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MECH 4860 – Engineering Design

Final Design Report

Column Transportation

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DECOR CABINET COMPANY

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- MECH 4860 PROJECT REPORT SUBMISSION -

Dr. Labossiere,

Our team is pleased to present to you our final report entitled *Column Transportation* on this Monday the 1st of December.

This report discusses the design and application of a custom cart that can be used for transportation of large wooden columns in the finishing department at Decor Cabinets, in Morden, Manitoba. Project objectives were satisfied and our team predicts a significant reduction in injuries due to heavy lifting.

If there are any inquiries regarding this report, please contact myself, or other members of the team via their University of Manitoba email.

Sincerely,

Wojciech Koch

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EXECUTIVE SUMMARY

The Decor Cabinet Company assigned our team to design a cart that could be used in their finishing department, to reduce the amount of injuries due to lifting heavy columns. After considering different design concepts, performing extensive research and discussing the solution with the customer, our team designed a custom cart that holds columns in place, while allowing rotational motion of the column on top of the cart, and having adjustable height.

A Dayton hydraulic scissor lift cart was selected as the base of the design due to its stability. It was proven that it is large enough to support the 10x3x0.5 foot columns. The height can be adjusted from 12-$^{1}/_{4}$ to 35-$^{1}/_{4}$ inches to accommodate a wide range of operator heights and aid in loading columns.

The SKF UT05CN turntable is attached on top of the cart to provide rotational motion for the fixture. It satisfies the established maximum load and moment capacity requirements, of 596 lbs and 3576 in·lbs., respectively.

Our team used various analytical techniques to design a fixture optimal for Decor's columns. The resulting fixture design is ¼" thick and manufactured out of ASTM A36 steel. Since the dimensions of each column vary, Decor has agreed to modify the interior of their columns, to uniformly fit the fixture designed by our team.

The final design has met the client-established project objectives. Our cart design will reduce the injury risk in the finishing department by removing the need to manually lift or flip large columns. The cart will also improve production efficiency by allowing all sides of a column to be operated on at once and providing easier transportation between cells.

1 INTRODUCTION AND BACKGROUND

The Decor Cabinet Company is a manufacturer of custom kitchen, bath, and speciality cabinets [1]. The company operates two production facilities and a showroom based in Morden, Manitoba, and is expanding throughout Canada and the USA. The company's modern 145,000-square-foot facility, quality materials, sophisticated equipment and highly-skilled workforce give Decor Cabinets the ability to create a high quality product [2].

During the last few years, people's preference shifted from traditional cabinet design to a modern one. The new style (Figure 1) requires the use of large columns and panels such as the ones shown in Figure 2 and Figure 3.

Figure 1: Modern kitchen design [1]

As these large parts are assembled and transported through the factory floor, they are awkward for employees to handle. Our project is specifically concerned with the finishing department, where there is excessive lifting, rotating and reworking of parts. The result of this excessive part handling has been an increase in body strain injuries and decrease in production flow efficiency. Over 16 injuries were reported in 2013 due to heavy lifting [3].

Figure 2: Large panels

Figure 3: Large column

Our design team focused solely on the oversized columns, leaving the panels out of the solution. The maximum column size is 10 feet long, 3 feet wide and 0.5 feet thick, and can weigh as much as 135 kg [3]. Each part goes through a 4-5 stage finishing process using carts for transportation and storage.

1.1 OBJECTIVES

In order to help our team obtain a solution, the following objectives were established during the first phase of the project:

- Design a system that reduces the number of workplace injuries caused by handling columns in the finishing department
- Reduce the amount of times the column must be directly handled by workers in the finishing department

- Maintain a similar level of efficiency and work flow with respect to the current design
- Gain customer acceptance

During the first phase of the project, the following constraints and limitations were identified through the problem analysis or provided by the customer:

- The solution must be purchased/manufactured for less than $2000 per cart
- The solution is to be manufactured in the customer's facility or outsourced to a nearby machine shop

1.2 TARGET SPECIFICATIONS

During the first phase of the project, our group established a list of requirements that must be satisfied by the solution. With help from our customer, all the requirements were prioritized according to their importance in the overall design. Once prioritized, each requirement was assigned a metric and quantifiable target (if applicable). The targets and needs have been tabulated and organized by category as shown in TABLE I.

Note: targets listed as "n/a" are subjective and "+ / -"signifies an increase or decrease from current norms.

TABLE I: TARGET SPECIFICATIONS

#	Category	Priority	Metrics	Unit	Target
1	**Solution ensures health and safety of workers throughout finishing process**				
1.1	Allows use by people of various heights	1	Employee height	in	52 - 74
1.2	Minimize chance of injury	1	Number of reported injuries	%	-50
2	**Solution ensures efficiency of production flow**				
2.1	Allows for smooth and rapid transportation between stages	2	Transportation time between cells	%	-10
2.2	Accommodates multiple parts	3	Number of large parts on cart	#	4
2.3	Integrates with heat tunnel system	3	Yes/No	n/a	Yes
2.4	Accommodates large parts	2	Maximum part weight	kg	135
			Maximum part size	ft	10x3x0.5
3	**Easy to use**				
3.1	Minimizes required amount of part handling	2	Number of loading/unloading	%	-50
3.2	Minimizes personnel to transport parts	4	Maximum number of employees required to transport the part	#	1
3.3	Makes product accessible for finishing on all external surfaces	2	Yes/No	n/a	Yes
4	**Solution has a long life span**				
4.1	Solution can sustain long term use	2	Minimum Lifetime	years	10
4.2	Resistant to chemicals applied during finishing processes	3	Yes/No	n/a	Yes
4.3	Easy to clean	4	Time required to clean it	min	10
4.4	Withstand high temperatures	3	Maximum temperature the cart can endure	°C	100
5	**Cost effectiveness**				
5.1	Can be manufactured locally	4	Maximum sourcing distance	km	50
5.2	Can be manufactured at a low cost	4	Maximum manufacturing cost	$ CDN	2000
6	**Ensures integrity of parts**				
6.1	Part on the cart does not get damaged	2	Number of discarded parts due to mishandling	%	-20
6.2	Can accommodate wet/drying parts	2	Number of reworks due to inconsistent drying	%	-20

TABLE I shows that minimizing chance of injury and allowing employees of varying heights to use the cart, were the most important specifications that our solution had to meet.

Therefore, our priority was to first improve the safety of the cart and then satisfy other specifications, such as smooth and rapid transportation and sustaining a long term use.

1.3 CURRENT METHODS

Current carts, an example of which is shown in Figure 4, were designed with small and light parts in mind. These carts consist of rows of bars that the part is placed on top of, or in the case of columns, the bars insert through the open face of the column. Placing large parts on the existing carts is unsafe, not ergonomic, and requires dangerous overhead lifting. Handling very large parts is a struggle; therefore usually two employees are required to operate the cart. To improve safety, some carts have been modified to have middle racks removed to allow for larger parts to be placed lower down.

Figure 4: Current cart

During the finishing process, carts are moved through 4-5 stages. Parts must be picked up, rotated, and moved to and from carts multiple times. A visual representation of the process flow is shown in Figure 5.

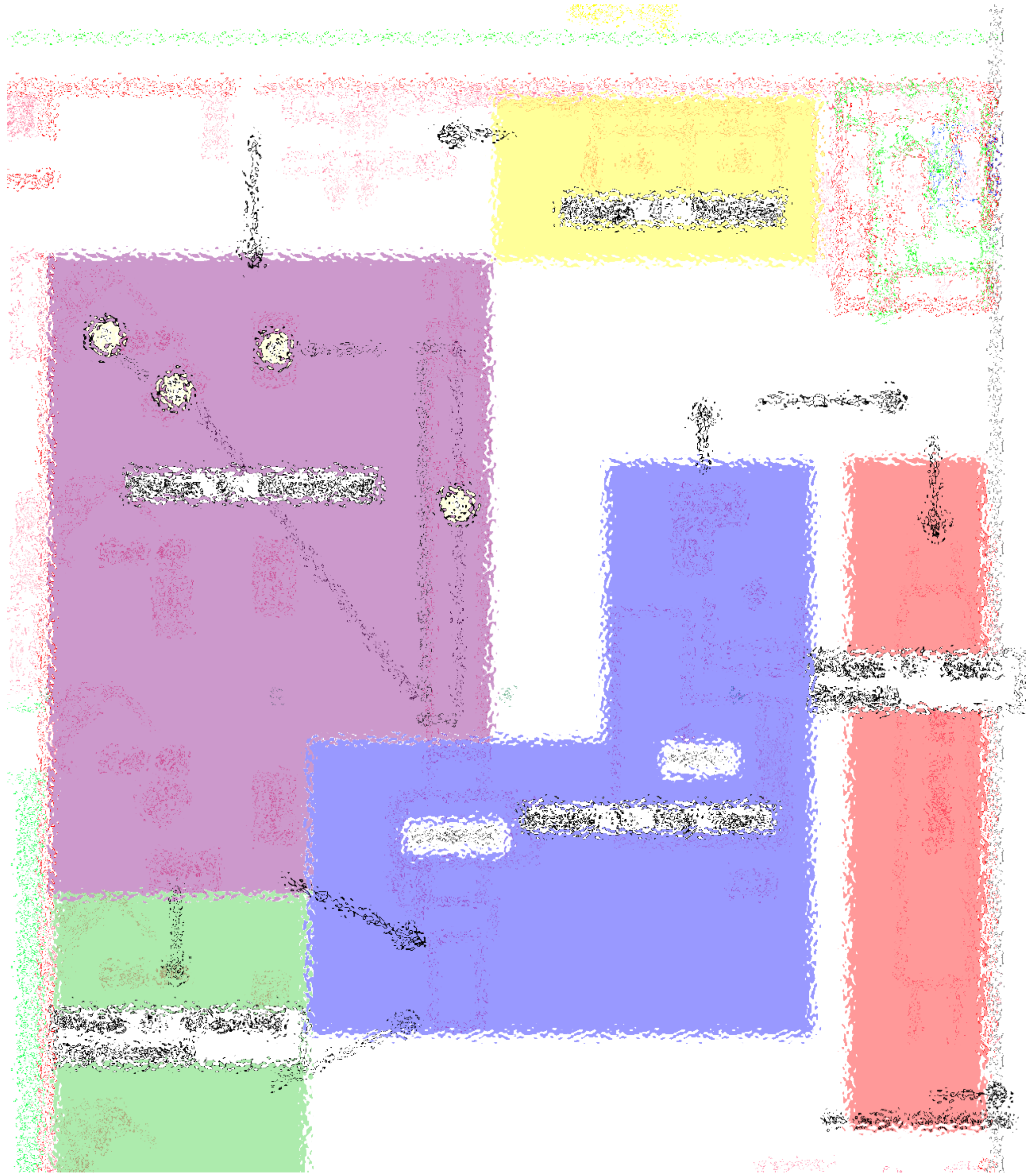

Figure 5: Finishing department layout [3]

1.4 CONCEPT DEVELOPMENT

Following the first phase of the project, six concepts were generated and screened as described in Appendix A. The final two concepts, the retrofitted table jig and an extendable arm attached to current cart were then presented to the customer.

During a meeting with Decor representatives, a new concept was developed, based on the retrofitted table jig concept. They asked for a cart that is capable of vertical translation, with a fixture on top that is free to rotate. The lift table concept was then developed by our team and became the final solution, as further discussed in Section 2 of this report. At that point, the customer narrowed the focus of our design to large columns only, leaving panel transportation out of the scope of the project.

In order to standardize the process of attaching the column to the cart, our customer agreed to build a substructure inside the column, similar to the one shown in Figure 6. The result is a simple and cost effective way of securing a column of any size to the cart, using only one fixture.

Figure 6: Column substructure

2 DETAILS OF DESIGN

The product our team has designed is a customized scissor lift cart, shown in Figure 7, which consists of three main components: a hydraulic scissor lift cart, an industrial turntable, and a custom fixture. This cart design will eliminate the need for part handling in Decor's finishing department, as it can be pushed directly into the staining booths, as well as provide access to each side of the column on which finishing operations are performed. This section provides details on the final cart design our team has generated for moving and storing oversized columns as they progress through the finishing department.

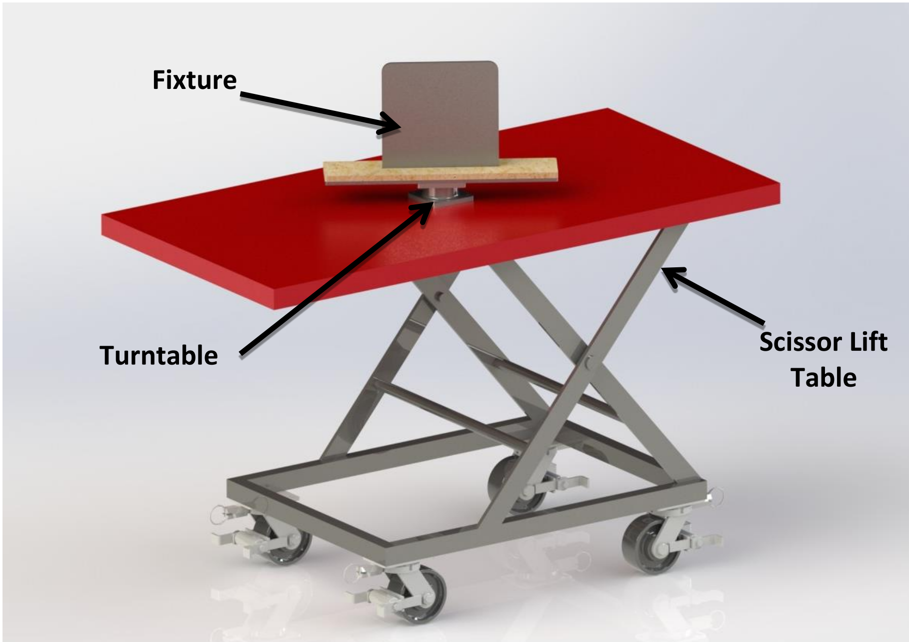

Figure 7: Final design features

2.1 DESIGN FEATURES

The foundation of our design is a hydraulic scissor lift cart. The hydraulic system of this cart provides vertical linear motion. This function allows for easy loading and unloading of a part before and after it enters the finishing department. It accommodates a wide range of operator heights and gives them the ability to adjust the height of the cart for their preference as they are working on it. They will also gain easy access to all sides of the part. Further details about the scissor table selection, as well as analysis and complete specification data, are described in Section 2.2.

The next component is an industrial turntable with the ability to support large loads. The turntable will be bolted down to the cart, and the fixture will be bolted to the top of the turntable. The turntable provides the ability to rotate the part, allowing access to all sides within the spray booth. Without the turntable, the entire cart would need to be rotated to gain access to all the column's sides, which may be dangerous and difficult if there is anything on the floor. The bolts used in the design are sized to the specifications of the chosen turntable. For the purpose of this design, we recommend using type 316 stainless steel bolts, washers and nuts for superior corrosion resistance. Further details about the industrial turntable selection, as well as analysis and complete specification data, are described in Section 2.3.

The column will be held in place by a fixture that will go through the open face of the column, as shown previously in Figure 6. The fixture consists of a vertical steel plate welded to a steel base. To provide a softer surface for the column to sit on, as well as protect it from the heads of the bolts, a pad made of wood will slip over the base of the fixture. As mentioned in Section 1.4, Decor will redesign the internal features of their columns to allow for a singular fixture size that will work for all of their column thicknesses. This fixture is to be fabricated at Decor's manufacturing facility. For further details about the fixture, including material selection, analysis and complete specification data see Section 2.4.

Our design will allow Decor's workers to place the column on the fixture once, as illustrated in Figure 8, prior to entering the finishing department. It can be moved directly into spraying or sanding booths, and give the workers access all five sides of the columns due to the vertical translation and rotational abilities of the fixture. Thus, our design eliminates the need for the column to be handled by workers within the finishing department and therefore reducing the risk of injuries, reducing the amount of part handling and improving production efficiency.

Figure 8: Final design with a column

2.2 SCISSOR CART SELECTION

Following a discussion with the customer, a scissor lift cart was selected for the design. Compared with a custom cart, an off-the-shelf product is easier to maintain, more cost effective, and can be purchased from many different retailers. A set of requirements was established to find the optimum industrial product which could be used at Decor.

The minimum cart capacity was found by considering the heaviest column manufactured at Decor. A safety factor of two was applied to the design, resulting in a weight capacity of 596 pounds, as determined by Equation 1.

$$Capacity = (Safety\ Factor) \cdot (Max.Part\ Weight) = 2 \cdot 298 = 596\ lbs \quad (1)$$

Since the cart will be used on a concrete shop floor, adequately large casters manufactured out of a soft and durable material were selected. With a minimum diameter of five inches, the casters are made of polyurethane to reduce the amount of force required to push the cart, as well as make sure there is no damage made to the concrete floor. Two casters are free to swivel and two are fixed, so as to easily control the cart as it rolls. A foot brake should be available at each caster, in order for the employees to be able to secure the cart in place while working on the column.

