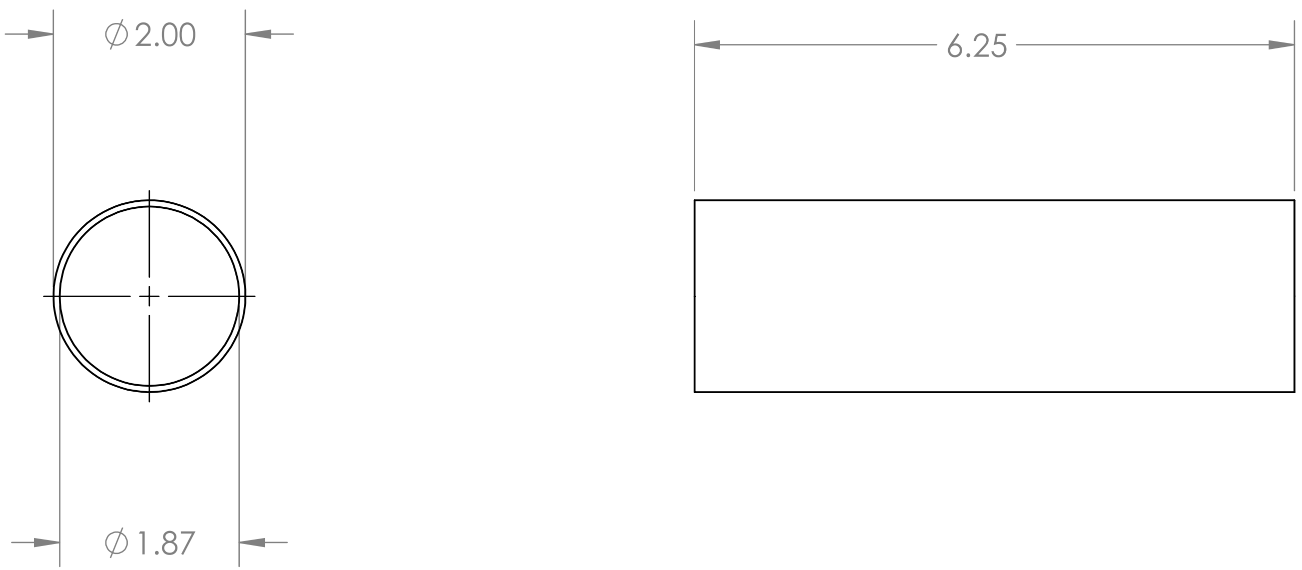
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Caster Mounting Plate — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 0.66	SCALE:1:2 — SHEET 7 OF 14



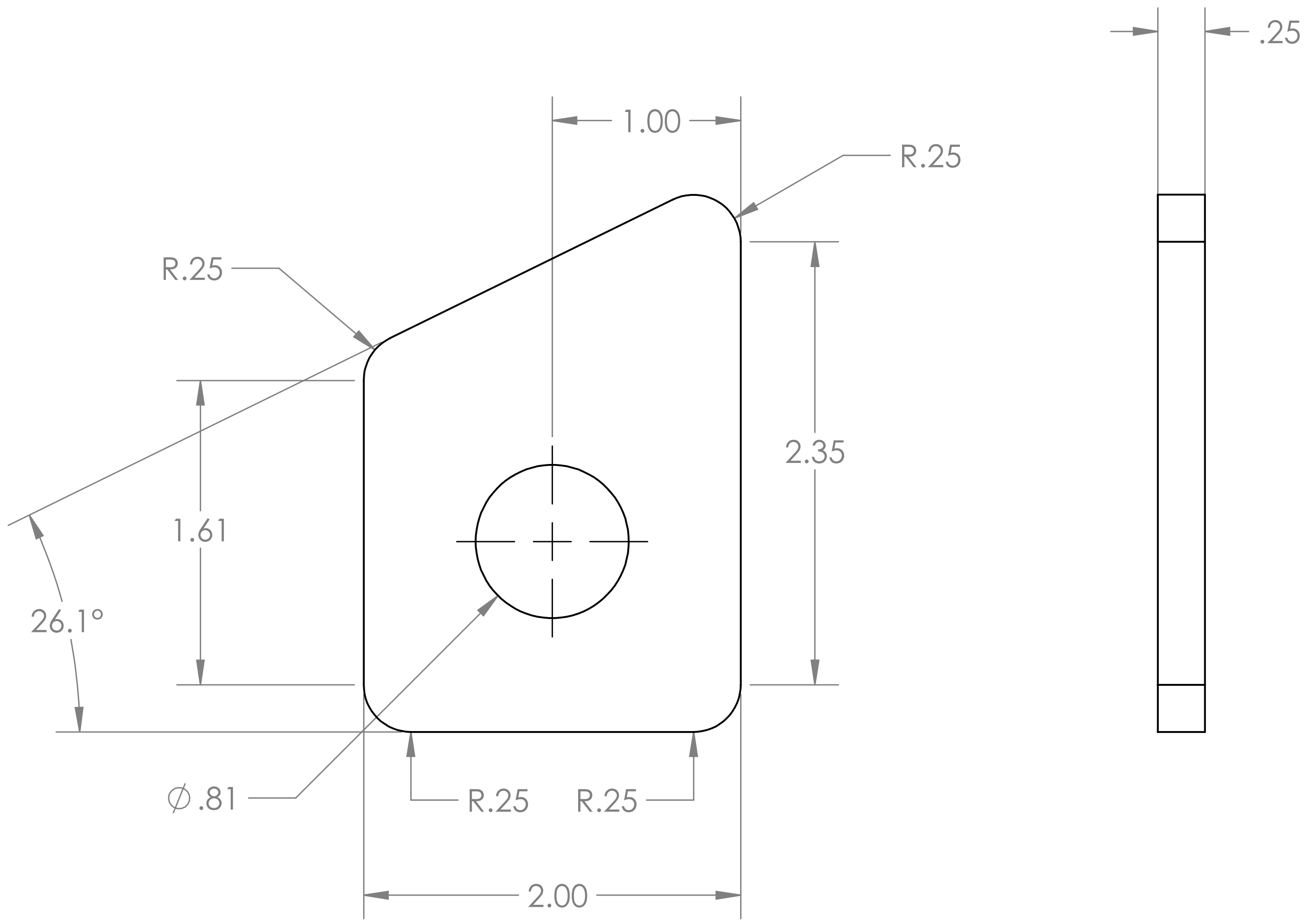
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Spring Mount — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 0.42	SCALE:1:2 — SHEET 8 OF 14