The height adjustment was an important parameter of the final design. As mentioned in the target specifications, it was important to make the final solution accessible for employees of a wide range of heights. A minimal height adjustment of 12 inches was therefore established as a requirement.

Global Industrial is a manufacturer of a mobile scissor lift cart, which supports up to 1100 lbs. The cart's table dimensions are 36 by 23 inches and can lift up to three feet. As shown in Figure 9, the scissor lift cart is mobile, with five inch casters and has a foot pump for the easy lifting motion. [5]

Figure 9: The Global Industrial lift cart, the typical lift cart on the market [5]

The model shown in Figure 9 is a typical scissor lift cart used for comparison purposes with a specific cart our team requires. A sufficient lift cart model for our project must be wider to support the ten foot column being placed on its surface. Therefore, our team found an industrial table that meets all the established requirements.

The lift cart chosen for our final design is the Dayton scissor lift table from Grainger (Figure 10). The lift table is made out of steel and has a maximum weight capacity of 1000 lbs. Rolling on two five inch fixed and two five inch swivel casters, the lift cart can move easily with a push on the handle. A hydraulic foot pump is used to increase the table height up to 35.25 inches, while a release brake is located on the top of the push bar to slowly reduce the height to a minimum of 12.25 inches. [6] The main advantage of the Dayton lift table over other models is its size. The table is 61 inches long and 31.5 inches wide, thereby making the cart more stable. Technical specifications of the selected scissor lift cart are shown in TABLE II.

Figure 10: Dayton scissor lift cart [6]

TABLE II: SCISSOR LIFT SPECIFICATIONS [6]

Property	Value
Maximum load capacity	1000 lbs
Platform length	63 inches
Platform width	31.5 inches
Caster diameter	5 inches
Foot pump system type	Hydraulic
Table weight	345 lbs

Our team made a series of calculations to ensure that the table will not flip when loaded with the largest column manufactured at Decor. Since the column placed on the table top will be able to freely rotate 360 degrees, the worst case scenario was considered. The column was assumed to be placed with its longest side parallel with the width of the table, while the table is raised to its highest point. The center of gravity of the cart was assumed to be in-between the table surface and the column, as indicated in Figure 11.

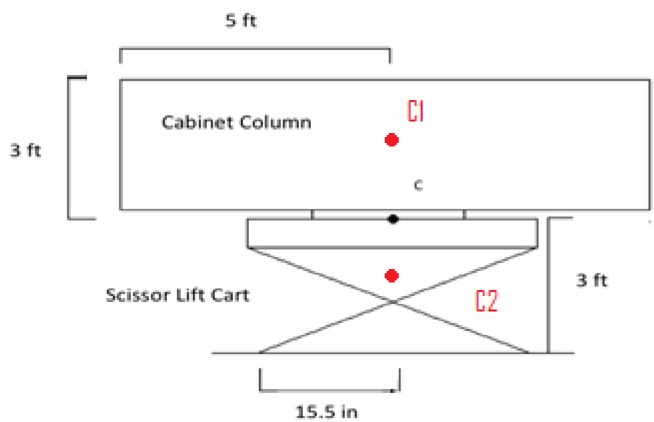

Figure 11: The center of gravity placement

The center of gravity C2 of the lift cart depends on the set height. If the worst case scenario is chosen as the most likely height to tip, the height of the cart is set to 3 feet. Due to the fact that the center of gravity of the cart C2 is unknown, C2 was assumed to be closer to the surface of the table. With the cart weighing more than the column, the resulting center of gravity C is assumed to be on the table surface of the scissor lift cart.

In order to calculate the amount of force required to tip the cart over, all forces acting on the cart significant to the analysis were considered, as shown in Figure 12.

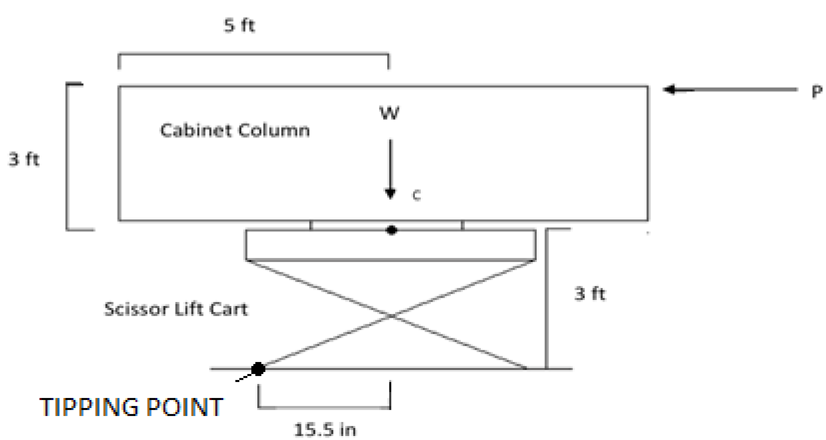

Figure 12: Horizontal load applied on column

Since the system is in equilibrium, the moments taken about the tipping point, TP, of the cart are equated to zero, as described by Equation 2.

$$\sum M_{TP} = 0 = -\mathrm{W}(15.5\mathrm{in}) + \mathrm{P}(72\mathrm{in}) \tag{2}$$

With the largest column placed on the table top, the total weight, W, including the cart was determined using Equation 3. The cart weighs 345 pounds while the largest column is 298 pounds.

$$W = 345 + 298 = 643 \text{ lbs.} \tag{3}$$

Substituting Equation 3 into Equation 2 resulted in a maximum pushing force, P, of 138 lbs. The pushing force cannot be higher than 138 lbs., or the cart will begin to flip over. With a thinner table, the likelihood of tipping increases, which is why the Dayton lift cart was chosen for our design instead of the typical lift cart.

Another scenario is considered to see if the cart is more likely to tip when the load P is being applied to the top of the part (someone leaning or accidentally pushing down on the part). The moment was similarly calculated using Equation 2, as indicated below.

$$\sum M_{C} = 0 = -\mathrm{W}(15.5\mathrm{in}) + \mathrm{P}(44.5\mathrm{in})$$

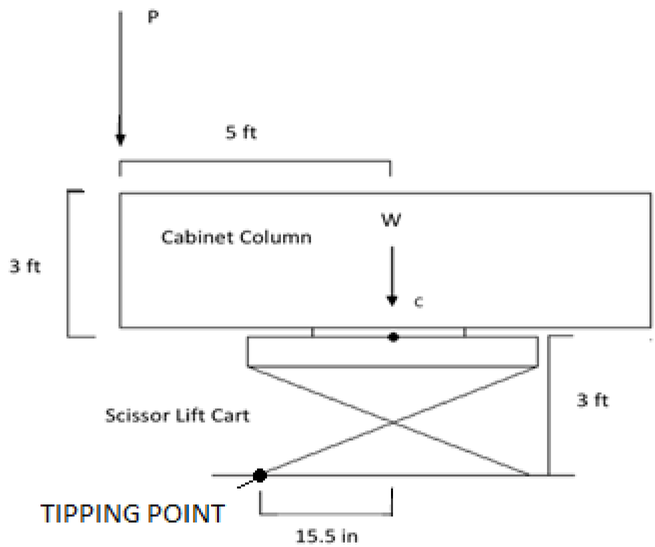

Figure 13: Downward load applied on column

Assuming the total weight of 643 lbs. the pushing force was determined to be 224 lbs. The table has a better chance of tipping over when the force is applied from the side of the part. Therefore, if an employee were to lean on the side of the column while it is on the table, a force of minimum 138 pounds would be required to tip the cart over. Since it is unlikely for an employee to apply such a force to a cart, the design is therefore considered safe.

The Dayton scissor lift cart is a crucial part of our design and is proven to be the better option than a typical scissor lift cart. A small modification has to be made to the push bar of the scissor cart. In order for the columns to swing 360 degrees around the cart, the bar with the release handle must be removed. The handle can be easily removed and placed on the side of the cart. Additionally, our design team recommends covering the lifting mechanism components to protect them from overspray and dust. An industrial quality scissor table curtain should be used for that purpose. It can be purchased at major retailers such as McMaster Carr.

2.3 TURNTABLE SELECTION

One of the main design requirements specified by the customer was the ability to rotate the column while it is secured onto the lift table. Many different solutions to that problem were considered in Phase 2 of the project, and our group decided to use a commercially available industrial turntable. Using an off-the-shelf product is more cost-effective when compared to a custom design. In order to pick an appropriate product, different design criteria were established and are discussed in the following sub-sections. These include the maximum load and moment capacity.

2.3.1 Maximum Load Capacity

Maximum load capacity is the maximum weight applied to turntable, which is evenly distributed. The turntable has to be capable of supporting at least 135kg (298lbs), since that is the maximum weight of the largest column. Our group decided to include a safety factor of two into the design, to ensure the safety of workers is not compromised. Applying a safety factor of two helps avoid any damage to the rotational mechanism, in case the cart is overloaded. The required load capacity, P, was calculated using Equation 4 as follows:

$$P = (Safety\ Factor) \cdot (Max.\ Part\ Weight) = 2 \cdot 298 = 596\ lbs \quad (4)$$

2.3.2 Moment Capacity

Moment capacity is the maximum moment the turntable bearing mechanism can withstand without getting damaged. The moment is a result of an off-centre load, P, applied at a certain distance, D_1, from the center of the turntable as indicated in Figure 14. The horizontal distance D_1, is measured between the center of the column and the point of load application.

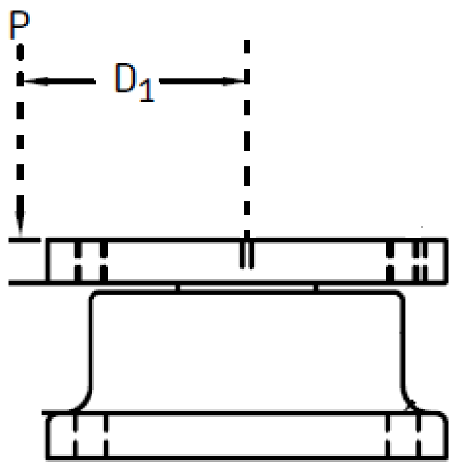

Figure 14: Off-centre load [10]

The maximum off-centre load was assumed by our group to be 59.6 pounds and applied at the farthest point from the centre of the column, as indicated in Figure 15. The magnitude of 59.6 pounds was chosen, since it represents 20% of the maximum part weight of 298 pounds.

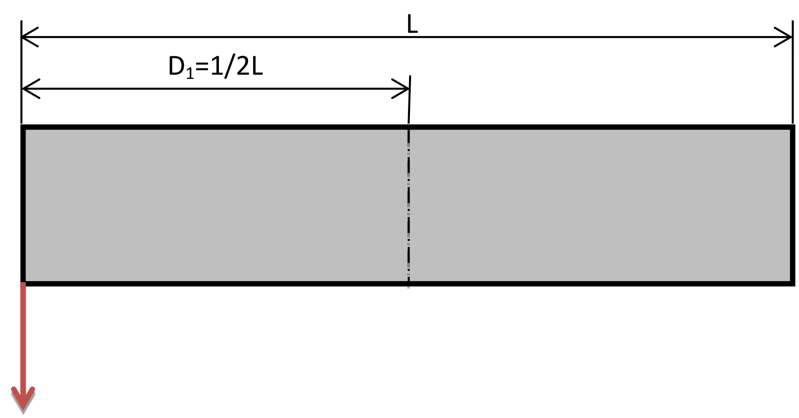

Figure 15: Assumed off-centre load position

The resultant moment, M, caused by the off-centre load, was calculated using Equation 5.

$$M = D_1 \cdot P \tag{5}$$

Since our group wanted to consider the worst case scenario, the off-centre distance was assumed to 60 inches, since that is half the length of the largest column manufactured at Decor. Therefore, the required turntable moment capacity was calculated as follows:

$$M_{max} = 60 \cdot 59.6 = 3576 \; in \cdot lbs.$$

Equation 5 was also used to calculate resulting moments for different off-centre distance values. The off-centre load magnitude was considered constant at P=59.6 pounds. Figure 16 represents the results of the analysis.

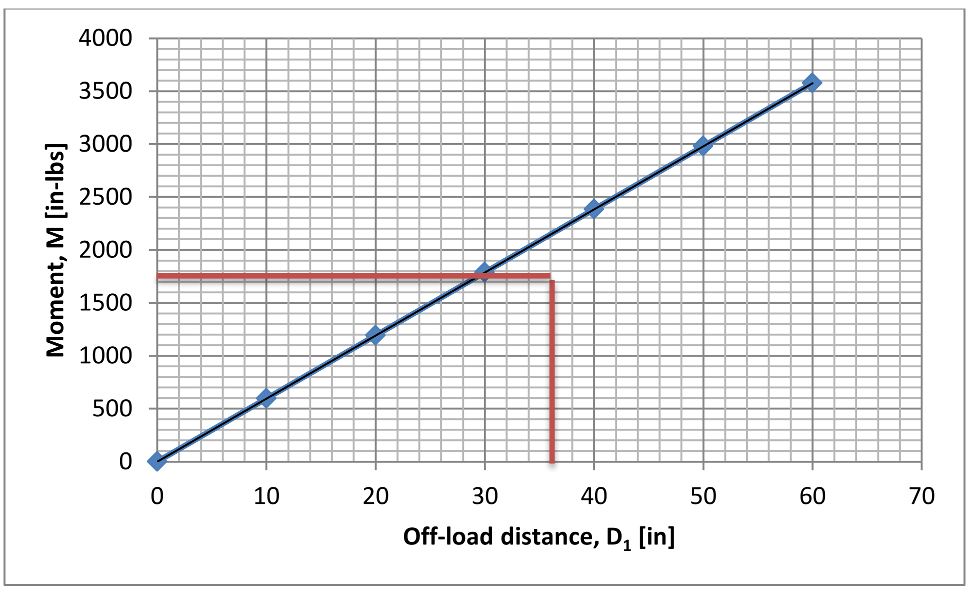

Figure 16: Moment vs. off-centre distance graph

Figure 16 shows the relationship between the resulting moment and the off-load distance is linear. Since the majority of column lengths do not exceed six feet (72 inches), the moment capacity requirement of 3576 inch-pounds is adequate. If ever required, a turntable with a higher moment capacity could be applied.

2.3.3 Turntable Selection

With the maximum load and moment capacity values obtained and equal to 596 pounds and 3576 inch pounds, respectively, a commercially available turntable mechanism was selected. Our group decided to use the UT05CN industrial turntable manufactured by SKF, similar to the one shown in Figure 17.

Figure 17: SKF UT05CN [10]

The UT05CN industrial turntable is ideal for welding and industrial worktables as well as paint booths [10]. The turntable is fitted with permanently lubricated and sealed bearings, eliminating the need for future re-lubrication. Since the bearings are sealed, the turntable is well suited for Decor's finishing department, where the mechanism will be exposed to different types of stains, paints and dust.

The SKF UT05CN has a capacity of 5000 pounds and a moment capacity of 3700 inch pounds, as specified by SKF (TABLE III). These values fully satisfy the requirements calculated and can therefore be safely used as part of the final design.

TABLE III: SKF TURNTABLE SPECIFICATIONS [10]

Part number	Load capacity (lbs) P	Moment capacity inch-lb Mt	Height A	Length B	Center C	Mt'g bolt size D	Height X	Height Y	Length Z	Weight
Standard or locatable										
UT 01 CN or UT 01 CL	1,000	650	1.77"	3.25"	2.50"	1/4"-20	0.39	0.38	2.25	3.5 lbs
UT 02 CN or UT 02 CL	2,500	1,400	1.92"	3.50"	2.75"	1/4"-20	0.39	0.38	2.75	4.5 lbs
UT 05 CN or UT 05 CL	5,000	3,700	2.43"	5.00"	4.00"	3/8"-16	0.50	0.50	3.75	10.5 lbs
UT 10 CN or UT 10 CL	10,000	8,500	2.72"	6.50"	5.50"	3/8"-16	0.50	0.50	5.00	19.0 lbs

The corresponding dimensions are shown in Figure 18. The bottom fixture can be either bolted or welded onto the lift table surface. Our group recommends bolting the bottom plate down, using 1.5 inch long $^3/_8$-16" type 316 stainless steel bolts, in order to make maintenance, as well as any future modifications to the lift table or the turntable mechanism, easier.

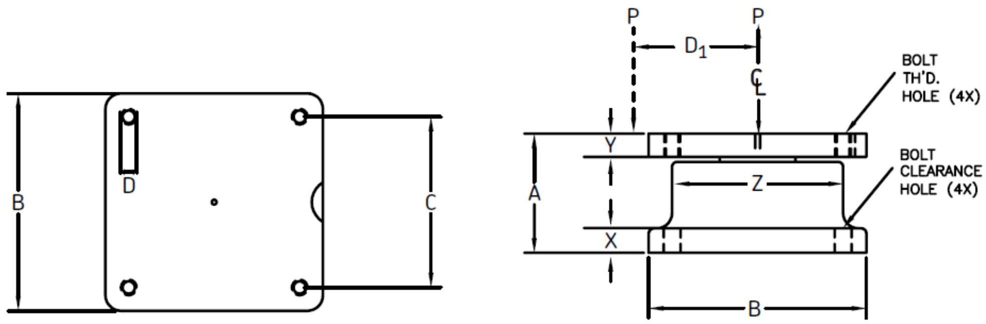

Figure 18: SKF turntable diagram [10]

2.4 FIXTURE DESIGN

The primary purpose of the fixture is to secure the column to the turntable. The fixture must allow access to five sides of the column for finishing processes. It is important that the fixture allows for easy loading and unloading, and does not interfere with the operation of the turntable.