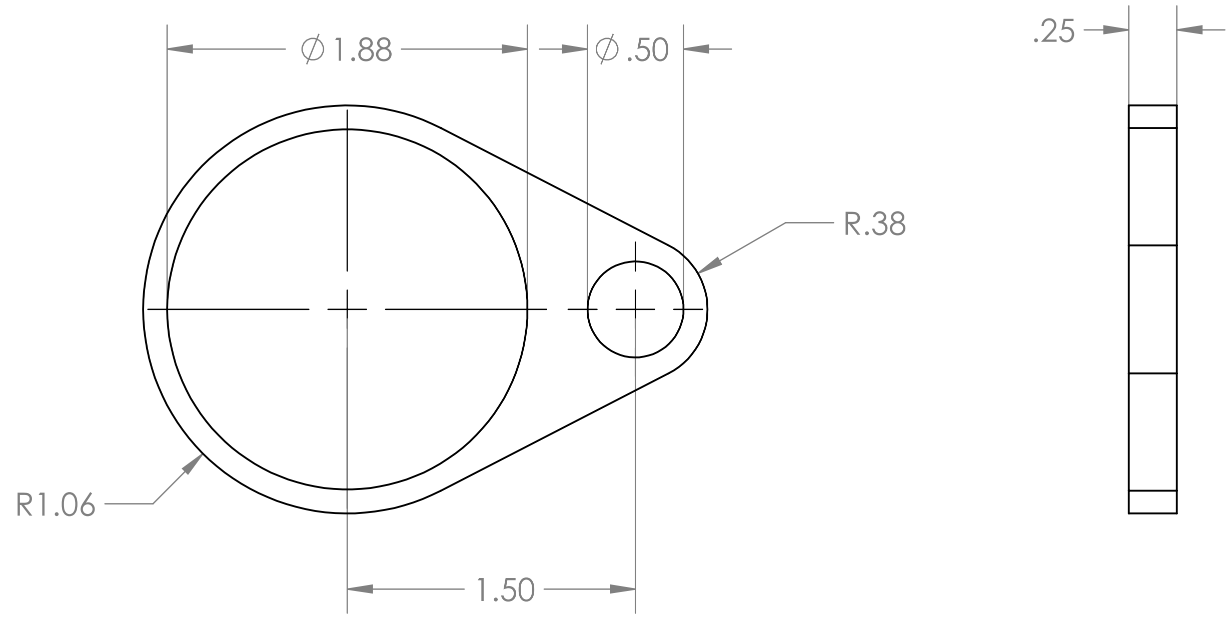
DECOR CABINET COMPANY	University of Manitoba	TITLE: MECH 4860: Engineering Design	
PEPARED FOR: JUHA KEINANEN	MATERIAL: 6061-T6 (SS)	DWG NO. Lower Sping Guide	A4
PREPARED BY: TEAM 13: DECOR-ATORS	WEIGHT: 0.37	SCALE:1:4	SHEET 9 OF 14



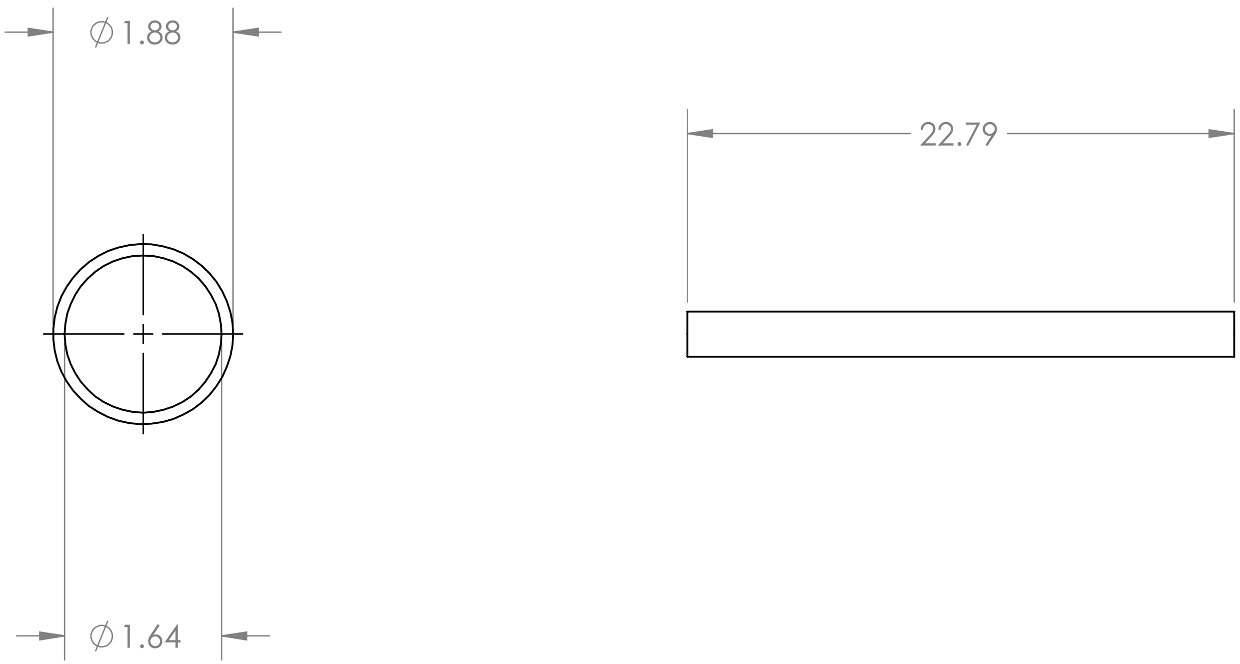
DECOR CABINET COMPANY	University of Manitoba	TITLE: MECH 4860: Engineering Design
PEPARED FOR: JUHA KEINANEN	MATERIAL: 6061-T6 (SS)	DWG NO. Upper Spring Guide — A4
PREPARED BY: TEAM 13: DECOR-ATORS	WEIGHT: 0.24	SCALE:1:2 — SHEET 10 OF 14



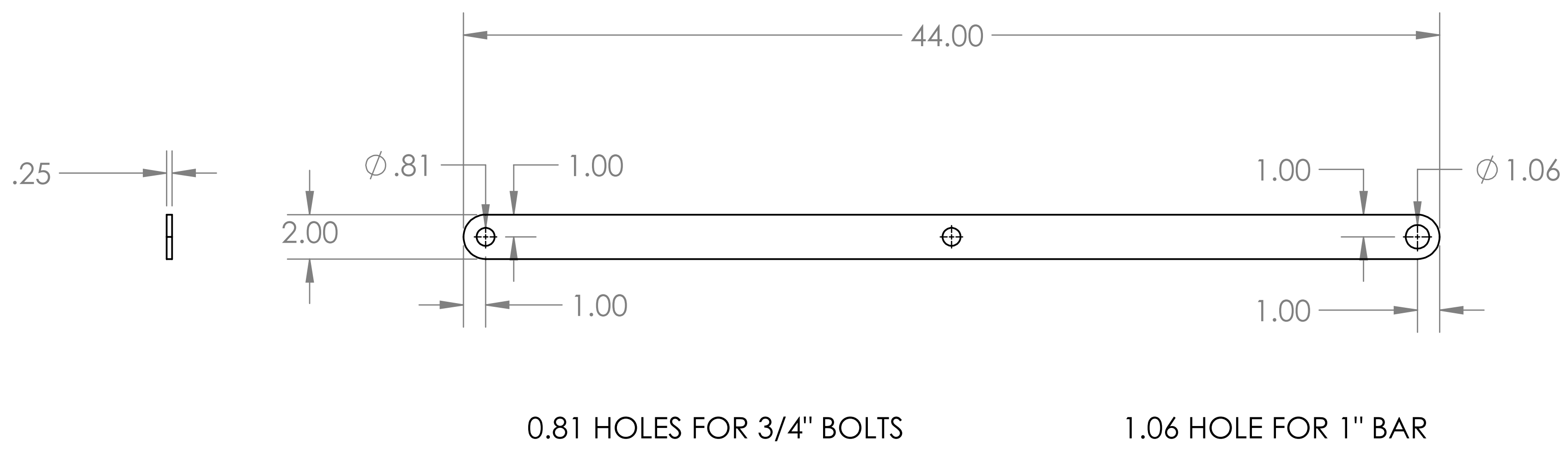
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: 6061-T6 (SS)	DWG NO. Scissor Anchor — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 0.11	SCALE:1:1 — SHEET 11 OF 14



DECOR CABINET COMPANY	University of Manitoba	TITLE: MECH 4860: Engineering Design
PEPARED FOR: JUHA KEINANEN	MATERIAL: 1023 Carbon Steel Sheet (SS)	DWG NO. Actuator Bar Collar — A4
PREPARED BY: TEAM 13: DECOR-ATORS	WEIGHT: 0.10	SCALE:1:1 — SHEET 12 OF 14



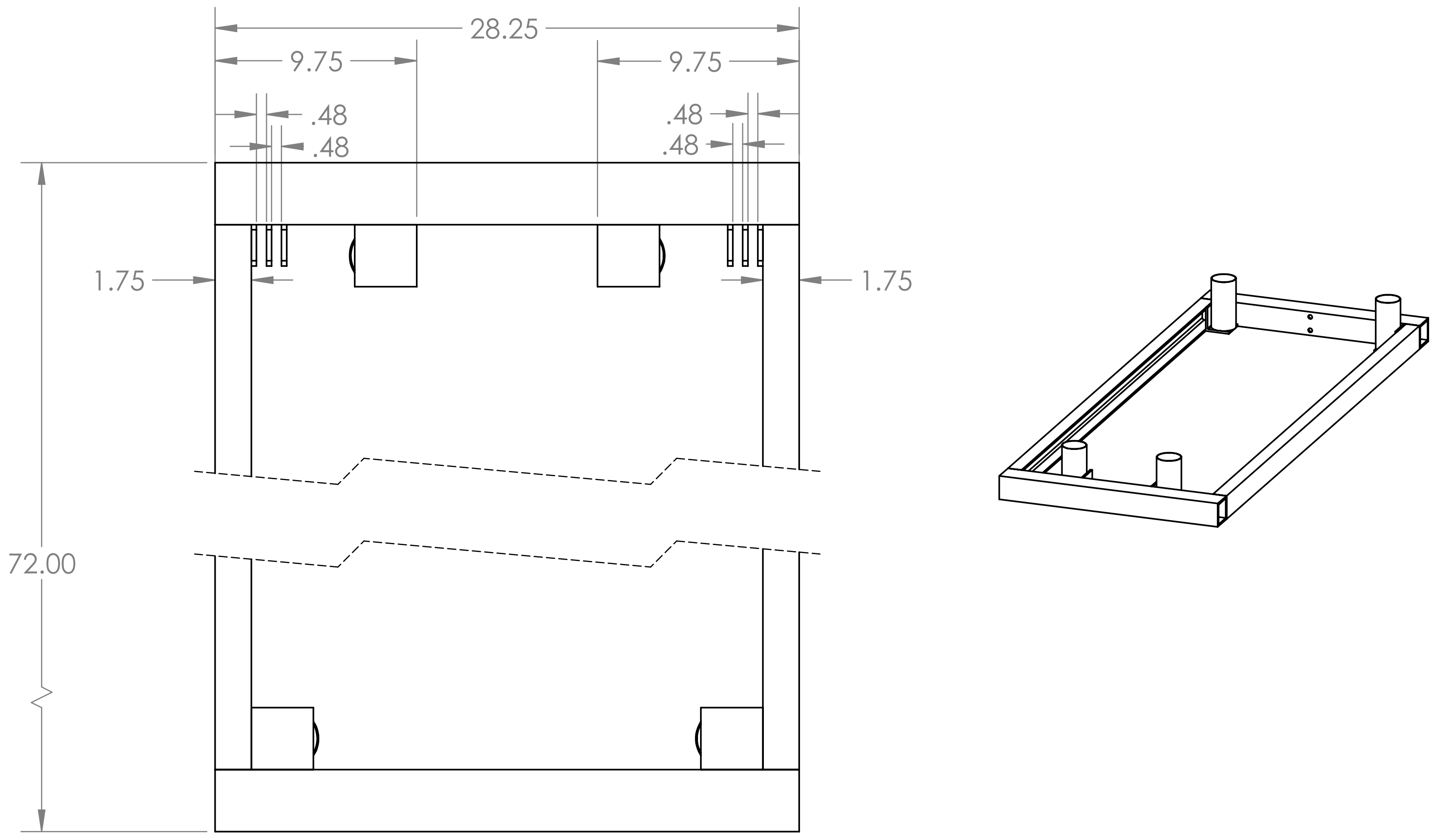
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**	
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: AISI 1020 Steel, Cold Rolled	DWG NO. Actuator Scissor Mount	A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 4.29	SCALE:1:8	SHEET 13 OF 14