After discussions with the client, they agreed to revise the design of their columns to include internal reinforcement to accept the fixture. This reinforcement will be standardized so that only one fixture sizes would be required for all of the varying column sizes. Original concepts for the fixture involve two or more prongs which insert into the base of the column, similar to a forklift or pallet jack. The column rests on a baseplate which is bolted to the turntable underneath it. To account for the bolt heads and keep the fixture free from finishing agents, a support pad is to be used. Figure 19 provides a detailed view.

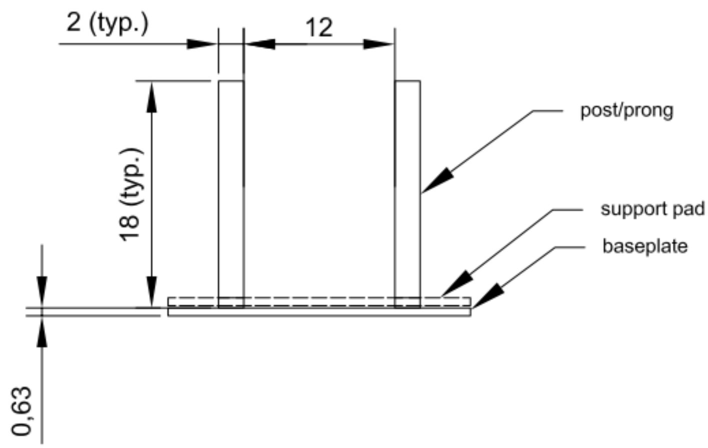

Figure 19: Fixture concept 1

Note: dimensions shown are in inches

Upon further discussions with the client, it was decided that it would be simpler to use one elongated post, as it will distribute the load more evenly, and make standardizing the reinforcement within the columns easier. The thickness of the post was designed to match the opening on the smallest columns, which have an outer thickness of 1.5" and inner thickness of ¼". The height of the post was also based on the smallest columns; at 12" it is half the height of the smallest columns. The length was selected at 12" as this was deemed long enough to distribute the load reasonably while making column placement easier. The material chosen for both the post and baseplate was A36 steel flat bar. This is because it is widely available in pre-formed sizes and is conducive to various modes of manufacture.

2.4.1 Analysis

This section provides engineering backing for our solution and assists in developing revisions to the design. Given the usage requirements, we have considered two critical loading types: resting load and pushing force.

2.4.1.1 Effects of Resting Load on Column

The resting load is purely the result of gravity acting on the column, which puts pressure on the baseplate and creates stress concentrations in the column near the edges of the baseplate. For this analysis, the largest column type was examined since it is the heaviest.

First, we considered the effect on the column itself. For this analysis, the largest column size, 120”x36”x6”, was selected to maximize the effect of the column’s weight. To provide a conservative estimate with respect to deflection, the selected material was MDF. Due to the fact that the specific internal geometry of the column is unknown an assumed model was created with the CAD program, Solidworks, for analytical purposes, as shown in Figure 6 in Section 1.4. The results are therefore produced exclusively from numerical solutions. To account for this, a conservative safety factor of 3.0 was applied. The material properties for MDF used in this analysis are detailed in TABLE IV.

TABLE IV: MATERIAL PROPERTIES FOR MDF [13]

Property	Value
Density	0.75 g/cm^3 (47 lb/ft^3)
Elastic Modulus	4 GPa (600 x 10^3 ksi)
Elongation at Break	0.5 %
Poisson's Ratio	0.25
Shear Modulus	2.5 GPa (360 x 10^3 ksi)
Specific Heat Capacity	1700 J/kg-K
Tensile Strength: Ultimate	(UTS)35 MPa (2.6 ksi)

The results from the FEA analysis were very positive. As can be seen in Figure 20, the maximum stress experienced in the column was 132 kPa, which is sufficiently below the yield strength for MDF.

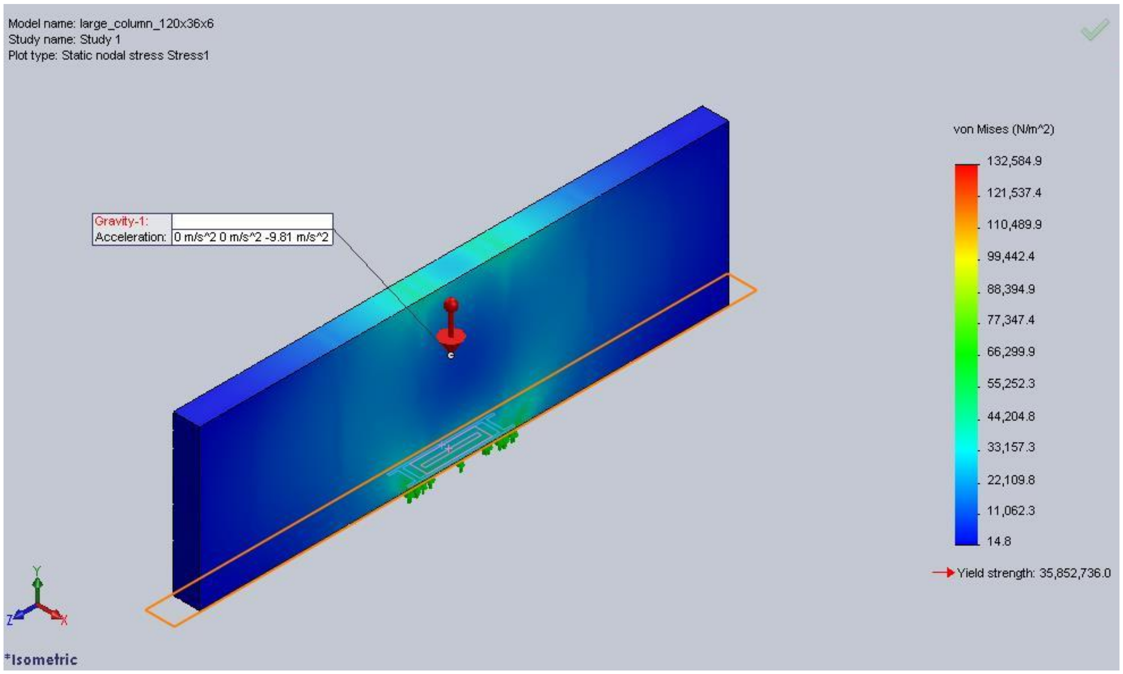

Figure 20: Resting load FEA stress results for column

Even using a safety factor of 3.0, we are close to 1% of the yield strength. The maximum displacement was noted at less than 0.3mm. We therefore have little concern regarding the integrity of the columns, where resting load is considered.

2.4.1.2 Effects of Resting Load on Fixture

Next, we analyzed the resting load on the fixture. This load is primarily a result of the weight of the column on the fixture baseplate. Stress concentrations were expected near the edges of the turntable upon which the fixture is mounted. Due to the nature of the loading and stress distribution, an analytical solution proved difficult. We therefore performed a numerical analysis using FEA in Solidworks. Once again, we used a safety factor of 3.0. The material properties used for steel A36 were pre-programmed in the software and are displayed in TABLE V.

TABLE V: MATERIAL PROPERTIES FOR ASTM A36 STEEL

Material Property	IP Units		SI Units	
Elastic Modulus	29007.55	ksi	200	GPa
Poisson's Ratio	0.26		0.26	
Shear Modulus	11501.49	ksi	79.3	GPa
Density	0.283599	lb/in^3	7850	kg/m^3
Tensile Strength	58.015	ksi	400	MPa
Yield Strength	36.259	ksi	250	MPa

The results of the analysis were promising. The maximum stress experienced was 45 MPa, as evident in Figure 21. The resultant stress after applying the safety factor of 3.0 is 135 MPa.

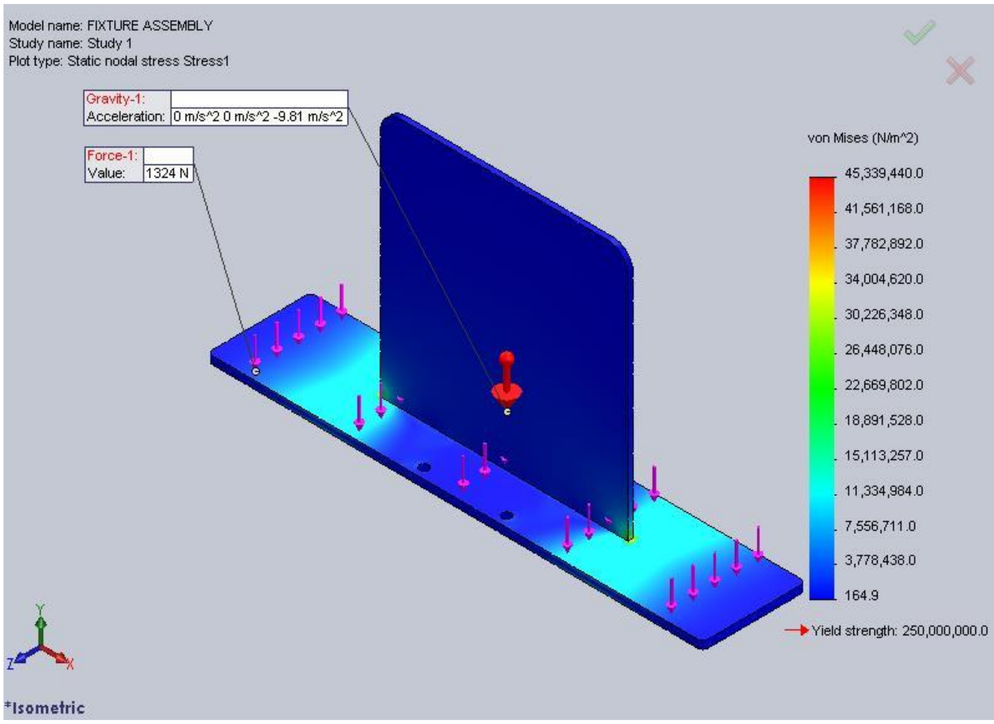

Figure 21: FEA for resting load stresses on fixture

Note that the weight due to the column was assumed as 1324N, which is based on the maximum column mass of 135kg, as provided by the client, and a gravitational constant of 9.81 [$kg \cdot m \cdot s^{-2}$]. The stress distribution appears to be at the edge of the turntable as expected; however, the maximum stress actually occurs on the post section. Figure 22 shows an expanded view:

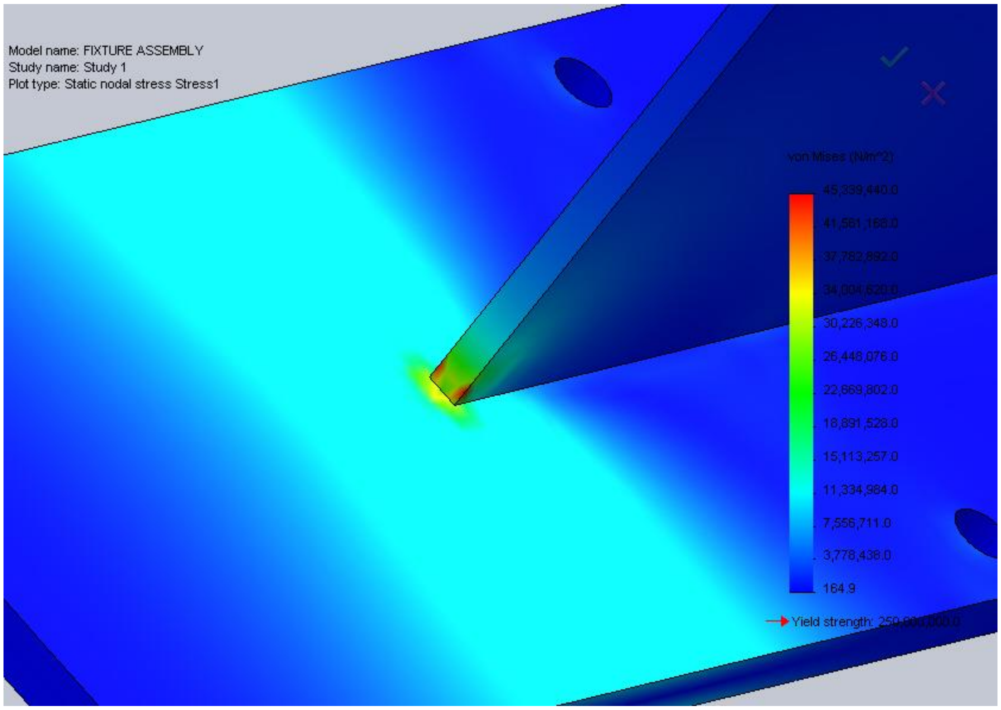

Figure 22: FEA for resting load stresses on fixture (expanded view)

This stress concentration can be explained by observing the strain on the baseplate, shown in Figure 23.

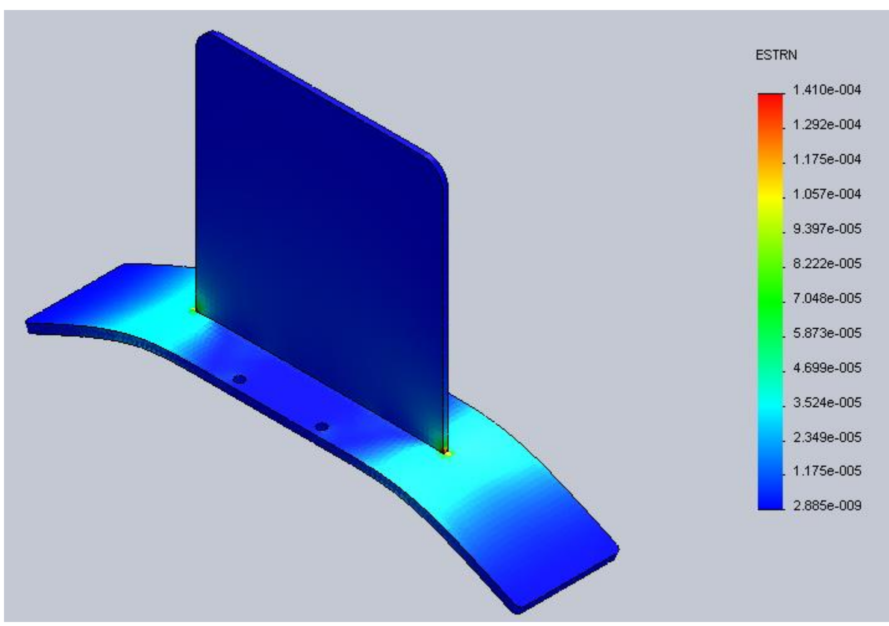

Figure 23: FEA for resting load strain on fixture

As can be seen in the above figure, the baseplate is deflecting and pulling on the post. (Note: the deformations shown have been scaled by 450X for illustrative purposes). The strain reaches a maximum close to the point of maximum stress, which confirms our assumption.

Regardless of the stress concentrations, the results were still below the elastic limit for steel (250 MPa). The maximum displacement was also found to be very small at less than 0.14mm. Based on these results it might be reasonable to reduce the baseplate thickness to ¼"; however, our team decided that there is little to be gained in weight and cost savings to offset the added risk.

2.4.1.3 Effects of Pushing Force on Column

The pushing force loading mode considers stresses experienced by the fixture due to lateral forces exerted on the column. These can be the result of workers leaning on the column, pushing the column to move the cart, or other unexpected lateral loading.

In consideration of the worst case scenario, we assumed a horizontal loading near the top edge of a 36" wide column. The force magnitude was conservatively approximated as 1000N, which is equivalent to a 320 lb person exerting 70% of their body mass.

First, we considered the maximum stress effect of a pushing force on the column. Here the stress is a result of the reaction force from the fixture post on the inner column. Therefore the region of maximum stress was expected to occur near the edges of the post on the inner supporting frame of the column. Since these were localized stresses, traditional analytical methods were not prudent and solutions were once again determined numerically from FEA analysis. A safety factor of 3.0 was applied once again.

The FEA model had a 1000N force concentrated in an 18” x 6” area located just below the top edge to mimic a person pushing on the column with both hands, as shown in Figure 24.