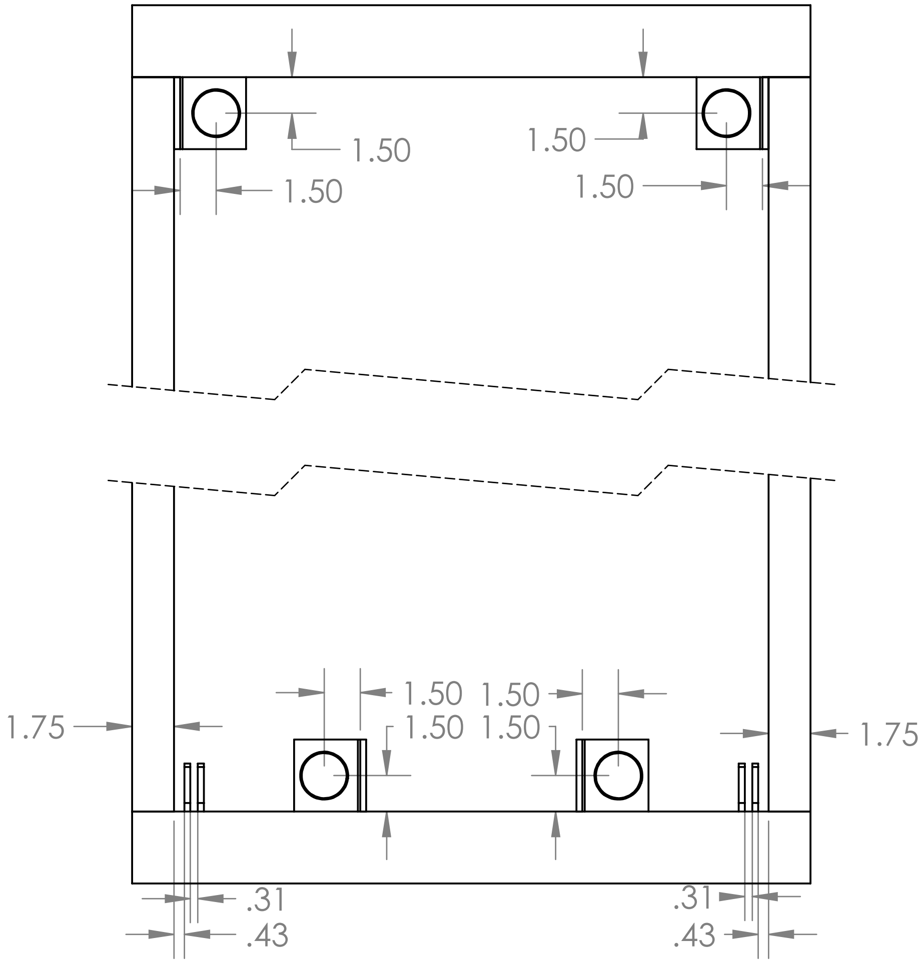
DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL: AISI 1020 Steel, Cold Rolled	DWG NO. Scissor Arm — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 6.06	SCALE:1:12 — SHEET 14 OF 14

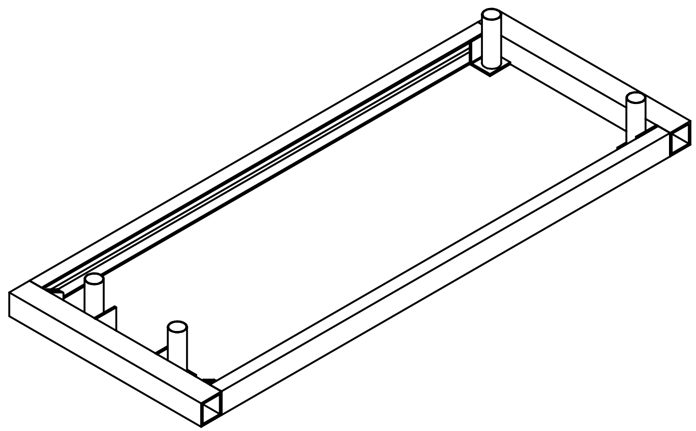
Appendix B: Weldments

Solidworks was used to model the critical weldments for the adjustable height mobile cart. Three weldments are required; the lower frame, the upper frame, and the actuator mounting arm on the scissor lift. All weights are measured in pounds and distances are measured in inches.

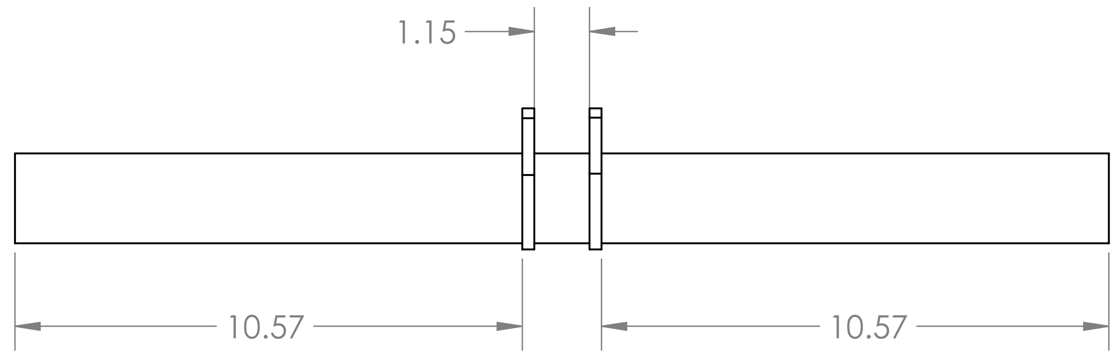


DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL:	DWG NO. Lower Frame Welded — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 36.42	SCALE:1:20 — SHEET 1 OF 3





DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL:	DWG NO. Top Frame Welded — A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 35.73	SCALE:1:20 — SHEET 2 OF 3



DECOR CABINET COMPANY	University of Manitoba	TITLE: **MECH 4860: Engineering Design**
PEPARED FOR: **JUHA KEINANEN**	MATERIAL:	DWG NO. Actuator Bar Welded / A4
PREPARED BY: **TEAM 13: DECOR-ATORS**	WEIGHT: 4.49	SCALE:1:8 / SHEET 3 OF 3

Appendix C: Acculift Quote

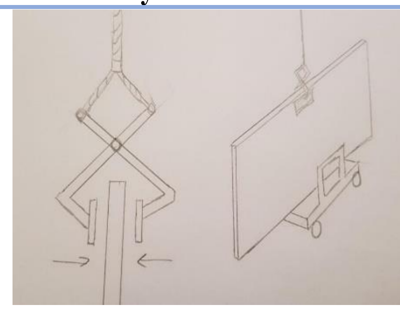
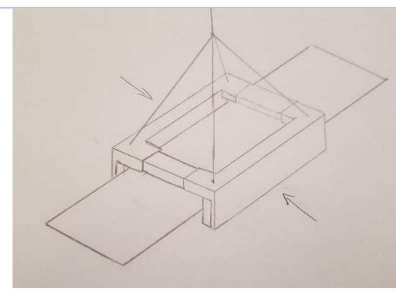
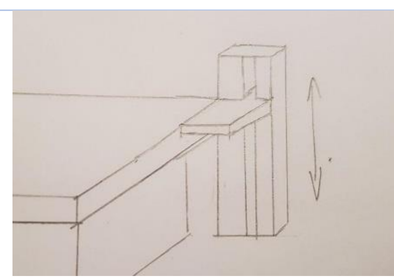
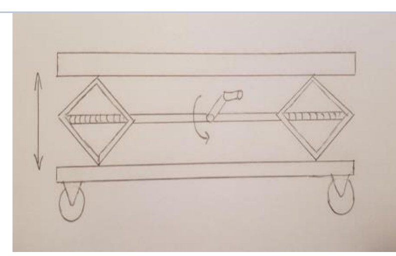
The team was able to meet with a representative from Acculift to discuss procuring a crane as a solution for this project. Details of Decor’s manufacturing layout was shown to the representative who specified a system to meet the needs of this project. The quote received is appended here.

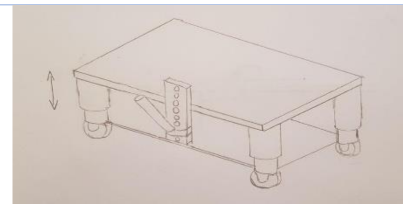
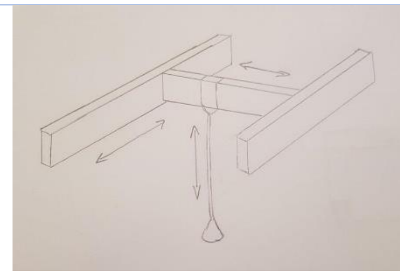
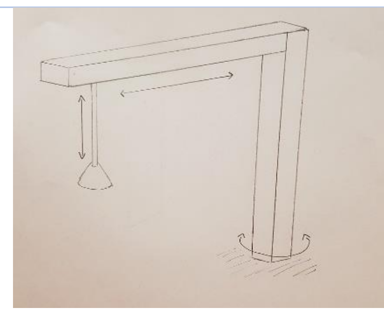
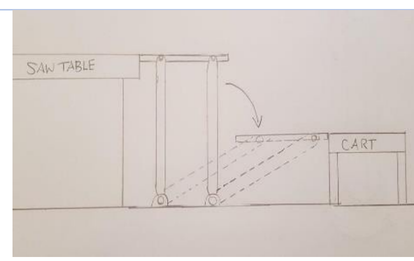
[redacted]

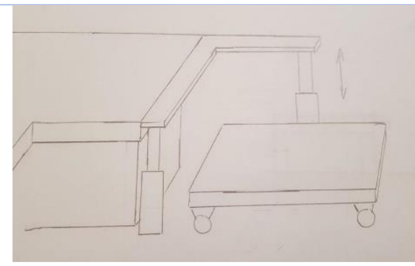
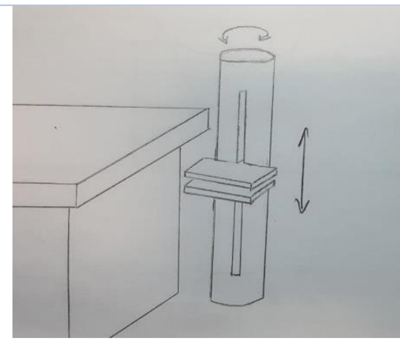
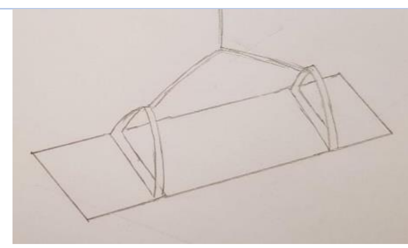
[redacted]

Appendix D: Concept Generation

Before the Vacuum Lift Jib Crane and the Adjustable Cart were selected as the final designs, there were a number of preliminary concepts developed. Many concepts were rejected for various reasons and the ones that were deemed suitable are summarized in this appendix along with a preliminary sketch of each. These concepts were the ones ranked in the decision matrix.

Ser	Concept Name	Description	Preliminary Sketch
1	Edge Gripper	A mechanical gripper that uses gravity and leverage to maintain hold of the panel, the Edge Gripper is to be mounted on a crane and winch system. It moves the panels at 90° to the flat, horizontal position.	 Figure 68: Edge Gripper
2	Phone Gripper	A device inspired by phone holders seen in cars, the Phone Gripper clamps the edges of the panel with rubber grips and is mounted on a crane and winch system.	 Figure 69: Phone Gripper
3	Easy Lift	Fixed at the end of the panel saw table, this device uses a type of gas strut lift to support the weight of one side of the panel as the operator lowers the panel onto the cart.	 Figure 70: Easy Lift
4	Adjustable Cart	The adjustable cart allows the operator to slide the panels directly horizontal from the saw table to the cart, without having to lift or lower the panels. As more panels are stacked up, the cart can be lowered, allowing the precise horizontal movement to be maintained. Various methods	 Figure 71: Adjustable Cart - Scissor Jack

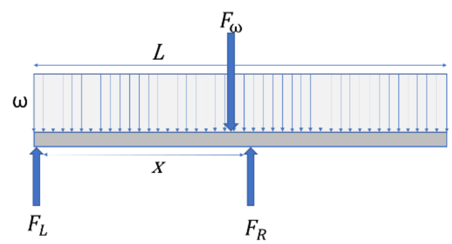
		of raising and lowering can be used.	 Figure 72: Adjustable Cart – Lever Jack
5	Vacuum Lift Gantry	A pump will create a negative pressure in a hose that will suction to the panels. The gantry crane will allow the panels to be easily moved around the workspace and placed on the mobile cart. The operator will not be required to lift the panel at all and the vacuum will not damage the panel.	 Figure 73: Vacuum Lift Gantry
6	Vacuum Lift Gib Crane	This is similar to the Vacuum Lift Gantry, except that the panels will be moved on a Jib Crane instead of a Gantry. This is a column with an arm that is able to swivel on the spot. The vacuum would be connected to a winch that can move up and down the arm. It would have less of a range of motion than the Gantry, however would take up less space.	 Figure 74: Vacuum Lift Jib Crane
7	Lever Lift	The lever lift is a platform at level with the panel saw table that is able to rotate down to the level of the cart. The operator would slide the panels onto the lift which would then rotate down to the height of the cart, maintaining a level, before sliding the panels onto the cart. This could be purely mechanical or could involve some type of pneumatic strut or electric motor.	 Figure 75: Lever Lift

8	L-Extension	The L-Extension is an extension of the end of the panel saw table. The panels would be slid over top of the cart while maintaining the end of the panel on the lift, before the lift is lowered to the height of the cart and the panel can be slid completely off of the lift. The lift would the resume its original position at the height of the table by either a strut or a spring of appropriate stiffness. The operator is required to support some of the weight of the panel.	 Figure 76: L-Extension
9	Clamp Lift Assist	Similar to the Easy Lift, the Clamp Lift Assist would support most of the weight of the panel as the operator lowers it onto the cart. The difference is that the Clamp Lift Assist will clamp onto the panel to prevent it from sliding off unexpectedly and to take more of the weight off of the operator.	 Figure 77: Clamp Lift Assist
10	Jib Crane Straps	This mode of transporting the panel is a set of straps that connect to the panel and are supported by a winch on either a jib crane or a gantry. The straps would be cumbersome to fix on, however would not damage the panel at all and the operator would not have to lift any weight.	 Figure 78: Jib Crane Straps

Appendix E: Stress Analysis

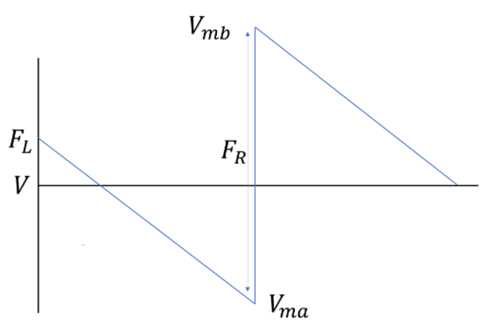
The first member of the cart that was analyzed is the C-channel that will be used as the track for the top scissor roller bearings. The weight of the panels will provide a distributed load along the C-channel. The scissors provide a vertical force in two locations denoted F_L and F_R in Figure 79. These loads will contribute to a shear stress and a bending stress in the C-channel. In Figure 79, ω represents the magnitude of the distributed load in lbf/in. F_ω is the total load from the distributed load in lbf, F_L is the reaction force from the scissor arm on the left and F_R is the reaction force from the scissor arm on the right. V_{ma} and V_{mb} are the shear forces at the point of highest shear as seen in Figure 80.