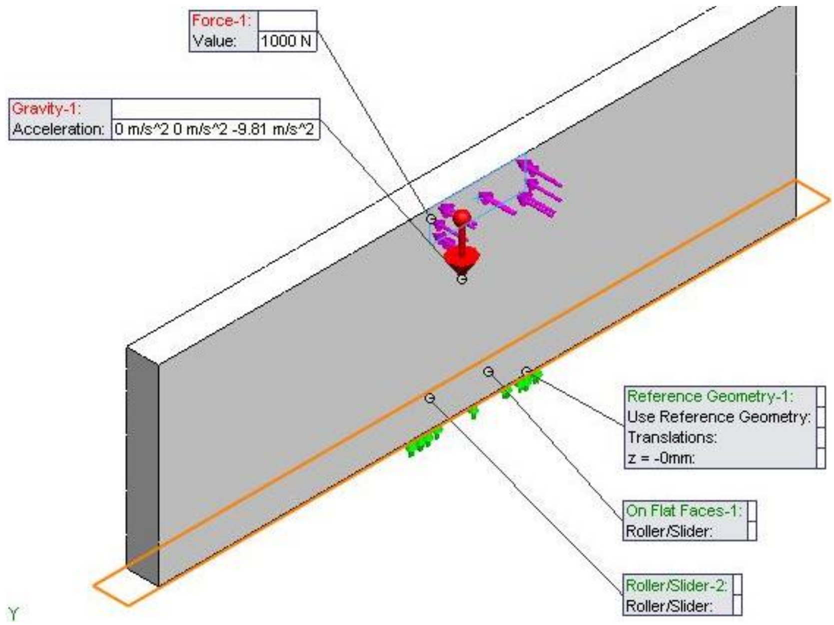

Figure 24: Pushing force distribution on column

Note the roller support at the base, titled: “On Flat Faces-1”. This represents the reaction from the fixture baseplate. The internal support, “Roller/Slider-2”, represents the reaction from the post. The resulting stress distribution is shown in Figure 25.

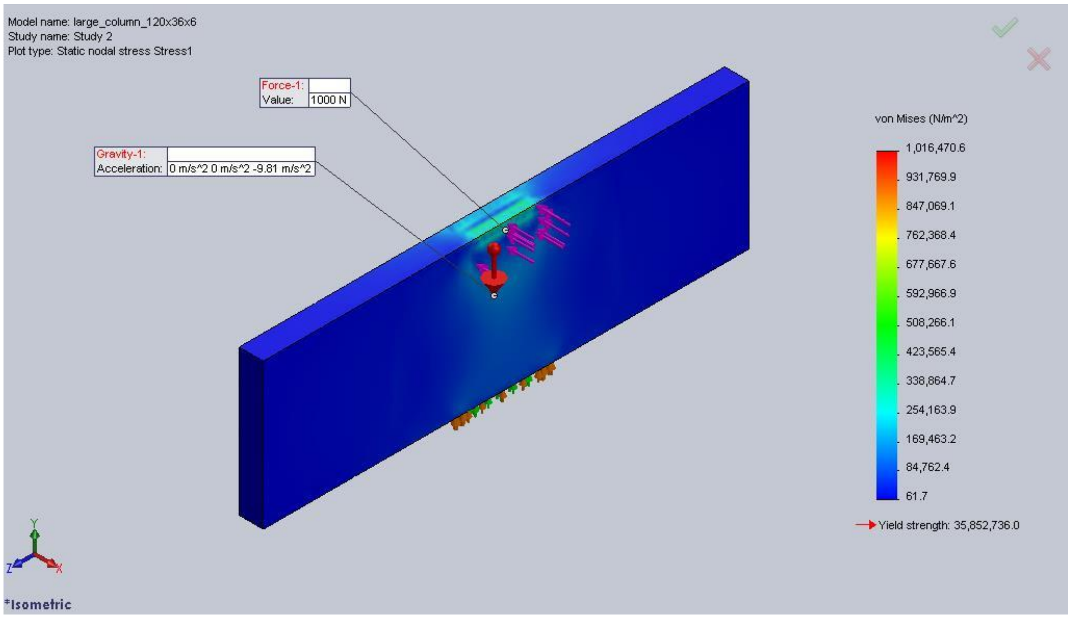

Figure 25: FEA for lateral stresses on column

The result was a maximum stress of 1 MPa, which is 1/35th the yield strength for MDF (or 1/10th when the safety factor is considered). As for the distribution of stresses, there appeared to be two areas of concentration: the load application point as shown in Figure 25 and the internal support structure surrounding the fixture, as shown in Figure 26.

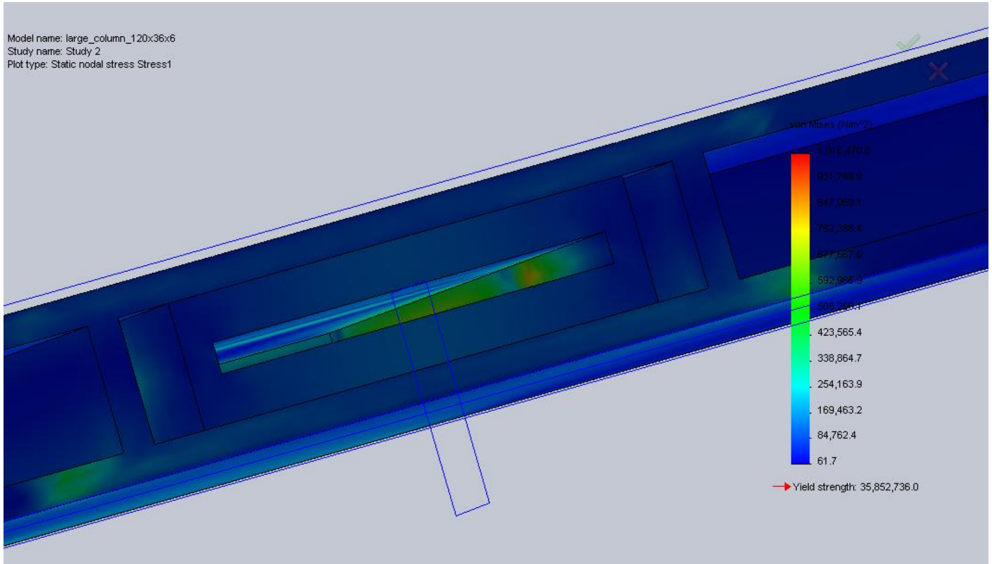

Figure 26: Internal stress distribution due to lateral loading on column

The internal stresses on the support structure were further analyzed by isolating it from the rest of the column, as shown in Figure 27.

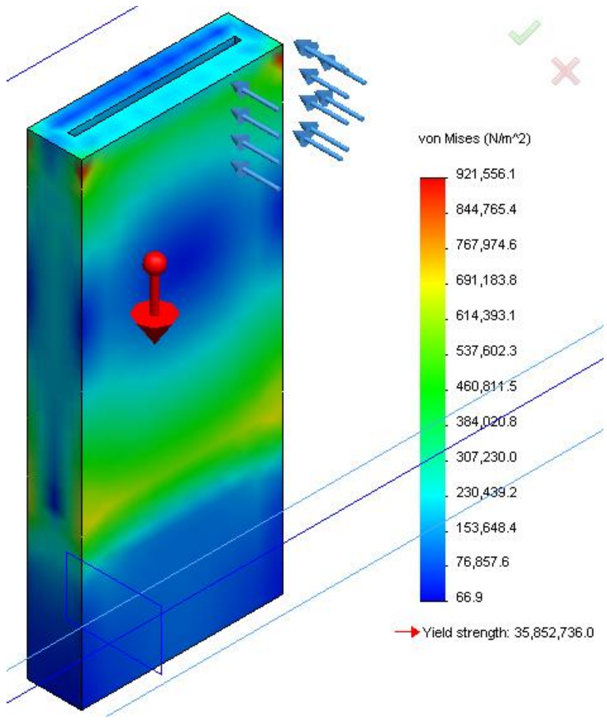

Figure 27: Stress distribution on internal support structure due to lateral loading on column

It is evident that the maximum stress occurred where the support structure met the top of the column. The secondary maximum occurred just above the location of the top of the fixture post. Since the construction of the internal support geometry is at the discretion of the client, special care will have to be taken to ensure these stress locations are adequately supported.

2.4.1.4 Effects of Pushing Force on Thin Column

A similar pushing force analysis was performed on a 96”x24”x1.5”column since the thinner construction would result in higher deflections and therefore, conservative solutions. The material properties were also assumed for MDF rather than HDF for similar reasons.

As can be seen in Figure 28, the maximum stress was 7.15 MPa and occurred near the top of the fixture (12” from the bottom of the column). Note that this is sufficiently below the yield strength of 35 MPa for MDF.

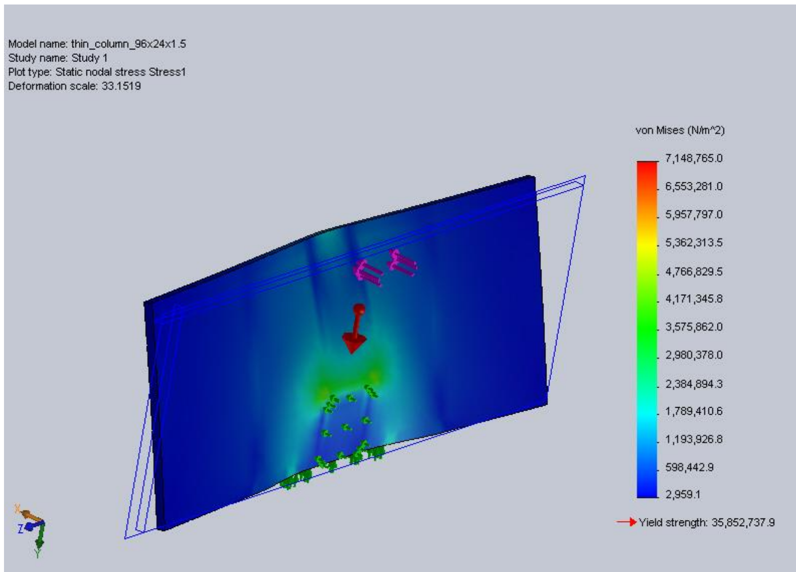

Figure 28: FEA stress results for column on fixture

The maximum deflection was found to be 7.4mm which occurred directly above the applied force. Note that since gravity was taken into consideration for this analysis, there is also a slight downward deflection of ~3mm at the bottom corners (Figure 29).

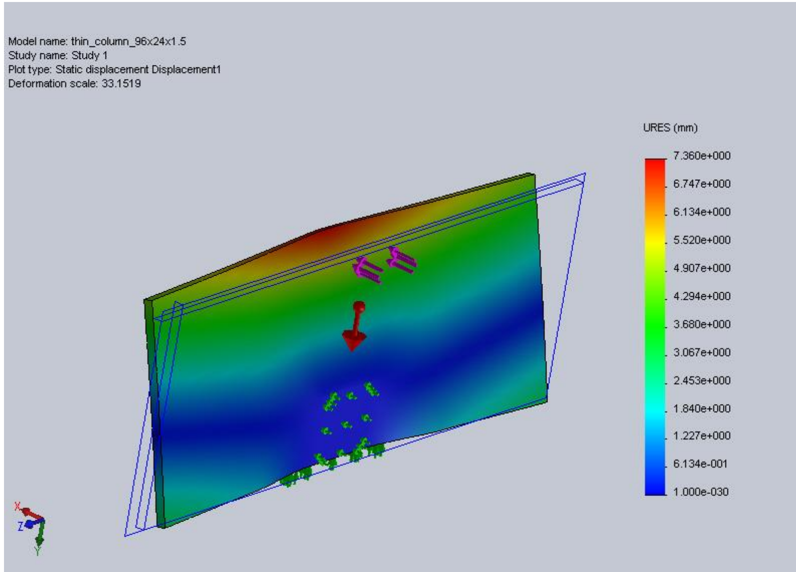

Figure 29: FEA displacement results for column on fixture

2.4.1.5 Effects of Pushing Force on Fixture

1. Maximum stress

Next, we considered the fixture assembly. The maximum stress was expected to occur at the base of the post where it is welded to the baseplate. For a lateral force, we expected the fixture to experience a distributed reaction force against the inside of the column. Since we assumed this to be a uniform distribution, we approximated an equivalent load at half the height of the post, as indicated in Figure 30.

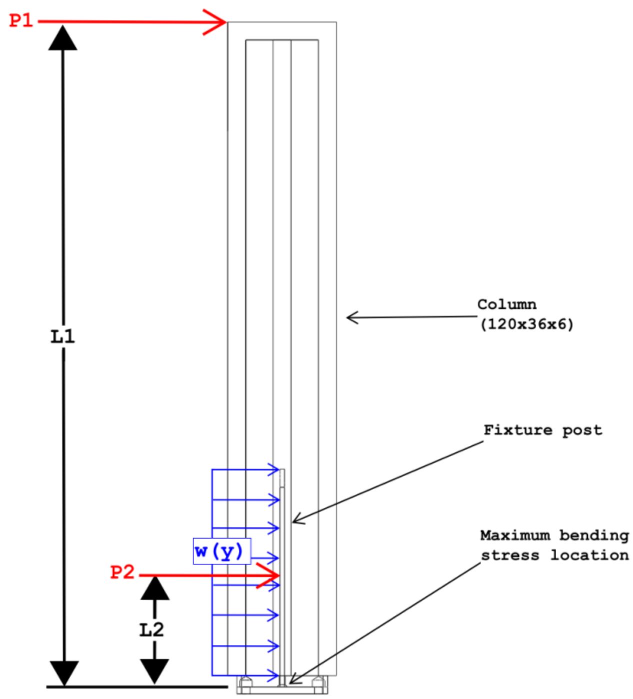

Figure 30: Representative lateral load on fixture post

We therefore modeled the post as a slender, cantilever beam and applied beam bending theory, as shown in Equation 6:

$$\sigma_{max} = \frac{M \cdot c}{I} \tag{6}$$

, where σ_{max} is the maximum bending stress, M is the maximum bending moment, given by Equation 7, c is the distance from the neutral axis to surface, and I is the moment of inertia, given by Equation 8.

$$M = P_1 \cdot L_1 \tag{7}$$

, where P_1 is the applied force at the edge of the column and $L_1$is the distance to the post/baseplate joint

$$I = \frac{b \cdot h^3}{12} \tag{8}$$

, where b is the cross-sectional width of the post, and h is the height.

The results of the analysis have been tabulated in TABLE VI.

TABLE VI: LEAN STRESS ANALYSIS ON FIXTURE

P_1, N	L_1, in	M, Nm	b, in	h, in	I, in^4	c, in	σ_{max}, MPa
1000	36	914.4	12	0.25	0.015625	0.125	446.40

Given the yield stress of 250 MPa for A36 steel, we far exceeded our limit with this design. This was further confirmed with FEA, as shown in Figure 31 and Figure 32.

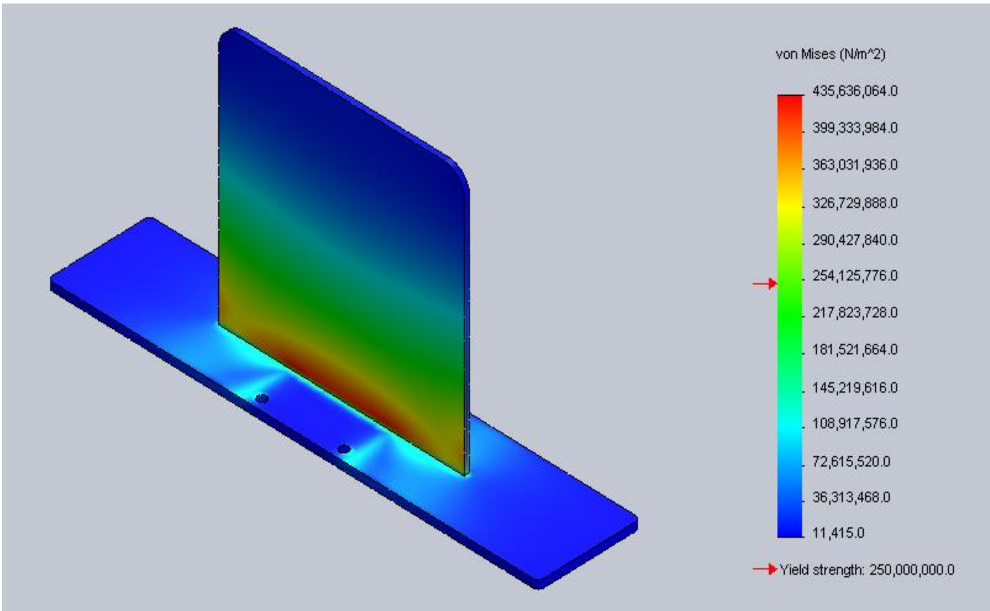

Figure 31: Stress distribution on fixture due to lateral loading

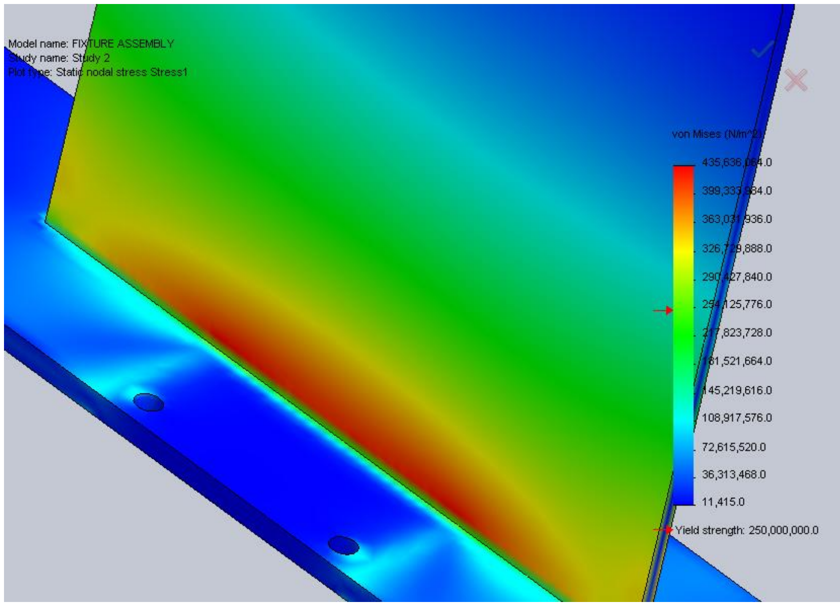

Figure 32: Stress distribution on fixture due to lateral loading (expanded view)

Note the stress concentration at the base of the post where normal stresses reach 435 MPa, which is close to the predicted, analytical value. This discrepancy was likely due to the fact that our analysis did not take fixture or column weights into consideration (the FEA model used a fixture weight of 22.87 lb and column weight 1324 N). The difference was considered to be insignificant since both solutions are only accurate in the elastic strain region (which we have exceeded). For a more accurate result, plastic deformations must be considered.