The analysis of the scissor starts with the static force balancing equations with the distributed load applied. The free body diagram and the equations are shown below as a function of θ. These equations are then used to find the force required to lift the load of panels at a given angle θ. The moment of inertia of the beam, calculated in Figure 81, is used to calculated the bending stress.



$$\sum M_{F_L} = 0 = xF_R - LF_w\left(\frac{L}{2}\right)$$
$$F_L = F_w - F_R$$

Figure 79: C-channel force diagram



$$V_{ma} = F_L - wx$$
$$V_{mb} = V_{ma} + F_R$$

The maximum shear is the absolute value of the larger shear force. The maximum bending moment occurs at the position of F_R.

$$M_B = xF_L - \left(\frac{w}{2}\right)x^2$$

Figure 80: Shear force diagram for top C-channel

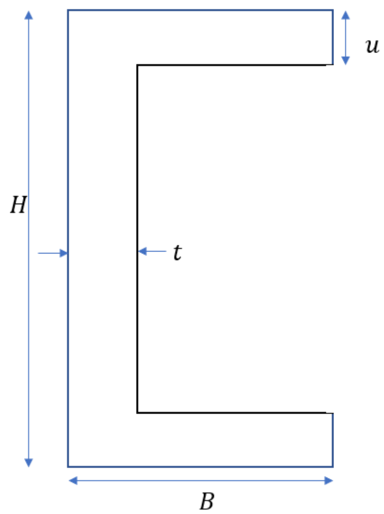


Figure 81: C-channel analysis

The moment of inertia of the c-channel can be found by:

$$I = \frac{1}{12}BH^3 - \frac{1}{12}(B-t)(H-2u)^3$$

The maximum bending stress can be found by:

$$\sigma_B = \frac{M_B\left(\frac{H}{2}\right)}{I}$$

The maximum shear stress can be found by:

$$\tau_{max} = \frac{V_{max}}{A}$$

Where A is the area of the cross section.

The C-channel selected for the top frame of the cart will be taking the distributed load of the panels. The selected C-channel is 6061-T6 aluminum alloy with a tensile strength of 44962 psi and a yield strength of 39885 psi. The dimensions of the cross section can be seen in Figure 82. By applying the dimensions of the cross section as well as the 500 lbf load, the following values were determined.

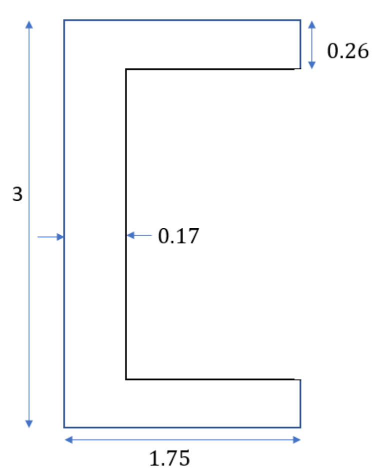


Figure 82: C-channel dimensions in inches

Var.	Value	Unit
F_w	500	lbf
w	6.9440	lbf/in
x	37.0773	in
L	66	in
F_L	50.3986	lbf
F_R	407.9054	lbf
V_{ma}	-207.0662	lbf
V_{mb}	200.8392	lbf
V_{max}	207.0662	lbf
M_B	-2904.4053	in-lbs
I	1.9292	in^4
σ_B	1129.1229	psi
A	3.8584	in^2 (total)
τ_{max}	77.7509	psi

Since both the bending stress and the shear stress are below the yield strength and tensile strength of the material for the C-channel, the beam in the top frame will not yield.

Choosing a spring for this application required the maximum and minimum values of separation of the top frame and the bottom frame. Using an arm length of 44" and the dimensions for the frame specified above, a maximum separation of 21.5" and a minimum of 6.75" was found. Using the separation values and the load at both positions, a spring coefficient was specified.

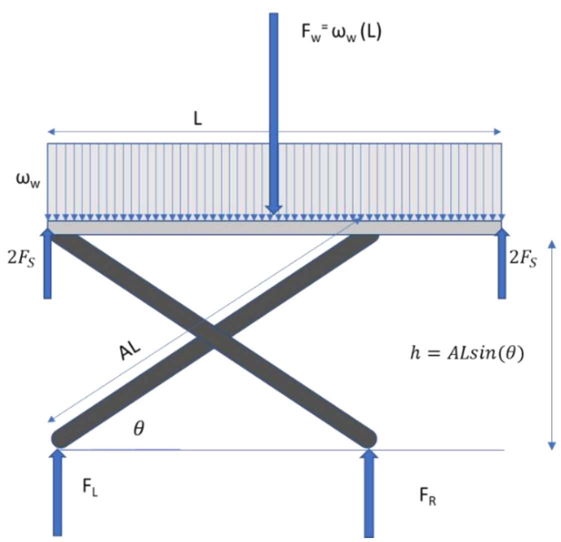
$$k_{total} = \frac{\Delta F}{\Delta x} = \frac{500 - 0}{21.5 - 6.75} = 33.90 \frac{lbf}{in}$$

With four springs in parallel, the coefficient for each spring is 8.475 lbf/in.

The selected spring has a spring coefficient of 7.85 lbf/in. At the minimum height of 6.75" one spring produces 127.65 lbs of force for a total load bearing capacity of 510.6 lbs.

$$F = kx = 7.85(23.302 - 6.75) = 127.65\ lbf$$

The free body diagrams used to calculated the forces in each scissor are shown in figures Figure *83*, Figure *84*, and Figure *85*.



$$\sum F_y = F_L + F_R + 4F_S - F_w = 0$$

$$\sum M =$$

$$F_R(AL)\cos(\theta) + 2F_S(L) - F_w\left(\frac{L}{2}\right) = 0$$

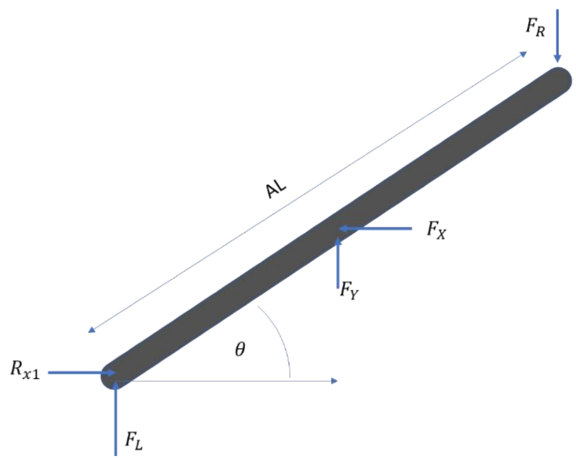
$$F_R = \frac{F_w(L/2) - 2F_S(L)}{(AL)cos(\theta)}$$