The results of the stress analysis for pushing force are troubling and represent a failure for this design. Before proceeding with possible solutions, it is worthwhile to verify the deflection to further test the accuracy of our FEA model.

2. Maximum post deflection

For a distributed loaded on a cantilever beam, the maximum deflection occurs at the free end. This was calculated using Equation 9

$$y_{max} = \frac{w \cdot L^3}{8E \cdot I} \quad (9)$$

, where w is the force per meter exerted by the column on the face of the fixture, L is the fixture height, E is the elastic modulus for A36 steel, and I is the moment of inertia.

The resulting deflection was 16.33mm, which is more than preferred (as expected). This result was confirmed by our FEA analysis as shown in Figure 33.

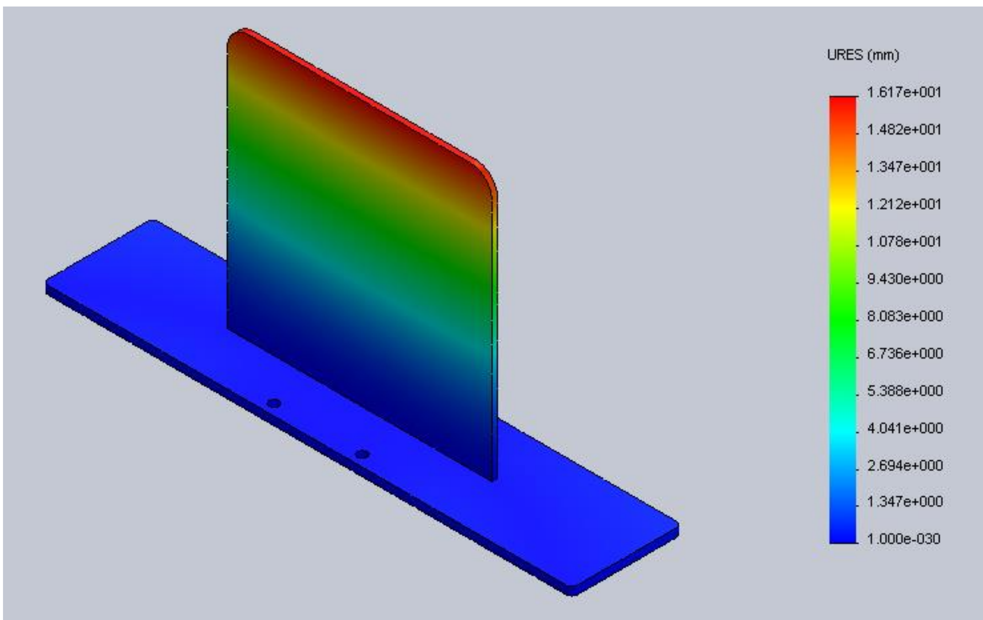

Figure 33: Displacement distribution for fixture under lateral loading

The FEA showed a displacement of 16.17mm which is within 1% of predicted values and thus further confirms our results.

2.4.1.6 Fixture Design Revision

In the previous section, it was found that the fixture assembly would experience yielding if the column was loaded laterally with a 1000N force. This is unacceptable since plastic deformation of the fixture reduces its effectiveness in securing the column and preventing injury. To solve this problem, the following three solutions were generated as candidates for design revision:

A) Modify the moment of inertia by increasing the cross-sectional area of the fixture post. To achieve a maximum normal stress of 125 MPa (i.e. 50% of yield strength) a minimum thickness of 12mm would be required (½" plate instead of ¼")

B) Modify the acceptance criteria to reduce the required force input for model. Since the 320lb weight and 70% pushing force are arbitrary, these can be adjusted to account for material limits. To achieve a 125 MPa maximum normal stress, the input force would need to be reduced from 1000N to 280N. Following our model, this would correspond to a 250 lb person exerting 25% of their weight.

C) Change the material for one with higher yield strength. ASTM A514 steel has yield strength of 690 MPa, which is above our yield criteria. If the 1000 N input force were reduced to 772 N then we could achieve a safety factor of 2.0.

2.4.1.7 Recommended Solution

Solution A is deemed unsuitable since a ¼" post thickness is a constraint due to column geometry. Option C has merit, however the cost of materials is higher, the welding processes are more difficult to perform, and to achieve a suitable safety factor the input loading must still be changed. Therefore our recommended solution is option B. This decision was motivated by the fact that the pushing force was arbitrarily defined and may be subject to revision. The 320 lb weight class has proven an excessive target to meet and thus overly conservative. We feel a 280N (63lb) maximum lateral force is a reasonable limitation to the design since it is not intended for the cart to be transported via column contact.

It is also worthwhile to note that we will be suggesting a 'two-sided fillet' weld to secure the post to the base plate (see Section 2.4.2.3). Through our research we have determined that if properly produced, this type of weld is twice as strong as the material being welded [11]. Therefore, the yield strength at the point of maximum stress will theoretically double. This provides additional support for our recommended solution.

2.4.1.8 Analytical Results

Based on the results in TABLE VII, we are confident that our design will maintain the integrity of all column sizes during normal operation. The fixture design also appears robust enough to handle the resting load of all column sizes. However, the lateral pushing load of 1000N was found to cause yielding and rupture in the fixture assembly where the post meets the baseplate. The reason was deemed to be an unreasonable test condition as the applied loading was considered excessive and unrealistic. As a result, the pushing load was reduced to 280N. This resulted in a 125 MPa maximum stress which is below the yield strength of A36 steel by a safety factor of 2.0.

TABLE VII: FIXTURE LOAD ANALYSIS SUMMARY

Load Test	Maximum stress (MPa)	Safety Factor	Resultant Stress (MPa)	Yield Strength (MPa)	Pass / Fail
Large Column Resting	0.13	3.0	0.39	35	**Pass**
Large Column Pushing	1.00	3.0	3.00	35	**Pass**
Small Column Pushing	7.15	3.0	21.45	35	**Pass**
Fixture Resting	45.00	3.0	135.00	250	**Pass**
Fixture Pushing	435.00	2.0	870.00	250	**Fail**

2.4.2 Final Fixture Design

This section describes the final design for the fixture and provides drawings and guidelines for manufacturing.

2.4.2.1 Fixture Overview

The final design consists of a 24” x 12” x $^{3}/_{8}$” base plate welded to a “12 x 12” x ¼” steel post. Both the post and base plate are constructed from ASTM A36 steel and are welded to one-another in a T-shaped geometry using a 2-sided fillet weld of ¼” depth. The base plate is to be fastened to the turntable using $^{3}/_{8}$”-16 bolts. There is a wooden support pad which rests upon the base plate and conceals the bolts. The assembly of the post, base plate and support pad is shown in Figure 34.


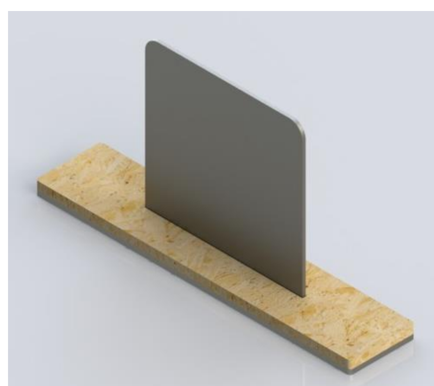

Figure 34: Installation of pad

The column is intended to rest upon the base plate and be secured from lateral movement by the post, as shown in Figure 35.

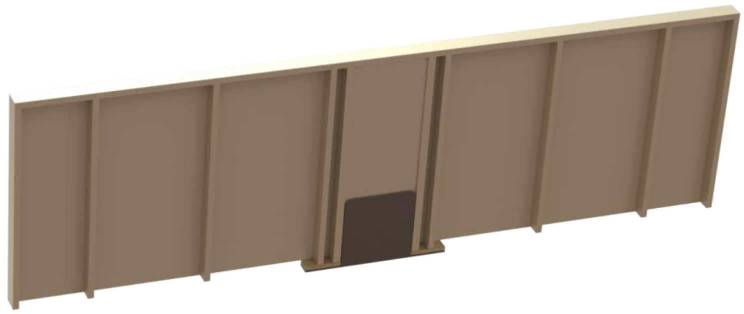

Figure 35: Column on fixture (cross-sectional view)

2.4.2.2 Engineering Drawings

- The fixture post / base plate assembly is shown in Figure 36. Note the weld bead at the base of the post.
- The fixture support pad is shown in Figure 37. Note the chamfer and recessed holes to allow for the weld and bolts, respectively.
- For the purposes of the design and analysis, an assumed column design was used. The details of this design are shown in Figure 38.

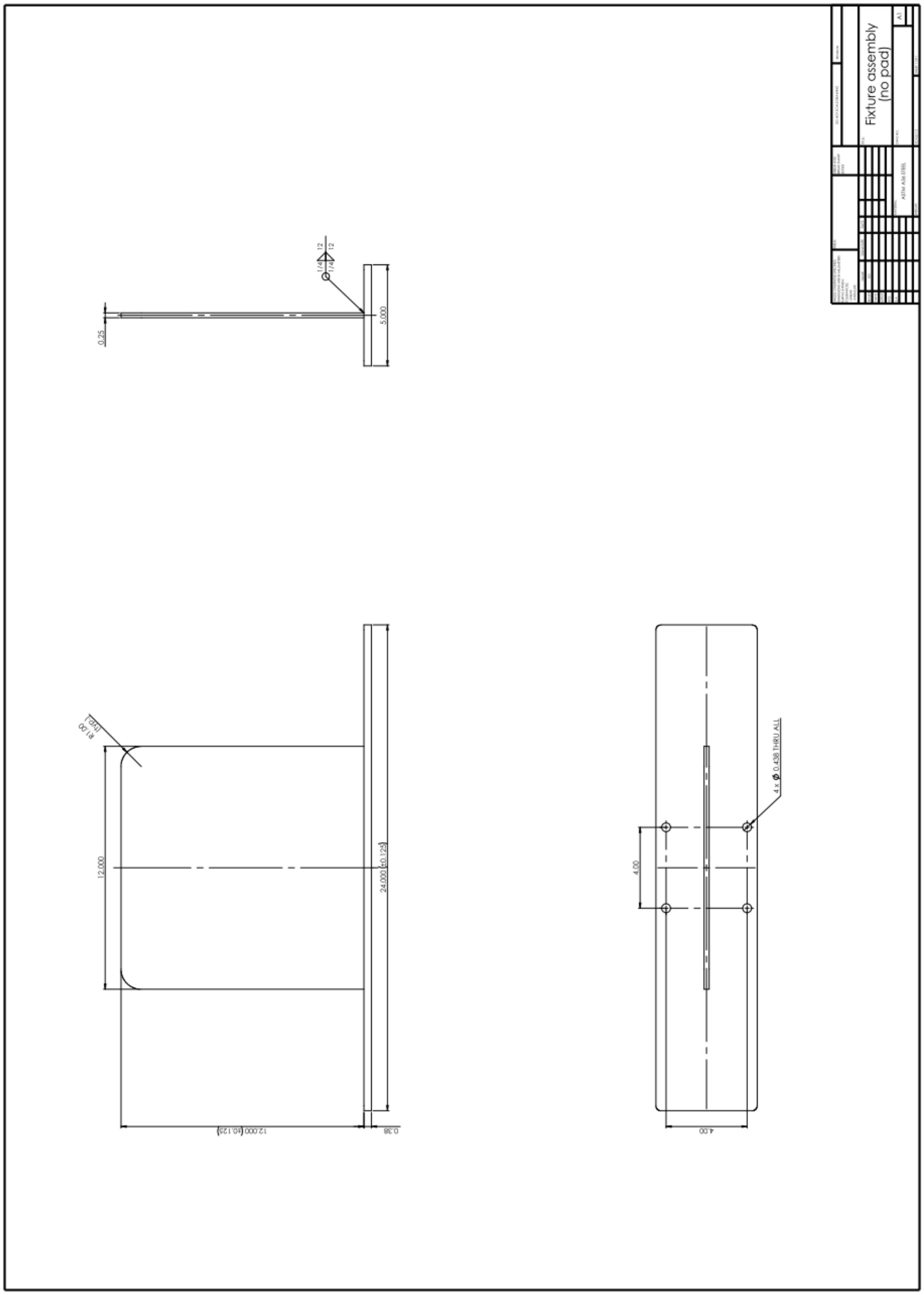

Figure 36: Fixture assembly detailed view

Note: Tolerances shown are based on supplier's product specifications (MetalsDepot®).

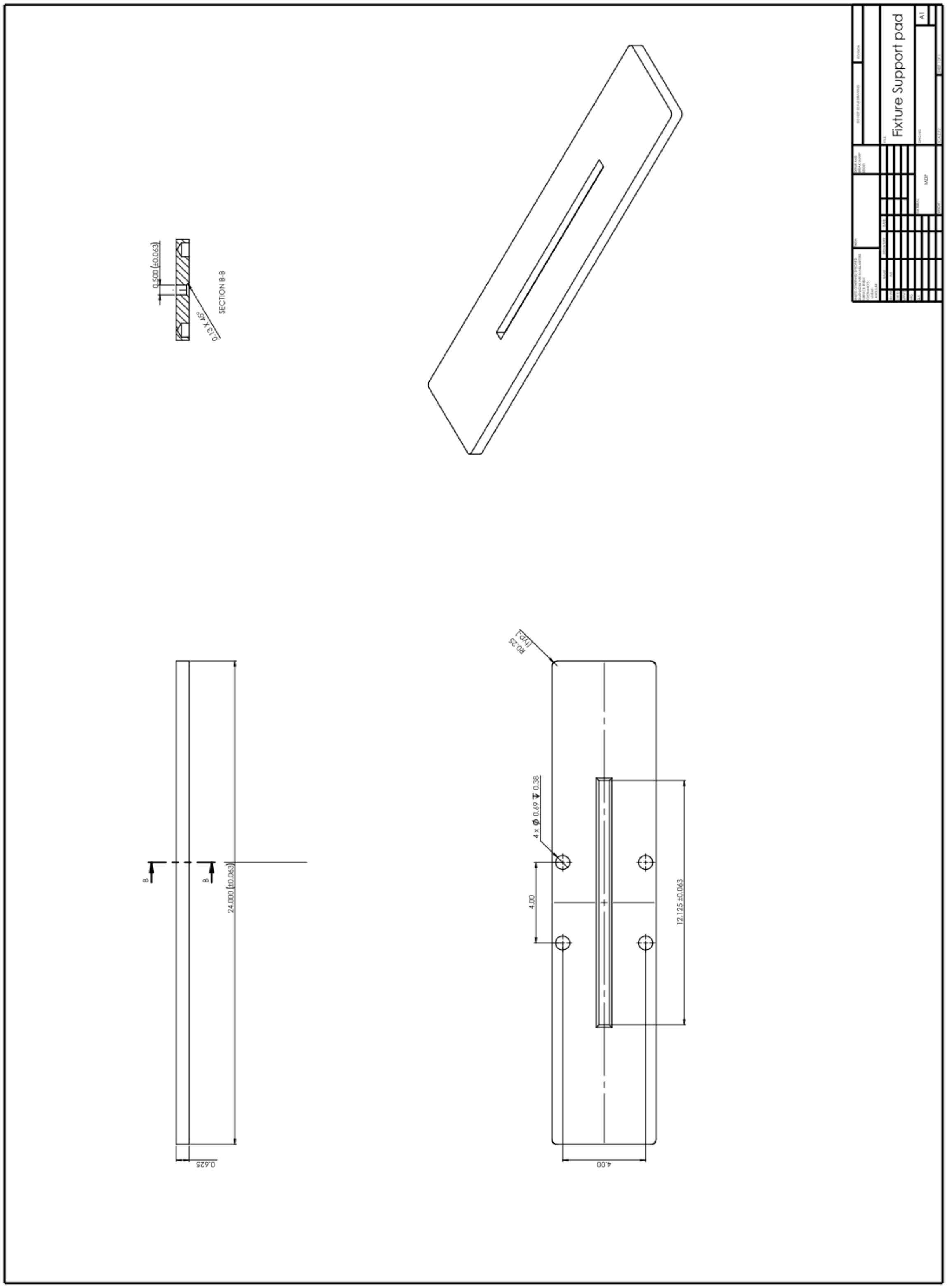

Figure 37: Fixture support pad detailed drawing

Note: Tolerances shown are assumed factory tolerances.

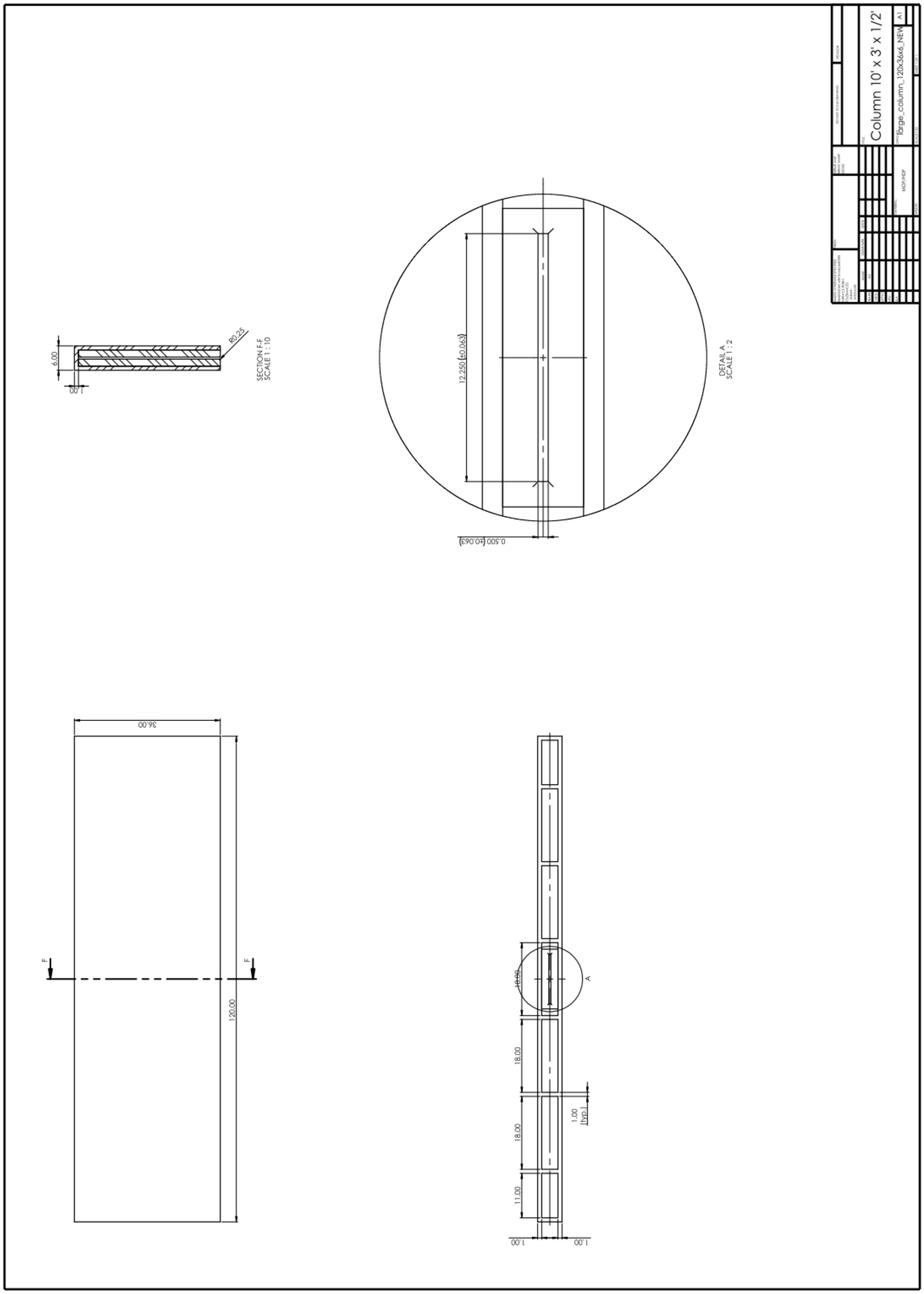

Figure 38: Detailed drawing of large column

2.4.2.3 Manufacturing Guidelines

This section details key manufacturing guidelines for the construction of the fixture. This is intended to be used for reference only, and actual processes are at the discretion of the manufacturer.

A. Base plate

1. Drill bolt-holes in baseplate
   a. According to ASME Standard B18.2.8, for 3/8" bolt use drill size 27/64" to achieve hole size .422 - .438" (loose fit) [9]
   b. Hole spacing is 4" O.C. centered on part (0.50" from outer edges)
   c. Tolerance for hole locations is maximum off-center hole spacing, and was determined to be ±.033" based on the following [10]:

$$t_b = \frac{c}{\sqrt{2}} \tag{11}$$

, where c is the hole clearance

Bolt	Hole	c	t^d
0.375	0.422	0.047	0.033

2. Use low-tolerance tool to fillet corners to reduce injury & part damage risk (e.g. grinder). Fillet radius should be approximately 1".

B. Post

1. Suggest fillet of post (1.00" radius) to ease column fitting and minimize damage
2. Weld post to base plate using '2-sided fillet weld'. Weld-beads should be at least 0.125" to match the strength of the post. [11]

3. For welding type we recommend either MIG (GMAW) using short circuit or globular transfer method or stick weld (SMAW) with low-medium penetration electrodes (e.g. type 7014, 7018).

C. Support Pad

1. Select wood strong enough to withstand repeated use, but soft enough to minimize damage to columns. Readily available wood sources, such as 5/8" MDF, are likely suitable; however, we suggest verification via field testing.
2. Overall pad dimensions should match base plate
3. Drill holes to match baseplate bolt locations (i.e. O.C. spacing 4.00", 0.50" from edge)
    a. Based on bolt head dimensions, holes should be 11/16" diameter to a depth of 3/8" (oversized to ensure fit). [12]
    (Note: a 3/8" bolt has .650" (max.) head diameter and .268" (max.) head height.)
4. Cut 0.5" x 12.125" slot into wood pad as per Figure 37. Part dimensions have been oversized to account for fit allowance and tolerance. Factory tolerance is assumed to be ±1/16".
5. Chamfer bottom of slot to account for weld-bead at post – baseplate connection. Set chamfer angle at 45° and 0.13" depth to clear weld-beads.
6. Securing to baseplate optional. Post and bolt heads should center wooden pad on baseplate.

D. Column

1. Ensure internal support structure is adequate to handle loadings (as shown in 2.4.1 Analysis). For reference see Figure 38: Detailed drawing of large column above.
2. Recommend fillet of opening to allow easier fitting of column on fixture. Fillet radius should be approximately ¼" or larger.

3 COST ANALYSIS

A cost effective solution was important for our customer. We were provided with a target budget of $1000 to $2000 CAD per cart including parts and manufacturing. The hydraulic lift cart can be purchased for $1252.00 from Grainger. A local SKF supplier, Wajax, gave us a price quotation for the UT05CN turntable for $158.63. This quote can be found in Appendix C. The fixture is made out of two pieces of ASTM A36 Flat Steel. Based on prices from Metals Depot, the ¼" thick piece for the fixture post and the $^{3}/_{8}$" piece for the base can be purchased for $19.89 and $21.02 respectively. These prices are shown in Appendix C. The cost of the hardware including the eight 1.5 inch long stainless steel $^{3}/_{8}$"-16 bolts, washers, and nuts, was estimated by using prices from McMaster-Carr to determine a price-per-unit and multiplying it by eight to find total prices of $8.00, $1.29, $1.50 respectively [14]. We estimate that the assembly of the cart will take a maximum of five hours. Decor will charge a labour cost of $80 per hour for a total of $400. TABLE VIII provides a summary of the costs of all the components of the cart, for a total of $1862.33. At this price our cart meets the budgetary expectations laid out by our customer.

TABLE VIII: COST SUMMARY

Part Name	Description	Quantity	Material/Component Cost
Dayton Hydraulic Scissor Lift Cart	Hydraulic Scissor lift cart w/ 1000 LB capacity, modified to lower the handle, and holes drill on the top surface to attach fixture	1	$ 1,252.00
SKF Industrial Turntable	Industrial turntable with permanently lubricated and sealed bearings	1	$ 158.63
Fixture Post	1 ft. of 1/4" X 12 Hot Rolled A36 Steel Flat, filleted corners	1	$ 19.89
Fixture Base	2 ft. of 3/8" X 5 Hot Rolled A36 Steel Flat	1	$ 21.02
Wood Base Pad	Wood (Decor's scraps can be used)	1	Use scrap wood
Bolts	Type 316 stainless steel 3/8"-16 bolts 1.5 inch long	8	$ 8.00
Washers	General purpose type 316 stainless steel washers	8	$ 1.29
Nuts	Type 316 stainless steel nuts	8	$ 1.50
Labour Cost (@ $80/hour)	Labour for assembly of parts	5 hours	$ 400.00
Total Cart Cost			$ 1,862.33

4 PROJECT SCHEDULE

Our group used the Gantt chart, shown in Figure 39 during all phases of the report. It helped our group stay on track and gave a preview of the progress if necessary. Our team's work efficiency increased significantly with each phase of the report. Some milestones, such as final poster preparation, were completed ahead of schedule. Because of good time management, all work was completed on time.

Project Planner

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1. Project Definition Report					
Team Forming	1	1	1	1	100%
Site Visit	3	1	3	1	100%
Identifying Needs and Requiements	4	7	4	7	100%
Constraints and Limitations	4	7	4	7	100%
Problem Background and Statement	11	3	11	3	100%
Project Objectives	11	3	11	3	100%
Compiling Report	12	7	12	7	100%
Preparing Oral Presentation	15	4	15	4	100%
Handing in the Report	20	1	20	1	100%
Oral Presentation	19	5	21	1	100%
2. Concept Design Report					
Design Research	24	7	25	6	100%
Concept Analysis & Development	29	7	30	7	100%
Concept Selection	36	3	31	5	100%
Compiling Report	39	7	36	10	100%
Handing in the Report	46	1	46	1	100%
3. Final Design Report					
Design Features	47	7	47	7	100%
Material Selection	54	6	54	6	100%
Stress Analysis	54	6	54	6	100%
Detailed Cost Analysis	60	3	60	3	100%
Preparing Engineering Drawings	63	7	63	7	100%
Compiling Report	70	7	70	7	100%
Poster Preparation	77	7	63	8	100%
Preparing Oral Presentation	77	7	76	5	100%
Final Oral Presentation	83	1	83	1	100%
Handing in the Report	84	1	84	1	100%

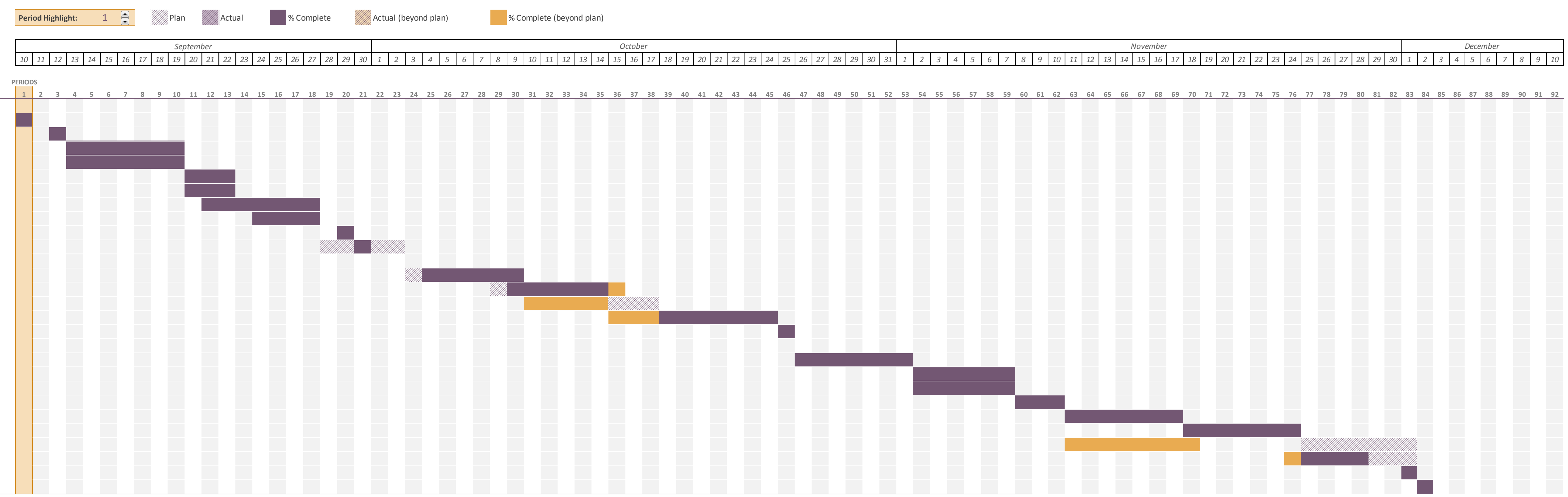

Figure 39: Gantt chart

5 CONCLUSION

In conclusion, our team designed a cost effective and simple cart to lift, transport and store large cabinetry columns in Decor Cabinets' finishing department. The final design consists of three major components: a Dayton Scissor lift table, an SKF UT05CN industrial turntable, and a custom fixture. The cart, with all the parts and labour included, costs a total of $1862.33.

The foundation of the design is a Dayton hydraulic scissor lift cart with a weight capacity of 1000 lbs. The hydraulic system of this cart provides vertical linear motion over a range from 12-¼" to 35-¼". This function provides easy loading and unloading of a part before and after it enters the finishing department. It will also allow accommodate a wide range of operator heights, by giving them the ability to adjust the height of the cart for their preference as they are working on it, and give them easy access to all sides of the part.

The SKF UT05CN industrial turntable has the ability to support large loads. The turntable will be bolted down to the cart, and the fixture will be bolted to the top of the turntable. The turntable provides the ability to rotate the part, allowing access to all sides within the spray booth. Without the turntable, the entire cart would need to be rotated to gain access to all the column's sides, which may be dangerous and difficult if there is anything on the floor.

The column will be held in place by a fixture that will go through the open face of the column. The fixture consists of a ¼" ASTM A36 steel plate attached to a steel base in a T-shaped geometry by using a 2-sided fillet weld of ¼" depth. To provide a softer surface for the column to sit on, as well as protect it from the heads of the bolts, a pad made of wood will slip over the base of the fixture. Decor has agreed to redesign the internal features of their columns to allow for our universal fixture design that will work for all of their column sizes. Decor has the capabilities to manufacture this fixture at their facility.

The cart can be wheeled directly into the spray or sanding booths without the need to remove the column from it. Operators will now be able to finish all sides of a column without waiting for the other sides to dry first. The final design meets the client's need to reduce the amount of injuries taking place in the finishing department by eliminating the need to manually handle large columns. Our team also fulfilled the secondary needs of increasing production efficiency and providing a solution that is easy to use.

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APPENDIX – A: CONCEPT SCORING

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LIST OF FIGURES

This appendix provides information on the other concepts consider by our team and the selection process used to determine the best approach to solving Decor's design problem.

1.1 BRAINSTORMING AND INITIAL SCREENING

The concept generation process began with multiple brainstorming sessions. Each team member came up with few ideas that were recorded in TABLE IX. To assist with concept generation, our group employed the TRIZ system to overcome design contradictions. The main contradiction we were faced with is improving the ease of operation within the finishing process, and maintaining productivity. For this contradiction, we chose the segmentation solution and split our problem into smaller problems. The three problems we had were flipping, transporting and storing parts. This allowed us to solve each problem individually. It also allowed us to create concepts for mechanisms that held one part at a time, instead of large designs that could accommodate multiple parts. Our group, based on the internal and external research, came up with 17 different ideas.

Initial screening was then performed as shown in TABLE IX to select the possible solutions. The screening process evaluated some very general characteristic of the concepts in order to narrow down the options for further investigation. Each idea was benchmarked against the current cart system of manually lifting and flipping large parts, using criteria such as cost effectiveness, ease of use or manufacturability. If the idea was better than the current system, it received a "+", if it was similar a "0" and if worse, a "-".

Due to screening, only six ideas were selected for further analysis. These ideas were strictly conceptual and required more development. The concepts were refined and sketches were prepared, as described in Section 3.2.