$$F_L = F_w - F_R - 4F_S$$

$$F_S = k(H - h)$$

Where H is the free length of the spring

Figure 83: Free body diagram of the scissor lift with the springs added



$$\sum F_y = F_L + Fy - F_R = 0$$

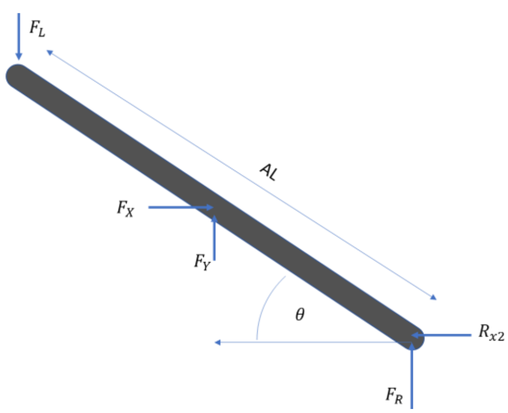
$$\sum F_x = R_{x1} - F_x \ = 0$$

$$\sum M = F_y\left(\frac{AL}{2}cos(\theta)\right) + F_x\left(\frac{AL}{2}sin(\theta)\right) - F_R(ALcos(\theta))$$

$$Fx = \frac{F_R(ALcos(\theta)) - F_y\left(AL\frac{cos(\theta)}{2}\right)}{AL\frac{sin(\theta)}{2}}$$

$$R_{x1} = F_X$$

Figure 84: Free body diagram the right arm



$$\sum F_x = F_x - R_{x2} = 0$$

$$\sum F_y = F_R - F_y - F_L = 0$$

$$F_y = F_R - F_L$$

$$F_x = R_{x2}$$

Figure 85: Free body diagram of the left arm

The forces are then divided into axial and tangential components to find compressive and bending forces.

The compressive forces in the actuator are shown in Figure 86 and the scissor arms are shown in Figure 87. As the table top is lowered, the load on the springs increases so that at a height of 6.45”, the force required by the actuator is 0.

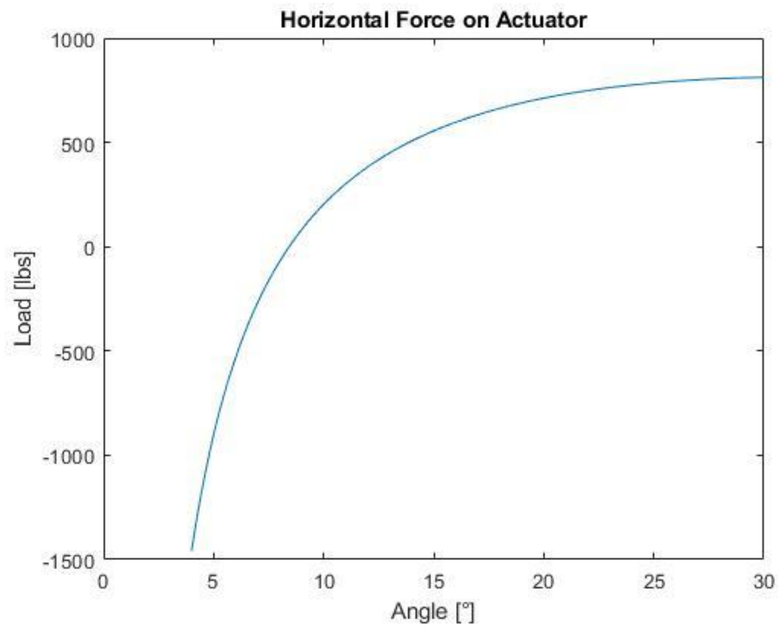


Figure 86: Force on the actuator with the springs

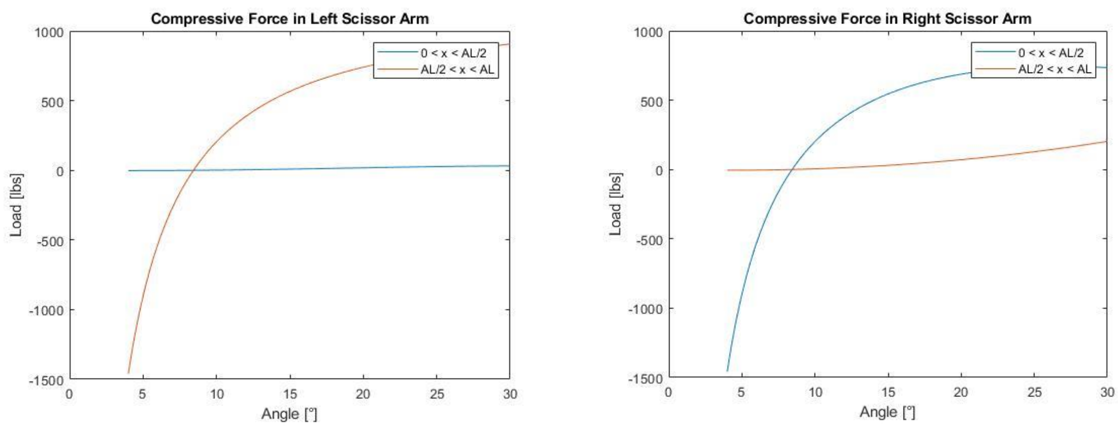


Figure 87: Compressive forces in each arm with the springs

The bending moments in the scissor arms are plotted as a function of θ in Figure 88. The maximum bending moment at the lowest height of 6.75" is plotted in Figure 89.