TABLE IX: INITIAL IDEAS

#	Idea	Easy to use	Manufacturability	Cost Effective	Heat Tunnel Compatible	Minimizes Personnel	Minimizes Part Handling	Pluses	Negatives	Total Score	Rank
1	Current System	0	0	0	0	0	0	0	0	0	
2	Overhead Railing System	-	-	-	-	+	0	1	4	-3	
3	Extended Arm with a Hoist	+	0	+	0	+	+	4	0	4	**1**
4	Flip Table Surface	+	0	+	0	+	+	4	0	4	**1**
5	Table Jig Retrofit	0	0	0	0	+	+	2	0	2	**3**
6	Rearranged Shop Layout	0	-	0	0	0	0	0	1	-1	
7	Ferris Wheel Cart	-	-	-	-	+	+	2	4	-2	
8	Conveyor Belt	0	-	-	-	+	0	1	3	-2	
9	Ground Railing System	0	-	-	0	0	0	0	2	-2	
10	Forklift	-	0	-	-	+	+	2	3	-1	
11	Robotic Suction Cup Railing System	+	-	-	-	+	+	3	3	0	
12	Clamp Attachment System with a Lift Cart	0	0	+	0	+	+	3	0	3	**2**
13	Hoist on Wheels with a Lift	0	0	+	-	+	+	3	1	2	**3**
14	Arm Retrofit to Current Carts	0	0	+	0	+	+	3	0	3	**2**
15	Actuated Mechanical Arm	+	-	-	0	+	+	3	2	1	**4**
16	Roller System	0	-	-	-	0	+	1	3	-2	
17	Magnetic Track	0	-	-	-	0	+	1	3	-2	

1.2 CONCEPT REFINEMENT

Our group further developed ideas selected in the screening stage. Because some of our initial concepts focused only on either transporting or flipping, these concepts were then combined to have full conceptual solutions that provided a way to move large parts and flip them, while eliminating the need for overhead lifting, and reducing risk of injury. For example, our team used the “extended arm with a hoist” idea and combined it with the current cart system, resulting in concept F described below. At this stage, results of our research were applied to establish more defined solutions.

Concept A: *Engine hoist with a custom adjustable jig to hold parts and allow rotation.*

This concept appeared as concept 12 on the initial concept list. An engine hoist is capable of lifting loads much larger than the maximum weight of a cabinet part. In general, one can lift a part from the floor to a maximum height of 7 feet. The hoist has wheels on the bottom, which would provide us with a solution for transporting the part. This solution would also require a custom jig to hold the parts, and allow for flipping the part over. A conceptual sketch for this jig appears below in Figure 40. The top part of the jig is adjustable to accommodate varying sizes of parts, up to 10 feet long. The part is held in place by clamps on either side, which are free to rotate. The widest part is 3 feet wide, so the space required from the top part of the jig, and the clamps is equal to half the width of the widest part, 1.5 feet.

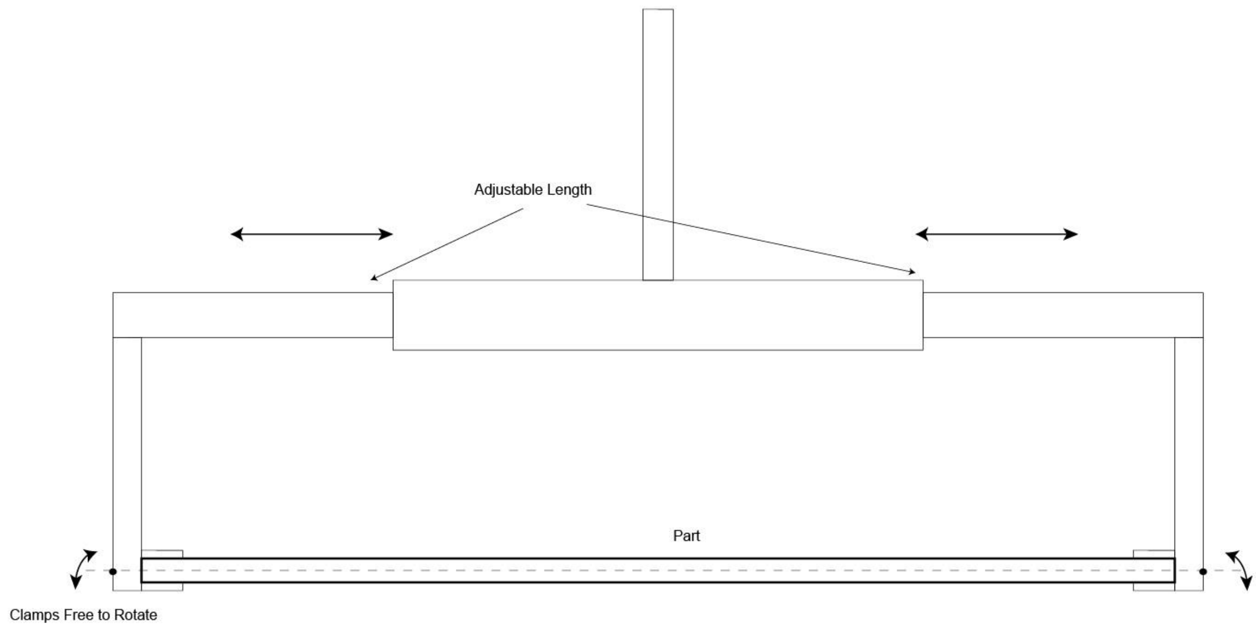


Figure 40: Concept A

***Concept B**: Mobile table with a top surface that flips, powered by air springs.*

The idea shown in Figure 41 is based on concept 4 from the initial concepts list. Each cart acts as a table, where staining, sanding and all other work can be done on the columns. The tables move on wheels for easy transportation and have a hydraulic lift spring attached to flip the surface of the table 90 degrees. The cart can be attached to a middle transfer table, where the part is easily flipped to another cart. Concept B satisfies all needs for the customer. By transporting, flipping and storing, the columns can be moved safely and quickly through the factory.

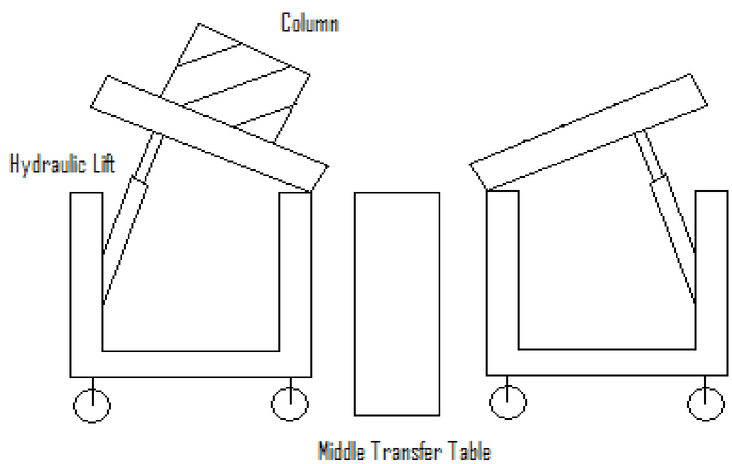


Figure 41: Concept B

***Concept C**: Retrofitted Table jig*

Concept C, shown in Figure 42, appeared as 5 on the original idea list. It consists of a vertical lift mechanism and 180° rotational mechanism to assist with flipping and rotating parts at the work tables. Retractable clamps secure the part during lifting and rotation. The jig is to be retrofitted to the current tables at the base support. Note that this concept only resolves the flipping issue, since existing carts must still be used to transport parts between stages.

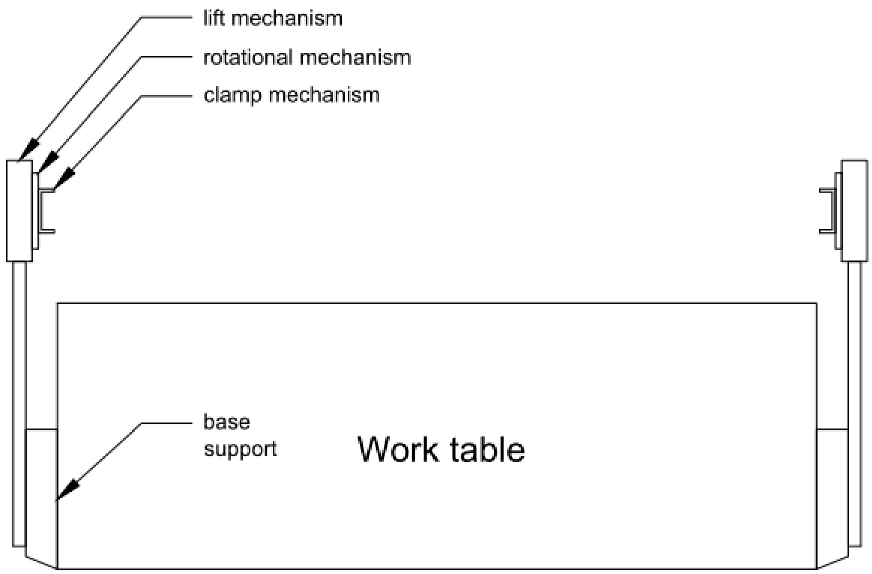


Figure 42: Concept C

Concept D: *Two carts with a rotational and lifting mechanism that are interconnected through the part itself.*

This concept appeared as concept 11 on the initial concept list and consists of two new carts. Each cart is equipped with a lifting mechanism as well as a set of clamps that hold the part in place. The clamps can rotate 360 degrees, giving the operator access to all sides of the part. Each cart has wheels on the bottom, which provides a solution for transporting the part. A conceptual sketch for this design appears below in Figure 43.

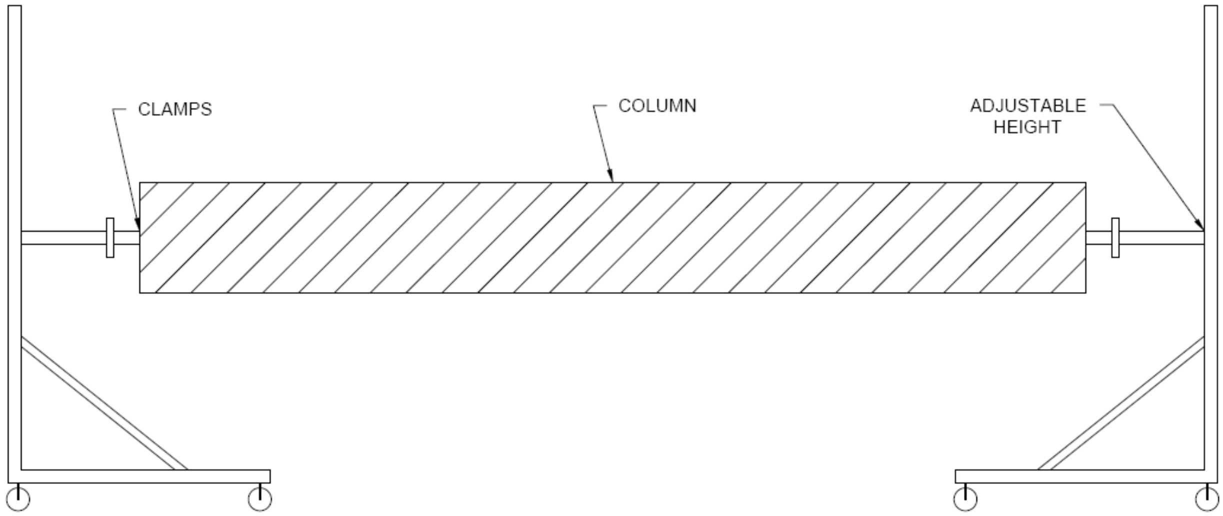


Figure 43: Concept D

***Concept E**: Extendable arm on a freestanding, fixed support.*

Concept E appeared as concept 3 on the original concepts list. It consists of a rotating clamp mechanism affixed to manually extendable arm which rotates about a pin support up to 270°. The arm assembly is supported by a lift mechanism which travels up and down a support shaft. This concept will be used in transporting parts between the cart and table, as well as flipping parts between operations. A secondary use may be the transfer of workpieces between the spray cells and work tables, but this would require 2 full units per stage. For visual representation see Figure 44 below.

Note: Since the clamp mechanism is assumed to grip the long side, flipping the part could prove problematic (e.g. a 10 ft. long piece rotating lengthwise). We are considering an alternative to the clamp mechanism such as a hoist with custom jig (similar to Concept A).

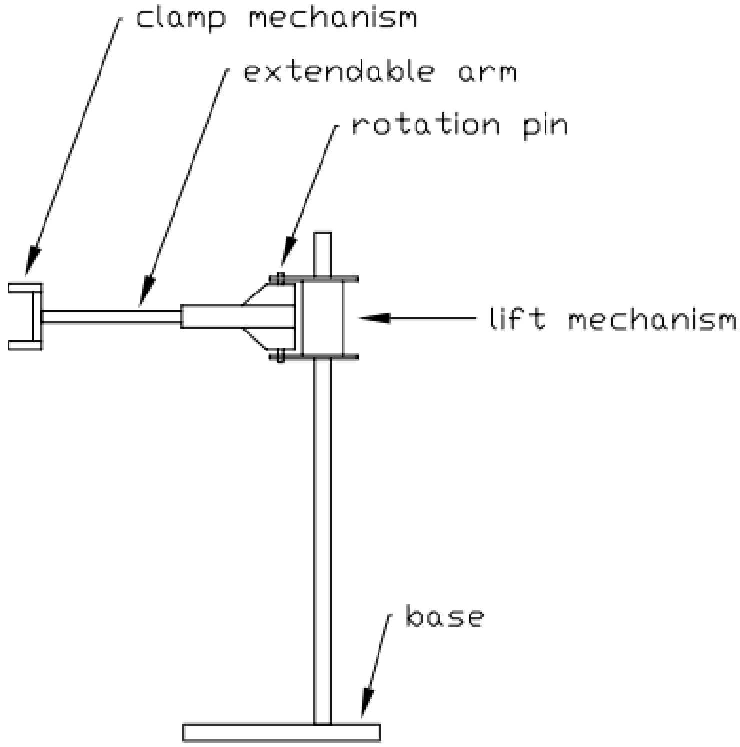


Figure 44: Concept E

***Concept F**: Extendable arm attached to current carts.*

This concept appeared as concept 13 on the initial concept list and consists of an arm attached to the current cart, which has been modified to accommodate large parts. The modification would include attaching the arm with a hoist, as well as extending the base of the cart to shift the center of gravity, resulting in a more stable structure. Current carts already have wheels on the bottom, which would allow the parts to be moved between cells. A conceptual sketch for this design appears in Figure 45 below.

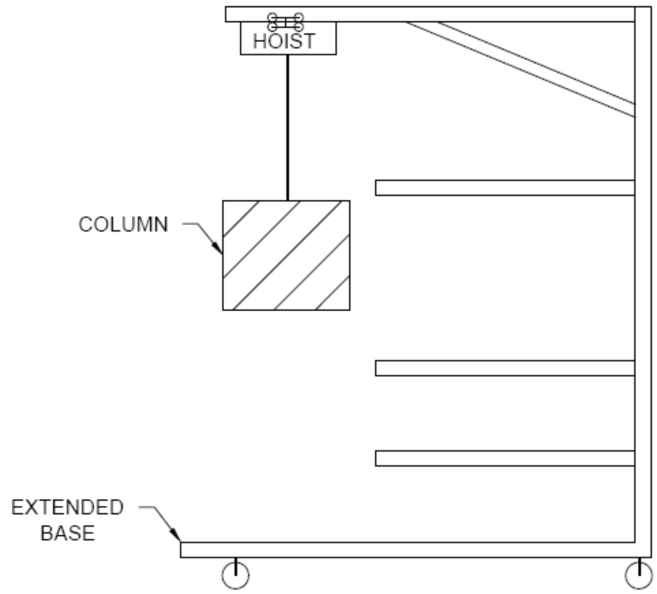


Figure 45: Concept F

1.3 CRITERIA WEIGHTING

The criteria weighting is an important step in the concept generation and analysis phase. Each criterion is compared against the other, giving a numerical value of how significant each measure is. Our group performed the analysis using a matrix shown in TABLE X. From examination, it was found that safety is the most important criterion with 29%, followed by integrity of parts and ease of use, with scores of 24% and 19%, respectively. The results obtained during the criteria weighing were applied to concept scoring in Section 1.4 of the appendix,

As an example, when comparing efficiency, referenced in the table as B, with safety, referenced as A, safety was found to be a more important criterion. Therefore, a letter A is recorded in the matrix as a result. Once the table was filled, a total number of “hits” was obtained for each criterion and weighted against other. The customer reviewed the results and approved them, before applying the weighted scores in further analysis.