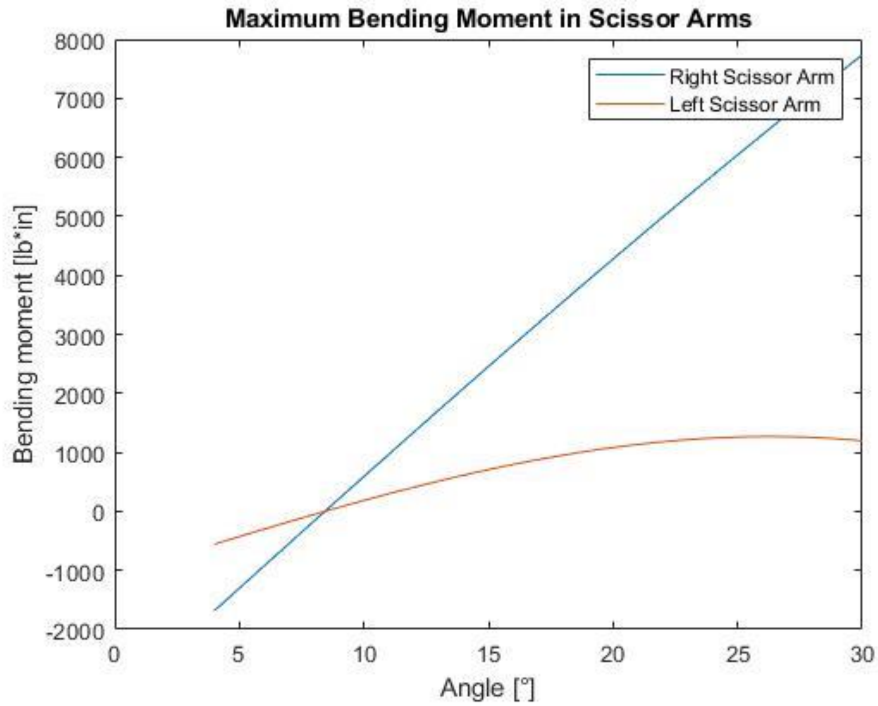


Figure 88: Moment as a function of angle in each arm with the springs

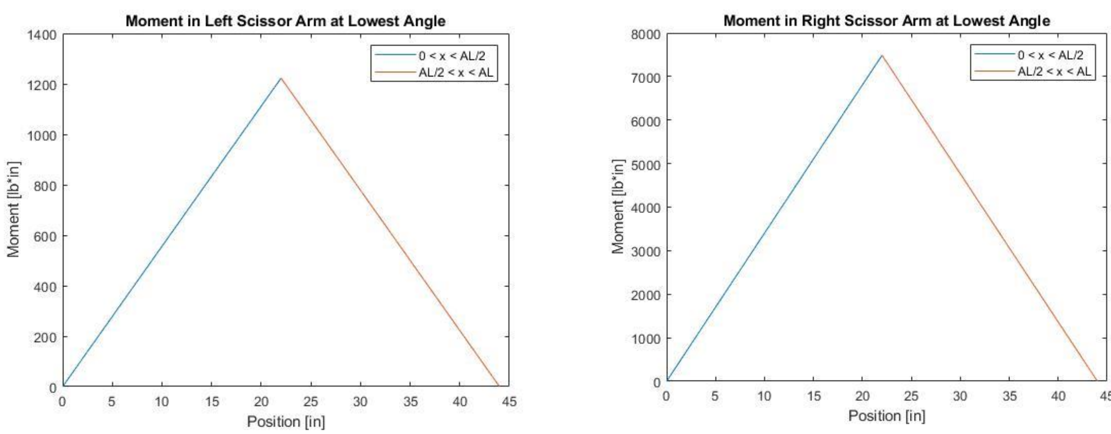


Figure 89: Maximum moment at lowest position in both arms

The maximum stress in the right scissor arm was calculated to be 46400 psi which translates to 11600 psi and factory of safety of 4.62 per arm. Similarly, for the left arm, the maximum stress is 9123.4 psi which translates to 4566.2 psi and a factor of safety of 11.76.

Next, the actuator mounting bar is analyzed with a maximum force of 810.27 lbs. This is the maximum force the actuator experiences during the loading. Using the fixed beam approximation, the maximum moment is 2304.2 lbf*in. The maximum stress in the bar is calculated using the following equation:

$$\sigma = \frac{(2304.2)\left(\frac{15}{16}\right)}{0.2559} = 8441.54\ psi$$

This gives a factor of safety of 6.36.

The lower frame was put under a 2000 lbf load in a finite element analysis in SolidWorks. Figure 90 shows the results of the simulation. The maximum Von Mises stress is 8056 psi, resulting in a factory of safety of 4.95.

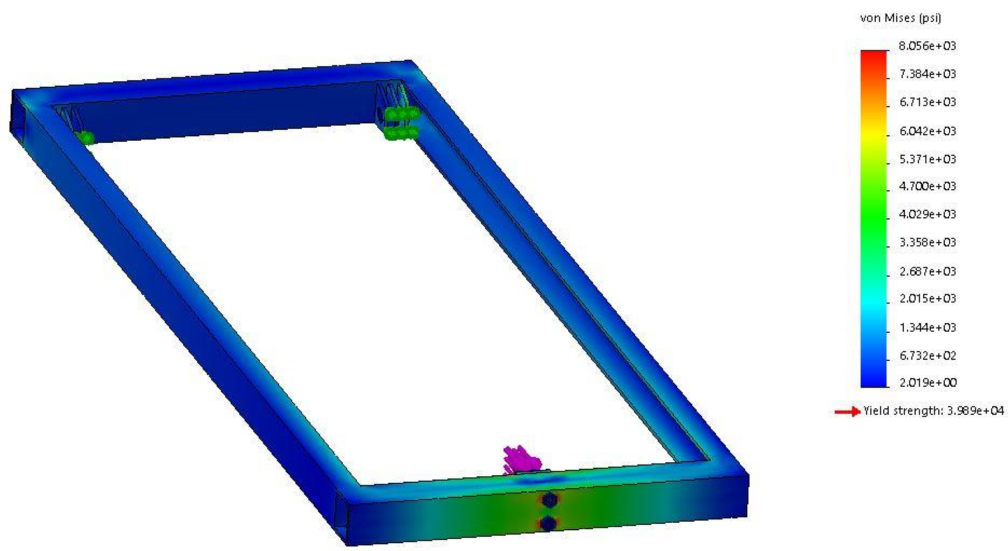
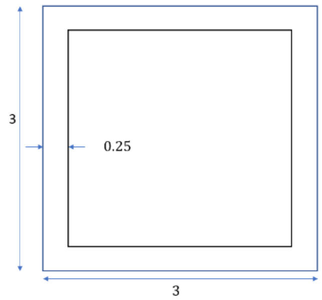


Figure 90: Von Mises stress in the lower frame under a 2000 lbf tensile load

The cart has six legs. For the analysis, only the front and rear legs will be considered because there will be times when the cart rolls over a bump or a ramp and the center legs are not touching the ground. The maximum normal stress in the legs can be found by:

$$\sigma_n = \frac{F_n}{4A} \quad [4]$$

Where F_n is the weight of the panels plus the weight of the cart and A is the cross-sectional area of a single leg shown in Figure 91.



Var.	Value	Unit
A	2.75	in^2
σ_n	59.5	Psi

Figure 91: Leg dimensions in inches

Given the stresses calculated in all the designed components and that the maximum force the linear actuator is 810.27 lbf which results is a factory of safety for the actuator of 2.46, the components are adequately specified for the loads place don them.

To ensure that the cart can be pushed around by a single operator, the team followed the procedure outlined in Rolling Resistance and Industrial Wheels [15] to find the sustained pushing force and the starting force to move the cart. To ensure ergonomic use of the cart this paper suggests that if 75% or more of the female population can move the cart, according to the Liberty Mutual Manual Materials Handling Manual [27], then the cart is adequately safe for the working environment. The sourced casters use phenolic wheels which offer a low coefficient of rolling resistance. With a fully loaded cart, 500 lbs of panels, the starting force was found to be 22.75 lbs and the sustained force was found to be 9.1 lbs. Using the most conservative values for frequency and pushing distance Liberty Mutual Manual Materials Handling Manual [27] gives 90% of the female population can move the cart. Thus, it is safe for one operator to move the cart.