TABLE X: CRITERIA WEIGHTING MATRIX

Criteria		Safety	Efficiency	Ease of Use	Life Span	Cost Effectiveness	Integrity of Parts	Manufacturability
		A	B	C	D	E	F	G
Safety	A		A	A	A	A	A	A
Efficiency	B			C	B	B	F	G
Ease of Use	C				C	C	F	C
Life Span	D					E	F	D
Cost Effectiveness	E						F	G
Integrity of Parts	F							F
Manufacturability	G							
Total Hits		6	2	4	1	1	5	2
Weightings		29%	10%	19%	5%	5%	24%	10%
Rank		1	4	3	5	5	2	4

1.4 CONCEPT SCORING

Concept scoring was performed to select the top two designs out of the six. The scoring was done by comparing concepts against each other in seven different categories, such as safety, efficiency, ease of use, life span, cost effectiveness, integrity of parts and manufacturability. Within each category, sub-categories were created. Each sub-category was assigned a metric and a target specification (if applicable), as shown in TABLE XI. Each concept was given a “yes”, if it satisfied the specified requirement and a “no” if it did not. Since no detailed technical specifications are known for each concept, our group used its best judgement and design experience to score each concept.

TABLE XI: CONCEPT EVALUATION

Category	Sub-category	Metric	Units	Target	Concept A	Concept B	Concept C	Concept D	Concept E	Concept F
Safety	Reduce part weight load on workers	Load reduction	%	50	Yes	Yes	Yes	Yes	Yes	Yes
	Reduce rapid/jerky movements	Smooth transportation	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Mitigate impact damage	Impact absorption system	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Minimize impact risk	Risk reduction	%	-50%	No	Yes	Yes	No	Yes	No
Efficiency	Minimize transportation time between stages	Max. average transport time	min	5	Yes	Yes	Yes	Yes	Yes	Yes
	Minimize movement time within stages	Max. lifting/rotation time	min	2	No	Yes	No	No	No	No
	Transport multiple large parts simultaneously	Max. load capacity	kg	135	Yes	Yes	Yes	Yes	Yes	Yes
		Acceptable part dimensions	ft.	10x3x0.5	Yes	Yes	Yes	Yes	Yes	Yes
		Min. number of large parts moved at the same time	#	2	No	No	Yes	No	Yes	Yes
Ease of Use	Minimize interaction required for securing parts	Max. actions to load / unload large parts	#	2	No	Yes	No	No	No	No
	Minimize interaction required for transporting parts	Max. actions to transport large parts	#	1	Yes	Yes	Yes	Yes	Yes	Yes
	Minimize complexity of use	Training time required before use	h	1	No	Yes	No	No	No	No
	Minimize personnel requirements	Max. users required to transport parts	#	1	Yes	Yes	Yes	Yes	Yes	Yes

(TABLE XI continued)

Category	Sub-category	Metric	Units	Target	Concept A	Concept B	Concept C	Concept D	Concept E	Concept F
Life Span	Solution is resistant to chemicals	Resistant to chemicals used in production	-	-	Yes	Yes	Yes	Yes	Yes	Yes
	Solution can sustain a long term use	Minimum lifetime	years	5	Yes	Yes	Yes	Yes	Yes	Yes
	Solution is easy to clean	Time required to clean	min	20	Yes	Yes	Yes	Yes	Yes	Yes
	Withstand high temperatures	Allowable operating temperature	°F	150	No	Yes	Yes	Yes	Yes	Yes
Cost effectiveness	Minimize cost of materials & purchased parts	Max. average or estimated cost	$	1000	Yes	Yes	No	No	Yes	Yes
	Minimize labour cost	Labour cost to manufacture the part	$	1000	Yes	Yes	Yes	Yes	Yes	Yes
	Salvage value at the end of lifetime	Min. salvage value	$	100	Yes	Yes	Yes	Yes	Yes	Yes
	Minimize Maintenance cost	Max. maintenance cost per year	$	100	Yes	Yes	Yes	Yes	Yes	Yes
Integrity of parts	Force exerted on part due to attachment fixture(s)	Max. stress caused by the attachment fixture	MPa	20	Yes	Yes	Yes	No	Yes	Yes
	Accommodate wet/drying parts	Min % area exposed to air & porous surfaces	%	80	Yes	Yes	Yes	Yes	Yes	Yes
Manufacturability	Availability of materials	Min. ratio of local to imported parts	% local	50	Yes	Yes	No	No	Yes	Yes
	Complexity of manufacturing equipment required	Simple manufacturing methods (ex. no CNCs needed)	-	-	Yes	Yes	No	No	Yes	Yes
	Manufacturing time	Max. lead time per unit	days	4	Yes	Yes	Yes	Yes	Yes	Yes

Once all concepts were reviewed and scored, all "yes" answer were calculated for each category and multiplied by the criteria weighing that was obtained in Section 1.3. The results are shown in TABLE XII below. Concept B ranked as number one and concept E ranked second, with a score of 3.50 and 3.45, respectively. There was a significant difference between the second and the third place, proving that the two selected concepts are better than all other ones.

TABLE XII: CONCEPT SCORING CHART

Category	Weighting	Score					
		Concept A	Concept B	Concept C	Concept D	Concept E	Concept F
Safety	29%	3	4	4	3	4	3
Efficiency	10%	3	4	4	3	4	3
Ease of Use	19%	2	4	2	2	3	2
Life Span	5%	3	4	4	4	3	2
Cost effectiveness	5%	4	4	3	3	3	3
Integrity of parts	24%	2	2	2	1	3	3
Manufacturability	10%	3	3	1	1	3	3
Final weighted score		2.68	3.50	2.87	2.24	3.45	2.82
Rank		5	1	3	6	2	4

1.5 HOUSE OF QUALITY

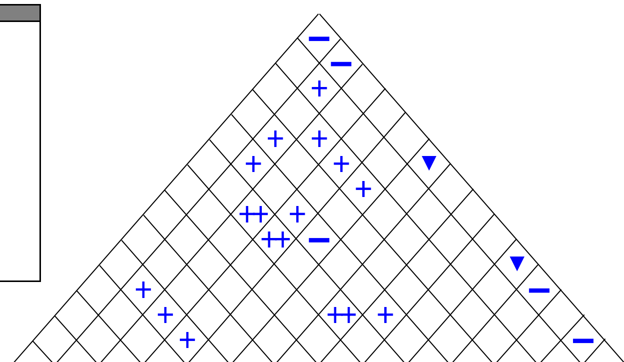
In order to create a successful solution, it was necessary to consider the relationships between the different functional requirements of our design and how they relate to our customer's needs. For this reason a 'House of Quality' was constructed. This tool is a method for determining the importance of each functional requirement relative to the design. We will use this information to help us assign the appropriate amount of resources to meet each of these requirements.

The way the House of Quality works is all of the functional requirements (i.e. how we meet customer needs) are set up across the top of the table and the customer requirements are listed down the side, see TABLE XIII below. These functional requirements were each detailed to be maximized, minimized or hit a target value which was written at the bottom of the table. In the main body of the house, each functional requirement was assigned a symbol for how strongly it relates to each customer requirement (e.g. <blank> = 'no relationship' and Θ = 'strongly related'). In the top of the house, the correlation between each functional requirement was analyzed and assigned a symbol (e.g. ▼ = 'strong negative correlation' and ╫ = 'strong positive correlation'). For example, 'Make the design durable' has a strong negative correlation with 'Minimize manufacturing costs' because of the increased cost of material. Lastly, at the bottom of the table each functional requirement was assigned a value from 1 – 10 to describe how difficult we thought it was to achieve.

In the bottom 'Results' section, the 'Relative weight' for each functional requirement was given as a function of all inputs mentioned, except 'Difficulty to achieve'. The 'Adjusted weight' then took difficulty to achieve into consideration. In the last row, the rank of each functional requirement was provided based on the adjusted weight. The top 3 rankings were 'Adequate size of the design', 'Make the design durable' and 'Reduce manual lifting'. The 3 lowest ranked were 'Reduce transportation time between Cells', 'Use Materials with a High Temperature Rating' and 'Minimize manufacturing budget'. These results confirm our preferred concepts as selected in the previous section since the top ranked functional requirements coincide with the categories in which the concepts scored highest (e.g. 'Safety', 'Efficiency' and 'Integrity of Parts').

TABLE XIII: HOUSE OF QUALITY

Legend	
Θ	Strong Relationship
O	Moderate Relationship
▲	Weak Relationship
++	Strong Positive Correlation
+	Positive Correlation
—	Negative Correlation
▼	Strong Negative Correlation
▼	Objective Is To Minimize
▲	Objective Is To Maximize
x	Objective Is To Hit Target



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Use Materials Resistant to Chemicals	Install a Heat Tunnel Track Connection	Reduce Manual Lifting	Reduce transportation time between cells	Adequate Size of the Design	Make the Design Durable	Doesn't Cause Damage to the Parts	Allows the Parts to Dry Consistently	Minimize the Number of Loading/Unloading	Design has High Load Capacity	Use Materials with a High Temperature Rating	Can be Operated by One Person	Eliminate Overhead Lifting	Minimize Manufacturing Costs
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	x	x	x	x	x	x	▼	▲	x	x	x	▼
1	9	7.0	5.0	alleviates shoulder strain from part handling			Θ						Θ			O	Θ	
2	9	7.0	5.0	accommodates physical abilities for male and female			O		Θ							O		
3	9	7.0	5.0	allows use for people of various heights			O		Θ								O	
4	9	7.0	5.0	solution minimizes chance of injury			Θ		Θ				Θ				Θ	
5	9	5.6	4.0	allows for smooth and rapid transportation between stages				Θ					O	Θ			O	
6	9	5.6	4.0	accommodates large parts					Θ					O				
7	3	5.6	4.0	makes product accessible for finishing on all external surfaces								O						
8	9	5.6	4.0	can be used year long						Θ								O
9	9	5.6	4.0	part in the fixture maintain their condition							Θ	Θ						
10	9	5.6	4.0	can accommodate wet/drying parts							Θ	Θ						
11	9	4.2	3.0	minimizes required amount of part handling			Θ	O					Θ			O	O	
12	9	4.2	3.0	resistance to chemicals applied during finishing processes	Θ													
13	9	4.2	3.0	accommodates multiple parts					Θ			O		Θ				
14	9	4.2	3.0	integrates with heat tunnel system		Θ			O									
15	9	4.2	3.0	withstand high temperatures		Θ									Θ			
16	9	2.8	2.0	accommodates workers of varying education background				O								Θ		
17	9	2.8	2.0	minimizes personnel to transport parts			Θ						Θ			Θ	Θ	
18	9	2.8	2.0	can survive impacts						Θ	Θ			O				
19	9	2.8	2.0	easy to clean	Θ													
20	9	2.8	2.0	can be manufactured locally					O									Θ
21	9	2.8	2.0	can be manufactured at a low cost					O									Θ
				Target or Limit Value			-50%	-10%	135 kg/120x36x4in	365 days	-20%	-20%	50%		150° F	1		
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	4	5	5	10	1	1	7	7	10	8	4	9	6	8
RESULTS				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9
				Weight / Importance	63.4	76.1	232.4	71.8	308.5	76.1	126.8	131.0	207.0	114.1	38.0	105.6	202.8	67.6
				Relative Weight	3.5	4.2	12.8	3.9	16.9	4.2	7.0	7.2	11.4	6.3	2.1	5.8	11.1	3.7
				Adjusted Weight	0.9	0.8	2.6	0.4	16.9	4.2	1.0	1.0	1.1	0.8	0.5	0.6	1.9	0.5
				Rank	7	7	3	11	1	2	6	6	5	8	10	9	4	10

APPENDIX – B: SKF TURNTABLE BROCHURE

SKF® industrial turntables

For industrial work stations, product displays, material container stands, paint booths and welding tables

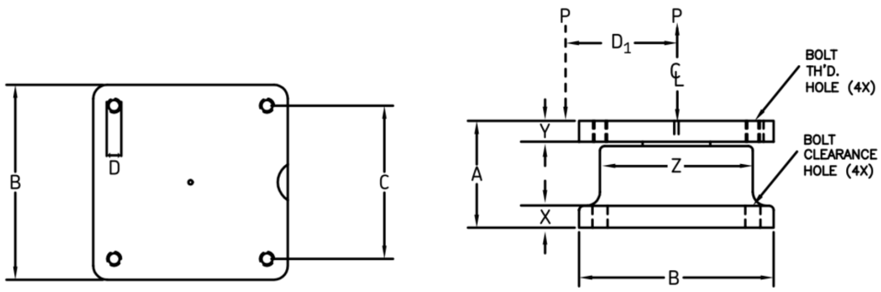
These industrial grade turntables are ideal for welding and industrial worktables, product displays, material handling stands, paint booths and many other "Lazy Susan" type applications.

Turntables may be mounted using the recommended bolts or welded directly to the fixture. The bottom flange is to be fastened first with standard size bolts. Top plates feature tapped holes to provide ease of assembly.

All sizes can be purchased as standard or locatable* units. Locatable units allow 90º indexing. All turntables are fitted with permanently lubricated and sealed bearings, eliminating the need for future re-lubrication. All turntables are engineered for safe, smooth, long-lasting operation.

Industrial turntables

Equipped with permanently lubricated and sealed bearings



Part number	Load capacity (lbs) P	Moment capacity inch-lb M†	Height A	Length B	Center C	Mt'g bolt size D	Height X	Height Y	Length Z	Weight
Standard or locatable										
UT 01 CN or UT 01 CL	1,000	650	1.77"	3.25"	2.50"	1/4"-20	0.39	0.38	2.25	3.5 lbs
UT 02 CN or UT 02 CL	2,500	1,400	1.92"	3.50"	2.75"	1/4"-20	0.39	0.38	2.75	4.5 lbs
UT 05 CN or UT 05 CL	5,000	3,700	2.43"	5.00"	4.00"	3/8"-16	0.50	0.50	3.75	10.5 lbs
UT 10 CN or UT 10 CL	10,000	8,500	2.72"	6.50"	5.50"	3/8"-16	0.50	0.50	5.00	19.0 lbs

†Moment Load Rating (M) maximum allowable off-center load in (inch-lbs) that the unit can support $M = P \times D_1$
Moment Load the resulting angular tilt is approximately 10 minutes of a degree.

Turntable nomenclature

UT **10** **XX**

Indicates U-Turn, SKF's turntable offering

Two digit number indicates the central load carrying capacity in pounds. (e.g. 10,000 lbs.)

Material and special features;
CN = cast iron/non-locatable
CL = cast iron/locatable

* Locating pins are not intended to be used as a mechanical (hard) stop.
** Only available in UT 10 Series.

Special order/custom turntables

Please consult Customer Service at 1-888-753-3477 or the SKF Engineering Hotline at 1-888-753-2000 for information and availability.

APPENDIX – C: COST ANALYSIS

WAJAX INDUSTRIAL COMPONENTS / COMPOSANTS INDUSTRIELS

Succursale / Branch:
Winnipeg

Tél / Phone ....:
Télécopieur / Fax.:

Soumission / Quotation
CSW04978184 Page: 1 de / of: 1
Originale / Original - 1

À / To

University Of Manitoba
Resource Services
Rm 410 Adm Bldg
Winnipeg, MB R3T 2N2
CA

Nom / Name: .....: University Of Manitoba
Tél / Phone ....: 204-474-9907
Télécopieur / Fax 12044747637
Courriel / Email ..:

Expédié à / Ship To:

University Of Manitoba
c/o Decor Cabinets

Date ....: 11/18/2014
Client comm. Order Account ....: UNMANI
No. de référence / Reference No...: Steven Nikkel
No. commande client / Cust PO ....:
Termes de pmt. / Pmt. Terms........: N30D
Expiration (jours) / Expires (days) .: 30
FAB / FOB ....: Notre Location / Our Location

Entrée par / Entered by..............: James Francis
Tél / Phone ....:
Télécopieur / Fax ....:
Courriel / Email ....:

Qté comm.	Qté en stock Qty in	Qté ES BO	Qty U/M	Item / Description	Promised del. date Livraison Promise	Prix unitaire Unit Price	Montant / Amount
1	0	1	EA	M/5906353 SKF M/5906353 Mounting Tools UT05CN Non-LOCKING	11/18/2014	158.63	158.63

Total de la ligne / Line total **158.63**

DELIVERY - 2-3 WEEKS EX USA

Représentant / Sales Rep: Kevin Mills

Termes et conditions disponibles au www.wajax-industrial-components.ca/fr/wajax-termes-conditions.aspx
Terms & Conditions available at www.wajax-industrial-components.ca/en/wajax-terms-conditions.aspx

Signature: ______________________

Sous/Sub total......................................:	158.63
Total frais divers / Total Misc. Charges:	0.00
ENVIRO ....:	0.00
Total (avant taxes / before taxes) .CAD	**158.63**

1. Shopping Cart 2. Checkout 3. Order Review 4. Finished

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	Stock Number	Item Description	Size	Status	Price Each	Totals
1	F2145	1/4 X 5 Hot Rolled A-36 Steel Flat	2 Ft.	In Stock	$14.02	$14.02
1	F2385	3/8 X 5 Hot Rolled A-36 Steel Flat	2 Ft.	In Stock	$21.02	$21.02
1	F214-12	1/4 X 12 Hot Rolled A-36 Steel Flat	1 Ft.	In Stock	$19.89	$19.89
					Sub-Total:	$54.93
					Shipping:	$0.00
					Total:	* $54.93

Notice: Due to current market conditions, prices are subject to change without notice.
* - Orders in KY are subject to a 6% sales tax.

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